ASSESSING COMMERCIAL TIMBERLAND ASSETS IN THE U.S.

by

BIN MEI

(Under the Direction of Michael L. Clutter)

ABSTRACT

In the past several decades, timberland ownership in the United States has changed dramatically. Traditional vertically-integrated forest products firms have been divesting their timberlands, while timberland investment management organizations (TIMOs) have been active acquirers. As a unique asset class, timberland has three return drivers, namely, the biological growth, timber price, and land price. Biological growth can be consistently estimated, land price is correlated with inflation, while timber price remains most unpredictable. The first part of this dissertation aims to model and forecast timber prices in 12 southern timber regions via different time series models. The results reveal that the vector autoregressive model (VAR) forecasts more accurately for 2009Q1-2009Q4, seven out of the 12 southern timber regions play dominant roles in the long-run equilibrium, and the conditional variances and covariances from the bivariate generalized autoregressive conditional heteroscedasticity (GARCH) model well capture market risks. The second part examines the financial performance of private- and public-equity timberland investments in the U.S. using both parametric and nonparametric asset pricing approaches. The results reveal that private-equity timberland investments outperform the market, and have low systematic risk, whereas public-equity timberland investments fare similarly as the market. The last part investigates real option values of investment, mothballing, reactivation, and abandonment in a hypothetical southern pine plantation using the contingent claims approach. The results reveal that these option values, while ignored by the discounted cash flow (DCF) analysis, do affect timber management decisions. The impacts of changes in the key economic parameters on changes in the option values are examined in the sensitivity analysis.

INDEX WORDS: CAPM, Real Options, Stochastic Discount Factors, Timberland Investments, Time Series

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DEDICATION

To my family - for the love, encouragement, and understanding you give me.

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INTRODUCTION AND LITERATURE REVIEW

History of Modern Timberland Investments

In the early twentieth century, most forest products companies in the United States were vertically integrated with both timberland holdings and manufacturing facilities. Through vertical integration firms acquire the ability to insure a certain portion of internal timber supply, thus alleviating 100% dependence on the open market for timber, the crucial raw material. However, in the past several decades, vertically integrated forest products firms have been divesting their timberlands and outsourcing the business of growing and harvesting timber. Wear and Clutter summarize the causative factors for timberland divestiture as follows: 1) shift in production from diversification to specialization to exploit the "returns to scale" rather than "returns to scope"; 2) reduced insurance value of timberland due to expending and reliable timber supplies; 3) fall in raw material costs caused by new technologies; 4) worldwide centrifugal force on manufacturing based on comparative advantages resulting from globalization; and 5) competing demand for timberland assets mainly from tax efficient organizations, e.g., Real Estate Investment Trusts (REITs). Moreover, recent mergers and acquisitions in the forest products industry have left huge amount of debts on the acquirers' balance sheets. As a value adding strategy, these firms tend to use the proceeds from timberland sales to lower their debts and acquire cash (Mei et al. 2009). In summary, when combined with forest products mills, timberland divisions usually cannot operate at optimum due to internal subsidies. Timberlands held by vertically integrated forest products companies have long been undervalued by Wall Street, and could only obtain fair values when they are managed as distinct entities (Wilent 2004). Therefore, the "invisible hand" separates this business in the market.

While traditional vertically integrated forest products companies have been perceived as primary sellers of timberlands, institutional timberland investors have been unprecedentedly active buyers over the past 15 years. According to a recent survey of top corporate and public pension funds, endowments, and foundations, institutional commitments to U.S. timberland assets have increased tenfold since the early 1990s, and the growth in such investments remains strong with endowments being the most common form of institutional investors (Corriero et al. 2003). One major motivation in timberland investments dates back to the implementation of Employee Retirement Income Security Act (ERISA) in 1974, which required pension fund managers to diversify into non-financial assets to minimize the risk of large losses. Thereafter, most funds began to consider a wide range of assets including timberland (e.g., Binkley et al. 1996; Conroy and Miles 1989).

As a result of the interaction between timberland sellers and buyers, over 40 million acres of timberland nationwide have changed hands in the past decade, more than 70% of which were transacted in the South (Clutter et al. 2008). Since this first foray into timberland as an alternative asset class, institutional timberland investors have developed rapidly. At the end of the 1980s, timberland assets managed by timberland investment management organizations (TIMOs) totaled merely $1billion; in 2008, this number exceeded $32 billion (Zinkhan 2008).

Timberland Return Drivers and Its Unique Features

Timberland return has three drivers: biological growth, timber price, and land price. These three drivers influence the performance of timberland investments both individually and jointly. Caulfield (1994, 1998) examines the three drivers in a hypothetical southern pine plantation over 1982-1997, and identifies biological growth as the primary driving factor. Recently, we update the analysis for 1992-2007 and find that, although biological growth still dominates, the contribution of timber price has fallen greatly. A closer examination reveals that this can be explained by the evolvement of timber prices in the last three decades. Overall, three phases of timber price development can be identified in the U.S. South, namely, the moderate growth phase (1977-1986), the rapid growth phase (1987-1998), and the adjustment phase (1999-2007) (Wear et al. 2007). Caulfied's study coincides with the rapid growth phase, resulting in a 33% contribution for timber price, whereas our update concurs with the adjustment phase when timber prices are declining or flat, resulting in a less than 1% contribution.

Corresponding to the three return drivers, timberland assets have several unique features. Among others, these have been gradually recognized by institutional investors. First, timberland has countercyclical returns or low (even negative in some cases) correlation with the financial assets, especially during market downturns (Mills and Hoover 1982; Redmond and Cubbage 1988; Zinkhan 1988, 2008). Therefore, timberland assets can be used as a potential diversifier. Second, timberland is an effective hedge against higher-than-expected inflation (Fortson 1986; Washburn and Binkley 1993a; Zinkhan 2008). Third, unlike other crop products with a narrow harvest window, trees keep on growing and increase in value for several years. If timberland investors can exploit the biological growth of timber, thus time the market, they can get higher and better returns (Caulfield 1998; Conroy and Miles 1989). Last, relative inefficiency exists in timberland markets (Caulfield 1998; Zinkhan and Cubbage 2003). Information on timberland assets has historically not been perfectly disseminated to market players, and thus not completely reflected in market prices. Many of the pioneers in timberland investments have exploited this opportunity after executing their due diligence.

Despite the attractivenesses, timberland investments do not come without risk. It has been well known that timberland bears risk from natural disasters, e.g., hurricanes, snowstorms, acid rain, insects, disease, and fire, although the risk of a complete loss for a rotation period is very low (Mills 1988; Molpus 2008). Also, commercial timberland assets are less liquid than other financial assets. Timberland funds normally have a lifetime of 10-15 years, or even longer under certain conditions.

Timberland Investment Entities

Prior to the 1980s, timberlands were mostly invested by farmers and large forest products firms. However, these passive investors have been perceived not actively involved in timber management (Zinkhan and Cubbage 2003). Moreover, for those large forest products firms, timber income is taxed at both the corporate and individual levels. Ever since the early 1980s when institutional investors initially express their interests in timberlands, forest products firms have responded by restructuring their timberland divisions to securitize the illiquid real assets. For instance, International Paper established captive master limited partnerships (MLPs), Georgia-Pacific created letter stocks, and most recently, Plum Creek converted itself from a MLP to a publicly-traded timber REIT. Both MLPs and REITs are more income-tax efficient for taxable investors because these structures are not taxed at the corporate level. In addition, publicly-traded timber REITs provide greater liquidity by offering their securities at stock exchanges, and therefore allow individual investors to enter the timberland markets by allocating only a modest amount of capital comparing to institutional investors.

Although restructuring activities like MLPs and letter stocks were once positively reacted by the financial markets, these kinds of timberland investment entities proved to be interim (Zinkhan et al. 1992). In contrast, TIMOs funded by institutional investors have gradually gained popularity in timberland investments, especially in large-scale transactions. TIMOs avoid "double taxations" by using either separate accounts or pooled funds. A separate account holds timberland properties of one major investor in a single portfolio, whereas a pooled fund allows multiple investors to participate in a relatively large, diversified portfolio of timberlands (Zinkhan and Cubbage 2003). Comparing to publicly-traded timber REITs, private TIMOs have higher requirements of minimum capital commitments, but less pressure from short-term cost of capital.

Three Issues to Be Investigated in Timberland Investments

Among the three timberland return drivers, timber price remains the most unpredictable, and so does its contribution to total timberland returns. In addition, periodic dividends paid to timberland shareholders from timber sales tie closely to timber prices. To maintain the regular dividends, timberland managers have to adjust their intermediate timber harvests (Caulfield and Flick 1999). Therefore, understanding the evolvement of timber prices over time becomes an interesting research question. Chapter 2 aims to model and forecast real pine sawtimber stumpage prices in 12 southern timber regions via different time series approaches.

Timberland becoming a popular investment alternative, it's necessary to assess its financial performance. Given the dissimilarities in organization structures and securitization liquidities between publicly-traded REITs and privat TIMOs, we suspect that timberland returns perform differently in these two markets. Chapter 3 analyzes this issue by applying various asset pricing models, both parametric and nonparametric, to timberland returns for public- and private-equity timberland investments in the U.S.

Timberland investments generally cost millions of dollars, and a majority of the initial cost is sunk or irreversible. However, timberland managers have some flexibility in timber production. First, trees keep growing for a long period of time. Harvesting can be delayed during bad economic times and restored later when the market recovers. Second, timber production can be easily suspended, and trees can be stored on the stump with little maintenance cost. Last, tree plantations can be abandoned should timber prices fall too low, and the salvage value in terms of timber and land sales usually more than offsets the exit cost. Using the contingent claims approach, Chapter 4 explicitly investigates various real option values in a hypothetic southern pine plantation in state Georgia.

This dissertation is organized as follows. Chapters 2 - 4 address the three issues aforementioned in timberland investments, and are formatted as autonomous journal articles, each with its own sections of introduction, literature review, data description, methodologies, results, and conclusions. Chapter 5 summarizes the key findings, and highlights some topics for future exploration. To avoid replication, I briefly review the literature in Chapter 1. More complete summarizations of previous research can be found in Chapters 2 - 4.

CHAPTER 2

MODELING AND FORECASTING PINE SAWTIMBER STUMPAGE PRICES IN THE U.S. SOUTH BY VARIOUS TIME SERIES MODELS[1]

[1] Mei, B., M. L. Clutter, and T. G. Harris. Accepted by *Canadian Journal of Forest Research*.
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Abstract

Among the three timberland return drivers (biological growth, timber price, and land price), timber price remains the most unpredictable. It affects not only periodic dividends from timber sales but also timber production strategies embedded in timberland management. Using various time series techniques, this study aimed to model and forecast real pine sawtimber stumpage prices in 12 southern timber regions in the United States. Under the discrete-time framework, the univariate autoregressive integrated moving average (ARIMA) model was established as a benchmark, whereas other multivariate time series methods were applied in comparison. Under the continuous-time framework, both the geometric Brownian motion (GBM) and the Ornstein-Uhlenbeck process were fitted. The results revealed that 1) the vector autoregressive (VAR) model forecasted more accurately in the one-year period by the mean absolute percentage error (MAPE) criterion; 2) seven out of the 12 southern timber regions played dominant roles in the long-run equilibrium; and 3) the conditional variances and covariances from the bivariate generalized autoregressive conditional heteroscedasticity (GARCH) model well captured market risks.

Introduction

Timberland return has three drivers—biological growth, timber price, and land price. These three return drivers affect the financial performance of timberland investments both independently and interactively. Biological growth refers to the growth in size and volume of trees over time. With biological growth, trees upgrade from lower-value product pulpwood to higher-value product sawtimber (Table 1). Larger-diameter trees are generally worth several times more per unit of volume than smaller-diameter trees (Figure 1). Bare land value measures the present value of future timber proceeds less periodic expenses provided the land is used for timber production in perpetuity. If all or part of a timberland has higher or better uses like commercial or residential development opportunities, the land price can be remarkably higher. Timber prices are observed in regional timber markets. Timber price uncertainty influences both periodic dividends paid to timberland shareholders and timber production strategies embedded in timberland management. Thus timber prices are crucial to timberland investors. In sum, biological growth has been well understood and can be readily simulated by growth and yield simulators (e.g., SiMS). Bare land value for southern pine plantations is somewhat correlated with inflation (Washburn and Binkley 1993a). Timber price remains the most unpredictable, and so does its contribution to total timberland returns. Therefore, modeling and forecasting timber prices is an interesting research question.

Caulfield (1998) examined the three return drivers in a hypothetical southern pine plantation for 1982-1997, and concluded that biological growth contributed about 61% to total returns. Under the same framework, we updated the calculation for 1992-2007, and found that although biological growth still dominated, timber price had contributed much less (Figure 2). The contribution of timber price dropped from 33% for 1982-1997 to 0.8% for 1992-2007, and accordingly the annualized timberland returns decreased from 14% to 12%. The declining contribution of timber price can be explained by recent sluggish timber market. As can be perceived from Figure 1, timber prices in the past decade have been declining for sawtimber and chip-n-saw, and flat for pulpwood, contrasting to the overall growth period when Caulfield's study was conducted. Therefore, timber price has been relatively less important in terms of its percentage contribution to total timberland returns for the last 15 years.

Like any other commodity, timber price is determined by supply and demand in equilibrium. Due to its bulky nature and substantial transportation cost, timber products are mostly traded in local markets. Nevertheless, regional timber markets can be integrated, and price movements in one market may affect neighbor markets as well. For example, the rapid growth phase of southern timber price in the early 1990's has been widely interpreted as a result of the harvest reduction from the Pacific Northwest after the spotted owl was listed as an endangered species. Thus, one must consider regional timber prices together to better understand the timber markets. On the other hand, there may exist lead-lag relationships among different regional markets, and correlations among different markets may be time-varying. For timber fund managers holding geographically diversified timberlands, these relationships are of vital importance.

In a word, stochastic properties of timber prices have been of great concern for timberland investors. This study aimed to address this issue by using various time series techniques to model and forecast timber prices in the southern United States. The southern timber market was chosen in that a majority of mill capacity in the U.S. is established in the South (Wear et al. 2007), nearly 60% of the nation's timber is produced by the thirteen southern states (Prestemon and Abt 2002), and a significant portion of commercial timberlands in the U.S.

as well as the world is located in the South (Cascio and Clutter 2008). Comparison of prediction accuracies of different models will help our understanding of timber prices in mean, and consideration of conditional heteroscedasticity will improve our understanding of timber prices in variance. Section II provides a brief literature review on timber price analyses; Section III describes the data and methodologies; Section IV summaries the results for each time series model, and compares their forecasting accuracies; and Section V concludes.

Literature Review

Previous research mostly examined the stochastic properties of roundwood prices and the interrelationships among regional timber prices, especially in Scandinavia and North America. Haight and Holmes (1991), Saphores et al. (2002), Hetemaki et al. (2004), Malaty et al. (2007), and Khajuria et al. (2009) applied alternative time-series methods to model stumpage prices. Haight and Holmes found that quarterly average stumpage prices followed a random walk, whereas monthly prices were mean-reverting. Saphores et al. combined bounds and the Monte Carlo test technique to stumpage prices of the Pacific Northwest, and found evidence of the jumps and autoregressive conditional heteroscedasticity (ARCH) effects. Hetemaki et al. explained the framework of the short-term forecasting system of the Finish forest sector. They demonstrated it by using a case study of German lumber import demand to analyze its impact on Finish lumber exports and sawlog demand. Malaty et al. investigated the Nordic pine sawlog markets in four Finnish regions by using monthly real stumpage prices. Their results indicated that the structural time series (state space) model with Kalman filter outperformed standard autoregressive moving average (ARIMA) and vector autoregressive (VAR) models in most cases. Khajuria et al. modeled Canadian timber prices as a mean reversion with jumps process, and examined its impact on harvesting decisions.

Murray and Wear (1998), Thorsen (1998), Toppinen and Toivonen (1998), Nagubadi et al. (2001), Yin et al. (2002), Stordal and Nyrud (2003), and Baek (2006) examined the integration of regional timber markets based on cointegration analysis. Murray and Wear evaluated the degree of integration of the Pacific Northwest and the U.S. South. Their results suggested a structural break in the relationship between the two regions' product prices around the time of the harvest restrictions, and a more integrated market thereafter. Using more disaggregated data, Nagubadi et al. examined market integration for three hardwood stumpage commodities in six states in the U.S. South. Their major finding was that markets were not fully integrated for any of those commodities. Likewise, Yin et al. found that a single market did not exist for southern pine sawtimber and pulpwood across the entire U.S. South. Baek examined the structure changes and dynamics of price relationships between the U.S. and Canada. He found that the North American lumber market was integrated, and the U.S. market played a dominant role. In Scandinavia, Thorsen presented an analysis of the spatial integration of the Nordic timber markets. Strong market integration was found with Finland and Sweden acting as price-leaders. At the same time, Toppinen and Toivonen studied the stumpage market in Finland, and found that the degree of stumpage market integration differed across wood assortments. Similarly, Stordal and Nyrud tested the law of one price and weak exogeneity in the Norwegian sawlog market. The Swedish sawlog market was found to impact price formation in the Norwegian market, indicating adequately functioning of the Norwegian sawlog market.

Washburn and Binkley (1990, 1993b), Yin and Newman (1996), and Prestemon (2003) addressed issues related to informational efficiency of the timber markets. They tested individual stumpage price series for serial autocorrelation to find or reject the necessary condition for informational efficiency. The conflicting conclusions could be owned to different assumptions on market behavior, the function of timber as an investment, and the causal relationship between price evaluation and commodity market efficiency (Prestemon 2003). Most recently, Prestemon (2009) simulated the statistical power of univariate and bivariate models of shock detection using intervention analysis, and found that bivariate models were more powerful than univariate ones when the time series were nonstationary and had cointegrating relationships.

Among these studies, that of Malaty et al. (2007) has some similarities to ours. Nevertheless, there are several key differences. First, we focused on different timber markets. They examined monthly timber prices in four Finnish regions, while we examined quarterly timber prices in 12 U.S. southern timber regions. Second, their structural time series model was univariate. This may ignore the structural restrictions on the system of equations (Durbin and Koopman 2001). We improved this by estimating a multivariate state space model. Third, continuous-time models were employed in addition to those discrete-time ones. Finally, we also examined the conditional time-varying variances and covariances of real pine sawtimber stumpage prices.

