Evaluating Market Efficiency of the US Forest Industry

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Abstract

The market efficiency of the US forest industry had evolved over the past decade. In this study, the entropy measurement, an econophysic approach, was applied to quantify the informational efficiency of timber real estate investment trusts (REITs), wood, furniture, and paper markets in the United States during the period from 1999 to 2012. In a relative context, indices on Treasury bonds were used to proxy the risk-free rate of returns, while Standard & Poor's (S&P) 500 stock returns were used as a yardstick for risky investments. The analysis indicated that the forest markets were considerably more informationally efficient than the Treasury market. Furthermore, most markets were marginally more efficient compared with the S&P 500 index, with the exception of REIT returns. Therefore, better arbitrage opportunities were present in REIT investments.

The economic interpretation of informational efficiency refers to the amount of information contained in prices in a given market. The less informational efficient a market is, the more predictable the future returns will be through various analysis tools. Intuitively, prices reflect only limited available information and behave less erratically in an inefficient market. Therefore, the main application of evaluating the informational efficiency in forest-related markets, including forest products industries (FPI), is to determine the likelihood of consistently outperforming the market by analyzing information such as historical data, financial statements, and private information.

Not only are profitable returns of great interest to investors, but strategies on outperforming the market have intrigued many stakeholders as well. Successfully forecasting future prices or returns allows investors to exploit arbitrage opportunities in which profits can be made by buying assets at low prices and simultaneously selling them at higher values (El Karoui et al. 1997). When markets operate inefficiently, the formation of over- and undervalued assets postulates the presence of arbitrage opportunities. On the contrary, if markets are completely efficient, investors cannot obtain arbitrage advantage over other traders because all information is instantaneously incorporated in current prices and accessible by everyone in the market.

According to Fama's study in 1970, there were three versions of market efficiency: weak form, semistrong form, and strong form. The emphasis of the following study is confined to analyzing the weak form market efficiency, which pertains to past price behaviors (Fama 1970). Therefore, the higher the level of weak efficiency that exists, the less likely for investors to identify under- or overvalued stocks through technical analysis. Performing fundamental analyses on financial statements and utilizing private information were the remaining options for investors to gain excess returns (Sun and Zhang 2001).

The objective of this article is not to provide an absolute answer to whether forest-related markets are efficient. Empirical evidence has suggested the predictability of high-frequency returns from past data, such as daily and weekly stock prices (Fama 1991). Nevertheless, some markets might be less efficient than others and offer greater chances of successfully earning additional returns. In this study, informational efficiency of different markets is measured by the entropy levels they possess.

Literature Review

Informational efficiency studies in the forest products industry

Previous studies on informational efficiency have focused primarily on different stock markets and foreign exchange markets. Although limited research on this topic exists in forest-related industries, available studies have yielded contradictory results. Washburn and Binkley (1990, 1993) indicated that 13 timber markets in the US South operated efficiently in the weak form on an annual and quarterly

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basis. The authors performed serial correlation tests on the return data from 1976 to 1989 and found independency in deviations from the mean of the series. Their results inferred that no particular rule of movements was present in timber prices because variations in past and current realizations were uncorrelated. According to the notion of weak form efficiency, potential gains would not be achieved by analyzing the path of past prices. However, they found that monthly prices did not capture all available information and were inefficient due to transactional costs in the process of finalizing sales.

In response to the previous results, Hultkrantz (1993) argued that even though prices were not autocorrelated, past information could still be used to investigate future returns if they exhibited stationarity. Therefore, market efficiency should not be claimed on the basis of the unpredictability of future residuals alone. His study showed that the stumpage price series in the US South was stationary with respect to a set of information, including timber growth rate, capital costs, and storage costs. Therefore, investors could examine past price activities in the context of time of sales in order to forecast the prospect price paths.

In agreement with the latter approach, several studies concurred regarding the presence of stationarity as an indication of informational inefficiency. Through an augmented Dickey-Fuller test, Haight and Holmes (1991) supported the stationarity of softwood sawtimber prices in North Carolina because the time series did not possess a unit root. Moreover, Yin and Newman (1996) further illustrated that 14 southern timber markets operated inefficiently by including one lagged term in their unit root tests. Hence, the result reinforced the hypothesis of market inefficiency. Their study revealed that stumpage prices were indeed stationary over the long horizon and followed a mean-reverting path.

