The Impact of Weekly Production Variability on Logging Cost, Return and Risk
by
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Abstract

Production variability is a significant determinant of logging investment outcome. This variability may result from either process variation or zero production weeks. Using assumptions for a “typical” Southern logging system, the Auburn Harvest Analyzer and a simulation model, the impacts of production variation on logging cost, investment return and risk were estimated. The expected value of logging cost remains constant across increasing levels of production variability except when the level of zero weeks is increased. Logging cost increases modestly as the number of zero weeks is increased due to high fixed cost. The expected value of logging investment returns, as measured by the internal rate of return (IRR), remains constant across increasing levels of production variability. The magnitude of the expected IRR depends primarily on percent profit margin, not on cut and haul rate. The greatest impact of production variability on logging investment is the impact on investment risk. In general, risk increases as production variability increases. This is true of production variation driven by either increased process variation or an increase in the average number of zero weeks. The effects of rising production variation are reduced by increases in profit margin. Given the adverse impacts of production variability on logging investment, there may be incentive for wood procurement organizations to manage production variation for the purpose of cost containment (reduction) and fiber supply security.

INTRODUCTION

A byproduct of the difficult business climate in the forest products industry of the U.S. Southeast in recent years has been the hardships endured by those investing in a logging business (Stuart and Grace, 1998). It seems that logging is a tough way to make a living.

The nature of a typical logging enterprise explains some of this difficulty. Loggers are generally contract service providers that offer the service of harvesting and transporting trees from the stump to designated delivery locations. Their efforts are tied very closely to the immediate needs of their clients and as such, they are usually unable to plan or move independently. Their method of management is often reactionary.

Loggers are also price takers. They conduct business in a very competitive environment where there is little opportunity for an individual to significantly alter the rate of payment for their services. The sales rate for logging services (or cut and haul rate) is typically set by market forces.

Logging is a capital-intensive enterprise (Greene and Zinkhan, 1997). Dun and Bradstreet (1993) reports that 55% of the logging businesses surveyed had total assets of greater than $500,000 and 30% had total assets greater than $1,000,000. Most of these assets are investment in heavy equipment that is required to conduct today’s highly mechanized timber harvesting.

Another characteristic of the logging business is that weekly production is highly variable. Sources of logging production variability include both those that are internal to the business and those that are external or outside of the business. Internal sources include on-the-ground management of the crew, equipment or mechanical failures and the myriad of labor issues that can impact production. External sources include tract conditions (both ground conditions and timber quality), weather and local market conditions or wood procurement systems. Production variation is both a characteristic of the business environment in which a logger must function and also a determinant of business success.

What is the relationship between production variability and logging investment financial performance? The objective of this study is to address this question by investigating the impact of production variability on:

1) average logging cost,
2) logging investment return and
3) logging investment risk.

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METHODS

To accomplish the study objectives, information about production variability, logging costs and logging revenues were required. Production variability information was available from weekly production data obtained from three logging crews operating in the coastal plain of the U.S. Southeast. These data consist of 134-week time series of total weekly production (tons per week) for each crew (See Figure 1). These data may not represent production patterns for all crews in all locations. It is assumed, however, that these records represent the actual experience of three logging crews for a given location and time and can be used for reasonable comparisons.

Notice from Figure 1 that there are two components to production variability. The first is variation about the mean level of production that is experienced during weeks when there was non-zero production. The associated cause may be from either internal or external sources. This component of production variation will be referred to as process variation.

The second component is variability introduced by weeks where there is no production. These weeks may result from adverse weather conditions, scheduled vacation, mill downtime or high mill inventory levels. The weeks in which there is no wood production will simply be referred to as zero-weeks.

Inspection of the three frequency distributions of weekly logging production (See Figure 2) indicates that the level of production is generally distributed about the mean in a symmetrical fashion. From this evidence it was hypothesized that weekly production for non-zero weeks is normally distributed. For the purpose of this study it was assumed that the distribution of non-zero weekly wood production could be reasonably estimated using a normal distribution. In addition, each crew experienced some fixed probability of a zero-week over the 134-week period (see Table 1). To realistically model weekly logging production, both aspects of variation must be taken into account.