Data and Methodologies

Data description

Timber Mart-South (TMS) is a non-profit corporation that compiles and publishes timber prices in three major products for 22 U.S. southern regions. The three products are sawtimber, chip-n-saw, and pulpwood (Table 1). The 22 regions, coded by the two-letter U.S. Postal Service state abbreviation and the number assigned by TMS (Figure 3), are delineated by terrain features, mill types, harvest activities, species mixes, etc. (Norris Foundation 1977-present). There have been some revisions on TMS reporting regimes since its inception. First, from 1988 reporting frequency changed from monthly to quarterly. Second, from 1992 reporting areas in most coastal states changed from three to two. Researchers had examined the temporal and spatial aggregation issues and the power of different statistical tests on TMS timber prices (e.g., Prestemon and Pye 2000; Prestemon et al. 2004). Following their recommendations, we maintained the sample size as long as possible (i.e., 1977Q1-2009Q4), used spot-sampling (middle month) quarterly series for 1977-1987, and transformed three-region series to two-region series by the conversion technique proposed by Prestemon and Pye (2000).[2]

Among the 22 timber regions, some have significant portions of missing observations (i.e., LA2, TN2 and TX1), and some are peripheral or have historically low annual timber removals (i.e., AR2, FL1, NC1, SC1, TN2, VA1 and VA2). Therefore, only 12 timber regions were included in our analysis, i.e., AL1, AL2, AR1, FL2, GA1, GA2, LA1, MS1, MS2, NC2, SC2, and TX2. Together, these 12 timber regions comprise about 90% of the total annual pine removals in the South (Forisk Consulting and Timber Mart-South 2007), thus well represent the southern timber market.

We only modeled pine sawtimber stumpage prices for two major reasons. First, timber prices of the three products are highly correlated, and sawtimber prices have most variability. Second, oligopsony power identified in the pulpwood market may impact the price formation of pulpwood (Mei and Sun 2008). To exclude inflation, nominal timber prices were deflated by Consumer Price Index (CPI for 1982-1984 = 100). Then Box-Cox transformations were conducted, and the results indicated that five series should be transformed by natural logarithm.

[2] Timber price series based on the TMS conversion method were also analyzed. Since similar results were found, these results were not reported separately, but available from the authors upon request.

For consistency as well as convenience of interpreting the differenced series as returns, we used natural logarithm transformation for all the 12 series. Data from 1977Q1 to 2008Q4 were used to build up the models, while those from 2009Q1 to 2009Q4 were used to evaluate the forecasting accuracy by the mean absolute percentage error (MAPE) criterion. The MAPE value is calculated as follows,

[1] $$MAPE = \frac{1}{T}\sum_{t=1}^{T}\left|\frac{A_t - F_t}{A_t}\right|$$

where A_t is the actual value, F_t is the forecasted value, and T is the total number of observations in the forecasting period.

Discrete-time models

Vector autoregressive model (VAR)

A k-dimensional VAR model of order p can be specified as in eq. 2,

[2] $$y_t = \mu + \Phi_1 y_{t-1} + \Phi_2 y_{t-2} + \cdots + \Phi_p y_{t-p} + a_t$$

where y_t is a $k \times 1$ vector time series, and Φ 's are $T \times k$ coefficient matrices. Different from the univariate ARIMA models, not only one's own series' lag values but also those of others are used to explain its current value. This enables us to study the lead-lag relationships between the k component series. A key process in building a VAR(p) model is to determine the lag length p. Several criteria have been commonly used, among which are sequential modified log likelihood ratio test (LR), final prediction error (FPE), Akaike information criterion (AIC), Schwarz information criterion (SBC), and Hannan-Quinn information criterion (HQ) (EViews 2007).

Error correction model (ECM)

If each component series in y_t is integrated of order one, $I(1)$, some of the series may be cointegrated. The notion that m series are cointegrated ($m < k$) means that although each of the

m individual series is nonstationary, their linear combination is actually stationary. Engle and Granger (1987) investigate an error-correction representation theorem for a cointegrated system. An ECM corresponding to the above VAR(p) is formulated as

$$[3] \qquad \Delta y_t = \mu_t + \Pi y_{t-1} + \sum_{i=1}^{p-1} \Phi_i^* \Delta y_{t-i} + a_t$$

where $\Pi = -I + \sum_{i=1}^{p} \Phi_i$, and $\Phi_i^* = -\sum_{j=i+1}^{p} \Phi_j$. The number of cointegrating relations is detected by the rank of the $k \times k$ matrix Π. Matrix Π can be decomposed into the product of two $k \times m$ full-rank matrices α and β in the way that $\Pi = \alpha\beta'$, where α is the adjustment coefficient denoting the speed to restore equilibrium, and β is the long-run parameter. The term $\beta' y_{t-1}$ represents the stationary linear combination of m individual series, and the whole term Πy_{t-1} is commonly known as the error correction term. Two tests in Johansen's multivariate cointegration analyses, the trace test and the maximum eigenvalue test, can be used to determine m, the number of cointegrating relations.

State space model

A multivariate local trend model under the state space framework can be described as in eq. 4,

$$[4] \qquad \begin{aligned} y_t &= \mu_t + e_t, & e_t &\sim N(0, \Sigma_e) \\ \mu_{t+1} &= \mu_t + \eta_t, & \eta_t &\sim N(0, \Sigma_\eta) \end{aligned}$$

where y_t, μ_t, e_t and η_t are $k \times 1$ vectors, and the error terms e_t and η_t follow multinormal distribution with mean zero ($k \times 1$) and variance-covariance matrices Σ_e and Σ_η ($k \times k$), respectively. The first equation is called the signal/observation equation, which defines the evolvement of the observations. The second equation is called the state equation, where the local level term μ_t follows a random walk. The whole system of equations can be estimated by the maximum likelihood method with Kalman filter (Harvey 1989). Contrasting to the ARIMA models, stationarity of the data is not required in the state space model, and unobserved components, such as level, trend, seasonality, and cyclicity can be specified explicitly into the model (Commandeur and Koopman 2007).

Continuous-time models

Two types of continuous-time models are commonly used in characterizing price processes. A geometric Brownian motion (GBM) can be viewed as the counterpart of random walk in the discrete-time framework, while an Ornstein-Uhlenbeck process can be viewed as the counterpart of mean-reversion. In empirical studies, the choice between these two models depends on the nature of the data, theoretical considerations, and analytical tractability (Dixit and Pindyck 1994). In forestry, both processes have been applied in studies related to optimal rotations and forest real options (e.g., Insley and Rollins 2005).

Geometric Brownian motion

A GBM is a continuous-time stochastic process in which the logarithm of the random variable follows a generalized Brownian motion, or a generalized Wiener process. It is widely used in economics and finance, especially in the field of option pricing, because a variable that follows a GBM can take any positive value and only the partial changes of the random variable are relevant. A GBM is a special case of the Itô process, and can be described by the following differential equation

[5] $$dP_t = \delta P_t dt + \sigma P_t dw_t,$$

where P_t is the real pine sawtimber stumpage price, δ and σ are the constant drift and volatility parameters, and dw_t is the increment of a Wiener process defined as $dw_t = \varepsilon_t \sqrt{dt}$ where ε_t is a standard normal random variable. Through Itô's lemma, it can be shown that $\ln(P_t)$ follows a generalized Wiener process with drift rate $\delta - \sigma^2 / 2$ and variance rate σ^2, i.e.,

[6] $$d\ln(P_t) = (\delta - \frac{\sigma^2}{2})dt + \sigma dw_t .$$

Tsay (2005) demonstrated the way to estimate δ and σ 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, $\hat{\delta} = \bar{r} / \Delta + s^2 / 2\Delta$ and $\hat{\sigma} = s / \sqrt{\Delta}$, 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. Conditional on price P_t at time *t*, the mean and variance of P_T ($T > t$) can be calculated as $E(P_T) = P_t e^{\hat{\delta}(T-t)}$ and $Var(P_T) = P_t^2 e^{2\hat{\delta}(T-t)}(e^{\hat{\sigma}^2(T-t)} - 1)$, respectively.

Ornstein-Uhlenbeck process

An Ornstein-Uhlenbeck process is another special case of the Itô process, and can be described as

[7] $$dP_t = n(m - P_t)dt + \sigma dw_t ,$$

where *m* is the long-run equilibrium level the prices tend to revert to, *n* is the speed of reversion, and σ and dw_t are similarly defined as in a GBM. An Ornstein-Uhlenbeck process differs from a GBM in the drift parameter, i.e., the drift is positive when the current price is lower than the equilibrium level *m*, and negative when the current price rises above *m*. In others words, the long-run equilibrium level pulls prices in its direction despite short-term oscillations. Given the fact that the price of a commodity should mirror its long-run marginal production cost, some researchers argued that a mean-reversion process could better describe the time path of many commodity prices (e.g., Schwartz 1997).

A discrete time approximation of the Ornstein-Uhlenbeck process is

[8] $P_t - P_{t-1} = m(1 - e^{-n\Delta t}) + (e^{-n\Delta t} - 1)P_{t-1} + \varepsilon_t$,

where $\varepsilon_t \sim N(0, \sigma_\varepsilon)$ and $\sigma_\varepsilon = (1 - e^{-2n})\sigma^2 / 2n$. By running the following regression

[9] $P_t - P_{t-1} = a + bP_{t-1} + \varepsilon_t$,

the relevant parameters can be calculated as $\hat{m} = -\hat{a} / \hat{b}$, $\hat{n} = -\ln(1 + \hat{b})$, and $\hat{\sigma} = \hat{\sigma}_\varepsilon \sqrt{(-2\hat{n}) / ((1 + \hat{b})^2 - 1)}$. Conditional on price P_t at time *t*, the mean and variance of P_T (*T* > *t*) can be calculated as $E(P_T) = P_t e^{-\hat{n}(T-t)} + \hat{m}(1 - e^{-\hat{n}(T-t)})$ and $Var(P_T) = (1 - e^{-2\hat{n}(T-t)})\hat{\sigma}^2 / 2\hat{n}$, respectively (Dixit and Pindyck 1994).

Bivariate generalized autoregressive conditional heteroscedasticity (GARCH) model

Bollerslev et al. (1992) provided an excellent overview of the theory and empirical evidence on ARCH-type modeling in finance. Here we briefly reviewed the ARCH model and its various extensions. Ever since Mandelbrot (1963) and Fama (1965), it has been well understood that the uncertainty of speculative prices, as measured by the variance and covariance, evolves over time. In other words, large changes in speculative prices tend to be followed by large ones, whereas small changes tend to be followed by small ones. To deal with this “volatility clustering” or “volatility persistence” issue, researchers proposed different models to mimic the time-varying second or higher order moments. Among these models, one that has been most widely used is the ARCH model of Engle (1982). The ARCH model specifies an unconditionally constant, but conditionally time-varying error variance, and the specification is autoregressive. In real applications of the ARCH model, sometimes, a long lag length is required. To provide a more flexible lag structure and thus smooth the time path of the conditional variance, Bollerslev (1986) generalizd the GARCH model in the same manner that an AR process is generalized to an ARMA process. A multivariate GARCH(1,1) model can be formulized as follows,

$$[10] \quad \begin{aligned} y_t &= c + e_t \\ \mathrm{H}_t &= \Omega\Omega' + \mathrm{A}' e_{t-1} e'_{t-1} \mathrm{A} + \mathrm{B}' \mathrm{H}_{t-1} \mathrm{B} \end{aligned}$$

where y_t, c, and e_t are $k \times 1$ vectors; the error term vector e_t is multinormal conditional on the information set F_{t-1} at time *t*-1, i.e., $e_t | F_{t-1} \sim N(0, \mathrm{H}_t)$; H_t is a $k \times k$ symmetric variance-covariance matrix; Ω is a $k \times k$ lower triangular matrix; and A and B are $k \times k$ diagonal matrices. Parameters c, H_t, Ω, A, and B can be estimated by the maximum likelihood method (EViews 2007).

Empirical Results

Results from the univariate ARIMA models

The univariate ARIMA model was used as a benchmark model for each state. Considering the potential shock of timber harvest restrictions in the Pacific Northwest on the timber market in the South, 1977Q1-1987Q4 was used as the pre-intervention period to establish the noise model. Then intervention was introduced to the rest of the data. Different formulizations were attempted, but no significant intervention was identified. We suspected several reasons for this. First, timber harvest reduction in the Pacific Northwest may only have significant influences on the nominal timber prices in the South, but not the real prices. Second, other events not as widely recognized may also impact real timber prices. Third, even harvest restrictions on the Federal forests themselves have been revised several times by the government. Hence timber markets may have already incorporated all the available information into timber prices. We also tested potential jumps in the data using the iterative procedure as in Cartea and Figueroa (2005). However, no significant jump effects were identified.

Standard ARIMA analysis was conducted for the whole estimation period 1977Q1-2008Q4 (Table 2). Mixed stochastic properties were found for the 12 timber prices series. One half followed a pure random walk, whereas the other half showed some serial correlations. Nevertheless, all the 12 timber price series were not stationary unless first differenced, meaning that each series was integrated of order one, *I*(1). Residuals of these ARIMA models behaved like white noise, indicating their adequacy.

Results from the VAR(2) model

Although univariate ARIMA models revealed the stochastic nature of each price series, they ignored the interactions among different timber regions. Thus a VAR model was established. The LR, FPE, AIC, SBC, and HQ criteria all indicated a VAR(1). However, diagnostic checks of the residuals suggested some serial correlations by the multivariate LM test and non-normality by the Jarque-Bera test. Therefore, higher-order VAR models were attempted, and finally the VAR(2) model was chosen. Serial correlations in the residuals had been corrected, while multi non-normality still existed due to some excess kurtosis in GA2, NC2, and SC2. Hence caution should be used when applying the VAR(2) model in these three regions. Lastly, seasonal and harvesting restriction dummies were attempted, but eventually excluded from the final model due to their insignificance.

Estimation results for the VAR(2) model are reported in Table 3. All timber price series but MS1 had significant coefficients on their own lags. Overall, the VAR(2) model fitted the data fairly well with the minimum R^2 0.698 for NC2, and the maximum R^2 0.875 for LA1. Another interesting question is the lead-lag relationships among the 12 timber regions as revealed by the significant coefficients for variables other than each region's own lags. However, as aforementioned, when all component series are $I(1)$, some series may be cointegrated, and the VAR model may be misspecified. Therefore, these lead-lag relationships were examined in the ECM model.

Results from the ECM model

The Augmented Dickey-Fuller (ADF) unit root test as well as results from the univariate ARIMA analyses showed that each timber price series was $I(1)$. Concerning the potential cointegration in some of the 12 regions, error correction models (ECM) were employed. The trace test suggested two cointegrating relations while the maximum eigenvalue test suggested five (both tests with no intercept and no trend). Hence both models were estimated. Results of the ECM model with five cointegrating relations, ECM(5), are reported in Table 4. ECM (2) model yielded similar results, thus were not shown separately. Comparing to the VAR(2) model, the R^2 values fell dramatically in the ECM(5) model. However, these R^2 values are not directly comparable since the ECM model is based on differenced series.

Another meaningful test related to the ECM model is the so-called weak exogeneity test. Weak exogeneity means that one component variable in y_t deviates the system from the long-run equilibrium, yet that variable itself is not influenced by the other variables. That is the variable plays a dominant role in the long-run equilibrium (e.g., Heikkinen 2002). The null hypothesis of the existence of a weak exogenous variable can be tested by setting restrictions on the i^{th} row of the adjustment coefficient, i.e., $H_0 : \alpha_{ij} = 0$, $j = 1,2,\ldots,m$. The corresponding likelihood ratio statistics has a χ^2 distribution with the degree of freedom equal to the number of cointegrating relations. As shown in Table 5, the null hypothesis could not be rejected for AL2, FL2, GA1, GA2, LA1, NC2, and SC2 in both the ECM(2) and ECM(5) models. Therefore, these seven regions could be considered as dominant players in the long-run equilibrium in the U.S. southern timber market.

Results from the state space model

Various specifications in the state space were attempted. Initially, a local linear trend model with seasonal dummies was estimated. However, there were no significant slope nor seasonality effects, and both AIC and SBC criteria favored the local trend model. So the final model was such specified. Results from the state space model are presented in Table 6. All the final state variables (the stochastic levels) were highly significant and converged to their levels in 2008Q4. Given the relatively high dimension and small sample size, the local trend model was more challenging to estimate. The higher AIC and SBC values indicated that the multivariate state space model showed no apparent advantages to the VAR (2) model in this particular case.

Results from the GBM model

Each timber price series was nonstationary, and the null hypothesis of no significant serial correlation in the continuously compounded return series r_t could not be rejected by the Ljung-Box statistics. All these validated the calculation of the drift and volatility parameters in the GBM process (Tsay 2005). The estimation results are reported in Panel A of Table 7. The drift parameters were estimated to be positive between 0.003 and 0.036 with the exception of GA2, whereas the volatility parameters were much larger in size, ranging from 0.161 to 0.283. Together, it could be concluded that real pine sawtimber stumpage prices in most regions had been considerably volatile, albeit with some slight increasing trends in the past three decades. Finally, the predicted timber prices for 2009Q1-2009Q4 were calculated based on their values observed at the end of 2008Q4.

Results from the Ornstein-Uhlenbeck process

Estimation results under the alternative mean-reverting assumption, the Ornstein-Uhlenbeck process, are reported in Panel B of Table 7. The long-run equilibrium level parameters were estimated between 18.55 and 23.19 $/ton, well beyond current observed price levels. Therefore, we would expect real pine sawtimber stumpage prices to rise in the future were they indeed mean-reverting. The speed of reversion parameters were estimated relatively low between 0.093 and 0.253. This implied that even though the timber markets were likely to recover, it would take a long time. The volatility parameters were estimated in $/ton. Using the long-run means, these values could be transformed to 0.088-0.141, The predicted timber prices for 2009Q1-2009Q4 were similarly calculated as in the GBM model.

