Technology Strategy in Commodity Industries

by

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and the School of Engineering
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Abstract

This thesis combines two methodologies, system dynamics and historical case studies, to derive a technology strategy for a commodity industry. The method is illustrated by the development of a technology strategy for a hypothetical firm in the softwood lumber industry of North America. A system dynamics finance model is built in five stages to quantify the profitability of the firm and the net present value of technology investments over the next 25 years. The model is used to decide how much emphasis should be placed on improvements to process technology vs. the creation of new lumber products.

The results from the modeling study are compared to case studies of other commodity industries. Conclusions show that emphasis for the lumber firm should be placed on new lumber products. A general methodology for the development of technology strategy in other commodity industries is presented.

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Title: Senior Lecturer, MIT Sloan School of Management.
Acknowledgments

The lumber industry....

"might warm the heart of Adam Smith but it would break the heart of any industrial research director." Mead (1966), citing Zivnuska.

I wish therefore to thank my thesis advisor, Henry Weil, for his generous and insightful guidance during the preparation of this thesis.

I would like to acknowledge the sponsorship of Weyerhaeuser Co. and thank Amar Neogi, Hank Montrey and Nancy Hunter for their assistance and advice.

I particularly appreciate the support and patience of my wife Cindy and dedicate the thesis to my mother and father.
How to Read This Thesis

This thesis describes a two-part methodology for the determination of a technology strategy in a commodity industry. The two parts to the methodology are...

1) Application of system dynamics to conduct a financial analysis of investment in new technology.
2) Analysis/discussion of historical case studies in other commodity industries.

The thesis attempts to combine these two methods. It is illustrated by the development and presentation of a technology strategy for a hypothetical firm in the softwood lumber industry of North America.

The thesis is divided into four sections.

Section 1. Introduction.
Section 2. System dynamics model development in five stages.
Section 3. Historical case studies.
Section 4. Summary and conclusions.

The model development is in five stages with independent interim summaries at the end of each sub-section. Readers who are interested only in the methodology should read the introduction and conclusions (sections 1 and 4). Readers who are interested in the forest products industry but not the methodology should read the introduction (section 1), the interim summaries (2.2.2, 2.3.3, 2.4.3, 2.5.4 and 2.6.4) and the conclusion (section 4). Readers with an interest in both should read all sections.

An appendix provides detailed documentation of the final version of the model.
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Introduction

1.1 Background

- Technology Strategy in Commodity Industries –

Webster’s Dictionary defines commodity as “a mass-produced unspecialized product”. At first glance, commodity industries may be viewed as mature, low margin businesses that are unlikely to be heavy investors in innovation. The phrase “technology strategy” has a more grandiose connotation, perhaps conjuring images of dynamic “high-tech” firms planning how their next product launch will force customers to upgrade their PC’s. What then is “technology strategy in commodity industries”?

In developed economies, advanced technologies are employed in production of even the humblest of commodities. Consider as an example, the use of lasers in cutting stacks of cotton cloth in mass produced dressmaking. At its simplest, technology strategy in such a case could be an articulation of how to acquire and employ this advanced manufacturing technique. In this example it seems intuitive that the dressmaker would not develop the laser himself but would purchase the capability from a vendor. A more complex strategy might consider whether investment in the laser is warranted given the dressmaker’s long-term plans of, say, diversifying into a new business that may not require it.

For situations in which “intuition” is not sufficient to determine a technology strategy several authors have discussed more rigorous techniques. Roberts (1983) has even defined technology planning as “attempting systematically to decide upon allocation of technological resources” (underline added). Among the techniques that have been used, system dynamics has received considerable attention and gained a successful reputation. Davis and O’Donnell (1997) have described in general terms how firms such as AT&T, the BBC, BT, Exxon, Ford, IBM, Shell and SmithKline Beecham have used system dynamics as part of their strategic planning activities. Lyneis (e.g. 1993), Weil (e.g. 1994) and others have published widely in this field. System dynamics is particularly useful because it forces assumptions to be stated explicitly and captures the complex time dependant interactions of variables. It has also proven valuable for scenario or “what-if” analyses. For example, returning to the hypothetical dressmaking example above, what
if the laser purchase decision is deferred for some time? Will the company remain profitable long
enough to diversify into the new business?

Other authors have taken a descriptive or “historical” approach to the evaluation of strategy.
Utterback (1994) has summarized the “dynamics of innovation” for numerous companies
engaged in a transition of their business. The “case history” method has also proven extremely
valuable, not least in bringing an element of “certainty” to an endeavor that is inherently not. In
the hypothetical dressmaking example, to know that four out of five clothing firms who did not
invest in a laser cutter went bankrupt would add tremendous value to any rigorous, but uncertain,
forward projection of cash flows that suggested that there might be profitability problems.

This thesis attempts to combine both system dynamics and case history methods to a problem of
technology strategy in a commodity industry. The particular industry is not mentioned in the title
because the interest of the reader should not be constrained by the setting. The purpose of the
thesis is to explore the combination of these two techniques. It is hoped that the learning gained
from this exercise would be of value in a number of otherwise unrelated industries. Focus is given
to a commodity industry because it is believed that such industries have an inherent and
interesting “tension” between investment in technologies that lower the cost of current production
vs. those that advance the company into new areas of business. For simplicity, these two
technology directions will be referred to throughout as “new process” and “new product”
respectively. Understanding how to find the right balance between these two directions is a
challenge for commodity industries. For “high-tech” industries making highly differentiated
products the decision is easier. For example, a leading pharmaceutical firm might decide to spend
100% of available R&D funds on developing new drugs and 0% on making them cheaper. It is
argued that the commodity case is the “general form” of this type of problem and that high-tech is
a special “reduced” sub-set.

1.2 The Setting

The commodity industry that this thesis addresses is not dressmaking but rather the sawn
softwood lumber industry of North America. Interestingly, both have considered the use of lasers
for their primary cutting operations although the reasons are different. In the case of the lumber
industry the driving force has been the importance of sawmill “yield” in the economics of
manufacture. Yield is the ratio of finished lumber volume to purchased log volume. Lasers were considered as a potential way to reduce "kerf losses" created by the thickness of the saw blade. They have however proven impractical for reasons of high energy consumption and low throughput (Tillman, 1985).

Yield continues however to be an important driver of the profitability of the industry. This fact has been heightened in recent years by the falling quality of logs. Size of the log and strength (or density) of the wood are the primary determinants of quality. The averages of both have been falling steadily as the industry completes the transition from cutting "old growth" natural stand timber to shorter rotation plantation wood. This so-called "2nd growth" timber is both smaller in size and lower in average strength. The smaller size lowers the yield factor and the lower average strength reduces the proportion of the wood that is suitable for sale into higher value structural uses. Both factors have contributed to declining profitability.