Nevertheless, Prestemon and Holmes (2000) and Prestemon (2003) noted that different assumptions and approaches would lead to contradicting conclusions on stationarity. Different from the findings of Hultkrantz (1993) and Yin and Newman (1996), the latter study aligned with the conjecture that stumpage prices were nonstationary in most southern markets. After adjusting the return time series according to the consumer price index, the author analyzed the monthly data of 27 submarkets in the southern region. As the result of an alternative lag selection procedure, the author applied longer lag lengths in his regressions for the augmented Dickey-Fuller tests. When higher orders of autocorrelation were considered, prices appeared to follow a martingale process in which the conditional expected future price would be equal to the last observed price. The outcomes suggested that technical evaluations would be useful to investors in only a few submarkets of timber.

Entropy measurements in informational efficiency studies

Different from the traditional approach, entropy or information theory is an econophysic framework that has gradually received more interest from economists because of its useful applications in assessing the performance of financial markets. Initially, entropy was used in physics to measure energy through examining thermodynamic processes (Georgescu-Roegen 1971). In 1948, mathematician Claude Shannon applied the concept of entropy into the statistical field in order to calculate information sizes and limits of transmitting signals (Downarowicz 2011). Since its inception, information theory has been used in various fields, including finance, statistics, neurobiology, and computer science (Cover and Thomas 2005). In finance, the entropy value of a market allows analyzing market efficiency in a relative context. Intuitively, when entropy is at zero, its smallest value, future occurrences can be predicted with certainty. On the other hand, when the entropy level is maximized, each possible outcome has an equal chance of happening (Luciano et al. 2011). Therefore, one cannot completely forecast future returns, as the pricing system operates in the most random state. Hence, maximized entropy implies that contemporaneous prices successfully reflect all past prices and that return volatilities are determined by other information so that there are no structured changes in stock prices (Philippatos and Wilson 1972, Gulko 1999, Sung and Anil 2009). In a weakly efficient market, regardless of how well historical price behaviors are understood, investors should be indifferent between making decisions with or without a technical analysis. Likewise, there exists trivial arbitrage opportunity based on previous price information.

In a recent study, Risso (2009) used Shannon entropy to compare 20 stock markets of different countries in terms of informational efficiency. The author showed that the Dow Jones US stock market was more efficient than the British Financial Times and London Stock Exchange from 1997 to 2007. However, both indices were less efficient than the Japanese Nikkei Stock Average. Under a similar methodology, Alvarez-Ramirez et al. (2012a) revealed that the Dow Jones market's informational efficiency depended on the time scale and varied over time. Daily prices were more efficient compared with the monthly and quarterly indices. In addition to Shannon entropy, Renyi and Tsallis are modified measurements of entropy. Bentes et al. (2007) used the three measurements of uncertainty to examine stock prices' volatility clustering. The different entropy indices produced consistent results in showing the Standard & Poor's (S&P) 500 as the most efficient stock market when compared with the Stoxx 50 and the NASDAQ 100.

Data

Relevant daily return data were available from the beginning of July 1999 to the end of December 2012. Forest-related markets, including timber real estate investment trusts (REITs), wood (North American Industry Classification System [NAICS] 321), furniture (NAICS 337), and paper (NAICS 322), were the scope of the research's interest. Because timber companies converted to REITs at different times, a dynamic REIT portfolio comprising Plum Creek (PCL), Rayonier (RYN), Potlatch (PCH), and Weyerhaeuser (WY) was constructed on the basis of their dates of conversion. The value-weighted portfolio initially contained returns from PCL, which was a pioneering REIT entity, and eventually incorporated data from other firms on their official structural changes. Specifically, RYN, PCH, and WY data were included in the portfolio from January 2004, 2006, and 2010, respectively. All REIT return series were obtained from the Center for Research in Security Prices database from Wharton Research Data Services (WRDS) in 2013, while the wood, furniture, and paper series were acquired from French's online data library (French 2013). The four time series were constructed using the average value-weighted returns, and each contained 3,397 observations.

In order to evaluate the degree of informational efficiency in each FPI, the S&P 500 index and the 3-month Treasury bill rates were utilized as relative thresholds for comparison purposes. The benchmark variables were selected because of the vast financial literature's indications regarding their levels of market efficiency. The US Treasury indices had been influenced by monetary policies and had not tended to change erratically. As it was unconstitutional for the government to default on the US Treasury debts, investments in Treasury bills involve minimal risk and volatility. Although the rates were determined through auctions, the future returns were highly predictable, and the liquid Treasury bill market had often been considered inefficient (Puglisi 1978, Vignola and Dale 1979). On the other hand, the S&P 500 index was chosen as an efficient market yardstick because a number of studies had provided empirical conclusions that supported the informational efficiency of the stock markets (Fama and French 1988, Fama 1991). These data were from WRDS.