Comparisons of forecasting accuracies of different models

MAPE values for the forecast period 2009Q1-2009Q4 were calculated for each of the 12 southern timber regions in Table 8. The mean MAPE values across regions suggested that the VAR(2) model performed best among all the time series models attempted in this study. However, it should be noted that some extremely large MAPE values (greater than 10%) existed. Therefore, all models had some difficulty in predicting timber prices precisely in certain areas.

Comparing to the univariate ARIMA models, the multivariate models fared better for most timber regions. Between the two univariate continuous-time models, the GBM model marginally outperformed the Ornstein-Uhlenbeck process. In sum, these proved that interrelationships among regional timber prices could help explain their stochastic behaviors. For illustration, actual values and predicted values with 95% confidence intervals from the VAR(2) model are plotted for GA2 and SC2 in Figure 4.

Conditional variances and covariances from the bivariate GARCH model

In addition to the means, timber investors also care about the variances of timber prices. Using GA2 and SC2 as examples, a bivariate GARCH model was estimated. Conditional time-varying standard deviations are shown in Figure 5. In most periods, they fluctuated around $4/ton. However, there were three apparent spikes—one in the late 1970s, one in the midlle1990s, and another in most recent years. Combining Figures 4 and 5, it could be easily observed that these spikes corresponded to the sharp movements of real pine sawtimber stumpage prices in these three sub-periods.

Supplemental to the variances, another piece of useful information from the bivariate GARCH model was the conditional time-varying correlations between GA2 and SC2 (Figure 6). For most times, real sawtimber stumpage prices in GA2 and SC2 were highly, positively correlated. However, the average conditional correlation, 0.784, was lower than the unconditional one, 0.864. For comparison purpose, we also modeled timber price series between GA2 and LA1. Results (not shown) indicated a lower conditional and unconditional correlation of 0.601 and 0.640, respectively. In sum, these results further supported the hypothesis that timber prices in geographically adjacent regions should be highly correlated.

Summary and Discussion

Timberland investments have come of age in recent years. Among the three timberland return drivers, timber price remains the most unpredictable. Accordingly, its contribution to total timberland returns varies substantially from time to time. Moreover, development of timber derivatives such as timber cutting contracts requires sound understandings of the timber market. Therefore, modeling and forecasting timber prices has been of great concern for timberland investors. Applying various time series models, this study examined real pine sawtimber stumpage prices in the 12 U.S. southern regions. Major findings include 1) the VAR(2) model had the highest prediction precision for 2009Q1-2009Q4 based on the MAPE criterion; 2) AL2, FL2, GA1, GA2, LA1, NC2, and SC2 were identified as the dominant players in the long-run equilibrium in the southern timber markets; 3) market risks in GA2 and SC2 were well captured by the conditional variances and covariances from the bivariate GARCH model.

From a practical standpoint, these results have some real world implications. First, the 12 southern timber regions should not be considered separate in terms of short-term forecasting. Recent timber prices in one's neighboring markets usually contain the most relevant information in addition to its own for future prices. However, in the long run, emphasis should be put on the seven leading timber regions. A close examination revealed that these seven regions had historically ranked high in terms of inventory, annual growth, and annual removals of pines. For example, GA2 alone accounted for 15%, 18%, and 16% of the total in the12 timber regions in the above three categories. Putting the seven leading regions together, these numbers added up to 65%, 67%, and 66%, respectively (Forisk Consulting and Timber Mart-South 2007). In other words, timber businesses had been traditionally more active in these timber regions, and market shocks on them could be gradually but eventually transited to the entire South. Consequently, regional timber markets should not be considered isolated one from another even though timber has long been regarded as a less liquid commodity.

Second, it should be realized that timber, as a real asset, is different from financial assets (e.g., bonds and stocks), which are more frictionlessly and continuously traded. The true rate of generation being unknown, timber prices can be best observed from periodic (not necessarily regular, but more frequent than monthly or quarterly) timber sales within a region. Monthly or quarterly timber prices may indeed denote an average of these more frequent prices. Therefore, information may be lost in the aggregation process and parameter estimates in the continuous-time models may be imprecise. Furthermore, it is well known that behaviors of commodity prices depend on the time span under consideration (e.g., Pindyck and Rubinfeld 1998). Given the relatively short sample period, it is hard to tell whether real pine sawtimber stumpage prices are purely random or mean-reverting. Hence, we caution the analyst against using these continuous-time series models in policy designs without justifications.

Third, volatilities evolved with levels of real pine sawtimber stumpage prices through time. Some causal factors for the time-varying volatilities may be the changing timber demand and supply, policy uncertainty, and overall economic conditions. The extent to which each timber region reacted to these events differed, however, geographically close areas had responded in a similar pattern most of the time. Regardless, it had been shown that the presence of ARCH and/or jump effects did impact optimal rotations (e.g., Khajuria et al. 2009; Saphores et al. 2002). The estimated time-varying variances and covariances may help timber managers in making their strategic decisions.

Another fact we observed from this study was that different conversion methodologies corresponding to the TMS reporting regime changes had limited impacts on the time-series models with respect to short-term forecasting. In our opinion, this lies in the structures of these models. For example, in the VAR(2) model, the further away an observation, the less weight it has on the current value. A complete comparison of the effects of all possible converting techniques on the stochastic properties of TMS prices series is beyond the scope of this study, but remains an interesting research topic. Prestemon and Pye (2000) and Prestemon et al. (2004) pioneered in this direction.

Finally, it should be noted that only a limited number of time series models were attempted in this study. It is possible that other alternative models may have better fitness thus stronger forecasting capabilities. In addition, theoretical economic models such as the rational expectations competitive storage model employed by Deaton and Laroque (1992) can be supplementary to our pure time series analyses. Overall, this study shed light on the ongoing endeavors in exploring the timber markets. Future research can probe how to link these timber price models to designing advanced timber derivatives, or developing regional timber policies.

Table 2.1. Timber product specifications

Product	Specification (DBH)	Value
Pulpwood	6” & up	Low
Chip-N-Saw	8”-11”	Medium
Sawtimber	12” & up	High

Note: These are general product guides. Specific requirements may vary by area and transaction.
Source: Timber-Mart South (Norris Foundation 1977-present).

Table 2.2. Univariate ARIMA models for real pine sawtimber stumpage prices in the 12 U.S. southern timber regions (1977Q1-2008Q4)

State	Model	Note
AL1	ARIMA(0,1,0)	Random walk
AL2	ARIMA(0,1,0)	Random walk
AR1	ARIMA(4,1,0)	AR term at lag 4 only
FL2	ARIMA(0,1,0)	Random walk
GA1	ARIMA(0,1,0)	Random walk
GA2	ARIMA(0,1,0)	Random walk
LA1	ARIMA(2,1,0)	--
MS1	ARIMA(2,1,0)	--
MS2	ARIMA(2,1,0)	AR term at lag 2 only
NC2	ARIMA(2,1,0)	--
SC2	ARIMA(0,1,0)	Random walk
TX2	ARIMA(3,1,0)	AR term at lag 2 only

Table 2.3. VAR(2) estimation results for real pine sawtimber stumpage prices in the 12 U.S. southern timber regions (1977Q1-2008Q4)

	AL1	AL2	AR1	FL2	GA1	GA2	LA1	MS1	MS2	NC2	SC2	TX2
AL1(-1)	0.40*	0.19	0.14	-0.01	-0.14	-0.05	0.26*	0.28*	0.06	0.03	-0.17	0.23
AL1(-2)	0.18	-0.09	-0.14	-0.03	0.20	0.02	-0.24*	-0.05	-0.26*	0.18	0.00	-0.26*
AL2(-1)	-0.01	0.32*	-0.08	0.07	0.29	0.17	-0.36*	0.20	0.39*	0.01	0.08	-0.10
AL2(-2)	-0.09	0.19	0.24	-0.06	-0.10	-0.05	0.26	0.25	0.26	-0.26	-0.07	0.19
AR1(-1)	0.00	0.14	0.30*	-0.04	-0.04	-0.02	0.04	-0.30*	-0.16	-0.04	0.10	-0.03
AR1(-2)	0.04	0.06	0.26*	0.07	0.00	-0.09	0.05	0.05	-0.09	0.06	-0.07	0.30
FL2(-1)	0.37*	0.18	-0.02	0.57*	-0.04	0.04	0.03	-0.15	-0.09	0.16	0.24*	0.07
FL2(-2)	-0.46*	-0.31*	-0.09	0.02	-0.27	-0.12	-0.14	-0.26	-0.24	0.02	-0.12	-0.24
GA1(-1)	0.00	-0.19	0.16	0.22*	0.61*	0.10	0.17	0.02	0.02	-0.02	0.02	0.06
GA1(-2)	-0.02	0.04	-0.10	-0.33*	0.08	-0.05	-0.15	-0.05	0.05	-0.12	-0.05	-0.02
GA2(-1)	0.06	0.29	0.00	0.01	0.35	0.69*	0.16	0.17	0.02	0.29	0.18	-0.02
GA2(-2)	0.23	0.33	-0.18	0.36*	-0.06	0.09	-0.21	-0.10	-0.11	-0.02	0.18	-0.16
LA1(-1)	-0.05	-0.14	0.09	-0.12	0.01	-0.11	0.24*	0.34*	0.25	-0.08	-0.08	0.15
LA1(-2)	0.25*	0.17	0.36*	0.09	0.18	0.06	0.32*	0.23	0.33*	-0.01	0.06	0.36*
MS1(-1)	0.45*	0.29*	0.33*	0.00	0.02	0.06	0.25	0.41	0.15	-0.16	0.02	0.40
MS1(-2)	0.07	-0.29*	0.03	-0.02	0.08	-0.06	-0.15	-0.12	-0.07	0.28*	0.08	-0.08
MS2(-1)	-0.25	0.01	0.08	0.00	-0.05	0.00	0.06	0.07	0.44*	0.26	0.01	-0.08
MS2(-2)	-0.03	0.06	-0.28	-0.05	0.01	0.07	0.03	0.07	-0.02	-0.15	-0.03	0.00
NC2(-1)	-0.04	-0.09	-0.05	0.07	-0.14	-0.05	0.01	-0.13	-0.04	0.40*	0.09	-0.13
NC2(-2)	-0.18	-0.10	-0.04	-0.10	-0.17	0.03	0.06	-0.03	-0.05	0.06	-0.12	-0.02
SC2(-1)	0.28*	0.14	0.36*	0.24	0.26	0.15	0.17	0.14	0.13	0.19	0.52*	0.29
SC2(-2)	0.04	-0.08	-0.11	-0.09	0.09	0.08	0.01	0.11	0.21	-0.02	0.08	0.04
TX2(-1)	-0.10	-0.02	0.08	0.21*	-0.12	0.00	0.31*	0.02	-0.09	0.00	0.04	0.48*
TX2(-2)	-0.17	-0.11	-0.34*	-0.09	-0.08	0.04	-0.21*	-0.17	-0.11	-0.04	-0.01	-0.43
R^2	0.834	0.797	0.853	0.767	0.800	0.836	0.875	0.832	0.835	0.698	0.821	0.863

Note: Asterisk indicates significance at the 10% level or better.

Table 2.4. ECM(5) estimation results for real pine sawtimber stumpage prices in the 12 U.S. southern timber regions (1977Q1-2008Q4)

	ΔAL1	ΔAL2	ΔAR1	ΔFL2	ΔGA1	ΔGA2	ΔLA1	ΔMS1	ΔMS2	ΔNC2	ΔSC2	ΔTX2
EC1	-0.39*	0.02	-0.16	-0.09	0.02	0.00	0.00	0.28*	-0.23*	0.19	-0.11	-0.06
EC2	0.02	-0.28	0.34*	0.01	0.14	0.07	-0.18	0.45*	0.69*	-0.23	-0.13	0.03
EC3	0.22*	0.34*	-0.21	0.14	0.05	-0.07	0.11	-0.20	-0.28*	0.02	0.06	0.26*
EC4	0.01	-0.05	0.07	-0.21*	-0.16	-0.03	-0.03	-0.39*	-0.31*	0.28*	0.19*	-0.13
EC5	0.03	-0.15*	0.11	-0.03	-0.02	0.07	0.05	-0.08	0.10	-0.07	-0.04	-0.03
ΔAL1(-1)	-0.15	0.17	0.24*	0.07	-0.18	-0.03	0.24*	0.05	0.29*	-0.14	-0.04	0.26*
ΔAL2(-1)	0.00	-0.31*	-0.33*	0.07	0.16	0.06	-0.21	-0.27	-0.27*	0.25	0.13	-0.15
ΔAR1(-1)	-0.14	-0.13	-0.35*	-0.13	-0.05	0.07	-0.05	-0.09	0.09	-0.08	0.05	-0.29*
ΔFL2(-1)	0.41*	0.26*	-0.04	-0.13	0.17	0.10	0.08	0.25	0.22	-0.07	0.08	0.21
ΔGA1(-1)	0.00	-0.05	0.07	0.30*	-0.19	0.05	0.15	0.08	-0.07	0.09	0.07	0.07
ΔGA2(-1)	-0.15	-0.27	0.27	-0.28	0.25	-0.06	0.30	0.16	0.20	0.12	-0.16	0.17
ΔLA1(-1)	-0.25*	-0.15	-0.32*	-0.09	-0.25	-0.06	-0.34*	-0.25	-0.38*	-0.05	-0.05	-0.34*
ΔMS1(-1)	-0.08	0.32*	0.03	0.05	-0.02	0.04	0.16	0.10	0.10	-0.24	-0.12	0.08
ΔMS2(-1)	0.09	-0.06	0.30*	0.07	0.00	-0.04	-0.03	-0.05	-0.04	0.11	0.08	0.00
ΔNC2(-1)	0.08	0.04	0.04	0.02	0.04	-0.06	-0.07	-0.02	-0.03	-0.22*	0.13	0.08
ΔSC2(-1)	0.08	0.16	0.10	0.15	-0.03	-0.06	-0.02	-0.02	-0.13	0.17	-0.09	-0.10
ΔTX2(-1)	0.25*	0.15	0.35*	0.14	0.15	-0.02	0.20*	0.19	0.12	0.11	0.01	0.39*
R^2	0.192	0.343	0.236	0.114	0.090	0.385	0.231	0.221	0.218	0.209	0.362	0.192

Note: 1) ECM(5) is the ECM model with five cointegrating relations corresponding to the VAR(3) model. 2) Asterisk indicates significance at the 10% level or better.

Table 2.5. Likelihood ratio tests of weak exogeneity for real pine sawtimber stumpage prices in the 12 U.S. southern timber regions (1977Q1-2008Q4)

	Two cointegrating relations		Four cointegrating relations	
	LR Stat.	*p*-value	LR Stat.	*p*-value
AL1	10.732	0.005	15.951	0.007
AL2	4.479	0.107	7.783	0.169
AR1	7.293	0.026	10.055	0.074
FL2	0.066	0.968	4.570	0.471
GA1	3.702	0.157	4.956	0.421
GA2	0.394	0.821	4.029	0.545
LA1	0.676	0.713	5.570	0.350
MS1	0.460	0.794	16.835	0.005
MS2	8.363	0.015	17.537	0.004
NC2	1.020	0.601	4.663	0.458
SC2	0.078	0.962	9.061	0.107
TX2	19.365	0.000	26.812	0.000

Note: The likelihood ratio statistics has a χ^2 distribution with degree of freedom equal to the number of cointegrating relations.

Table 2.6. State space estimation results of real pine sawtimber stumpage prices for the 12 U.S. southern timber regions (1977Q1-2008Q4)

	Coefficient	Root MSE	*p*-value
State variable			
AL1	14.26	0.94	0.000
AL2	17.42	0.92	0.000
AR1	15.35	1.22	0.000
FL2	15.03	0.57	0.000
GA1	12.55	0.71	0.000
GA2	13.86	0.32	0.000
LA1	15.04	1.10	0.000
MS1	14.50	1.19	0.000
MS2	17.02	0.88	0.000
NC2	16.47	1.10	0.000
SC2	16.11	0.51	0.000
TX2	14.83	0.71	0.000
Log likelihood		1049.34	
Akaike info. criterion		-16.02	
Schwarz criterion		-15.49	
Hannan-Quinn criterion		-15.80	

Note: Coefficient estimates were transformed back from their natural logarithm values, and root mean squared errors (MSE) were calculated by the Delta method.

Table 2.7. Estimation results of real pine sawtimber stumpage prices for the 12 U.S. southern timber regions from the continuous-time models (1977Q1-2008Q4).

	AL1	AL2	AR1	FL2	GA1	GA2	LA1	MS1	MS2	NC2	SC2	TX2
Panel A: Geometric Brownian motion												
δ	0.025	0.019	0.032	0.016	0.026	-0.001	0.021	0.030	0.025	0.013	0.003	0.036
σ (%)	0.246	0.231	0.278	0.211	0.243	0.161	0.253	0.267	0.247	0.234	0.172	0.283
Panel B: Ornstein-Uhlenbeck process												
M	20.26	23.19	21.21	19.86	18.55	22.45	20.26	21.28	22.86	20.16	21.52	20.91
n	0.145	0.135	0.138	0.184	0.127	0.093	0.110	0.145	0.121	0.253	0.114	0.110
σ ($/ton)	2.66	2.77	2.99	2.32	2.38	2.02	2.58	3.08	2.92	2.60	1.90	2.81

Table 2.8. Comparison of forecasting accuracies of different models by the MAPE criterion for real pine sawtimber stumpage prices in the 12 U.S. southern timber regions.

	ARIMA	VAR(2)	ECM(5)	State space	GBM	O-U
AL1	0.155	0.048	0.071	0.076	0.173	0.196
AL2	0.338	0.093	0.176	0.123	0.354	0.372
AR1	0.064	0.063	0.166	0.063	0.163	0.263
FL2	0.187	0.027	0.139	0.070	0.199	0.229
GA1	0.107	0.123	0.120	0.157	0.112	0.118
GA2	0.050	0.084	0.123	0.020	0.049	0.087
LA1	0.051	0.061	0.097	0.064	0.071	0.079
MS1	0.050	0.031	0.077	0.055	0.088	0.110
MS2	0.212	0.114	0.237	0.101	0.243	0.254
NC2	0.207	0.082	0.192	0.113	0.230	0.258
SC2	0.127	0.041	0.050	0.081	0.129	0.153
TX2	0.170	0.125	0.152	0.114	0.198	0.203
Max	0.338	0.125	0.237	0.157	0.354	0.372
Min	0.050	0.027	0.050	0.020	0.049	0.079
Mean	0.143	0.074	0.133	0.087	0.168	0.193

Note: 1) O-U stands for the Ornstein-Uhlenbeck process. 2) MAPE values were calculated for the one-year forecasting period 2009Q1-2009Q4.