The industry is also subject to external change factors such as the rise of substitute raw materials in the construction market. In recent years there has been a resurgence of interest in the use of light gauge steel in residential construction. This has come about primarily for two reasons. First, logging restrictions in the Pacific Northwest of the US led to increases in the price of lumber. This made the use of steel more cost competitive. Second, the poorer quality of second growth timber has led to the surfacing of latent dissatisfaction with lumber as an unreliable building material. Steel framing captured some 4-6% of the US residential housing market over the period 1992-1995 (American Iron and Steel Institute, 1998). This is discussed in more detail in section 2.5.1.

The industry as a whole has responded to these changes and threats in various ways. Firstly, unprofitable mills have closed and production consolidated at more efficient facilities. This is particularly true of older mills that were not equipped to handle small diameter logs. Secondly, continuing investment has been made to improve processing technology to lower the costs of lumber manufacture. Thirdly, there has been investment made in the development of high quality "engineered" wood-based alternatives to lumber such as the wood I-beam. A wood I-beam made from oriented strand board and laminated veneer lumber is illustrated in figure 1.1.
This thesis attempts to combine the system dynamics and case history methods to derive a technology strategy for the softwood lumber industry. It addresses the “macro-level” question of what proportion of future R&D and capital expenditures should be directed at improving the economics of lumber manufacture through yield or other improvement vs. the creation of new product technology (such as the I-beam). Attention is also given to some of the important “2nd-level” options that exist. The “make vs. buy” decision in the acquisition of technology to improve yield or to develop/acquire engineered products is given consideration. Other tradeoffs such as the aggressiveness and timing of strategies are also discussed.

1.3 Literature Review: Technology Strategy in the Lumber Industry

Much has been written about the lumber and forest products industries in general. Ellefson and Stone (1984) provide a useful summary on the general structure of the US industry. Relatively little has been written however about technology strategy in the lumber industry, no doubt due in part to the proprietary nature of such strategies. A notable exception is the work of Schuler, Thompson, Vertinsky and Ziv (1991).

Schuler et.al. constructed a mathematical model of the softwood lumber industry in Canada acting in competition with its US counterpart. The model calculates the impact on profitability of future changes in log quality and investment in R&D. A distinction is made between investment in new process technology and new product technology. The paper attempts to derive a suggested portfolio balance between the two. The model is a “cross-impact analysis” in which selected variables interact with each other in a time dependant fashion. Interactions are defined by coefficients laid out in matrix form. The intersection of “row” and “column” variables defines the pair-wise “cross-impact” of one variable on another and leads to a projection of trends over a 25 year period. The approach may be criticized from several respects.
1) The separation of technology strategy into Canadian vs. US firms is not necessarily realistic when one considers that some of the largest lumber companies have operations in both the US and Canada. For such firms, their technology strategy is likely to be “corporate” in nature with an equal effect on both the US and Canadian operations of the same firm. Also, equipment suppliers have made many of the advances in process technology. These advances are diffused rapidly through the industries of both countries.

2) The evaluation of technology strategy aggregated at the national level is not necessarily helpful to individual firms in the market. For example, Schuler et.al. conclude that a mixed portfolio of investment in process and product R&D is the recommended strategy for the Canadian industry. This does not help individual firms decide if they should all adopt the “average” investment portfolio or if the national average can be attained by some firms focusing on new processes whilst others focus on new products. Individual players within an industry are often characterized by widely different strategies. In fact, polarization of strategies can allow more than one firm within an industry to derive an “economic rent” and prevents “regression to the mean” in which all players earn mediocre returns.

3) The analysis that Schuler et.al. present does not allow for an easy interpretation or critique of the “dynamics” that are involved (no pictorial presentation of the interaction of all the variables is presented). In addition, values of variables resulting from modeling are presented on a 0 to 1 scale that makes interpretation in real terms tedious. The quantitative methodology itself is also open to question as to whether it provides for realistic non-linearities, feedbacks and delays.

4) An additional consideration is that the N. American lumber industry is characterized by a very large number of firms (7500 were reported by Lenard, 1977). Only a small number of these might be capable of funding R&D at the “critical mass” level required to make a meaningful contribution to progress of either process or product technology.

Notwithstanding the above criticism, the analysis of Schuler et.al. is very valuable in that it collates some useful reference sources about the industry and presents some interesting formulations. It is an important starting point for the analysis presented here and will be cited throughout.

Tillman (1985) in a book titled “Forest Products: Advanced Technologies and Economic Analyses” provides an excellent summary of technological change affecting the forest industries. The book contains a number of interesting case analyses of recent innovations in the industry and some “worked examples” of their financial evaluation. Of particular note is a detailed consideration of the discount rates (cost of capital) for various types of technology investment.
2. Model Development

2.1 The Approach to Modeling

The approach to modeling taken here is embodied in the following quote...

"The future is not some place we are going to, but one we are creating. The paths are not to be found, but made..."-Scharr (1997)

A key implication is that there is not a "single" or fatalistic future that can be predicted with precision. In this respect, the output from the model should be viewed as providing possible future outcomes resulting from deliberate choices made at points along the way.

The model is designed around the concept of a single, hypothetical, firm operating in competition with the rest of the industry. The model will be didactic, i.e. for the purpose of learning. It is not intended to be a strategic or forecasting model for a particular firm or specific product. The data used is drawn from public domain sources and contains many aggregations of "lower level" detail. In the words of Schuler et.al. (1991) the model will therefore only address the "geometry" of the system but not attempt to construct its precise "arithmetic".

The model will be built and presented in 5 stages, with each stage adding a new level of complexity. Interim conclusions are drawn after each stage, which are then challenged and modified in the next section. It is hoped that this will allow the reader to follow the evolution of the thought process and facilitate understanding at each stage. In modeling of this type most assumptions are open to critique. One of the features of modern system dynamics software is the ease with which these assumptions can be altered. Altering key assumptions within the extremes of their uncertainty is used to test the robustness of conclusions from the model.