Table 1. Production summary for three individual logging crews operating in the coastal plain of the U.S. Southeast during a 134-week period.

<table>
<thead>
<tr>
<th>Weekly Production Characteristics</th>
<th>Crew #1</th>
<th>Crew #2</th>
<th>Crew #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>(excludes zero-weeks)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average tons/week</td>
<td>1587</td>
<td>1241</td>
<td>2163</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>512</td>
<td>519</td>
<td>582</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>32%</td>
<td>42%</td>
<td>27%</td>
</tr>
<tr>
<td>Total # of zero weeks</td>
<td>8</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Zero-weeks per year</td>
<td>3.10</td>
<td>2.72</td>
<td>1.94</td>
</tr>
</tbody>
</table>

The second piece of information required for this investigation was logging cost. This was estimated for a “typical” logging system using the Auburn Harvesting Analyzer (AHA), a widely used spreadsheet for estimating logging costs (Tufts et al. 1986, Green and Lanford, 1997). Inputs for the model include estimates of average stand and stock conditions for harvested stands, logging system information, machine productivity information and associated costs. The “typical” southern logging system is assumed to consist of:

1 – felling machine
2 – skidders
1 – loader and
6 – haul trucks (3 owned and 3 leased).
For the purpose of this analysis, it was assumed that an investment in logging consists of starting a new crew by purchasing all new equipment. An investment of $1,067,000 is required to purchase the designated array of equipment (See Table 2). The out-of-pocket cash requirement is about 20% of this amount or $253,400 with the balance being financed for 4 years at 8% interest. The AHA indicates that the average weekly production for such a crew will be 1521 tons (or about 62 loads) per week with an average cost of $10.85 per ton.

Total cost for a given week can be estimated as:

\[
C_T = 10,750 + 4.04(\text{TPW})
\]  

where \(C_T\) is total weekly cost in dollars per week and \(\text{TPW}\) is tons of wood produced per week. These coefficients were taken directly from the AHA and may be interpreted such that 10,750 is the weekly fixed cost in dollars and 4.04 is the variable cost expressed in dollars per ton.

Table 2. Equipment cost for hypothetical logging investment.

<table>
<thead>
<tr>
<th>Equipment Item</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feller-buncher</td>
<td>200,000</td>
</tr>
<tr>
<td>Skidder</td>
<td>170,000</td>
</tr>
<tr>
<td>Loader</td>
<td>120,000</td>
</tr>
<tr>
<td>Haul Truck</td>
<td>94,000</td>
</tr>
<tr>
<td>Haul Truck</td>
<td>94,000</td>
</tr>
<tr>
<td>Haul Truck</td>
<td>94,000</td>
</tr>
<tr>
<td>Pickup Truck</td>
<td>25,000</td>
</tr>
<tr>
<td>Service Truck</td>
<td>50,000</td>
</tr>
<tr>
<td>Office/Shop/Misc.</td>
<td>50,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,067,000</strong></td>
</tr>
</tbody>
</table>

The final information required is an estimate of logging revenue. Total weekly revenue can be calculated as:

\[
R_T = (CH)(\text{TPW})
\]

where \(R_T\) is total dollars of weekly revenue, \(CH\) is the cut and haul (or sales) rate expressed in dollars per ton and \(\text{TPW}\) is as previously defined. From an informal survey of procurement foresters, a “typical” range of cut and haul rates was determined to be between $11.00 per ton and $13.00 per ton.

To assess the impact of production variation on logging investment performance, a simulation model was developed using the Statistical Analysis System (SAS). The model was designed to simulate a logging investment with a four-year duration. The investment begins with the initial input of $253,400. The model generates a net weekly cash flow determined as:

\[
NET = R_T - C_T
\]

where \(NET\) is equal to the net weekly cash flow in dollars and all other variables are as previously defined. The initial investment is subtracted from the weekly net cash flow in the first week. Weekly production is a stochastic process with a fixed probability of zero-weeks. The non-zero weekly production volumes are assumed to be distributed such that \(\text{TPW} \sim N(1571, CV^*1571)\), where \(CV\) is the coefficient of variation of weekly production. The \(CV\) is calculated as the standard deviation of a random variable divided by its mean and then multiplied by one hundred (to express the ratio as a percentage).