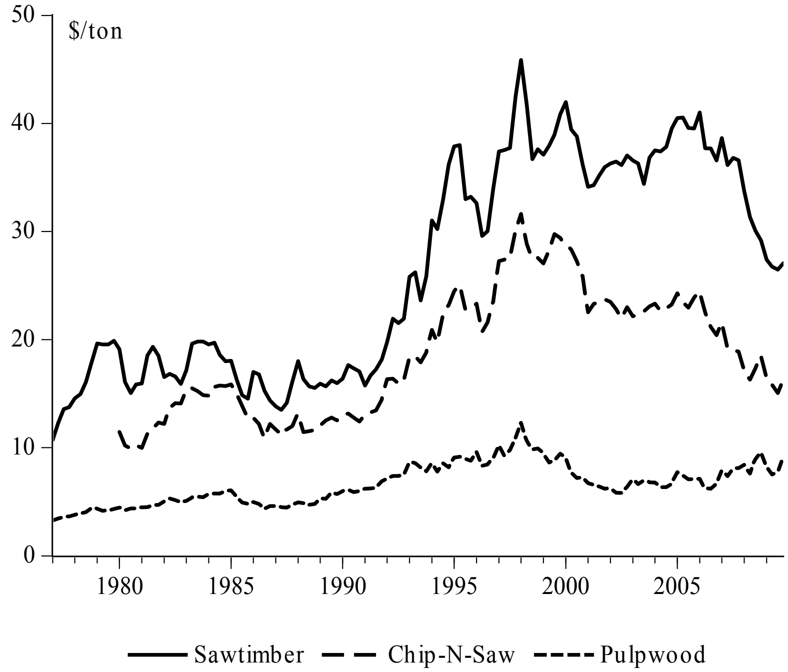

Figure 2.1. Nominal southern pine stumpage prices (South average, 1977Q1-2009Q4).

Source: Timber Mart-South (Norris Foundation 1977-present).

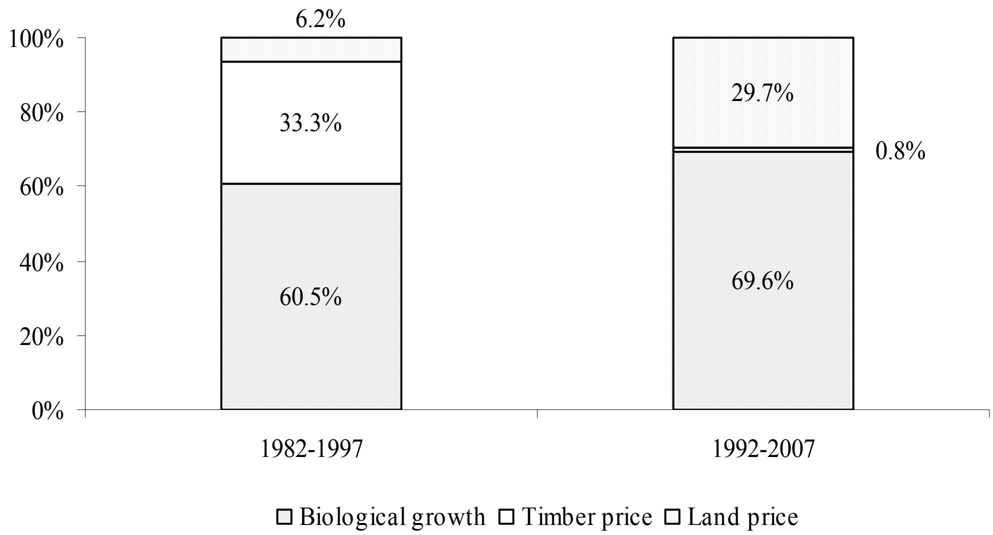

Figure 2.2. Comparison of percentage contributions of the three timberland return drivers over two different time periods.

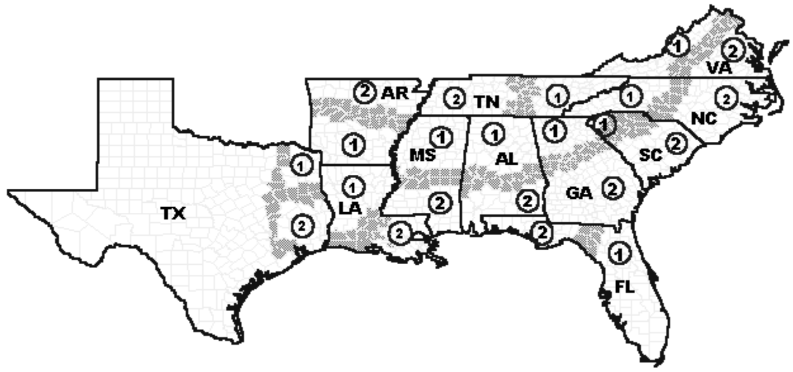

Figure 2.3. Timber Mart-South reporting areas in the U.S. South.

Source: Timber Mart-South (Norris Foundation 1977-present).

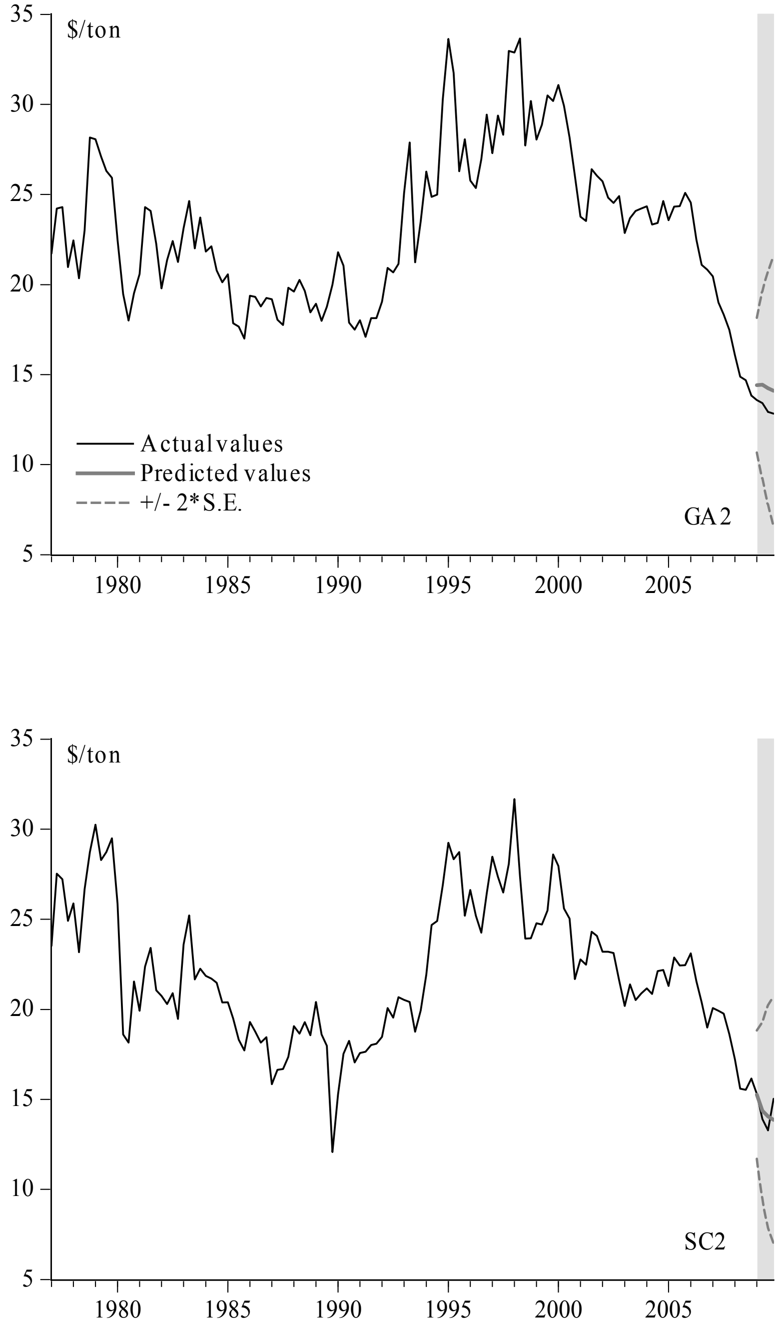

Figure 2.4. Actual values and predicted values with 95% confidence intervals for real pine sawtimber prices in GA2 and SC2 from the VAR(2) model.

Note: 1) Shaded areas are of out-of-sample forecast. 2) Predicted values were transformed back from their natural logarithm values, and standard errors were calculated using the Delta method.

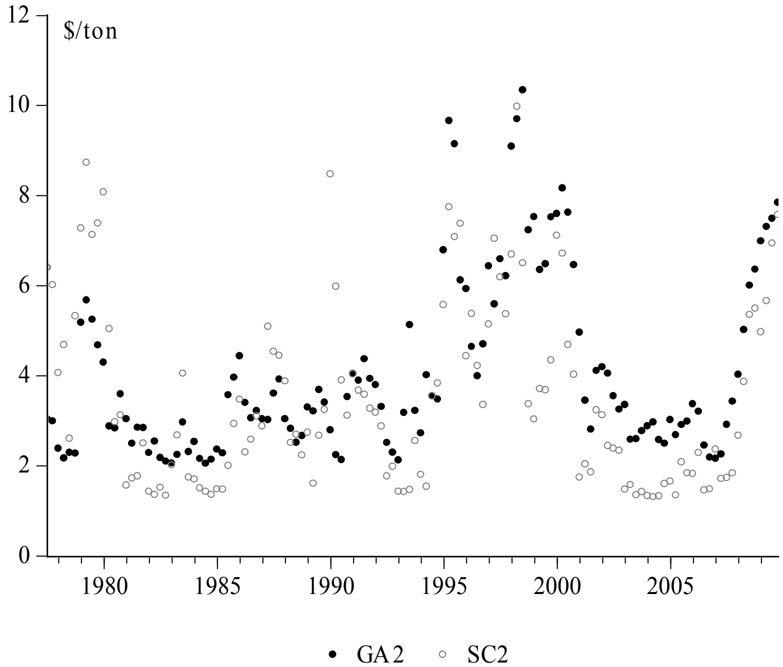

Figure 2.5. Conditional time-varying standard deviations of real pine sawtimber stumpage prices in GA2 and SC2.

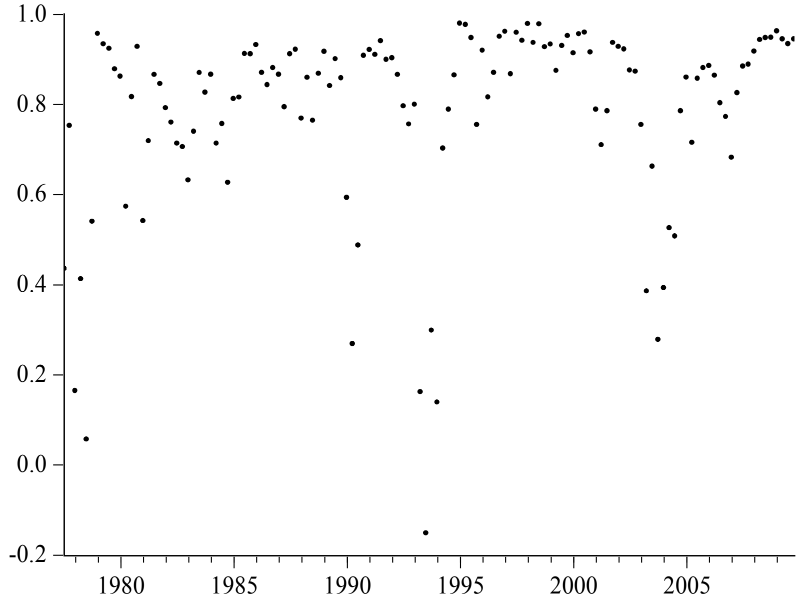

Figure 2.6. Conditional time-varying correlations between real pine sawtimber stumpage prices in GA2 and SC2.

CHAPTER 3

EVALUATING THE FINANCIAL PERFORMANCE OF TIMBERLAND INVESTMENTS IN THE U.S.[3]

[3] Mei, B. and M. L. Clutter. Accepted by *Forest Science*.
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Abstract

Timberland properties have gained increasing attention in recent decades. The attractiveness of this asset primarily lies in its unique feature—the biological growth, which is independent of traditional financial markets. Using both parametric and nonparametric approaches, this study reexamines the financial performance of private- and public-equity timberland investments in the United States. Private-equity timberland returns are proxied by the NCREIF Timberland Index, whereas public-equity timberland returns are proxied by the value-weighted returns on a dynamic portfolio of the U.S. publicly-traded forestry firms that had or have been managing timberlands. The parametric analyses reveal that private-equity timberland assets outperform the market and have low systematic risk, whereas public-equity timberland assets fare similarly as the market. The nonparametric analyses reveal that both private- and public-equity timberland assets have higher excess returns.

Introduction

Timberland investments have been unprecedentedly active in the past few decades. Several factors have motivated public attention toward timberlands. On the supply side, due to the internal subsidies from timber divisions to processing mills, timberland properties managed by traditional vertically-integrated forest products firms have been undervalued by Wall Street. To deal with this mispricing, these firms began divesting their timberlands as a strategic move. For example, International Paper, a global leading forest products firm, has disposed most of its timberlands and focused on its core business of paper and packaging products in recent decades. It is postulated that no forest products firms in the United States will own timberlands in the next few years (Clutter et al. 2008). On the demand side, institutional investors, i.e., organizations with fiduciary obligations such as pension funds, university endowments, foundations, and trusts, have diversified into non-financial assets such as timberlands on the passage of Employee Retirement Income Security Act (ERISA) in 1974.

There are several ways to invest in timberlands. High-net-wealth families and individuals can participate in commingled (pooled) funds, or they can own timberland properties directly. Others can buy stocks and bonds of publicly-traded forestry firms that maintain timberland business. Most institutional investors hold timberland properties via timberland investment management organizations (TIMOs). TIMOs manage their institutional assets in either separately managed accounts (individually managed accounts) or pooled funds. A separately managed account holds timberland properties of one investor in a single portfolio while a pooled fund collects capital from a number of investors and allocates it to a portfolio of timberland properties. Investors tend to have more discretion with separate accounts than pooled funds (Zinkhan and Cubbage 2003). In 2008, there were about 30 TIMOs in the U.S., and the total value of their timberland assets exceeded $35 billion (Zinkhan 2008).

Since the public recognition of timberland as an alternative asset class, a number of studies have been conducted to assess the financial performance of timberland investments. The major findings of previous research can be summarized as follows. 1) Timberland has countercyclical returns or low (even negative in some cases) correlation with the financial assets (Binkley et al. 1996; Cascio and Clutter 2008; Mills and Hoover 1982; Redmond and Cubbage 1988; Washburn and Binkley 1990b; Zinkhan 1988, 2008). 2) Timberland can be an effective hedge against higher-than-expected inflation (Fortson 1986; Washburn and Binkley 1993a). 3) If timberland investors can exploit the biological growth of timber thus time the market, they can get higher and better returns (Caulfield 1998; Conroy and Miles 1989; Haight and Holmes 1991). 4) Relative inefficiency tends to exist in timberland markets (Caulfield 1998), although this situation has been alleviated through time (Washburn 2008; Zinkhan 2008). 5) Among a variety of forestry-related investment vehicles, institutional timberland investments and timberland limited partnerships have low risk levels but excess returns (Sun and Zhang 2001). 6) In the long run, timber and/or timberland returns are cointegrated with other nontimber financial instruments (Heikkinen 2002; Liao et al. 2009).

Almost all of the above studies are based on the single-period capital asset pricing model (CAPM). Sun and Zhang (2001) extend the literature by employing the arbitrage pricing theory (APT); Heikkinen (2002) and Liao et al. (2009) expand the research by using cointegration analysis; but all these methodologies are parametric in nature. This study has several contributions in the area of timberland investments. First, timberland assets are considered separately in private and public markets, and their returns are compared. Second, supplementary to the ordinary least squares (OLS) estimation of CAPM and Fama-French three-factor model, a state space model with Kalman filter is employed to examine the time-varying risk-adjusted excess return (alpha) and systematic risk (beta). Finally, nonparametric stochastic discount factor (SDF) approach is introduced to pricing timberland returns.

The major results are 1) private-equity timberland investments have significant excess returns but low systematic risk, whereas public-equity timberland investments fare similarly as the market; and 2) intertemporal consumption decisions do affect the intertemporal marginal rate of substitution of timberland investors, thus impact the rational pricing of timberland assets. These results can further our understanding of the financial aspects of commercial timberland assets in the U.S. The next two sections describe the methodologies and the data. Section 4 explains the empirical results, and the last section concludes.

Methods

For the parametric method, an explicit model is needed. Two candidate models prevalent in the finance literature are CAPM and Fama-French three-factor model. The parametric method is often criticized for the "joint hypothesis tests" problem, i.e., testing the asset pricing model and the abnormal performance (market efficiency) simultaneously. The nonparametric method does not require such an explicit model specification, and is therefore not subject to these critiques. The SDF approach is a general, nonparametric asset pricing approach, and is complement to the parametric ones.

Capital Asset Pricing Model

Built on Markowitz's (1952) groundwork of mean-variance efficient portfolio, Sharpe (1964) and Lintner (1965) develop its economy-wide implications—CAPM. CAPM states that the expected return on an asset or a portfolio $E[R_i]$ equals a risk free rate R_f plus a premium which depends on the asset's beta β_i and the expected risk premium on the market portfolio $E[R_m]-R_f$, i.e.,

$$E[R_i]=R_f+\beta_i(E[R_m]-R_f). \tag{3.1}$$

In empirical regression analysis, CAPM can be estimated in the excess return form

$$R_i-R_f=\alpha_i+\beta_i(R_m-R_f)+\mu_i, \tag{3.2}$$

where ex post realized returns R_i and R_m rather than ex ante expected returns $E[R_i]$ and $E[R_m]$ are used. The intercept α_i is called Jensen's (1968) alpha. A positive alpha suggests that the individual asset outperforms the market, and earns higher than risk-adjusted return, whereas a negative alpha suggests that the individual asset underperforms the market, and earns lower than risk-adjusted return. Therefore, Jensen's alpha has become a commonly used measure of abnormal performance, and testing whether it is zero has been widely employed in the empirical asset pricing literature.