A set time period of 25 years was chosen as the modeling horizon. This is long enough to capture the major expected declines in log quality and allows time for the net present value of projects to approach their steady state (long run) equilibrium.
2.2 Model Stage I: Declining Log Quality

Figure 2.1 Model Stage I. Effect of Declining Log Quality on Profitability

Stage I of the model considers the effect of declining log quality on profitability in the absence of any other factors. Figure 2.1 shows the basic relationships between important variables. The polarity of the arrows refers to the direction of the influence of one variable on another. For example, the positive arrow between the cost of logs and production costs means that when log cost rises so do production costs. At this stage in the modeling however the exogenous variables such as log cost (those not effected by others in the model) are held constant. The model is initialized with the values shown in table 2.1.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Initial Value (units)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log Quality</td>
<td>0.6 (dimensionless)</td>
<td>Schuler et.al. (1992)</td>
</tr>
<tr>
<td>Recovery Factor</td>
<td>0.48 (dimensionless)</td>
<td>Schuler et.al. (1992)</td>
</tr>
<tr>
<td>Cost of Logs</td>
<td>250 ($/mbf)*</td>
<td>Univ. of Georgia (1998)</td>
</tr>
<tr>
<td>Other Production Costs</td>
<td>40 ($/mbf)</td>
<td>Tillman (1985)</td>
</tr>
<tr>
<td>Price of Residuals</td>
<td>160 ($/mbf)</td>
<td>Schuler et.al. (1992)</td>
</tr>
</tbody>
</table>

* mbf = thousand board feet. 1bf = a piece 1”x 1” x 12”. 1000 board feet = 2.359 m³
** This is a composite price of a wide range of standard lumber products.

Table 2.1 Initial Values of Variables in Model Stage I.
Schuler et al. (1992) give a simple formulation for an index of log quality as the ratio of annual volume of logs going to the sawmill divided by the annual volume of roundwood harvested. A composite value of those derived by Schuler for the US and Canada is used here. It is initialized at 0.6 and allowed to fall to 0.5 over the 25-year period for which the model is run in accord with the analysis that Schuler presents. Recovery factor is the ratio of outgoing lumber volume to incoming log volume and moves in direct proportion to the log quality. The term “Other Production Costs” includes labor, maintenance, overhead and energy costs in accord with the analysis given by Tillman (1985). It should be noted that the majority (~85%) of the production costs are due to the log cost. This later assumption varies by region of the country (log costs are currently higher in the NW of the US than the SE) but is typically in the range 65%-85%.

2.2.1 Model Stage I: Output and Analysis

![Graph for Profitability](image)

**Figure 2.2 Model I: Graph of Profitability**

Figure 2.2 shows the base case run. It can be seen that the profitability of the hypothetical firm is currently only ca. $6/mbf of harvested log which represents about 2.2% of total sales (sales = 0.48*400 + 0.52*$160 = $273/mbf). This is projected to fall with time and become unprofitable in about 10 years. A sensitivity analysis was conducted using the model in which each key variable was altered by 10% (holding all others constant) and looking at the effect on the initial (year zero) profitability. Results are shown in table 2.2 below.
<table>
<thead>
<tr>
<th>10% change in...</th>
<th>From...</th>
<th>Results in Change in year zero Profitability from...</th>
<th>Which is an increase of...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Logs</td>
<td>250 to 225</td>
<td>6 to 31 $/mbf</td>
<td>417 %</td>
</tr>
<tr>
<td>Price of Lumber</td>
<td>400 to 440</td>
<td>6 to 25.2 $/mbf</td>
<td>320 %</td>
</tr>
<tr>
<td>Initial Recovery Factor</td>
<td>0.48 to 0.528</td>
<td>6 to 15.6 $/mbf</td>
<td>160 %</td>
</tr>
<tr>
<td>Price of Residuals</td>
<td>160 to 176</td>
<td>6 to 14.3 $/mbf</td>
<td>139 %</td>
</tr>
<tr>
<td>Other Production Costs</td>
<td>40 to 36</td>
<td>6 to 7.9 $/mbf</td>
<td>32 %</td>
</tr>
</tbody>
</table>

Table 2.2: Sensitivity Analysis of Key Variables in Model I.

The results show that the variable with the highest “leverage” on the basic cost structure is the Cost of Logs. Log cost is determined by factors associated with forest operations and the external market dynamics (supply/demand). It is clearly a critical variable that merits further study and is discussed in more detail in section 2.5.2.

The second most important variable is lumber price. This is determined at auction in a fully competitive market and as such is not a leverage point that the individual firm can typically control. Notwithstanding this statement however it is worth pointing out that if a firm could add market value of say just $4/mbf (1% above market) at a cost of $1/mbf then the initial profitability rises from 6 to 7.44 $/mbf or an increase of 24%. One element of a technology strategy might therefore explore incremental product improvements aimed at justifying a marginal price premium of the companies’ lumber over that of the competition.

The recovery factor is clearly an important leverage point and is the focus of model stage II. Price of residuals is also seen to be very important. In fact if the residuals from sawmilling were not sold then the operation would be fundamentally unprofitable. This can be easily seen in the model where all of the cost is ascribed (for illustrative purposes) to the lumber production. The initial value of the production cost is ca. $561/mbf of lumber produced and rises to $665/mbf at the end of the 25 year period. In all cases this cost is higher than the selling price of $400/mbf. The close link between sawmill profit and the price of residuals is one reason for the integration of sawmills and pulp production facilities on the same site. It has also provided the impetus for historical industry developments such as the “chipping headrig”. This device aims to maximize the production of high value pulp “chips” and minimize the production of low value sawdust whilst
maintaining an acceptable lumber yield. Lastly, "Other Production Costs" are clearly less important and have received proportionally less attention.

### 2.2.2 Model Stage I: Interim Summary

The expected decline in log quality over the next 25 years will erode profitability of sawmill operations if no action is taken and if no changes in market conditions occur. Mills most effected will be those with high cost of logs such as in the NW of the US. The following strategic options to improve profits exist in order of "leverage" on the cost structure of the business....

- Secure lower cost logs
- Add incremental value to command a small price premium
- Improve recovery factor
- Obtain a higher price for residuals

Historically the sawmill industry appears to have focussed on the recovery factor option despite its lower leverage. This may result partly from the fact that recovery is within the direct control of the sawmill operation. This option is examined in stage II of the model. It is worth noting however that firms who are integrated backwards into log production (forestry) and forwards into pulp (residuals market) should not restrict their strategy to lumber recovery.

### 2.3 Model Stage II: Spending on Process R&D

In this second stage of the model consideration is given to the effect of spending money on process R&D in an attempt to offset the declining profitability of figure 2.2. The assumption is made that the output of the research effort has a direct effect on the recovery factor of the sawmilling operation. In order to construct the model it is necessary to "scale" the operations of the hypothetical firm (i.e. to describe what volume of logs is processed in a year (mbf/year) in order to convert the profitability measure ($/mbf) into a profit ($/year) figure). An arbitrary scale for the firm is chosen as 6.25 Bbf/year of annual log harvest (or purchase) which yields 3 Bbf/year of lumber production at the initial recovery factor of 0.48. This scale was chosen to be consistent with funding of R&D at some "critical mass" (see below) and is representative of the
scale of operations of some of the larger companies in the industry (Weyerhaeuser Co. Annual Report, 1997). It is also assumed that the hypothetical firm operates 30 mills that each produces a nominal 100,000 mbf/year of lumber (at a recovery factor of 0.48). This is an important consideration in the assignment of a capital expenditure for each process innovation used. The model assumes that each process innovation can be implemented for $1M per mill and that this capital expenditure is initiated at the “completion” of the R&D phase. A time constant determines how fast the capital expenditure is made to simulate the gradual implementation of new technology at the 30 mills in the system. Each of the above assumptions can be altered in the model to conduct a sensitivity analysis.