The simulation model generates a weekly net cash flow for 208 consecutive weeks (4 years * 52 weeks) and then terminates, assuming the sale of the business. This sale is incorporated into the cash flow by adding the estimated ending equity amount to the net cash flow in the final week of the investment period. The period ending equity is assumed to be $253,400 and consists of the salvage value of the fully depreciated equipment (also estimated to be 20% of the purchase price). An internal rate of return (IRR) on a pre-tax basis and the associated average logging cost per ton for the investment period is calculated for each 208-week period. The 208-week investment is repeated 5000 times for each set of assumptions and the mean and standard deviation of IRR and logging cost is determined for the 5000 trials.

For the cost structure and logging system described above, the simulation model was used to investigate the impact of various degrees of production variability at various sales rates. The factors that were varied and the associated values considered in the simulations were as follows.

1) The average number of zero-weeks per year (0, 1, 2, 3, 4 weeks per year),
2) The coefficient of variation of the non-zero production (0, 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%), and
3) A range of cut and haul rates that are expressed as dollars per ton ($11.00, $11.25,
The various combinations of the above variables lead to the examination of 405 (5x9x9) simulation runs. All other investment factors were held constant.

RESULTS AND DISCUSSION

The impact of increasing production variability on the expected value of logging cost was investigated. In a stochastic production environment, logging costs may vary greatly week to week. For a fixed logging system and cost structure, however, the expected value (long term average) of logging cost per ton does not vary as production variability is increased. In this study, as the coefficient of variation (CV) of production increased from 0% to 40%, the expected value of logging cost remained constant. For example, a logging system with an expected cost of $11.00 per ton may experience wide variation in weekly costs as production varies, however, the expected or average cost over time will remain at $11.00 per ton, regardless of the level of production variability. This assumes that the level of zero weeks is held constant.

The expected per unit value of logging cost does increase, however, as the average number of zero weeks is increased (See Figure 3). As the average number of zero weeks moves from 0 to 4, the expected logging cost increased from $10.85 per ton to $11.42 per ton, an increase of 5.3%. This equals an increase of about 1.3% for each additional zero-week or an increased average cost of approximately $0.15 per ton for each additional zero-week. This cost increase may be attributed directly to the high proportion of fixed costs associated with logging operations. In general, as the number of zero-weeks increases, the total annual production decreases. The fixed cost must then be spread over fewer total tons resulting in a higher per unit logging cost.

The expected internal rate of return (IRR) of the hypothetical logging investment increases as the cut and haul rate increases. This result is intuitive since for an operation with a stationary per unit cost, increasing revenues will naturally result in a higher rate of return. One point to note is that IRR is driven by the size of the profit margin not necessarily the magnitude of the cut and haul rate. For example, a 5% profit margin added to an $11.00 per ton logging cost (a cut and haul rate of $11.55) produces the same IRR as a 5% profit margin added to a $12.00 per ton logging cost (a cut and haul rate of $12.60). Even though the difference between the cut and haul rates is $1.05 per ton, the IRR in both cases is equivalent.

For a given profit margin, expected IRR is "essentially" constant across the full range of production variation. The word "essentially" is used to denote that a very slight increase was observed in some instances. For example, in a simulation with 4 zero weeks per year and a profit margin of 6%, the IRR of the logging operation increased from 14.82% to 15.44% as the CV of production increased from 0% to 40%. This difference of 0.62% translates into an increase of less than 0.02% for each one-percent increase in the CV of production. This slight increase is due primarily to the simulation methodology.