Fama-French Three-Factor Model

Given the empirical evidence that small size stocks outperform large size stocks, and value (high book-to-market) stocks outperform growth (low book-to-market) stocks on average, Fama and French (1993) develop a model that includes these extra two factors to adjust for risk

$$E[R_i]-R_f=\beta_{RMRF,i}E[R_{RMRF}]+\beta_{SMB,i}E[R_{SMB}]+\beta_{HML,i}E[R_{HML}], \tag{3.3}$$

where $R_{RMRF}=R_m-R_f$ is the same market factor as in CAPM, representing the market risk premium; $R_{SMB}=R_{small}-R_{big}$ is the size factor, representing the return difference between a portfolio of small stocks and a portfolio of large stocks (SMB stands for "Small minus Big"); $R_{HML}=R_{highBM}-R_{lowBM}$ is the book-to-market factor, representing the return difference between a portfolio of high book-to-market stocks and a portfolio of low book-to-market stocks (HML stands for "High minus Low"); and betas are called factor loadings, representing each asset's sensitivity to these factors. When estimating Fama-French three-factor model, ex post realized returns are used as in the case of CAPM, and an intercept is added to capture the abnormal performance

$$R_i - R_f = \alpha_i + \beta_{RMRF,i} R_{RMRF} + \beta_{SMB,i} R_{SMB} + \beta_{HML,i} R_{HML} + \varepsilon_i \,. \qquad (3.4)$$

CAPM and Fama-French Three-Factor Model under the State Space Framework

CAPM (Equation 2) and Fama-French three-factor model (Equation 4) are usually estimated by OLS, possibly with some correction for the autocorrelations in the errors. One restrictive nature of the OLS method is that the coefficients in the regression are imposed to be constant. This may be unrealistic in real asset pricing modeling. For instance, one would suspect that both alphas and betas should be time-varying. To solve this problem, we can estimate CAPM and Fama-French three-factor model in the state space framework with Kalman filter (Appendix A). Using CAPM as an example, in the state space framework, the system of equations is specified as

$$\begin{aligned} R_{i,t} - R_{f,t} &= \alpha_{i,t} + \beta_{i,t}(R_{m,t} - R_{f,t}) + \mu_{i,t} \\ \alpha_{i,t+1} &= \alpha_{i,t} + \xi_t \\ \beta_{i,t+1} &= \beta_{i,t} + \tau_t \end{aligned} \qquad (3.5)$$

where $\mu_{i,t}$, ξ_t, and τ_t are normally and independently distributed mean-zero error terms. In the state space model, the first equation in (5) is called the observation or measurement equation, while the second and third equations are called the state equations. In this particular case, each state variable follows a random walk.

One advantage of the state space approach with time-varying parameters is that it can incorporate external shocks, such as policy and regime shifts, economic reforms, and political uncertainties, into the system, especially when the shocks are diffuse in nature (Sun 2007). This approach has been applied to a variety of issues, including demand systems (e.g., Doran and Rambaldi 1997), aggregate consumptions (e.g., Song et al. 1996), policy analysis (e.g., Sun 2007), and price modeling and forecasting (e.g., Malaty et al. 2007).

Stochastic Discount Factor Approach

The single-period asset pricing models ignore the consumption decisions. In effect, investors make their consumption and portfolio choices simultaneously in an intertemporal setting. In the framework of an exchange economy in which an investor maximizes the expectation of a time-separable utility function (Lucas 1978), it can be proved that (Appendix B)

$$E_t[(1+R_{i,t+1})M_{t+1}] = 1, \qquad (3.6)$$

where $R_{i,t+1}$ is the return on asset *i* in the economy, and M_{t+1} is known as the stochastic discount factor, or intertemporal marginal rate of substitution, or pricing kernel (e.g., Campbell et al. 1997).

Hansen and Jagannathan (1991) demonstrate how to identify the SDF from a set of basis assets, i.e., the derivation of the volatility bounds. These bounds are recognized as regions of admissible mean-standard deviation pairs of the SDF. Their major assumptions are the law of one price and the absence of arbitrage opportunities. Accordingly, there are two particular solutions for the SDF—the law of one price SDF and the no-arbitrage SDF. The process of retrieving the reverse-engineered law of one price SDF is equivalent to the following constrained optimization problem

$$
\begin{aligned}
&\underset{M_t}{Min} \quad \sigma_{M_t} = \left[\frac{1}{T-1} \sum_{t=1}^{T} (M_t - v) \right]^{1/2} \\
&s.t. \quad \frac{1}{T} \sum_{t=1}^{T} M_t = v \\
&\qquad \frac{1}{T} \sum_{t=1}^{T} M_t (1 + R_{i,t}) = 1
\end{aligned} \tag{3.7}
$$

for a range of selected v (mean of M_t), and for all assets $i = 1,2,\cdots,N$. Under the stronger condition of no arbitrage, another positivity constraint on M_t is needed. Therefore, the only difference between the law of one price SDF and the no-arbitrage SDF is whether M_t is allowed to be negative. In this study, no-arbitrage SDF is used. Following Hansen and Jagannathan (1991), nonnegativity instead of positivity restriction $M_t \geq 0$ is added to retrieve the no-arbitrage SDF. Lastly, sample size *T* should be sufficiently large such that the time-series version of law of large numbers applies, that is, the sample moments on a finite record converge to their population counterparts as the sample size becomes large (Hansen and Jagannathan 1991).

Provided the existence of a risk free asset, it can be shown that

$$E_t[(R_{i,t+1} - R_f)M_{t+1}] = 0. \tag{3.8}$$

This equation presents the basis for testing the risk-adjusted performance of a portfolio (Chen and Knez 1996). Namely, one can test whether

$$\alpha_i = E_t[\alpha_{i,t}] = E_t[(R_{i,t+1} - R_f)M_{t+1}] = 0. \tag{3.9}$$

Ahn et al. (2003) point out that this measure generalizes Jensen's alpha, and does not count on a specific asset pricing model. Based on this method, they reassess the profitability of momentum strategies, and find that their nonparametric risk adjustment explains almost half of the anomalies.

Data

Timberland Returns

Returns for both private- and public-equity timberland investments are analyzed. Although TIMOs have become the major timberland investment management entities for institutional investors as well as high-net-wealth families and individuals, their financial data are rarely publicly available. To provide a performance benchmark, several TIMOs, together with National Council of Real Estate Investment Fiduciaries (NCREIF) and the Frank Russell Company, initiated the NCREIF Timberland Index in early 1992 (Binkley et al. 2003) (Appendix C). NCREIF members can be divided into data contribution members, professional members, and academic members. Data contribution members include investment managers and plan sponsors who own or manage real estate in a fiduciary setting. Professional members include providers of accounting, appraisal, legal, consulting or other services to the data contribution members. Academic members include full-time professors of real estate. Data contribution members submit their data on a quarterly basis for computation of the NCREIF Property Index. Regarding the NCREIF Timberland Index, it is some TIMOs that are the major data contribution members. The quarterly NCREIF Timberland Index is reported at both regional (the South, the Northeast, and the Pacific Northwest) and national levels, and extends back to 1987. In this study, the national-level NCREIF Timberland Index (1987Q1-2008Q4) is used as a return proxy for the U.S. private-equity timberland investments.

Returns on public-equity timberland investments are proxied by the value-weighted returns on a dynamic portfolio of the U.S. publicly-traded forestry firms that had or have been managing timberlands. These firms include Deltic Timber, The Timber Co, IP Timberlands Ltd, Plum Creek, Pope Resources, Potlatch, Rayonier, and Weyerhaeuser. Deltic Timber and Pope Resources are natural resources companies focused on the ownership and management of timberland; The Timber Co and IP Timberlands Ltd are subsidiaries of Georgia-Pacific and International Paper that track the value and performance of their timberland properties; Plum Creek, Potlatch, and Rayonier are publicly-traded real estate investment trusts (REITs) that are engaged in timberland management; and Weyerhaeuser is a forest products firm that has a significant portion of its business in timberlands. The market value of each firm is calculated as the product of stock price and total shares outstanding at the end of each quarter. Financial data for these forestry firms are obtained from the Center for Research in Security Prices (CRSP). To be consistent with the NCREIF Timberland Index, the sample spans from 1987Q1 to 2008Q4.

Basis Assets

To mimic the complete investment opportunity set that is available to investors, a parsimonious set of basis assets needs to be specified. King (1966) proves that industry groupings maximize intra-group correlation and minimize inter-group correlation, and concludes that market and industry factors capture most of the common variation in stock returns. Following Hansen and Jagannathan (1991), we construct the reference set by forming industry portfolios according to SIC code. In this study, two sets of basis assets are chosen—one is the five-industry portfolios plus long-term treasury bonds, and the other is the ten-industry portfolios plus long-term treasury bonds. The industry groups are derived from stocks listed on NYSE, AMEX, and NASDAQ based on their four-digit SIC codes. The five industries are classified as consumer goods, manufacturing, Hi-Tech, healthcare, and others, while the ten industries are classified as consumer non-durables, consumer durables, manufacturing, energy, Hi-Tech, telephone and television transmission, shops, healthcare, utilities, and others. Value-weighted returns on the industry portfolios are obtained from Kenneth R. French's website, and returns on the portfolio of long-term treasury bonds are obtained from CRSP. Presuming that the basis assets are rationally priced, the SDF can be retrieved.

Other Indices

Market returns are approximated by the value-weighted returns on all NYSE, AMEX, and NASDAQ stocks from CRSP. Risk free rate, as approximated by the one-month Treasury bill rate from Ibbotson Associates, Inc., and Fama-French factors are available on Kenneth R. French's website.

Empirical Results

Estimation of CAPM and Fama-French Three-Factor Model

Panel A of Table 3.1 presents the OLS estimation of CAPM and Fama-French three-factor model using the quarterly NCREIF Timberland Index after adjusting for the seasonality. Significant positive alpha from CAPM suggests that private-equity timberland investments have a risk-adjusted excess return of about 9.36% (2.34% × 4) per year. This excess return is slightly larger after accounting for Fama-French factors. Market betas from both models are insignificantly different from zero, but significantly less than one. This means that private-equity timberland investments are not only weakly correlated with the market, but also less risky than the market. The small magnitudes with high *p*-values of the coefficients for SMB and HML signify that these two extra factors add limited explanatory power to CAPM in pricing private-equity timberland returns.

In contrast, CAPM and Fama-French three-factor model fit the returns on the dynamic portfolio of forestry firms much better as implied by the higher R^2 values (Panel A of Table 3.2).

This is within our expectation since these forestry firms are publicly-traded and are more exposed to the market. However, alphas are insignificant albeit positive, indicating no abnormal performance. Market betas are significantly different from zero, but not from one. In addition, betas for SMB and HML in Fama-French three-factor model are highly significant, meaning these factors capture some variations in the portfolio returns that are not explained by the market premium. As a result, the abnormal performance (alpha value) has dropped by 50%. The magnitudes of betas indicate that the dynamic portfolio is dominated by mid-large firms with middle book-to-market ratios.

State Space Estimation of CAPM and Fama-French Three-Factor Model

Panel B of Table 3.1 presents the state space estimation of CAPM and Fama-French three-factor model using the NCREIF Timberland Index. Those OLS coefficient estimates are used as the starting values. Only alpha is specified as a state variable (stochastic level) in that little time-variation is observed in beta, and both AIC and SBC favor the deterministic-beta model. Back to the model specification in system (5), this is equivalent to restrict $\tau_t = 0$. The magnitudes of the parameter estimates are similar to the OLS ones. The AIC and SBC are marginally larger than those for the OLS estimation due to the relatively small sample size. Figure 3.1 depicts the evolution of the risk-adjusted excess returns of the NCREIF Timberland Index estimated from CAPM. For most time in the last 22 years, the NCREIF Timberland Index has achieved positive abnormal returns with an average of 10.6% per year (calculated from the estimated alpha series). Nevertheless, in certain years (2001-2003) the alpha is low and even negative, indicating no abnormal performance. Although not reported here, the time-varying alphas estimated from Fama-French three-factor model exhibit similar patterns.

For the dynamic portfolio, however, only beta is specified to be stochastic since little time-variation is observed in alpha, and both AIC and SBC favor the deterministic-alpha model. The time-varying beta of the dynamic portfolio of forestry firms is plotted in Figure 3.2. Overall, there is a decreasing trend in the market beta. The average beta over the sample period is 1.06, which is not significantly different from the market risk.

Abnormal Performance Measured by the SDF Approach

The mean of the no-arbitrage SDF M_t is specified in the selected range of [0.9750, 1] with an increment step of 0.0025. When the five-industry portfolios plus the long-term treasury bonds are used as the basis assets, the global minimum variance of M_t is identified at $v =$ 0.9800; when the ten-industry portfolios plus the long-term treasury bonds are used instead, the global minimum variance of M_t is identified at $v = 0.9750$.

The SDF performance measures for both the NCREIF Timberland Index and the returns on the dynamic portfolio of publicly-traded timber firms are reported in Table 3.3. The alpha values for both return indices have increased, and the latter has become marginally significant. This indeed implies that intertemporal consumption decisions play a key role in pricing timberland assets. In a word, there is clear evidence of statistically as well as economically significant excess returns for the NCREIF Timberland Index, but only some evidence of economically significant excess returns for the portfolio of publicly-traded timber firms.

Conclusions

Employing both parametric and nonparametric techniques, this study reexamines the financial performance of timberland investments. Private-equity timberland returns are approximated by the NCREIF Timberland Index, whereas public-equity timberland returns are approximated by the value-weighted returns on a dynamic portfolio of the U.S. publicly-traded timber firms. The parametric analyses reveal that private-equity timberland assets outperform the market but have low systematic risk, whereas public-equity timberland assets perform similarly as the market. Therefore, inclusion of private-equity timberland properties can improve the efficient frontier, albeit such potential is limited for public-equity timberland properties. Unlike the parametric methods, the nonparametric SDF approach does not rely on any specific asset pricing models hence are not subject to the "joint hypothesis tests" criticisms. Results from the SDF approach suggest higher excess returns for both private- and public-equity timberland investments, which in turn signify the important role of intertemporal consumption decisions in rational pricing of timberland assets.

The positive alpha of private-equity timberland returns may be associated with the patience of institutional investors toward timberlands' embedded strategic options (Zinkhan 2008). If a timberland property has potential for higher and better use such as residential or commercial development opportunities, or if it is suitable for conservation easements, or if it has mineral or gas opportunities, it may have extra income sources, and the land value can be dramatically higher. The positive alpha may also be related to the liquidity risk that institutional investors bear since a typical TIMO has an investment time horizon of 10-15 years or even longer. In contrast, stocks of publicly-traded timber firms can be easily traded on the stock exchanges. Moreover, initiation of a TIMO-type separately managed account usually requires a capital commitment of $25 to $50 million, while participation in a TIMO-type pooled fund generally requires a minimum capital commitment of $1 to $3 million (Zinkhan and Cubbage 2003). The large capital amount may enable the investors to achieve some degree of diversification.

The lower excess returns of the NCREIF Timberland Index around 2001-2003 may be associated with its relative weak performance during that time. In 2001Q4, the NCREIF Timberland Index fell by 6.5%, the largest drop it ever had, which is primarily caused by the capital loss from the shrinking timberland values. In the same period, the S&P 500 index went up by 7.8%. The overall decreasing trend in beta for the dynamic portfolio of forestry firms may be related to the massive restructurings of these firms. For instance, Plum Creek, Potlatch, and Rayonier have converted themselves into timber REITs in recent years. With improved tax efficiency and increased concentration on timberland management, these timber REITs are expected to be less risky.

Another interesting fact noted in this study is that, despite the current economic downturn triggered by the sub-prime residential mortgage blow-up, private-equity timberland returns remain relatively strong. While the CRSP market index went down 39% in 2008, the NCREIF Timberland Index achieved a 9% return, or on the risk-adjusted basis, an excess return of 10% (calculated using the estimated alpha series in 2008). In contrast, the portfolio value of publicly-traded timber firms fell 39% just like the market. However, it should be noted that most of those forestry firms do have non-timberland business, such as paper and lumber mills, which may be more sensitive to the overall economic conditions. A close examination of the three publicly-traded timber REITs reveals that they were less affected by the gloomy market. Looking ahead, global economic crisis will last for some time, multiple factors will affect timberland returns, and the net effect on timberland properties has yet to be observed (Washburn 2008).

It should be noted that there have been some concerns about the data and method consistency of the NCREIF Timberland Index. As pointed out by Binkley et al. (1996), there is no standardized appraisal and valuation practice in forestry so heterogeneity may exist in the data. In addition, due to lack of quarterly appraisals for many properties in the NCREIF Timberland Index, quarterly return series may be less useful than the annual ones. Finally, the NCREIF Timberland Index is a composite performance measure of a very large pool of commercial forestland properties acquired in the private market for investment purposes. Hence caution should be used when interpreting the NCREIF Timberland Index, especially from an individual investor's perspective.

Appendix 3A

State space model with Kalman filter

The multivariate time series model can be represented by the following state space form

$$y_t = Z_t\alpha_t + \varepsilon_t, \qquad \varepsilon_t \sim NID(0, H_t) \tag{3A1}$$

$$\alpha_{t+1} = T_t\alpha_t + R_t\eta_t, \qquad \eta_t \sim NID(0, Q_t) \tag{3A2}$$

for $t = 1,\ldots,N$, where y_t is $p \times 1$ vector of observed values at time *t*, Z_t is a $p \times m$ matrix of variables, α_t is $m \times 1$ state vector, T_t is called the transition matrix of order $m \times m$, and R_t is an $m \times r$ selection matrix with $m \geq r$. The first equation is called the observation or measurement equation, and the second is called state equation. The parameters α_t, H_t, and Q_t in the system of equations can be estimated jointly by the maximum likelihood method with the recursive algorithm Kalman filter. The intention of filtering is to update the information of the system each time a new observation y_t is available, and the filtering equations are,

$$\begin{aligned}
v_t &= y_t - Z_t a_t, \\
F_t &= Z_t P_t Z_t' + H_t, \\
K_t &= T_t P_t Z_t' F_t^{-1}, \\
L_t &= T_t - K_t Z_t, \\
a_{t+1} &= T_t a_t + K_t v_t, \\
P_{t+1} &= T_t P_t L_t' + R_t Q_t R_t',
\end{aligned} \tag{3A3}$$

for $t = 1,\ldots,N$. The mean vector a_1 and the variance matrix P_1 are known for the initial state vector α_1 (Durbin and Koopman 2001; Harvey 1989).