One of the most important aspects of system dynamics modeling is the assignment and interaction of delays. A crucial delay in the system under consideration is how long it takes any R&D investment to bear fruit. There are many ways in which such a delay could be formulated. The method chosen must reflect the fact that the delay itself is dependent upon the rate of R&D spending, i.e. the faster one spends R&D money the quicker one expects to see results. This of course makes the assumption that there are no “bottlenecks” in the system such as might exist in, say, regulated testing in drug development. The simplest way to represent this delay dependence is to assume that progress is “incremental” with spending, i.e. only when a “critical mass” input of $X$ of R&D has been invested will there be a yield (output) of “$Y” in terms of improvement to the recovery factor. The rate of spending then determines the length of the delay. It is also intuitive to allow for a “law of diminishing returns” to capture the fact that as the “limit” of the process technology is reached each increment of yield improvement “$Y” will require a larger R&D spending “$X”. For the purpose of this model it is assumed that the limit of the recovery factor is approximately that existing at the beginning of the 25-year period. This assumes that the process for sawing today’s logs is already a mature and therefore optimized technology. Model II is shown in figure 2.3 below. It can be seen towards the top of the figure that the model calculates the profitability of the sawmill operation both in the presence and absence of the benefit from any R&D expenditure. By taking the difference in profitability, a net present value (NPV) analysis of the incremental cash flows deriving from the R&D investment is calculated as shown in the bottom right of the figure. Some conventional financial nomenclature is used in the model for brevity.²

¹ Bbf – billion board feet
Figure 2.3 Model Stage II.
An important point must be made concerning the calculation of the incremental cash flow deriving from R&D ("EBIT due to R&D"). In the absence of R&D expenditure the profitability of the firm becomes increasingly negative after about 10 years (figure 2.2). It is not reasonable to assume that the firm continues to operate this way for the remaining 15 years of the simulation. The company would take action to minimize its losses in various ways such as lowering production, raising prices, cutting overhead or shutting down. At this point in the model no attempt is made to explicitly model these responses. Therefore to avoid an unreasonable "overestimation" of the contribution of process R&D the variable "Profitability without R&D" is prevented from becoming negative. In essence this adjustment assumes that the firm is able to just maintain a break-even position by conventional cost-cutting or other reactionary measures.

2.3.1 Model Stage II: Output and Analysis

The model is first run by varying the initial rate of R&D spending from zero to $2M per year. Results for profitability and net present value are shown in figures 2.4 and 2.5 respectively.

![Graph for Profitability with R&D](image)

**Figure 2.4 Graph for Profitability with Process R&D Expenditure.**

The calculations are made using a risk adjusted pioneering real discount rate of 19% in accord with the detailed analysis given by Tillman (1985) for an "advanced controls sawmill". In figure 2.4 it can be seen that a profitable operation can be maintained by spending on process R&D. In figure 2.5 it can be seen that there is however a "preferred" rate at which R&D expenditures should be made (approximately $1M/year in this example). This preferred rate changes of course with the assumptions made. Given the dynamics which have been assumed, there is no benefit to
rushing to develop and install technologies which do not bring benefit until the quality of logs has fallen with time.

![Graph for NPV of R&D Projects](image)

*NPV of R&D Projects*: No R&D
*NPV of R&D Projects*: $0.5M R&D
*NPV of R&D Projects*: $1M R&D
*NPV of R&D Projects*: $2M R&D

![Figure 2.5 Graph of Incremental Net Present Value of Process R&D Projects](image)

An analogy could be drawn here with a prudent pace of expenditure on software development that tries to keep pace with, but not exceed, the capabilities (e.g. speed) of microprocessors.

The above model can be used to perform a test for the approximate Internal Rate of Return (IRR) for the R&D investment. The discount rate is altered to find the limiting value which causes the NPV of the project to be ZERO at the end of the time period under consideration. Such an analysis is shown in figure 2.6 below for the case of spending R&D at $1M/year. The data set “IRR test” is at a real discount rate of 36%.

![Graph for NPV of R&D Projects](image)

*NPV of R&D Projects*: $1M R&D
*NPV of R&D Projects*: IRR test

![Figure 2.6 Graph of Net Present Value of Process R&D. IRR test is at 36% Discount Rate.](image)
This result implies that the process R&D investment can be expected to earn a return of about 17% above the cost of capital (36%-19%) over this 25-year period. This result is consistent with those of Tillman (1985) and typical of the types of simplistic analyses that are run on spreadsheets. It is however believed to be overly optimistic. Tillman himself noted that “revenue estimates assume the sale of all lumber produced, which may or may not be reasonable given the current overcapacity in the sawmill sector of the FPI” (FPI = forest product industry). This criticism applies equally to the current model (model II) in which the real price of lumber is assumed to remain constant over the 25 year period. Up to this point no consideration has been given to the effects of production, demand and importantly, price, in the industry. This set of interactions is taken up in the third stage of the model. Before leaving this stage of the analysis however it is instructive to consider the “make vs. buy” decision with respect to the acquisition of process improvement technologies.

2.3.2 Model Stage II: The “make vs. buy” Decision for Process Technology.

Instead of spending on internal R&D the company could decide to purchase all process improvement technology from equipment vendors. This has a couple of important benefits. Firstly the money saved on R&D can be put towards capital expenditure. Secondly the “riskyness” of the investment is reduced as greater choice can be exercised in selecting a suitable technology from amongst presumably proven alternatives. As explained by Tillman (1985) this reduces the real discount rate (in Tillman’s analysis it is lowered from 19% to 13%). The important trade-off to consider is whether some competitive advantage is forgone by not having developed proprietary process technology. In sawmilling the case for development of patented or trade secret technology that provide advantage is rather weak. First, many sawmill improvements involve computer technology that is widely available, difficult to patent and easy to duplicate. Second, the sheer number of equipment vendors interested in such developments may render the effort of the individual user firm marginal at best.

A simple analysis of the monetary value of the “make-buy” trade-off can be carried out by “turning off” some critical links in figure 2.3. The R&D tax shield and the connection between the rate of R&D spending and the free cash flow due to R&D are both eliminated. The model is run, as before, to simulate capital expenditure (on four vendor technologies) made over the 25-year period. Capital spending is at the same rate as under the $1.0M R&D/year scenario since it is
assumed that the vendor firms R&D cost is insignificant on a per-machine-sold basis and does not affect materially the capital costs to the purchasing firm. Under the "buy" scenario the discount rate is lowered to 13%. NPV results are shown in figure 2.7.