Methodology

Entropy measurement

Let $X = (x_1, x_2, \ldots, x_i)$ be a return time series of interest. The Shannon entropy of the market is calculated as follows:

$$S(x) = -\sum_{i=1}^{n} p_i \log_b p_i$$

where p_i is the probability of getting return x_i.

Value of the log base, b, refers to the unit of measurement. When $b = 2$, 10, or e, the information efficiency will be measured in bit, dit, and nat, respectively. Hence, different units of the log base will result only in different readings of the information size. For consistency purposes, this study used base e to calculate the entropies.

Probability assessment

Empirically, a normal distribution assumption is often violated. Hence, the Jarque-Bera test is utilized to determine the presence of kurtosis and skewness in the sample data. Possessing various useful properties, entropy measurement does not rely on the assumption that the sample random variables must propend to a normal distribution (Masud 1987). For that reason, the equidistant histogram approach is implemented on rejection of the null hypothesis. The probability of each interval is then calculated from a histogram-based method. Once the probability of each bin is determined, Shannon entropy is calculated on the basis of the return intervals and their corresponding probability.

Test statistics utilizing rolling windows

On the basis of the sole measurements over the entire sample period, one could not conclude whether the entropy levels between any two markets were profoundly different. Hence, a rolling window approach was utilized to examine the statistical significance of entropy differences among the six markets. Each time series was divided into 31 subsamples in which there were 1,000 observations, with the exception of the last period, with n equal to 997. Every subsequent rolling window began after 80 lagged days from its preceding period's starting date so that consecutive episodes were approximately 3 months apart. The same entropy measurement and probability calculation procedures were then applied to the six series for each rolling window. As a result, a sample size of 31 for every variable was generated and allowed for pairwise t test comparisons between different forest-related markets.

Business cycles

To examine the changes of informational efficiency for each market, the study further investigated the entropy values according to historical business fluctuations. During economic downturns, the number of businesses shrunk, and the market became less competitive in addition to having lower expected payoffs (Balvers et al. 1990). Thus, under the market efficiency framework, markets were less efficient during recessions due to aggregate cynical expectations (Fama 1990). On the contrary, markets should be more efficient during economic booms because of fierce competition among a greater number of businesses.

Since 1999, the US economy has experienced three complete cycles, which included two contractions and an expansion. According to the National Bureau of Economic Research, a short, mild recession lasted from March to November 2001, followed by an economic recovery and growth for approximately 2 years. Recently, the economy underwent a prolonged contraction from December 2007 to June 2009. The reference dates of the business fluctuations were March 2001 and December 2007, when the economy reached its peaks, and November 2001 and June 2009, during which the economy was in its troughs. According to the discussed time line, four different episodes were generated for each return series. For every economic episode, the data from 3 months prior and 3 months after the turning point date were utilized to calculate Shannon entropies.

Empirical Results

The probability density function for a normal distribution could not be applied, as the Jarque-Bera test rejected the null hypothesis in all six cases (Table 1). Therefore, equidistant breaks were utilized to divide each return data set into 20 bins. To a certain extent, Shannon entropy

Table 1.—Jarque-Bera test for normal distribution.[a]

Market	χ^2	Degrees of freedom	P value
REIT	20,773.270	2	0.000
Furniture	3,691.729	2	0.000
Paper	2,504.294	2	0.000
Wood	1,965.775	2	0.000
S&P 500	7,600.090	2	0.000
Treasury bill	13,977,420.000	2	0.000

[a] Codes for furniture, paper, and wood industries are North American Industry Classification System (NAICS) 337, NAICS 322, and NAICS 321, respectively. REIT = timber real estate investment trusts; S&P 500 = Standard & Poor's 500.

measurements showed similar results to past studies. As expected, future returns were more unpredictable for the S&P 500 index while less stochastic in the case of the Treasury bill rates. When allowing the entropy values of the Treasury bill and the stock markets to act as relative minimum and maximum of informational efficiency, the REIT market lay within the spectrum encompassed by the two benchmarks (Table 2). The pairwise *t* tests at the 99 percent confidence interval indicated that such differences between the three markets were statistically significant (Table 3). Nevertheless, the REIT index seemed to be closer to the efficient end of the scale. Likewise, the three wood products markets were much more informationally efficient than the Treasury market at the 99 percent confidence interval. In comparing entropies of the FPI to the other markets, the empirical results at the 99 and 95 percent significance levels induced two possible ranking scenarios (Table 4). However, at the 90 percent confidence interval, the outcomes provided one consistent inference on the relative efficiency among the six variables (Table 5).