Appendix 3B

Heuristic proof of Equation 3.6

In a pure exchange economy with identical consumers, a typical consumer wishes to maximize the expected sum of time-separable utilities

$$\begin{aligned} &\underset{C_t}{Max} \quad E_t\left[\sum_{i=0}^{\infty}\beta^i U(C_{t+i})\right] \\ &s.t. \quad \sum_{j=1}^{N} x_t^j p_t^j + C_t = W_t + \sum_{j=1}^{N} x_{t-1}^j (p_t^j + d_t^j) \end{aligned} \tag{3A4}$$

where x_t^j is the amount of security *j* purchased at time *t*, p_t^j is the price of security *j* at time *t*, W_t is the individual's endowed wealth at time *t*, C_t is the individual's consumption at time *t*, d_t^j is the dividend paid by security *j* at time *t*, and β is time discount. Express C_t in terms of x_t^j, and differentiate the objective function with respect to x_t^j, then we can get the following first order condition:

$$E_t[U^{'}(C_t)p_t^j] = E_t[\beta U^{'}(C_{t+1})(p_{t+1}^j + d_{t+1}^j)] \tag{3A5}$$

for all *j*. After rearranging the terms, we can reach Equation 3.6, where

$$\begin{aligned} M_t &= \frac{\beta U^{'}(C_{t+1})}{U^{'}(C_t)} \\ R_{t+1} &= \frac{p_{t+1}^j + d_{t+1}^j}{p_t^j} - 1 \end{aligned} \tag{3A6}$$

Appendix 3C

NCREIF Timberland Index

The NCREIF Timberland Index has two components, the income return and the capital return. The income return is also known as EBITDDA return, which represents earnings before interest expenses, income taxes, depreciation, depletion and amortization. The capital return is derived from land appreciation. The formulas to calculate these returns are

$$IR_t = \frac{EBITDDA_t}{MV_{t-1} + 0.5(CI_t - PS_t + PP_t - EBITDDA_t)} \quad (3A7)$$

$$CR_t = \frac{MV_t - MV_{t-1} - CI_t + PS_t - PP_t}{MV_{t-1} + 0.5(CI_t - PS_t + PP_t - EBITDDA_t)} \quad (3A8)$$

where IR_t and CR_t are the income return and capital return, respectively; $EBITDDA_t$ equals the net operating revenue obtained from the tree farm (primarily from timber sales); CI_t equals the capitalized expenditures on the tree farm (e.g., forest regeneration and road construction); PS_t equals the net proceeds from sales of land from the tree farm; PP_t equals the gross costs of adding land to the tree farm; MV_t equals the market value of the tree farm (Binkley et al. 2003).

Table 3.1. Estimation of CAPM and Fama-French three-factor model using the NCREIF Timberland Index (1987Q1-2008Q4)

CAPM			FF3		
Coefficient	Estimate	*p*-value	Coefficient	Estimate	*p*-value
Panel A: OLS estimation					
α	2.34	0.001	α	2.38	0.000
β	0.04	0.369	β_{RMRF}	0.06	0.336
			β_{SMB}	-0.06	0.464
			β_{HML}	-0.03	0.558
H_0: $\beta = 1$		0.000	H_0: $\beta_{RMRF} = 1$		0.000
R^2	0.14		R^2	0.15	
Log likelihood	-230.48		Log likelihood	-230.04	
S.E. of regression	3.83		S.E. of regression	3.86	
Durbin-Watson stat.	2.05		Durbin-Watson stat.	2.06	
Akaike info. criterion	5.56		Akaike info criterion	5.60	
Schwarz criterion	5.65		Schwarz criterion	5.74	
F-stat.	6.50		*F*-stat.	3.41	
Panel B: State space estimation					
α	2.47	0.062	α	2.53	0.048
β	0.01	0.919	β_{RMRF}	0.04	0.649
			β_{SMB}	-0.13	0.221
			β_{HML}	-0.04	0.681
H_0: $\beta = 1$		0.000	H_0: $\beta_{RMRF} = 1$		0.000
Log likelihood	-254.71		Log likelihood	-253.29	
Akaike info. criterion	5.86		Akaike info criterion	5.87	
Schwarz criterion	5.94		Schwarz criterion	6.01	

Note: 1) OLS estimates after correction for the fourth-order autocorrelation in the residuals; and 2) Only alpha is specified stochastic under the state space framework, while beta is specified deterministic due to its lack of variation and AIC criterion.

Table 3.2. Estimation of CAPM and Fama-French three-factor model using returns on a dynamic portfolio of the U.S. publicly-traded forestry firms (1987Q1-2008Q4)

CAPM			FF3		
Coefficient	Estimate	*p*-value	Coefficient	Estimate	*p*-value
Panel A: OLS estimation					
α	0.57	0.562	α	0.28	0.756
β	0.95	0.000	β_{RMRF}	0.92	0.000
			β_{SMB}	0.47	0.012
			β_{HML}	0.45	0.001
H_0: $\beta = 1$		0.328	H_0: $\beta_{RMRF} = 1$		0.246
R^2	0.45		R^2	0.56	
Log likelihood	-318.18		Log likelihood	-308.60	
S.E. of regression	9.10		S.E. of regression	8.26	
Durbin-Watson stat.	2.16		Durbin-Watson stat.	2.32	
Akaike info. criterion	7.28		Akaike info criterion	7.10	
Schwarz criterion	7.33		Schwarz criterion	7.22	
F-stat.	69.48		*F*-stat.	34.13	
Panel B: State space estimation					
α	0.57	0.610	α	0.23	0.788
β	0.95	0.000	β_{RMRF}	0.89	0.000
			β_{SMB}	0.47	0.005
			β_{HML}	0.45	0.000
H_0: $\beta = 1$		0.388	H_0: $\beta_{RMRF} = 1$		0.442
Log likelihood	-329.48		Log likelihood	-319.86	
Akaike info. criterion	7.56		Akaike info criterion	7.38	
Schwarz criterion	7.64		Schwarz criterion	7.52	

Note: Only beta is specified stochastic under the stochastic framework, while alpha is specified deterministic due to its lack of variation and AIC criterion.

Table 3.3. Performance measures of timberland investments by the nonparametric SDF approach (1987Q1-2008Q4)

Mean of $M_t (v)$	S.D. of M_t (σ_{M_t})	Performance measure (α)		p-value (one tail)	
		(1)	(2)	(1)	(2)
Panel A: Five-industry portfolios plus long-term T-bonds					
0.9775	0.199	2.625	1.585	0.000	0.119
0.9800	0.176	2.599	1.355	0.000	0.156
0.9825	0.217	2.573	1.125	0.000	0.202
Panel B: Ten-industry portfolios plus long-term T-bonds					
0.9725	0.244	2.762	2.033	0.000	0.056
0.9750	0.237	2.749	1.823	0.000	0.082
0.9775	0.255	2.769	1.595	0.000	0.116

Note: Column (1) is for the NCREIF Timberland Index; and Column (2) is for returns on a dynamic portfolio of the U.S. publicly-traded forestry firms that had or have been managing timberlands.

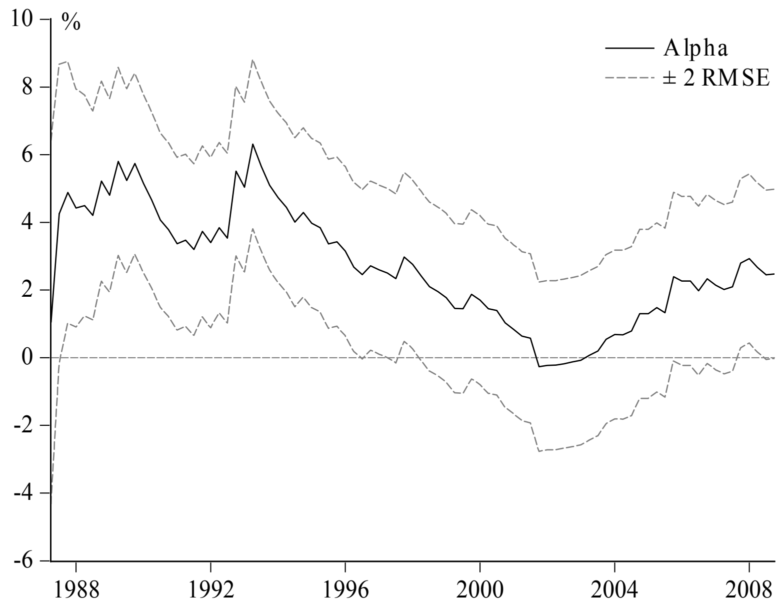

Figure 3.1. Evolution of alpha over time from the state space estimation of CAPM using the NCREIF Timberland Index (1987Q1-2008Q4).

Note: The time-varying alpha estimated from Fama-French three-factor model exhibits similar patterns, thus is not shown separately. The graph is available from the authors upon request.

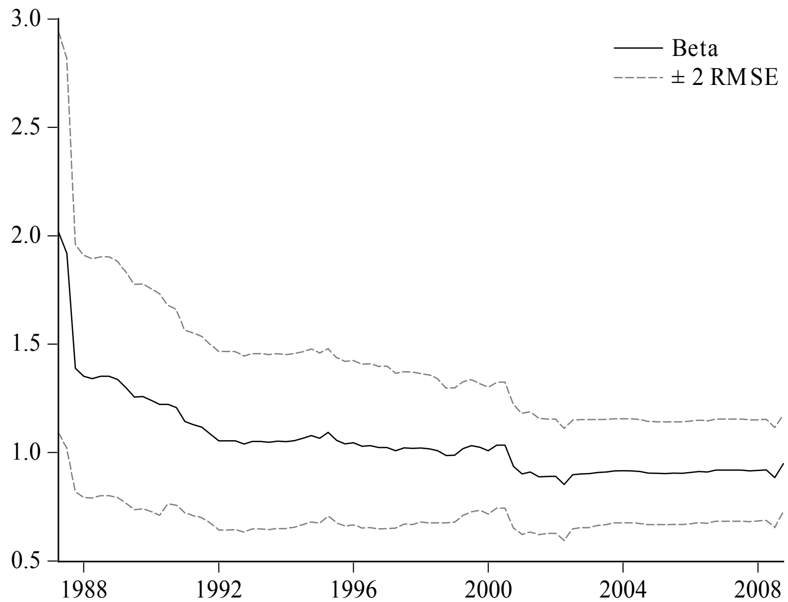

Figure 3.2. Evolution of beta over time from the state space estimation of CAPM using returns on a dynamic portfolio of the U.S. publicly-traded forestry firms (1987Q1-2008Q4).

Note: The time-varying beta estimated from Fama-French three-factor model exhibits similar patterns, thus is not shown separately. The graph is available from the authors upon request.

CHAPTER 4

INVESTIGATION OF VARIOUS OPTION VALUES IN TIMBERLAND INVESTMENTS[4]

[4] Mei, B. and M. L. Clutter. Submitted to *Journal of Forest Economics*, January 2010.

Abstract

Static net present value (NPV) analysis ignores management flexibility in timberland investments. Using contingent claims approach, this study investigates the option values of investment, mothballing, reactivation, and abandonment in a hypothetical southern pine plantation when the timber price follows a geometric Brownian motion. The contingent claims approach starts with constructing a riskless hedging portfolio that earns risk-free rate of return. In the continuation region a partial differential equation is established. Substituting in the general solutions and applying boundary conditions, a system of nonlinear equations is formed and solved numerically. Then various option values is calculated. As a robust check, a mean-reverting process for the timber price has been assumed. However, minor differences have been identified. Finally, sensitivity analyses are conducted to examine the partial effects of changes in the key economic factors on changes in the option values.

Introduction

Prior to the 1980s, most commercial timberland properties in the U.S. were managed by the forest products firms. These firms viewed their timberland assets as an additional insurance on their timber supply. However, the timberland properties have long been undervalued by Wall Street analysts due to the internal subsidize from the timberland divisions to the manufacturing divisions, and recent mergers and acquisitions within the industry have left huge debts on their balance sheets (Mei et al. 2009). As a strategic move, the forest products firms began to liquidate their timberland properties, primarily by selling them to institutional investors seeking for alternative investment opportunities. Institutional investors hold timberland assets typically through timberland investment management organizations (TIMOs), which use either separately managed accounts (individually managed accounts) or commingled (pooled) funds (Zinkhan and Cubbage 2003). In 2008, more than 30 TIMOs existed in the U.S., and the total value of their timberland assets exceeded $35 billion (Zinkhan 2008).

Timberland investments usually cost millions of dollars, and part of the initial cost is sunk or irreversible. The expected future payoffs take the forms of regular timber sales and land appreciation. Both timber price and bare land price involve uncertainty. The former has been historically more volatile, while the latter has been proved to be somewhat correlated with inflation (Washburn and Binkley 1993a; Zinkhan 2008; Zinkhan et al. 1992). Nevertheless, timberland has several unique features, and these features enable investors even more flexibility in developing strategic plans than those in other industries. First, trees keep growing for a long period of time, and increase in volume and quality. By postponing harvesting, more valuable products can be produced. Faustmann (1849) concludes that the optimal rotation length is when the value of current annual increment caused by delaying harvest equals its opportunity cost in terms of the interest on standing timber and land rent. Second, trees can be stored on the stump with minimum maintenance cost. Timber production can be easily mothballed during bad economic times, and later reactivated when timber prices rise again. Finally, tree plantations can be abandoned should the timber price fall too low. The salvage value in terms of timber and land sales usually more than offsets the exit cost.

Static net present value (NPV) analysis ignores these implicit options in that it is based on the assumption that any investment opportunity is a now or never proposition. This may result in undervaluation of the timberland assets. Contrasting to the static NPV analysis, the option approach requires less stringent assumptions, and considers management flexibility. The option to invest always has a positive value as long as the price is greater than zero, and this option value should be counted as an opportunity cost when a firm makes an irreversible investment decision. In that sense, an investment decision is analogous to a call option—whenever exercised, the investor gives up the opportunity to wait for more information in return for an asset whose value is uncertain. Once a project is established, the manager has the options to mothball, reactivate, and permanently abandon it should market conditions vary. In short, all these options should also be priced in valuating a timberland project.

The objective of this study is to use contingent claims approach to explicitly investigate real option values in timberland investments under stochastic timber prices. These option values are shown by a simple numerical example. Section II reviews the literature in timberland management and investment that considers real option values. Section III describes the real option approach. Section IV applies the contingent claims approach to a hypothetical southern pine plantation in state Georgia. Section V examines the robustness and sensitivity of the option values with respect to timber price assumptions and key parameters. The last section concludes the article.

Literature Review

A number of studies expand the Faustmann model by considering stochastic rather than deterministic stumpage price and/or inventory. Clarke and Reed (1989) and Reed and Clarke (1990) apply various types of stochastic processes for timber prices and wood volume in establishing the barrier rule of optimal harvesting. Morck et al. (1989) use a contingent claims approach within the context of Merton's (1973) intertemporal capital asset pricing model to value a hypothetical leased white pine forest, where both prices and inventories follow a standard Ito process. Thomson (1992) models timber prices as a lognormal diffusion process, and by computing the option values numerically with the binomial procedure, he finds a generally longer rotation length, a higher stand value, and a nonlinear pattern in net present value (NPV) gain as timber price volatility increases. Plantinga (1998) argues that the reservation price strategy (e.g., Brazee and Mendelsohn 1988; Haight and Holmes 1991) per se is equivalent to considering the option value in determining the optimal rotation age. Insley (2002) probes the general numerical solution technique in solving the optimal harvesting problem for an even aged stand of trees within a single rotation. Significant different stand values and cutting times are found under different timber price assumptions. Insley and Rollins (2005) improve the numerical solution technique in Insley (2002) by extending it to the multi-rotation case.

Several studies investigate forest real options from other perspectives. Conroy and Miles (1989) find a higher return and a lower variance by setting a benchmark timber price that is 5% above the rolling 12-month trend line. Zinkhan (1991) values timberland conversion options, and posits that neglecting land-use conversion options can lead to underestimation of the intrinsic value of timberland. Reed (1993), Conrad (1997), Forsyth (2000), and Saphores et al. (2002) assume stochastic amenity value or timber prices, and derive the minimum amenity value required for conserving a old-growth forest. Yin and Newman (1999) address a timber producer's entry, exit, mothballing, and reactivation decisions given random timber prices. Hughes (2000) prices a sale of a New Zealand forestry corporation as a call option, and argues his approach has advantages in that only volatility of future timber prices needs to be estimated. Yin et al. (2000) use the example of linerboard production to evaluate option values of timberland ownership on operating decisions. Yin (2001) points out the limitations of stand-level analysis in assessing forestry investments, and demonstrates a new framework by combining forest-level analysis with the options valuation approach. Assuming mean-reverting timber prices, Gjolberg and Guttormsen (2002) explain that low discount rates in forestry may indicate rational pricing of comparatively low-risk, long-term investments with real option values included. Schatzki (2003) considers return uncertainty and sunk costs in a real option model, and examines land conversion from agriculture to forest. Yap (2004) models the Philippine forest plantation lease as an option, and asserts that timber price uncertainty could explain why leaseholders have insufficient incentives for immediate planting.

Our summary of the literature reveals two features related to the objective of this study. One feature is that most previous research considers timberland option values implicitly in making strategic decisions (e.g., optimal rotation, and entry and exit decisions). Little research has examined the option values explicitly. The other feature is that most previous research assumes geometric Brownian motion timber prices without justification. In this study, various option values in timberland investments are investigated via a hypothetical southern pine plantation. The robustness of the geometric Brownian motion assumption is checked by examining timber price data under the alternative mean reverting process. The effects of changes in the key parameters on changes in the option values have been examined in the sensitivity analysis.