![Graph for NPV of R&D Projects](image)

"NPV of R&D Projects" : MAKE $\quad$ "NPV of R&D Projects" : BUY $

Figure 2.7 Comparison of the "Make vs. Buy" Decision for Four Process Technologies.

It can be seen that the "buy" scenario is considerably more profitable than the "make". Further analysis shows that about 80% of the increase in the 25-year NPV results from the lower discount rate. R&D savings account for the balance of the improvement.

**2.3.3 Model Stage II: Interim Summary**

Spending on process R&D is calculated to yield a return of 17% over the cost of capital over the 25-year period. This conclusion is subject to the condition that price for lumber remains steady. It is also shown that it is considerably less risky to buy process technology from vendors. This latter strategy nearly triples the NPV of the capital investment in new process technology.

**2.4 Model Stage III: The Impact of Supply, Demand and Price.**

Up to this point the analysis has occurred in a "market vacuum". In other words it has been assumed that the firms actions have no direct bearing on the external market which has been assumed to remain constant over time. Neither of these assumptions is valid.
Even when the operations of a firm are small in comparison to the overall market this is not
sufficient justification to isolate its actions from those of the market. It is not reasonable to expect
other firms in the industry to take no action when facing the same threats and forces as the firm
under consideration. It is known that information and technology moves very freely among
players in the lumber industry. Mead (1966) has described a study that supports this statement. A
simplifying initial assumption therefore is to suppose that all firms take approximately the same
action at the same time. The following sections describe some implications of this assumption.

2.4.1 Cyclical Price Changes

![Graph for Price of Lumber]

<table>
<thead>
<tr>
<th>Time (Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Price of Lumber : Steady</th>
<th>$/MBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price of Lumber : Cyclical-1</td>
<td>$/MBF</td>
</tr>
<tr>
<td>Price of Lumber : Cyclical-2</td>
<td>$/MBF</td>
</tr>
</tbody>
</table>

**Figure 2.8 Three Hypothetical Price Trends for Lumber**

It is well known that the softwood lumber industry (like many commodities) is subject to cyclical
price changes. Such changes are linked to the interactions of inventories in the supply chain and
can be readily modeled using system dynamics. In the stage II model of figure 2.3 the impact of
periodic changes in price around some mean or “trend” price can be explored by introducing a
sinusoidal input for the “Price of Lumber” variable. Two hypothetical examples of cyclical price
variations are shown in figure 2.8 above. Cyclical trend 1 shows a $100/mbf variation around the
mean with a period of about 2 years. Cyclical trend 2 shows a $40/mbf variation around the mean
with a period of about 7 years.

In section 2.3 (model stage II) a description was given of how the firm would take corrective
action if it became unprofitable. It was assumed in the model that the firm would somehow break-
even in the long run if faced with the prospect of a 15-year outlook of negative profitability.
Under the current conditions of cyclical price (and hence profitability) changes this assumption must be challenged. A lumber firm who becomes unprofitable over relatively short periods (due to cyclicality of price) is less likely to be interested or able to take "evasive action". At the extreme they would simply "wait out" the down cycle until the upturn. Under these conditions it is now reasonable to ascribe the monetary value of "losses forgone" as a benefit of R&D. This change was reflected in the structure of model III by relaxing the negative profitability constraints of model II.

The impact of these considerations (under cyclical price trends) on the NPV of investing $1M/year in process R&D is shown below in figure 2.9. It can be readily seen that the cyclical variation of price has a significant positive impact on the value of spending on process R&D vs. the case of "steady" price. What this really means is that there is considerably more incentive to improve the process when periodic rather than long-term losses are experienced. The fact that there is little difference between the two cyclical price cases is not surprising when one considers that over the long-run the price (and hence profitability) "overshoots" will almost exactly offset the price "undershoots". The minor differences are caused by the accounting rule that the tax shield from R&D spending does not apply when the operation is unprofitable.

![Graph for NPV of R&D Projects](image)

*Figures 2.9 The NPV of R&D Spending Under 3 Conditions of Price Fluctuation.*

This now raises the question of what happens if the rate of R&D spending is not kept steady but is in some way coupled to a cyclical profitability of the operation? This can be explored by simple modifications of model II. As an example, the rate of R&D spending is cut back by 20% when the profitability of the operation is zero or negative. This modification was explored for the
two cyclical price trends shown in figure 2.8. Results are shown in figure 2.10 and are compared to the situation in which the R&D spending rate is NOT coupled to the profitability.

The results are consistent with expectations. Cutting back on R&D in unprofitable periods causes a modest retardation in the timing (and hence magnitude) of the expected payback. This conclusion appears valid for profitability variations of different periodicity.

![Graph for NPV of R&D Projects](image)

Figure 2.10 NPV of R&D Spending When Coupled or Uncoupled to Cyclical Profitability.

In conclusion, it seems as if improving the process will be more valuable to a firm experiencing swings in short-term profitability. Process improvement “fills in the valleys” and “raises the peaks” of the profitability horizon. It appears however as if price and R&D spending fluctuations (within sensible limits) do not materially alter the strategy of the firm; process improvement makes sense under all these conditions. Based on this finding there would appear to be no reason to introduce supply chain inventory structure to endogenously generate such price fluctuations in the model. This logic however can be challenged when one stops to consider the mechanism by which equilibrium (long-run) price is attained in a free market. This subject is taken up below.

### 2.4.2 Changes in the Equilibrium Price.

The classical theory of economics provides a means to consider the establishment of equilibrium price in the softwood lumber market. First it will be helpful to state some assumptions about the drivers for demand in the industry. Since the majority of lumber is used in residential construction, annual housing starts provide the baseline for lumber demand. The purchaser of the house is motivated to build or buy a house primarily by macroeconomic factors such as the
interest rate on loans. The prospective homeowner is generally somewhat isolated from the price of lumber and its effect on the cost of building a home by actions of the builder. The builder of the house usually pays the bill for raw material and can switch to a substitute material (such as steel) should the price of lumber become too high. Classical economics embodies the “decision rule(s)” by which the builder chooses to switch to a substitute, or the supplier decides how much to manufacture, in the concept of “elasticity”. Using elasticities for both the demand and supply side of the problem a new equilibrium price can be determined following a shift in either housing starts or lumber availability. A limitation of classical economics is that this equilibrium is attained “statically”. It does not reflect the real dynamics, and therefore the real equilibrium that is attained in the market. This subject is described in the system dynamics online “Road map” (1998) which provides more detailed information on this effect and model structure to accomplish the task of determining equilibrium price. Because of the extreme sensitivity of the present model results to price (as shown in table 2.2.) it is necessary to introduce such structure to explore its implications. Table 2.3 shows the details of the demand and supply “decision rule” schedules that are assumed in the model. These are shown graphically in figure 2.11.