When simulating weekly financial performance, total revenue is largely determined by production level. In any given week the lowest financial performance possible results when zero production is experienced. During a zero-week the logging business loses an amount equal to the weekly fixed cost ($10,750). This means that for all levels of production variability, the very worst week can never exceed the loss of the fixed cost. In this sense, weekly financial performance has a lower bound. This is not the case, however, with the upper end of weekly financial performance. As the level of production variability increases so does the possibility or opportunity for weeks with higher revenues. Thus revenue does not have a firm boundary on the upper side; the upper limit increases with production variability. The net result of this situation is that at higher levels of production variability, the frequency distribution of IRR may be positively skewed. The small increase observed in the expected value of IRR as production variation increased is an artifact of the modeling process and is not an indicator that higher rates of production variability actually result in higher returns. A more reasonable conclusion about the relationship between logging investment return and production variability is that the expected value of IRR remains relatively constant across increasing levels of production variability.
variability and that the magnitude of expected IRR depends primarily on percent profit margin.

Risk in many investments, including logging, may be measured by the standard deviation of IRR. Bodie et al. (1998) indicates that the standard deviation is a reasonable measure of risk as long as the return distribution is symmetrical or approximately normally distributed. It was noted above that at high levels of production variation, a slight positive skew was observed in the frequency distribution of IRR. In the discussion that follows, it is assumed that the magnitude of this skewness was not sufficient to invalidate the standard deviation as a representative measure of risk.

Since the standard deviation is an absolute measure of variability, it is not always suitable for directly comparing investments, especially when the investments have different expected returns (Moyer et al., 1998). When this is the case, the coefficient of variation (CV) provides a better measure of risk. In this study, CV will be used for all risk comparisons and an increase in the CV of IRR can be interpreted as an increase in the level of risk associated with that investment.

Note that the following consideration of risk was restricted to situations where IRR values were greater than or equal to 5% and where the CV of non-zero production had values greater than or equal to 10%. These restrictions reduced the number of observations from 405 to 259 and were imposed for several reasons. The primary reason is that the production variability-risk relationship in the excluded range was not especially “well-behaved” and posed significant modeling problems, while the relationships within the prescribed range are essentially linear. Also, the exclusion of investments with low IRR values does not particularly hamper the analysis since the area of greatest interest for most investors will likely be above the 5% minimum. In addition, excluding the situations with extremely low non-zero production variability should not be a problem since production CV values below 10% were not observed in the historical data and likely do not occur with great frequency in operational environments.

For the case considered here, the CV for the internal rate of return (CV_I) can be expressed as a function of three determinants. These are the coefficient of variation of weekly non-zero production (process variation) expressed as a percent (CV_P), profit margin expressed as a percent (PM) and the expected number of “zero weeks” per year (ZW).

The regression analysis indicates a positive relationship between CV_I and CV_P. If other factors are held constant, CV_I increases in a linear fashion as CV_P increases. There are significant interaction terms, however, indicating that the impact of CV_P on CV_I is reduced at higher levels of PM. The impact of increased CV_P is also reduced by higher levels of ZW, although, the level of ZW is less important than the level of PM. For example, if PM is equal to 2 and ZW is equal to 0, an increase of one unit of CV_P produces a 2.08% increase in CV_I. If the same one unit increase in CV_P takes place when PM is increased to sixteen, the resulting CV_I change is less than one percent (0.47%). If this same calculation were repeated with ZW equal to 4, and PM equal to 2 and then 16, the corresponding changes in CV_I would be 1.33% and 0.33%, respectively. These relationships hold true over the entire range of CV_P values (10% to 40%). In general, increases in CV_P increase the risk associated with logging investments, especially when profit margins are low.

In much the same fashion as CV_P, a positive relationship exists between CV_I and ZW. If other factors are held constant, CV_I increases in a linear fashion as ZW increases. There are significant interaction terms, as before, indicating that the impact of ZW on CV_I is reduced at higher levels of PM. The impact of increasing values of ZW is also reduced by higher levels of CV_P, although, CV_P is less important than the level of PM. For example, if PM is equal to 2 and CV_P is equal to 10, an increase of one unit of ZW (from 0 to 1) produces an increase of 11.18% in CV_I. If the same ZW increase takes place when PM is increased to 16%, the resulting CV_I increase is

### Table 3. Least squares parameter estimates for the regression equation relating the coefficient of variation of logging investment internal rate of return (CV_I) to the coefficient of variation of weekly non-zero production expressed as a percent (CV_P), profit margin expressed as a percent (PM) and the expected number of “zero weeks” per year (ZW).