Methodologies

The Basic Model

As described in McDonald and Siegel (1986), consider a firm's investment decision as the choice of the optimal time to install an investment with a lump-sum cost *I* in return for a project with an uncertain value *V*, given that the capacity installation is irreversible. From this perspective, the firm's investment opportunity is just like a call option on the project with an excise price *I*. Denoting the value of the investment opportunity by *F*, the optimal rule can be expressed as

$$F = \max_{T} E[(V_T - I)e^{-\rho T}] \tag{4.1}$$

where *E* represents the expectation, *T* is the time to invest, ρ is the cost of capital (Dixit and Pindyck 1994). Since *V* and *F* are contingent or derivative assets, whose values rely on that of the more basic asset (end product) *P*, they are usually expressed as functions of *P*, i.e., *V*(*P*) and *F*(*P*). In empirical studies, two forms of stochastic processes for *P* are generally assumed—the geometric Brownian motion and the geometric Ornstein-Uhlenbeck process. The former can be viewed as the counterpart of random walk in the discrete-time framework, while the latter can be viewed as the counterpart of mean-reversion.

A geometric Brownian motion can be described as

$$dP = \alpha P dt + \sigma P dz \tag{4.2}$$

where α is the drift (growth rate) parameter, σ is the volatility (proportional variance) parameter, and *dz* is the increment of the standard Wiener process defined as $dz = \varepsilon_t \sqrt{dt}$, ε_t being a standard normal random variable. Tsay (2005) demonstrates the way to estimate α and σ 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 $\hat{\sigma} = s/\sqrt{\Delta}$, 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.

A geometric Ornstein-Uhlenbeck process can be described as

$$dP = \eta(\bar{P} - P)dt + \sigma P dz \tag{4.3}$$

where η is the speed of reversion, $\bar{P}$ is the long-run equilibrium level that *P* tends to revert to, and *dz* is similarly defined as in the geometric Brownian motion. A discrete time approximation to the geometric Ornstein-Uhlenbeck process is

$$P_t - P_{t-1} = \eta\bar{P}\Delta t - \eta\Delta t P_{t-1} + \sigma P_{t-1}\sqrt{\Delta t}\varepsilon_t . \tag{4.4}$$

Dividing both sides by P_{t-1}, Equation 4.4 can be estimated by running the following regression

$$r_t = c(1) + c(2)\frac{1}{P_{t-1}} + e_t \tag{4.5}$$

where $c(1) = -\eta\Delta t$, $c(2) = \eta\bar{P}\Delta t$, and $e_t = \sigma\sqrt{\Delta t}\varepsilon_t$ (Insley 2002).

The difference between the two is in their drift term. For the geometric Brownian motion the drift term remains constant, but for the geometric Ornstein-Uhlenbeck process it depends on the current value of the process, and can be either positive or negative. For illustration purpose, the following solution is based on geometric Brownian motion timber prices. The solution under the alternative assumption can be found in Dixit and Pindyck (1994).

Solution by Dynamic Programming

Since the investment opportunity $F(P)$ produces no cash flows till time T when the investment is made, the only return comes from capital appreciation, i.e., the Bellman equation is

$$\rho F dt = E[dF]. \tag{4.6}$$

Expand dF using Ito's Lemma and substitute it back, then the Bellman equation becomes the following differential equation

$$\frac{1}{2}\sigma^2 P^2 F''(P) + (\rho - \delta) P F'(P) - \rho F = 0 \tag{4.7}$$

where $\delta = \rho - \alpha$ is the dividend (convenience) yield.

The general solution to this equation is

$$F(P) = A_1 P^{\beta_1} + A_2 P^{\beta_2} \tag{4.8}$$

where A_1 and A_2 are positive constants to be determined,

$$\beta_1 = \tfrac{1}{2} - (\rho - \delta)/\sigma^2 + \sqrt{[(\rho - \delta)/\sigma^2 - \tfrac{1}{2}]^2 + 2\rho/\sigma^2} \tag{4.9}$$

and

$$\beta_2 = \tfrac{1}{2} - (\rho - \delta)/\sigma^2 - \sqrt{[(\rho - \delta)/\sigma^2 - \tfrac{1}{2}]^2 + 2\rho/\sigma^2}\ . \tag{4.10}$$

Applying the boundary conditions, the solution can be further simplified to $F(P) = A_1 P^{\beta_1}$ (Dixit and Pindyck 1994).

Solution by Contingent Claims Analysis

Unlike the dynamic programming approach, the contingent claims (option pricing) approach does not require an arbitrary, exogenous, constant discount rate ρ, but assumes an overall equilibrium in capital markets. It starts by constructing the following dynamic risk-free portfolio: Long one unit of the option to invest, short $F'(P)$ units of the basic assets. The value of this portfolio is $F - F'(P)P$. The total return on this portfolio over a short time interval *dt* is $dF - F'(P)dP - \delta PF'(P)dt$, where $\delta = \mu - \alpha$, and μ is the risk-adjusted expected return based on the capital asset pricing model (CAPM). Using Ito's Lemma, the return on the portfolio becomes $[\frac{1}{2}\sigma^2 P^2 F''(P) - \delta PF'(P)]dt$. To avoid arbitrage opportunities, the following equation must hold

$$[\tfrac{1}{2}\sigma^2 P^2 F''(P) - \delta PF'(P)]dt = r[F - F'(P)P]dt \tag{4.11}$$

Rearranging terms leads to the following differential equation

$$\frac{1}{2}\sigma^2 P^2 F''(P) + (r - \delta)PF'(P) - rF = 0\,. \tag{4.12}$$

Comparing to Equation 4.7, the only difference is that the risk-free rate *r* is used instead of the discount rate ρ. Therefore, the same solution $F(P) = A_1 P^{\beta_1}$ can be obtained except that *r* replaces ρ in the equations for the exponent β's. In other words, if one assumes $\rho = \mu = r$, then both methods lead to the same solution (e.g., Yin 2001; Yin et al. 2000; Yin and Newman 1999). Each method has its own advantages and disadvantages. A detailed discussion can be found in Dixit and Pindyck (1994) and references therein.

Entry and Exit Options

Suppose the payoffs of a project rely on the end product price *P*, then the value of the project can be specified as a function of *P*. Using the contingent claims approach, *V(P)* can be derived. Since a firm makes decisions between being idle and being active, the firm has a call option on the other in either state. Denoting $V_0(P)$ as the value of an idle firm (option value to invest), $V_1(P)$ as the value of active firm (profit from operation plus the option to abandon if the price falls too far), Dixit and Pindyck (1994) show that

$$V_0(P) = A_1 P^{\beta_1},\ P \in [0, P_H] \tag{4.13}$$

$$V_1(P) = B_2 P^{\beta_2} + P/\delta - C/r\,,\ P \in [P_L, \infty] \tag{4.14}$$

where A_1 and B_2 are parameters to be determined, *C* is the variable cost of operation. Note the first term in Equation 4.14 represents the option value of abandonment, while the last two terms represent the value of operating profits (losses). Applying the value matching and smooth pasting conditions, the following system of four equations with the four unknowns, A_1, B_2, P_H and P_L, can be established

$$-A_1 P_H^{\beta_1} + B_2 P_H^{\beta_2} + P_H/\delta - C/r = I \tag{4.15}$$

$$-\beta_1 A_1 P_H^{\beta_1 - 1} + \beta_2 B_2 P_H^{\beta_2 - 1} + 1/\delta = 0 \tag{4.16}$$

$$-A_1 P_L^{\beta_1} + B_2 P_L^{\beta_2} + P_L/\delta - C/r = -E \tag{4.17}$$

$$-\beta_1 A_1 P_L^{\beta_1 - 1} + \beta_2 B_2 P_L^{\beta_2 - 1} + 1/\delta = 0 \tag{4.18}$$

where P_H and P_L are price thresholds for entry and exit, and *E* is the lump-sum abandoning cost. Given the nonlinear nature, the system of equations should be solved numerically.

Entry, Mothballing, Reactivation, and Exit Options

Denoting the maintaining cost as *M*, the mothballing cost as E_M, the reactivation cost as *R*, and the price thresholds for mothballing and reactivation as P_M and P_R, Dixit and Pindyck (1994) show that a system of eight equations similar to Equations 4.15-4.18 can be established and solved. In addition to Equation 4.13, the value of an operating firm is

$$V_1(P) = B_2 P^{\beta_2} + P/\delta - C/r\,,\ P \in [P_M, \infty] \tag{4.19}$$

and the value of an mothballed firm is

$$V_M(P) = D_1 P^{\beta_1} + D_2 P^{\beta_2} - M/r\,,\ P \in [P_L, P_R]. \tag{4.20}$$

Contrasting to the first term in Equation 4.14, $B_2 P^{\beta_2}$ in Equation 4.19 now represents the option value of mothballing, which in fact derives its value from the possibilities of future reactivation or abandonment. In Equation 4.20, the first term represents the option value of reactivation; the second term represents the option value of scrapping; and the last term is the present value of the maintenance cost provided the project is laid up forever. In sum, option values of investment, mothballing, reactivation, and abandonment can be stated as

$$O_I(P) = A_1 P^{\beta_1},\ P \in [0, P_H] \tag{4.21}$$

$$O_M(P) = B_2 P^{\beta_2},\ P \in [P_M, \infty] \tag{4.22}$$

$$O_R(P) = D_1 P^{\beta_1},\ P \in [P_L, P_R] \tag{4.23}$$

$$O_A(P) = D_2 P^{\beta_2},\ P \in [P_L, P_R]. \tag{4.24}$$

A Numerical Example

Consider the following hypothetical 25-acre southern pine plantation, in which a 25-year harvest strategy is employed (Conroy and Miles 1989). That is, at the beginning of each year timber ranges in age from zero to 24 on each acre of the land, while at the end of each year timber ranges in age from one to 25. The 25-year old timber is harvested at the end of the year, and that acre of land is replanted at the beginning of the following year. Therefore, the timberland owner will have the same timber yield in any particular time from year to year. The 25-year harvest strategy is a rather simple and naive assumption, however, it is consistent with the forest-level analysis as in Yin (2001) and Yin and Newman (1999).

Table 4.1 shows timber yield in green tons in three products (pulpwood, chip and saw and sawtimber) for the hypothetical southern pine plantation at the end of each year. The volume is simulated by SiMS 2006, a growth-and-yield simulator for southern pine. Key parameters used include: 700 trees planted per acre, site index 65, chemical site preparation, and no thinning. Each year the age 25 stand is harvested producing 155.6 tons of timber (68.5 tons of pulpwood, 76.1 tons of chip-n-saw, and 11 tons of sawtimber), whereas the age 1-24 stands are left on the ground and treated as inventory (1,049.3 tons of pulpwood, 487.9 tons of chip and saw, and 26.6 tons of sawtimber). Prices for the three products are obtained from Timber Mart-South. The volume of each product at age 25 is used as weights to derive the synthetic end product (timber) prices.

Based on previous studies (e.g., Cascio and Clutter 2008; Conroy and Miles 1989; Yin and Newman 1999), the following cost parameters are assumed (all the values have been deflated by consumer price index (CPI) and stated in constant U.S. dollars as of 1982): site preparation \$55/ac; planting and seedling \$35/ac; miscellaneous management practices (e.g., fire and insect control) \$2/ac; property taxes \$2.5/ac; prescribed burning for five times in a rotation \$25/ac; bare land value \$555/ac; real risk-free rate 4%; and real risk-adjusted rate of return for a southern pine plantation 5%. The annual operating cost is 55+35+(2+2.5)×25+25=\$227.5, which includes site preparation and replanting costs for one acre, management cost and taxes for 25 acres, and prescribed burning cost. The annual land rent is 555×25×0.04=\$555, and the annual opportunity cost in standing timber is (1,049.3×3.44+487.9×7.76+26.6×14.12)×0.04= \$310.76. Therefore, the annual per unit variable cost C is (227.5+555+310.76.2)/155.6= \$7.03/ton. The lump-sum investment cost is 555×25+7769.07+55+35=\$21,734.07, which includes bare land value of 25 acres, inventory value of standing timber, and site preparation and planting costs of one acre. On a per unit basis, investment cost I is 1,734.07/155.6=\$139.68/ton. The abandonment cost E (-\$46.56/ton) is assumed to be roughly 1/3 of the investment cost I, and the negative sign reflects the salvage value of timber and land sales.

Since timber production can be easily suspended and reactivated without incurring heavy expenses, and only property taxes are paid for a mothballed plantation, the mothballing cost

(E_M) is assumed to be zero, the reactivation cost (*R*) is assumed to be \$1/ton, and the maintenance cost (*M*) is calculated as 2.5×25/155.6=\$0.40/ton. Finally, timber price growth rate α and volatility σ are estimated to be 0.03 and 0.15, respectively. Table 4.2 summarizes the production and market parameter values and the numerical solution to the system equations given these parameters.

Taking consideration of timber price uncertainty, the entry threshold timber price is higher than the Marshallian long-run average cost $C + rI$, and the exit threshold timber price is lower than the Marshallian threshold $C - rE$. When entry and exit options are considered only, the entry threshold timber price is \$5.03 higher and the exit threshold timber price is \$3.86 lower. When mothballing and reactivation options are also considered, the exit threshold timber price is even lower. The reason is that, facing price uncertainty an investor is less willing to invest, and the manager of an active project is less willing to exit. This is especially true given the considerably large initial lump-sum cost in timberland investments. In other words, the option to wait for more information, the option to temporarily suspend production, the option to reactivate a mothballed project, and the option to abandon an ongoing project to prevent further losses, all have values.

Figure 4.1 displays the values of an idle firm, an active firm, and the abandonment option for the numerical example when entry and exit options are considered only. The two vertical dashed lines indicate the entry and exit threshold prices. Both values of an idle firm and an active firm increase with price in that the higher the price the higher the revenue. The option value of abandonment decreases with price in that the higher the price, the less likely this option will be exercised. It should also be noted that at each switching point, the value-matching conditions apply. That is, at P_L it is optimal to exercise the abandonment option, forgoing

$V_1 + E$ and receiving V_0. Therefore, V_0 exceeds V_1 by the abandonment cost *E*. Since *E* is negative in our case, V_1 is above V_0 at P_L. Similarly, at P_H it is optimal to invest so that V_1 exceeds V_0 by the investment cost *I*.

Figure 4.2 combines entry, mothballing, reactivation, and exit options. The two vertical dashed lines indicate the mothballing and reactivation threshold prices. For the same reasons, the option values of investment and reactivation increase with price, and the option values of mothballing and abandonment decrease with price. Between P_L and P_R, the option value of reactivation is higher than that of investment from scratch because less cost is involved. In the same price range, the option value of mothballing is higher than that of abandonment because a mothballed plantation has the possibility to be reactivated later. Table 4.3 compares the values of the plantation at each threshold price. Again, the value-matching conditions apply.

Robustness and Sensitivity Analysis

Although the geometric Brownian motion has been widely used in modeling commodity prices, it has some unrealistic implications. For instance, the expected value and variance of price can grow without bound, and if price falls to zero, it will stay at zero for ever. In reality, commodity prices should be related to the long-run marginal production costs. In other words, they ought to move towards the marginal production costs in the long run, although they may evolve randomly up and down due to market shocks in the short run. Statistical tests such as unit root test can detect the stationarity of a price process. However, the result usually depends on the length of the sample period. Consequently, theoretical considerations and analytic tractability are preferred when choosing between a random walk and a mean-reverting process (Dixit and Pindyck 1994).

For robustness check, we also examine timber prices under the geometric Ornstein-Uhlenbeck process. Using equation [5], the following parameters are estimated: $\hat{\eta} = 0.10$, $\hat{\sigma} = 0.15$, and $\hat{\bar{P}} = 9.92$. The speed of reversion is very low and the volatility estimate is the same as in the geometric Brownian motion. Therefore, these two price assumptions should have minor impact on the valuation process in our example.

The sensitivity analysis is conducted in Table 4.4. Row (1) corresponds to the base case with parameter values specified in Table 4.2. Rows (2)-(11) correspond to some alternative cases, each row representing a case in which only one parameter changes values while the others remain constant. When the real risk-free rate drops to 3%, it implies that the opportunity cost is lower. Therefore, all threshold prices fall. As a result, investors are more likely to exercise the options of investment and reactivation, and these option values approach further to their intrinsic values. The opposite is true for mothballing and abandonment options so their values increase comparing to the base case. When the real risk-adjusted rate of return increases, it implies the convenience yield increases. From the contingent claims perspective, the portfolio holder has to pay more dividends on the short positions. This essentially increases the cost of holding the portfolio, thus increases all the threshold prices, decreases the option values of investment and reactivation, and increases the option values of mothballing and reactivation. A decline in the price growth rate is equivalent to a rise in the real risk-adjusted rate of return in that both lead to an increase in the convenience yield. Hence similar effects are observed in rows (3) and (4).

When price volatility increases, more uncertainty is involved. Investors will be more reluctant to invest but less likely to abandon a project. Thus the threshold prices for investment and reactivation increase and those for mothballing and abandonment decrease. All else equal, higher price volatility results in higher option values. If lump-sum investment cost decreases, an investment becomes cheaper, so the threshold price for investment increases and the option to invest becomes more valuable. In the meantime, a lower investment cost implies a relatively higher salvage value, so investors are more willing to abandon a project, i.e., exit at a higher threshold price, and the abandonment option becomes more valuable. Since investment cost is sunk, it has little impact on the mothballing and reactivation decisions. Using the same rationale, similar effects are observed for a decrease in the exit cost (rows (6) and (8)).

When variable cost rises, production becomes more expensive so all threshold prices go up. Investment and reactivation options become less attractive, while mothballing and abandonment options become more feasible. Thus values of the former options decline but those of the latter options increase. When mothballing cost increases, mothballing becomes less valuable an option. In the extreme case, if mothballing cost exceeds abandonment cost, there will be no mothballing option at all. Higher mothballing cost indicates less management flexibility thus less option values, which in turn results in a higher entrance threshold price to adjust for the risk, a higher reactivation threshold price to offset the mothballing cost, a lower mothballing threshold price to delay temporarily lay-up, and a lower exit threshold price to expand the life of an active project in hope that sunk costs can be recovered when more favorable information arrives.