<table>
<thead>
<tr>
<th>Price ($/mbf)</th>
<th>Quantity Demanded (Mmbf/year)</th>
<th>Quantity Supplied (Mmbf/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>2.25</td>
<td>3.75</td>
</tr>
<tr>
<td>800</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>400</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>200</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>100</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2.3 : Demand and Supply Schedules for Model III.

![Demand and Supply Curves](image-url)

Figure 2.11 Demand and Supply Curves
Figure 2.12 shows the basic additional structure that is added to model II (figure 2.3) to create model III. The model is initiated with supply and demand in equilibrium at 3Mmbf/year.

![Diagram showing the basic additional structure of Model III that determines price]

**Figure 2.12 Basic Additional Structure of Model III that Determines Price**

There are various ways in which this "price determining" structure can be linked to the main model. The simplest way is to allow it to operate entirely independently and to "feed" the resultant price into the model. This method simulates the operation of the "typical" independent competing firm and as such represents price determination by the "rest of the industry". If this is done without changing the demand from its initial value of 3Mmbf/year then price remains steady at $400/mbf as expected. If demand is "shocked" upward by introducing a step increase in demand at some time then an oscillatory price results (also as expected) that settles at some new, higher equilibrium level. An example of this type of oscillatory behavior is shown in figure 2.13. This results from an upward demand "step" of just 3% above the previous long-run demand. In this example the delay for changing price is set at two weeks. Notice that despite the fact that the price is adjusted every two weeks it takes about two years for the price to return to a stable long-run equilibrium. Interestingly, when a similar drop in demand takes place the oscillatory price that results is un-damped and continues indefinitely. The absence of damping is a direct consequence of the inelasticity of demand below a price of $400. Pricing dynamics is an
interesting and important subject in its own right but is not the focus of this thesis. What is important here is that in the case of either a step up or down in long-run demand the NPV of the process R&D investment remains basically\(^3\) unchanged under the cyclical price changes in agreement with the earlier findings of section 2.4.1.

![Graph for Price](image)

**Figure 2.13 Oscillatory Price Resulting From Rapid Step UP in Demand at Year-5.**

The above price analysis has embedded in it an important assumption that there is readily available excess capacity in the system that can be “turned on or off” at will. In the case of sawmilling this assumption is quite reasonable as throughput is very flexible and the industry believed to be in an overcapacity state. This state of overcapacity however raises an interesting question. What if the expected decline of log quality over time was used to “draw down” industry capacity over a long period? In other words what if instead of determining supply by the schedule of table 2.3 it was allowed to fall from the present value in direct proportion with the expected fall in recovery factor. Such an analysis was run using model III by “de-coupling” the supply from the supply price schedule and connecting it to the “Annual Lumber Production Rate” variables of model II. A duplicate price determination sector was also constructed for the model running with R&D spending and the EBIT variables were scaled using the respective “shipment” values. Figure 2.14 shows this complete version of model III. The results from this analysis on price are shown in figure 2.15.

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\(^3\) In a damped oscillation the price “overshoots” may not precisely compensate for the “undershoots” but the differences are too small to materially alter the NPV.
Figure 2.14 Model Stage III: Analysis of Falling Lumber Production With Decline in Quality
It can be seen in figure 2.15 that the price of lumber increases markedly as the supply falls with time due to the falling log quality! If R&D is expended and if the resultant improvements in recovery are used to restore the supply then price remains approximately constant. Not surprisingly the 25-year NPV of R&D investment is very negative (-$250M!) under these hypothetical conditions. It is paradoxical that the decline in lumber quality could be a major “windfall” to the industry if it was used to gradually remove excess capacity from the industry. Economic forces however make it difficult to maintain a capacity reduction from the system.

Figure 2.15 Results of Letting Industry Supply “Draw Down” as a Result of Log Quality Falling.

If a mill is closed the equipment may be sold to another company. The buyer can then return the capacity to the system and operate competitively under a low capital cost (having paid little to acquire it). The incentive to remove capacity is thus weak. Unfortunately there is little precedent for collective or simultaneous informed thinking on the part of the industry and to “arrange” for it would be in violation of Anti-trust laws! Given this state of affairs the industry has resorted to a “last man standing” type of policy in which “he with the lowest cost structure wins”.

2.4.3 Model Stage III: Interim Summary

In the absence of further complications the conclusions reached in section 2.3.3 that one should aggressively seek vendor technology for process improvement (to ensure a low cost structure) seem to hold up under the rigor of cyclical and equilibrium pricing dynamics. But what of these “further complications”?
2.5 Model Stage IV: Further Complications, Competitive Materials

2.5.1 Reversibility and “Stickiness” in Demand

The dynamics of model III and the “decision rules” embedded in the Demand/Supply curve of figure 2.11 imply complete and “instant” reversibility of demand. In the case of construction materials these are not entirely reasonable assumptions. Salesmen of alternative construction materials will no doubt claim, “just try my new material once…you won’t go back”. In some percentage of cases, though presumably small, this could turn out to be true. Reluctance to switch, both to and from an alternative material can be referred to as “stickiness” in demand. “First-order stickiness” has already been introduced by the price-demand schedule of table 2.3. In accord with this schedule builders will only use less lumber when the price rises above $400/mbf. As the schedule currently stands however all of these builders are assumed to switch back when the price of lumber falls again. In reality a “two steps forward, one step back” situation seems more likely. Under this scenario builders who have gone to the trouble of switching to an alternative will require a greater or more prolonged drop in price to return to using lumber. Others may discover unforeseen benefits of the substitute and never return to using lumber. These effects might be collectively referred to as “second-order stickiness”.

It was stated in the introduction (section 1.2) that in the period 1992-1995 light gauge steel framing captured some 4-6% of the US residential housing market. Skeptics about the seriousness of this threat may point out four things. Firstly the size of the threat appears small at 6%. Secondly there is evidence that some builders who have used steel have switched back to lumber and that interest to try steel among those who have not yet tried it is waning (The Merchant Magazine, 1997). Thirdly they will point out that nearly all of the builders “real” driver to use steel is embedded in cost and has little if anything to do with the “claimed” advantages of straightness, warp and rot resistance etc. Thus, it is claimed that as soon as the price of lumber comes back down that interest in steel (and other substitutes) will disappear. Fourthly skeptics may point to the fact that due the heavily regulated and traditional nature of the building industry that it takes an extremely long time for new materials to become accepted. Thus they may argue why get concerned about steel. The skeptics may well be correct on all four counts but even so a critical look should be taken at the implications of these changes.
Oster and Quigley (1977) have shown in a study of the diffusion of innovation in house building that the pace of change is severely limited by the action of regulatory bodies. They show data for example in the US of the “proportion of jurisdictions permitting innovation” in the substitution of 2 x 3 studs for 2 x 4 studs. Their data shows that it took some 40 years for only 50% of the jurisdictions to approve even this simple change, let alone for builders to adopt it! Steel construction in housing has been known in the US since the 30’s but has always been more expensive than wood. Two factors conspired to effect this situation in recent years. First the constriction of log supplies (due to Spotted Owl habitat restrictions in the West) temporarily raised the price of lumber. Second, endemic overcapacity in the world steel industry and advances in steel mini-mill and energy reduction technology have lowered the price of steel.