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Estimate</th>
<th>t-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV_P</td>
<td>0.239001</td>
<td>49.378</td>
</tr>
<tr>
<td>(1/PM)</td>
<td>7.639263</td>
<td>7.682</td>
</tr>
<tr>
<td>ZW</td>
<td>0.969317</td>
<td>8.052</td>
</tr>
<tr>
<td>(CV_P)*(1/PM)</td>
<td>3.682235</td>
<td>93.380</td>
</tr>
<tr>
<td>(CV_P)*(ZW)</td>
<td>-0.013372</td>
<td>-2.798</td>
</tr>
<tr>
<td>(1/PM)*(ZW)</td>
<td>24.153134</td>
<td>35.311</td>
</tr>
<tr>
<td>(CV_P)<em>(1/PM)</em>(ZW)</td>
<td>-0.346938</td>
<td>-13.451</td>
</tr>
</tbody>
</table>

Observations: N=259

R^2 = 0.9979
reduced to 2.13%. If this calculation were repeated with $CV_p$ increased to 40% and PM equal to 2% and then 16%, the corresponding changes would be 5.58% and 1.08%, respectively. The relationships described above hold true over the entire range of ZW values (0 to 4 weeks). In general, increases in ZW increase the risk associated with logging investment, especially when profit margins are low.

From the above paragraphs, it might be concluded that ZW has a more significant impact on CV\textsubscript{I} than does CV\textsubscript{P}. It must be noted, however, that the size of the range of each variable must be considered when comparing their relative impact on CV\textsubscript{I}. In this study, ZW ranges from 0 to 4 weeks, while CV\textsubscript{P} ranges from 0 to 40%. A one unit change (1 week) in ZW represents a 25% movement across its range while a one unit change in CV\textsubscript{P} (1%) represents a movement of 2.5% across its range. Another comparison of interest is to consider how the impact produced by a one-week increase in ZW compares to the impact produced by a 10% increase in CV\textsubscript{P}. This comparison reveals that when scaled by their respective ranges, a change in CV\textsubscript{P} produces a larger impact than a comparable change in ZW. The impact from changing CV\textsubscript{P} by 10% produces a change in CV\textsubscript{I} approximately twice as large as the impact produced by a one-week change in ZW. Stated another way, a one-week increase in ZW has roughly the same impact on CV\textsubscript{I} as a 5% increase in CV\textsubscript{P}. This difference is easily demonstrated by multiplying the estimated CV\textsubscript{P} impacts in the paragraph above by a factor of 10 and then comparing to the reported ZW impacts. While determination of their relative impact may ultimately depend upon perspective, it is clear that both CV\textsubscript{P} and ZW significantly impact logging investment risk.

The relationship between PM and CV\textsubscript{I} is very different from the previously mentioned variables. If other factors are held constant, CV\textsubscript{I} decreases in a nonlinear fashion as PM increases. The most dramatic decreases occur at low levels of PM and the impact declines as PM is increased. There are significant interactions in these relationships such that the impact PM has on CV\textsubscript{I} increases at higher levels of both CV\textsubscript{P} and ZW. For example, if PM is equal to 2, ZW is equal to 0 and CV\textsubscript{P} is equal to 10%, an increase of one unit of PM (from 2% to 3%) produces a decline of 7.41% in CV\textsubscript{I}. If the same increase in PM takes place when CV\textsubscript{P} is equal to 40%, the resulting CV\textsubscript{I} decline is 25.82%. If the above calculations were repeated, only this time with PM changing from 15% to 16%, ZW still equal to 0 and CV\textsubscript{P} again equal to 10% and then 40%, the corresponding CV\textsubscript{I} reductions would be 0.18% and 0.65%, respectively. Again, note that the impacts decline and are nonlinear with respect to PM.