When maintenance cost increases, the mothballed state of a project becomes less preferable. Accordingly, investors will respond by delaying entry (a higher entry threshold price), advancing reactivation for a mothballed project (a lower reactivation threshold price), postponing suspension (a lower mothballing threshold price), and considering earlier termination (a higher exit threshold price). In other words, option values of investment and mothballing will decrease, and those of reactivation and abandonment will increase. An increase in the reactivation cost has similar effects as an increase in the mothballing cost (rows (9) and (11)). Again, in the extreme case, if the reactivation cost exceeds the initial investment cost, there will be no reactivation option at all since an investor can simply choose to start from scratch.

Concluding Remarks

Using contingent claims approach, this study investigates various option values in a hypothetical southern pine plantation when timber price evolves stochastically. Both a geometric Brownian motion and a geometric Ornstein-Uhlenbeck process have been attempted to fit the timber price series, however, minor difference has been identified. Due to analytical tractability, a geometric Brownian motion timber price has been assumed, and the option values of investment, mothballing, reactivation, and abandonment have been solved numerically.

Sensitivity analysis of the option values with respect to the key parameters reveals that 1) The option value of investment tends to increase with the real risk-free rate and timber price volatility, while decrease with the convenience yield, investment cost, variable production cost, abandonment cost, mothballing cost, maintenance cost and reactivation cost; 2) The option value of mothballing tends to increase with the convenience yield, timber price volatility and variable production cost, while decrease with the real risk-free rate, investment cost, abandonment cost, mothballing cost, maintenance cost and reactivation cost; 3) The option value of reactivation tends to increase with the real risk-free rate, timber price volatility, abandonment cost and maintenance cost, while decrease with the convenience yield, variable production cost, mothballing cost, and reactivation cost; and 4) The option value of abandonment tends to increase with the convenience yield, timber price volatility, variable production cost and maintenance cost, while decrease with the real risk-free rate, investment cost, abandonment cost, mothballing cost and reactivation cost.

In recent years, timberland price in the U.S. South has been chased to an unprecedentedly high level owing to a sharp increase in timberland demand. This makes timberland investments more expensive. In the numerical example, the land value is based on recent transactions in state Georgia. Historically, it has been significantly lower. On the other hand, timber prices have been flat (pulpwood) or declining (chip-n-saw and sawtimber) in the past several years. All these factors make new timberland investments less favorable. For those existing tree plantations, however, timber prices fall into the range between mothballing and existing thresholds. Therefore, most of these plantations should be in a temporary suspension state. Actually, this has been evidenced by a lower timber production in recent years, especially for larger-size wood (Schiller et al. 2009).

It should be noted that the analysis in this study is based on pure timber production. It may be true that certain timberland properties may have higher-and-better uses such as residential or commercial development opportunities, or they may have embedded with mineral or gas opportunities. All these opportunities have values and affect an investor's decision. However, that is beyond the scope of this study. In addition, the hypothetical southern pine plantation is a rather simplified example for illustration purpose only. Various aspects can be improved in future studies. For instance, commercial thinnings can be added in the forest management efforts; biological growth and/or real risk-free rate can be assumed stochastic as well rather than deterministic; and a timberland portfolio that has different species and is geographically diversified can be examined likewise. Finally, it is worth pointing out that the

25-year harvest strategy can be interrupted when the mothballing option is exercised. However, on a forest-level basis, this has minor effects in valuating timberland investments.

Table 4.1. Simulated timber yield in three products for the hypothetical southern pine plantation at the end of each year

Age	Pulpwood	Chip-N-Saw	Sawtimber
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.0	0.0	0.0
4	0.0	0.0	0.0
5	0.1	0.0	0.0
6	2.3	0.0	0.0
7	8.5	0.0	0.0
8	17.7	0.0	0.0
9	28.0	0.3	0.0
10	38.1	1.2	0.0
11	47.1	2.8	0.0
12	54.7	5.4	0.0
13	60.9	8.9	0.0
14	65.7	13.3	0.0
15	69.3	18.5	0.0
16	71.9	24.2	0.0
17	73.5	30.1	0.4
18	74.4	36.4	0.7
19	74.6	42.8	1.3
20	74.4	49.1	2.0
21	73.7	55.3	3.1
22	72.8	61.2	4.5
23	71.5	66.7	6.2
24	70.1	71.7	8.4
25	68.5	76.1	11.0
26	66.8	79.9	14.1
27	65.0	83.1	17.7
28	63.2	85.6	21.8
29	61.4	87.5	26.3
30	59.6	88.7	31.3

Note: 1) Timber yield in green tons; 2) The volume is simulated by SiMS 2006, a growth-and-yield simulator for southern pine; 3) Key parameters used include: 700 trees planted per acre, site index 65, chemical site preparation, and no thinning.

Table 4.2. Parameter values and numerical solutions to the system equations assuming geometric Brownian motion timber prices

Production parameter	Value	Market parameter	Value
Rotation	25	Real risk-free rate r	0.04
Investment cost I	\$139.68/ton	Real discount rate μ	0.05
Variable cost C	\$7.03/ton	Timber price growth rate α	0.03
Abandonment cost E	-\$46.56/ton	Timber price volatility σ	0.15
Mothballing cost E_M	\$0/ton	Convenience yield $\delta = \mu - \alpha$	0.02
Maintenance cost M	\$0.4/ton	β_1	1.54
Reactivation cost R	\$1/ton	β_2	-2.31
Static entry threshold $C + rI$	\$12.61/ton		
Static exit threshold $C - rE$	\$8.89/ton		

Numerical solution

Entry and exit		Entry, lay-up, reactivation, and exit	
A_1	6.93	A_1	6.93
B_2	2251.59	B_2	2307.59
P_H	\$17.64/ton	D_1	10.06
P_L	\$5.03/ton	D_2	818.10
		P_H	\$17.63/ton
		P_R	\$7.57/ton
		P_M	\$5.74/ton
		P_L	\$4.72/ton

Table 4.3. Values of the hypothetical southern pine plantation at each threshold price

Threshold Price	Idle state V_0	Mothballed state V_M	Active state V_1	Description
$P_L = 4.72$	75.15	121.71	—	$V_M = V_0 - E$
$P_M = 5.74$	101.51	151.79	151.79	$V_1 = V_M$ since $E_M = 0$
$P_R = 7.57$	155.29	223.17	224.17	$V_M = V_1 - R$
$P_H = 17.63$	569.18	—	708.86	$V_0 = V_1 - I$

Note: All values are on the $/ton basis.

Table 4.4. Sensitivity analysis

No.	Case	New value	P_H	P_R	P_M	P_L	O_I	O_R	O_M	O_A
1	Base case	—	17.63	7.57	5.74	4.72	238.18	157.89	36.51	12.94
2	Δr	$r = 0.03$	15.12	6.07	4.51	3.87	218.00	151.71	42.40	15.25
3	$\Delta \mu$	$\mu = 0.06$	18.64	7.61	5.78	5.30	93.46	69.01	57.46	22.79
4	$\Delta \alpha$	$\alpha = 0.02$	18.64	7.61	5.78	5.30	93.46	69.01	57.46	22.79
5	$\Delta \sigma$	$\sigma = 0.20$	20.19	7.81	5.60	4.23	260.65	172.19	54.85	16.94
6	ΔI	$I = 100$	15.11	7.57	5.74	5.28	257.00	157.89	40.08	16.52
7	ΔC	$C = 8$	18.93	8.63	6.63	5.14	229.02	146.82	52.85	15.53
8	ΔE	$E = -60$	17.52	7.57	5.75	5.43	238.46	157.84	45.81	22.20
9	ΔE_M	$E_M = 1$	17.66	7.8	5.5	4.69	238.09	157.34	34.95	12.54
10	ΔM	$M = 1$	17.66	6.92	5.20	4.93	238.09	165.94	35.07	17.88
11	ΔR	$R = 2$	17.65	7.84	5.53	4.72	238.11	156.85	35.61	12.74

Note: 1) All values except those for market parameters are on the $/ton basis; 2) Option value of investment is calculated at price $10/ton, whereas option values of reactivation, mothballing, and abandonment are calculated at price $6/ton.

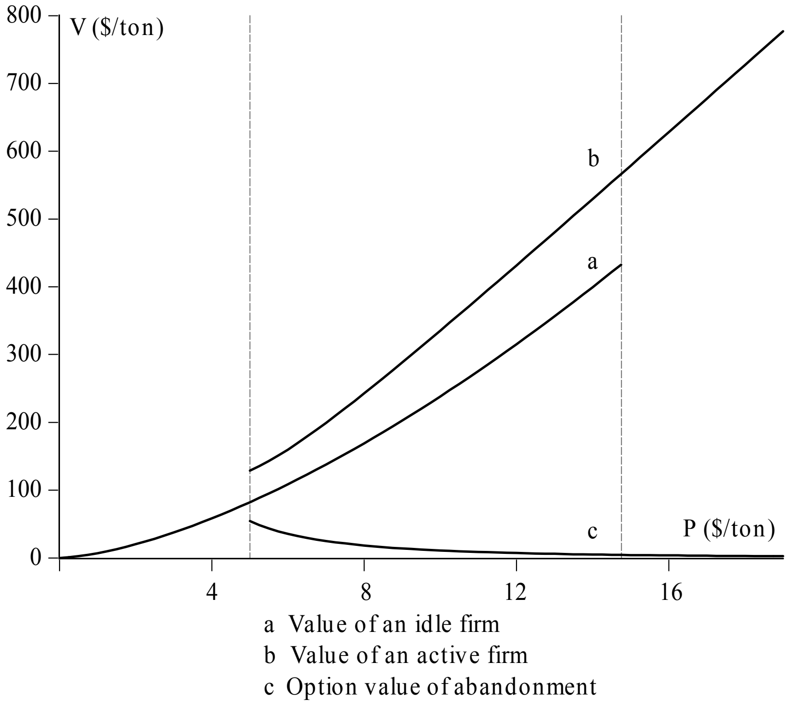

Figure 4.1. Values of an idle firm, an active firm, and the abandonment option for the hypothetical southern pine plantation.

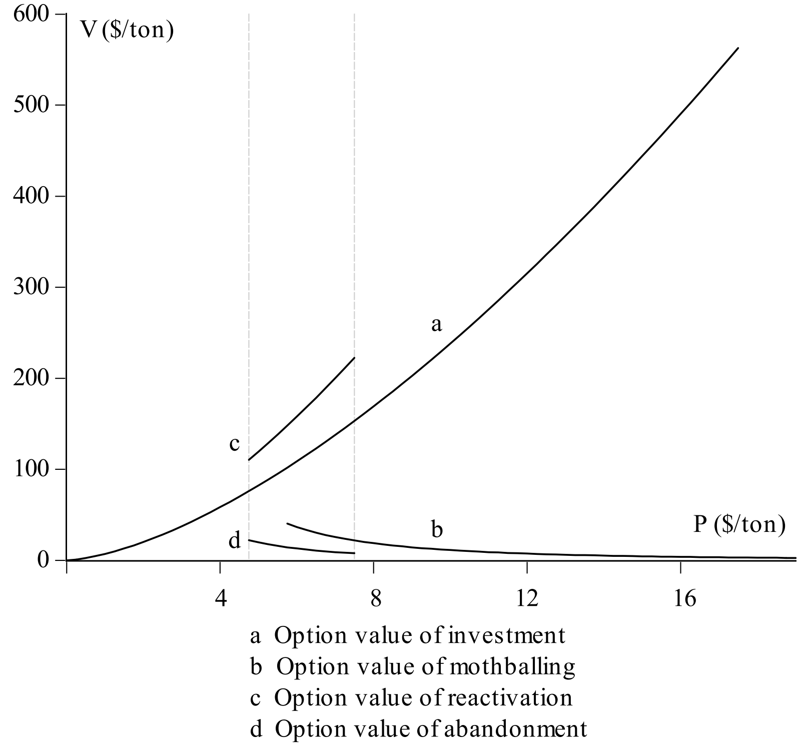

Figure 4.2. Option values of investment, mothballing, reactivation, and abandonment for the hypothetical southern pine plantation.

CHAPTER 5

DISCUSSIONS AND CONCLUSIONS

As an alternative opportunity, timberland investment has come of age. However, research in this area has been limited. With this dissertation three issues related to timberland investments are examined, i.e., stochastic properties of timber prices in the U.S. South, financial performance of private- and public-equity timberland investments in the U.S., and various option values in managing a hypothetical southern pine plantation.

Chapter 2 examines the real pine sawtimber stumpage prices in the 12 U.S. southern timber regions via a number of time series models. Based on the MAPE criterion, the VAR(2) model forecasts more accurately in the one-year period. However, each model is incapable of predicting timber prices accurately in some areas. Hence, caution should be used when interpreting regional timber prices simply by these time series models. In addition, conditional variances and covariances for GA2 and SC2 have been estimated by the bivariate GARCH model. The results reveal that the conditional variances well capture the uncertainty of timber prices in these two areas. Besides, the average conditional correlation is lower than the unconditional one. Finally, the weak exogeneity tests in the cointegration analysis indicate that AL2, FL2, GA1, GA2, LA1, NC2, and SC2 are dominant regions in the long-run equilibrium in the southern timber market.

Since a limited number of time series models have been attempted in this study, it is possible that other alternative models may have fit the data better. Meanwhile, other theoretical economic models such as the rational expectations competitive storage model employed by Deaton and Laroque (1992) can be supplementary to these pure time series models in understanding timber prices. Overall, this study sheds light on the ongoing endeavors in exploring the timber markets. Future research can probe how to link the findings from these timber price models to designing timber derivatives, or developing regional timber policies.

Chapter 3 reexamines the financial performance of timberland investments in the U.S.. Private-equity timberland returns are approximated by the NCREIF Timberland Index, and public-equity timberland returns are approximated by the value-weighted returns on a dynamic portfolio of the U.S. publicly-traded timber firms. The parametric analysis reveals that private-equity timberland investments outperform the market but have low systematic risk, whereas public-equity timberland investments fare similarly to the market. Therefore, inclusion of private-equity timberland investments can improve the efficient frontier, albeit such potential for public-equity timberland investments is limited. The nonparametric SDF approach does not rely on any specific asset pricing models hence are not subject to the "joint hypothesis tests" criticisms. Results from the SDF approach confirm the findings that private-equity timberland investments outperform the market, while public-equity timberland investments cannot beat the market.

The positive alpha of timberland investments in the private market is may be associated with the patience of institutional investors toward timberlands' embedded strategic options (Zinkhan 2008). If a timberland property has potential for higher and better use such as residential or commercial development opportunities, or if it is suitable for conservation easements, or if it has embedded with mineral or gas opportunities, it may have extra income sources, and the land value can be dramatically higher. The positive alpha may also be related to the liquidity risk that institutional investors bear since a typical TIMO has an investment time horizon of 10-15 years or even longer. In contrast, stocks of publicly-traded forestry firms with timberland business can be easily traded on the stock exchanges. Moreover, initiation of a TIMO-type separately managed account usually requires a capital commitment of $25 to $50 million, while participation in a TIMO-type pooled fund generally requires a minimum capital commitment of $1 to $3 million (Zinkhan and Cubbage 2003). The large capital amount may enable the investors to achieve some degree of diversification.

The lower excess returns of the NCREIF Timberland Index around 2001-2003 may be associated with its relative weak performance during that time. In 2001Q4, the NCREIF Timberland Index fell by 6.5%, the largest drop it ever had, which is primarily caused by the capital loss from the shrinking timberland values. While in the same period the S&P 500 index went up by 7.8%. The overall decreasing trend in beta for the dynamic portfolio of forestry firms may be related to the massive restructurings of these firms. For instance, Plum Creek Timber Co, Potlatch, and Rayonier have converted themselves into real estate investment trusts (REITs) in recent years. With improved tax efficiency and increased concentration on timberland management, these timber REITs are expected to be less risky.

Another interesting fact noted is that, despite the current economic downturn triggered by the sub-prime residential mortgage blow-up, private-equity timberland returns remain relatively strong. The market went down about 39% in 2008, while the NCREIF Timberland Index achieved a 9% return, or on the risk-adjusted basis, an excess return of 10% (calculated using the estimated alpha series in 2008). In contrast, the portfolio value of publicly-traded forestry firms fell 36% just like the market. However, most of those firms have non-timberland business, such as paper and lumber mills, which may be more sensitive to the overall economic conditions. A close examination of the three publicly-traded timber REITs reveals that they were less affected by the gloomy market. Looking ahead, global economic crisis will last for some time, multiple factors will affect timberland returns, and the net effect on timberland properties has yet to be observed (Washburn 2008).

It is worth noting that there have been some concerns about the data and method consistency of the NCREIF Timberland Index. As pointed by Binkley et al. (1996), there is no standardized appraisal and valuation practice in forestry, and thus heterogeneity may exist in the data. In addition, the NCREIF Timberland Index is a composite performance measure of a very large pool of commercial forestland properties acquired in the private market for investment purposes. Hence caution should be used when interpreting the NCREIF Timberland Index from an individual investor's perspective.

Using contingent claims approach, Chapter 4 investigates various option values on a hypothetical southern pine plantation when timber price evolves stochastically. Both a geometric Brownian motion and a geometric Ornstein-Uhlenbeck process have been attempted to fit the timber price series, however, minor difference has been identified. Due to analytical tractability, a geometric Brownian motion timber price has been assumed, and the option values of investment, mothballing, reactivation, and abandonment have been solved numerically.

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It should be noted that the analysis in this study is based on pure timber production. It may be true that certain timberland properties may have higher-and-better uses such as residential or commercial development opportunities, or they may have embedded with mineral or gas opportunities. All these opportunities have values and affect an investor's decision, but are beyond the scope of this study. Moreover, the hypothetical southern pine plantation is a rather simplified example for illustration purpose only. Various aspects can be improved in future studies. For instance, commercial thinnings can be added in the forest management efforts; biological growth and/or real risk-free rate can be assumed stochastic as well rather than deterministic; and a timberland portfolio that has different species and is geographically diversified can be examined likewise. Finally, it is worth pointing out that the 25-year harvest strategy can be interrupted when the mothballing option is exercised. However, on a forest-level basis, this has minor effects in valuating timberland investments.

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