Given the above profusion of factors, for which good numerical estimates are lacking, it might be unreasonable to attempt to model “second-order stickiness” at this early stage in the attack by steel. However it seems reasonable to explore the conservative assumption that substitute materials steadily reduce the exogenous long-run demand for lumber by only 6% over a 25-year period. This is no more than is known to have occurred in a three-year period and allows for much “to-ing and fro-ing” in the adoption of substitutes over this period. This 6% demand drop assumption (linear decline) was embedded into the “demand shock” variable of model III. The following curve for profitability (figure 2.16) results when spending on process R&D is maintained at $1M/year.

![Graph for Profitability with R&D](image)

"Profitability with R&D": test $/MBF

Figure 2.16 Profitability with R&D Spending at $1M/year with a 6% fall in Demand Over 25 Years

The results show that despite having invested in maintaining a state of the art sawmill throughout the 25-year period the operation is still fundamentally unprofitable after only 8 years. Without
R&D the mill is unprofitable after 5 years. This is a critical result. It shows that a commodity business that is only marginally profitable is extremely vulnerable to only small drops in long-run demand. In this case the “limit” of profitability of the system has been set at that existing at the start of the period (by capping the recovery factor at 0.48). Under such conditions, investment in process technology (whether “made or bought”) is simply not capable of restoring the business to profitability no matter how aggressively it is pursued. For those who believe in miracles, it is worth noting that even an unexpected (and zero cost) discovery in year 5 of a technology that boosts recovery factor by an extra 10% (0.05) only prolongs the agony until year 23.

2.5.2 The Cost of Logs and the Value of Residuals

To this point the cost of logs and the value of residuals have been largely ignored. It was shown in table 2.2 that the profitability of sawmilling was very sensitive to these parameters. In the above case (section 2.5.1) where the long-run demand for lumber was allowed to fall by 6% it is reasonable to ask what would happen to the cost of logs during the same period. Qualitatively one would expect the price of logs bought on the open market to fall due to the reduction in lumber demand and in this way offset, at least partially, the “damage” done by material substitution. Log prices do fluctuate widely and follow the same kind of cyclical trends as lumber prices (no doubt for similar structural reasons). The question then is how far is it reasonable to expect log prices to fall and, critically, could this fall offset all of the damage to lumber profitability? From a historical perspective the price of logs has been trending up over the last 20 years. Price trends for logs in Georgia are shown in figure 2.17.
Some pine sawtimber stumpage price trends for Georgia, adjusted for inflation by the 1996 Producer Price Index

![Graph showing price trends over time for different regions in Georgia.]

**Figure 2.17 Price Trend Example for Logs Over a 20 Year Period (University of Georgia, 1998).**

This upward price trend has been fuelled in recent years by harvesting restrictions and tougher environmental legislation that have added cost to forest management and the logging operation (Weyerhaeuser Co. Annual Report, 1997). There are no indications that these environmental pressures on log price are likely to ease over the next 25 years. To this can be added the fact that log sales are not restricted to a single captive market. Logs can be sold for export or used domestically in panel products or pulp and paper operations so the pressure on log price exerted by US lumber demand is weakened. A full analysis of the interactions that determine log price is beyond the scope of this thesis but it is not likely that a concomitant fall in log prices on the open market will be the savior of the sawmilling industry.

Having said that log prices will not save the industry what can be said about the individual firm that maintains its own supply of timber? Such firms of course will try to maximize the return from their timberland and will generally use some form of internal transfer pricing that reflects the “market value” of the logs that they send to their sawmills. Here it is important to distinguish between the “cost” to grow and harvest the log and the internal or market “price” that is charged to the sawmill. The following strategic question can now be asked. What if the firm decides to spend some R&D money on lowering the cost of log production? If it is successful in this
endeavor the lower cost logs can be sold internally to the sawmill. The value to the firm is embedded in the lower cost and will be the same whether it is ascribed to the timberland or sawmill division. In order to calculate the value of the potential gain model III was modified to allow the log cost to fall steadily (linearly) over the 25-year period. A series of model runs was made to determine the sensitivity of profitability to changes in the log cost (both in the presence and absence of process R&D spending at $1M/year). In this series of runs the long-run steady fall in demand (6% over 25 years due to “stickiness” from material substitution) is still present. Results are shown in table 2.4.

<table>
<thead>
<tr>
<th>An “X”% Linear Decline in Log costs over 25 years...</th>
<th>...Results in Profitability with NO R&amp;D....</th>
<th>...or Results in Profitability with $1M/year R&amp;D expense....</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>Falling from $6/mbf to a steady (equilibrium) value of $4/mbf after 25 years.</td>
<td>Rising from $6/mbf to $14/mbf over 25 years.</td>
</tr>
<tr>
<td>6%</td>
<td>Falling from $6/mbf to minus $6/mbf over 25 years.</td>
<td>Remaining steady at about $4/mbf over 25 years.</td>
</tr>
<tr>
<td>5%</td>
<td>Falling from $6/mbf to minus $8/mbf over 25 years.</td>
<td>Falling from $6/mbf to $1.5/mbf over 25 years.</td>
</tr>
<tr>
<td>0%</td>
<td>Falling from $6/mbf to minus $21/mbf over 25 years.</td>
<td>Falling from $6/mbf to minus $11/mbf over 25 years.</td>
</tr>
</tbody>
</table>

Table 2.4 Sensitivity Analysis: Steady Decrease in Log Costs Over 25 Years

The results show that only a 6% fall in log costs over a 25-year period would allow the firm to remain consistently profitable if it spent on process R&D. A 10% fall in log costs would allow it to remain profitable without making any process R&D investment. The extreme sensitivity of the system to log costs makes it tempting to consider putting some effort in this area as part of a technology strategy.