In both cases, the wood industry was the most efficient market, followed by the paper industry and the S&P 500 index. Because the test statistics failed to reject the similarity between the paper and stock markets, the result implied that they exhibit the same efficiency. Depending on the selected interval estimations, the furniture industry could be placed first or second as a relatively efficient market. Therefore, at the 95 percent or higher confidence interval, it was ambiguous whether the furniture or the wood time series held the most efficient position among all variables. On the other hand, the paper, furniture, and stock markets were equally efficient at the 90 percent confidence level. Nevertheless, the timber REIT was less efficient than the other FPI, as indicated by the substantial lower entropy levels. In addition, the empirical evidence supported the notion that the timber REIT index operated marginally less efficiently than the stock market did. The statistical significant entropies showed that the Treasury bill was evidently the least informationally efficient market.

During the course of approximately 13 years, the efficiency levels of each market had evolved over time

Table 4.—Rankings based on 95 and/or 99 percent confidence interval.

Rank[a]	Market[b]	
	Scenario 1	Scenario 2
1	Wood	Wood and furniture
2	Paper, furniture, and S&P 500	Paper and S&P 500
3	REIT	REIT
4	Treasury bill	Treasury bill

[a] Rankings: 1 = relatively efficient; 4 = relatively inefficient.
[b] Codes for furniture, paper, and wood industries are North American Industry Classification System (NAICS) 337, NAICS 322, and NAICS 321, respectively. S&P 500 = Standard & Poor's 500; REIT = timber real estate investment trusts.

Table 5.—Ranking based on 90 percent and higher confidence interval.

Rank[a]	Market[b]
1	Wood
2	Paper, furniture, and S&P 500
3	REIT
4	Treasury bill

[a] Rankings: 1 = relatively efficient; 4 = relatively inefficient.
[b] Codes for furniture, paper, and wood industries are North American Classification System (NAICS) 337, NAICS 322, and NAICS 321, respectively. S&P 500 = Standard & Poor's 500; REIT = timber real estate investment trusts.

Table 2.—Comparison of entropy levels for the six markets (1999 to 2012).[a]

Market	Entropy level
REIT	1.439
Furniture	1.818
Paper	1.775
Wood	1.896
S&P 500	1.610
Treasury bill	0.334

[a] Codes for furniture, paper, and wood industries are North American Industry Classification System (NAICS) 337, NAICS 322, and NAICS 321, respectively. REIT = timber real estate investment trusts; S&P 500 = Standard & Poor's 500.

Table 3.—Pairwise t test statistics for entropy levels among the six markets.[a]

	Wood	Paper	Furniture	S&P 500	Treasury bill
REIT	0.000 ***	0.098 *	0.048 **	0.003 ***	0.000 ***
	−4.220	*−1.708*	*−2.060*	*−3.201*	*12.016*
Wood		0.002 ***	0.055 *	0.094 *	0.000 ***
		3.393	*2.000*	*1.730*	*11.307*
Paper			0.422	0.471	0.000
			−0.815	*−0.731*	*11.767*
Furniture				0.860	0.000
				0.178	*8.758*
S&P 500					0.000
					16.560

[a] ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively; *t* ratios are in italics. Codes for furniture, paper, and wood industries are North American Industry Classification System (NAICS) 337, NAICS 322, and NAICS 321, respectively. REIT = timber real estate investment trusts; S&P 500 = Standard & Poor's 500.

Table 6.—Entropy levels during complete business cycle since 1999.[a]

Reference date	Business cycle	REIT	Wood	Paper	Furniture	S&P 500	Treasury bill
Mar 2001	Peak	2.392	2.599	2.560	2.203	2.499	1.897
Nov 2001	Trough	2.216	2.155	2.286	2.013	2.370	1.836
Dec 2007	Peak	2.442	2.731	2.772	2.508	2.589	1.157
Jun 2009	Trough	2.496	2.495	2.704	2.628	2.380	2.056

[a] Codes for furniture, paper, and wood industries are North American Industry Classification System (NAICS) 337, NAICS 322, and NAICS 321, respectively. REIT = timber real estate investment trusts; S&P 500 = Standard & Poor's 500.