Although not shown here, a similar pattern is evident regarding interactions between PM and ZW. In a very real sense, profit margin (PM) buffers against the impacts of production variation from both CV\textsubscript{P} and ZW and the incremental buffering effect of a small increase in PM diminishes at higher levels of PM. In general, the risk associated with logging investment decreases as profit margin increases.

Production variation is a fact of life for investors in a logging business. A substantial proportion of production variability is simply unavoidable. Weather, site conditions, and equipment failures are just a few of the uncontrollable factors. There are, however, some factors contributing to production variation that can be reduced or mitigated by the management actions of wood procurement organizations. Opportunities may exist to reduce production interruptions through improved wood inventory management, sourcing plans that do not include excessive logging capacity, and prudent administration of wood quotas. Inefficient management in these areas often limits production opportunities for logging contractors.

Wood procurement organizations often adopt as their mission the development of a high quality, secure, and stable fiber supply, at a minimum cost. Traditionally, there is recognition among managers that a tradeoff exists between fiber security and cost, where increased security typically means higher cost. The findings in this study suggest that there may be economic incentives for wood procurement organizations to consider efforts to actively manage production variation. The rational might go as follows.

Loggers and investment in logging are a vital component of current and future fiber supply plans. The nature and characteristics of the logging force impact fiber security, quality, and cost. Economic rationality dictates that there must be an economic incentive for logging investment. In other words, if the logging force is not receiving an acceptable rate of return on their logging investment, there is very little incentive for individuals to continue logging. Wood procurement organizations (who are in business for the long-term) must consider the incorporation of this view into their strategic plans.

This study demonstrates that increasing zero production weeks increases logging cost. It also indicates that the rate of return on logging investment is primarily driven by profit margin. Thus, for the same rate of return, higher profit margins are required when costs are higher. To achieve some target rate of return, it seems logical for procurement organizations to support efforts to minimize logging cost. Lower costs allow lower cut and haul rates to achieve the
same internal rate of return. One way for procurement organizations to assist in this effort is to manage procurement activities in such a manner as to minimize zero production weeks. This will help minimize logging cost and subsequently cut and haul rates.

This study also reveals that increased production variability increases the risk associated with logging investment. As risk increases, investment at the same expected rate of return may be less desirable for an individual logging investor (assuming some level of risk aversion). High levels of risk indicate that the likelihood of an unacceptable rate of return has increased. Logging force stability declines as the probability that an individual investor may experience an unacceptable level of return and opt (or be forced) out of the logging business increases. From the standpoint of wood procurement organizations, an increase in logging investment risk is actually a decrease in fiber security due to the increased turmoil within the logging force. The impact of an individual producer leaving the production force becomes even more significant as investment in training and expectations for safety and environmental performance increases. Clearly, efforts by wood procurement organizations to reduce production variability contribute to fiber security. The specific strategies and management techniques required to efficiently achieve this reduction require additional study and development.

**CONCLUSIONS**

Production variability is a significant determinant of logging investment outcome. Both process variation and the average number of zero-weeks contribute to the level of production variability experienced by logging investors.

The expected value of logging cost remains constant across increasing levels of production variability except when the level of zero weeks is increased. Logging cost increases modestly as the number of zero weeks increases due to the impact of high fixed cost.

The expected value of the internal rate of return of logging investment remains relatively constant across increasing levels of production variability. The magnitude of the expected IRR depends primarily on percent profit margin.

The greatest impact of production variability on logging investment is the impact on investment risk. In general, risk increases as production variability increases. This is true of production variation increased by either process variation or an increase in the average number of zero weeks. The impacts of production variation are decreased by increases in profit margin.

Given the adverse impacts of production variability on logging investment, there may be incentives for wood procurement organizations to manage production variation for the purpose of cost containment (reduction) and fiber supply security. More study is required to determine the most efficient management strategies to affect this change.

**LITERATURE CITED**