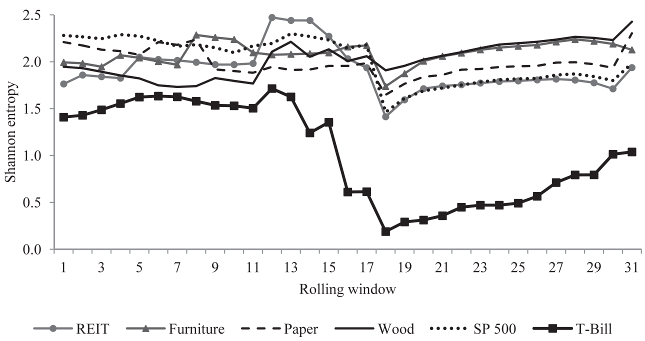

Figure 1.—Entropies over 31 subperiods (1999 to 2012).

(Fig. 1).[1] Entropy outcomes of the four economic episodes showed that the informational efficiency of most markets had changed according to the business oscillations (Table 6). Entropies of all markets, except for the Treasury bill index, tended to be higher during boom periods than during bust periods. Therefore, markets had performed more efficiently during peaks and, conversely, less efficiently during troughs. Nevertheless, the REIT and furniture markets had gradually improved in terms of informational efficiency when the last contraction ended in June 2009. Their entropy indexes in the last episode were slightly higher than the indexes in the preceding ones.

Discussion and Conclusion

Past studies often determined the informational efficiency of timber-related markets in an absolute context. Nevertheless, entropy measurements were able to quantify the informational efficiency of the given markets despite the model's simplicity. Therefore, in a relative context, this study indicated that the magnitude of efficiency varied across different markets. Among the six markets, the Treasury bill rates operated most inefficiently. Intuitively, changes in microeconomic conditions happened more frequently than changes in macroeconomic settings because decisions made by individuals and businesses often took place more rapidly than did the central government's decisions. Hence, macroeconomic variables, such as the federal fund rates, bond rates, and Treasury bill rates, tended to be slow in incorporating and reflecting historical information.

On the other hand, the timber REIT market was perceived to be rather less efficient compared with the S&P 500 index. Hence, the present returns did not completely reflect all available historical price behaviors. As an implication, there were arbitrage opportunities for investors to capture additional returns by actively trading REIT stocks. However, the same arguments could not be made for the furniture, paper, and wood industries. FPI had either similar or higher entropy than the stock market did. Although the differences in entropy indexes between the S&P 500 market and the FPI were minimal, only the paper industry appeared to have the same informational efficiency with the stock market in all plausible scenarios.

On the basis of the reported test statistics, the differences in efficiency levels between wood prices and other forest-related markets could raise important economic questions because they were unlikely to happen by chance. At the 90 percent confidence level, the entropy of the wood market returns was indeed higher than the indexes of all other markets. Empirically, the possibility of outperforming the market using historical data seemed to be most trivial in the wood market. Therefore, fundamental analyses would be more appropriate in forecasting wood prices, whereas technical analyses should be effective in predicting future values of timber REITs and could provide some insight into the price behaviors of furniture and paper.

Furthermore, the results showed that the movements of entropy level reflected the financial fluctuations in the US economy. Similar to some past studies, the empirical evidence found that the markets underwent the most efficient period from around 1990 to 2000 in the past century (Alvarez-Ramirez et al. 2012b). The strong and extended period of business expansion during the 1990s aided the efficiency of the US market during the economic boom of 2001. The following brief contraction was due mainly to the September 11 event, and the economy quickly recovered thereafter (Hall 2001). Therefore, the entropy levels slightly decreased as the result of the mild contraction. During the economic growth in 2007, information efficiency was considerably improved, as indicated by the higher entropy indexes. The reported entropies were at their highest around the business peak of 2007, during which the US economy had experienced stable and extended growth. Subsequently, the measures of entropy for the markets tended to be lower during the latest recession, with the exceptions of the REIT, furniture, and Treasury bill markets. Hence, further studies are needed to investigate the abnormal informational efficiency during the recent business cycle. Intuitively, as the number of businesses increase during expansions, the market is more competitive; hence, outperforming the market is less likely.

Many individual stock buyers rely on accessible information, including corporations' historical price data and financial statements, to make their investment decisions. Given constrained resources, investors must exploit the most amount of information and be selective in investing

[1] For a robustness check, the entropy level for each return series assuming a *t* distribution was calculated. The results were generally consistent and are available from the authors on request.

their funds. Therefore, the ordinal positions of different markets in terms of informational efficiency can be a useful guide to overperformance. Knowing whether a price series employs relatively more or less past information enables stockholders to select the appropriate analytical instruments in projecting future returns. Furthermore, the entropy methodology can be extended to examine other publicly traded assets in order to make comprehensive comparisons with forest-related markets.

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