Attention can now be turned to the price of residuals. If the price of residuals rises steadily over 25 years by, say, 30% then the profitability of the operation, in the absence of R&D expenditure is as shown in figure 2.18 (a 6% drop in long-run demand is still assumed in this scenario). It can be seen that the profitability is restored. How might a 30% rise in the price of residuals be brought about? In section 2.6 the possibility of creating a market for “engineered residuals” as feedstock for the manufacture of an engineered lumber substitute is explored as a possible way to create a high value market for residuals.
2.5.3 Model Stage IV: The Trade Off Between Log Quality and Log Cost

In section 1.2 it was stated that the size of the log and strength (or density) of the wood are the primary determinants of quality. Secondary factors such as size and distribution of knots are also important. Excessive knots reduce both the visual appeal and strength of the wood and therefore effect the suitability of the lumber for sale into high value "appearance" or "select structural" grades. Hopkins (1962) describes wood quality issues in some detail. He makes reference to the use of silvicultural practices such as pruning (to reduce knots) and genetic manipulation to enhance other wood quality factors. These practices are generally long term in nature and influence wood quality over time scales of 30 to 100 years. Genetic and silvicultural manipulation therefore are not "short-term" fixes to wood quality problems and of course add cost to the production of logs. They are, nevertheless, an important part of the long term R&D investment strategy of some timber-producing companies' (Weyerhaeuser Co. Annual Report, 1997).

In order to enhance the log quality available to the sawmill in the short term, companies have at least two important options. Firstly, they can only make use of the market mechanism to purchase, for example, high quality logs at a premium. This raises the question of how "efficient" is the market at pricing logs to accurately reflect their value when sawn? An interesting case is known in the petroleum industry (Weil, 1998) in which some companies gained a temporary
advantage by focussing their technology on the refining of less expensive (heavier, higher sulphur) crude oil. This strategy improved profitability for some time until the technology and information "asymmetries" were eroded by competitive forces and the price of "low-grade" crude increased. There is anecdotal evidence that the price differential between high-grade and low-grade crude has cycled over time depending on the relative supply/demand balance. Lumber companies should explore carefully the optimization of the log cost/quality trade off. The complexity of the market may lead to temporary inefficiencies in the pricing of logs. Sawmilling technology could also be directed at exploiting a particular low or high grade of log. The current "Log Quality" variable of model IV is not suited to an analysis of this trade off since it is an aggregate index (annual average quality of all grades in the US and Canada) as explained in section 2.2. In principal however, the details required to explore this trade off would be relatively easy to incorporate.

The second option to enhance log quality available to the mill involves "pre-screening" of the logs. Lumber grading is traditionally conducted on the finished piece via a non-destructive test or visual grading method. The true or "resultant" value of the log is therefore not known until after it has been sawn. This represents an important "information gap" in the accurate pricing of logs. An opportunity for R&D is therefore to explore technologies for non-destructive evaluation of the log or standing tree (e.g. density, strength, knot location). Such technologies could provide competitive advantage by allowing more accurate allocation of logs to the appropriate end use market and permit efficient breakdown to maximize yield of high value grades. Model IV is not structured to conduct an analysis of such technologies but the same modeling logic used to evaluate recovery improvement could be applied in a more detailed strategic model of a specific firm.

2.5.4 Model Stage IV: Interim Summary

The gradual erosion of long-run demand as a result of material substitution is likely to have a serious detrimental effect on the profitability of sawmilling. Modest long run demand erosion could easily negate any gains from process technology (even when purchased from vendors) and render such improvements of little or no value. This directs the attention of the technology strategy towards lowering log costs, exploring the log cost - log quality trade off and creating a higher value use(s) for residuals.
2.6 Model Stage V: Engineered Products

A “holistic” technology strategy would look at the whole log as potential raw material for structural uses and eliminate the concept of creating residuals as an unwanted byproduct. Under this approach the problem would become one of optimizing the value of the whole log and not just optimizing the productivity of the sawmill sector. Such holistic strategies are not new. In order to explore this concept it is helpful to review a couple of historical innovations in the industry that exemplify this approach.

2.6.1 The Chipping Headrig and Parallam

The chipping headrig is a device used in sawmills to produce a square sectioned “cant” from the initially round log. The cant is subsequently sawn into lumber. The chipping headrig was developed to produce uniformly engineered (similar shaped) pulp chips for paper manufacture. When conventional sawing is used to produce the cant, the “slab wood” (1/4 moon shaped slice) which results is of very low value. Pulp chips have a higher market value than slab wood and other types of residual such as planer shavings (produced when rough sawn lumber is planned to final dimension after drying) or sawdust (produced by the “kerf” of the saw blade). The chipping headrig also improves the throughput of the operation by obviating the difficulty of holding a round log firmly whilst sawing the cant. The goal of the chipping headrig is to maximize the value from the two main products, lumber and pulp chips.

One limitation of the chipping headrig is that one would expect the two product prices to be antagonistic. For example, when demand for lumber is strong lumber production, price and profitability will increase. The supply of pulp chips will however increase with lumber production. This in turn will somewhat depress chip prices, which will have a negative influence on the profitability of the sawmill operation. In the parlance of system dynamics there is a balancing loop at work in this two-product system.

This raises the question of what if the residual pulp chip product was replaced by an engineered “wood strand” for use in the production of an engineered lumber alternative such as the I-beam shown in figure 1.1? Now if there were an increase in overall demand for construction materials then the demand for both types of material would presumably increase. Such a demand increase could be met by increasing the overall throughput of logs in the mill. Over a long period of time
as the market acceptance of engineered products grows and the use of dimension lumber declines the overall profit of the “log conversion” operation might be maintained. The changing ratio of demand for the engineered product vs. the lumber product could be met by merely altering the proportion of the log that is converted to each type. Another feature of this strategy might be to require that the “wood strand” be of such geometry that it could be readily converted into standard pulp chips. This would enable rapid “disposal” of excess strands into a secondary market when engineered lumber demand was low.

Tillman (1985) has described engineered products such as Parallam® and Com-Ply®. These have some of the characteristics of the hypothetical product described above. Both involve the gluing together of engineered wood pieces to make alternatives to dimension lumber. Parallam is made and sold commercially by Trus Joist MacMillan (TJM) whose sole line of business is the manufacture and sale of engineered wood products. None of these products however were designed specifically with the idea of being manufactured from “slab wood” or of being directly tied to the process of manufacture of conventional lumber. The value of this possibility will now be explored.

2.6.2 Evaluation of Investment in New (Engineered) Product R&D

In order to model the economic feasibility of making an engineered lumber product linked to a sawmill residual many assumptions would need to be made. Since the composition and nature of the hypothetical product are not yet known this might seem impossible. The main interest of the analysis however is in the ultimately profitability of such products and not the underlying cost structure. In this light, financial data from the annual report of TJM might serve as a proxy since TJM’s only line of business is engineered wood products. Since TJM makes a broad range of such products the average profitability of their operation can be used as a guide to the expected returns from bringing an average new entrant to the market. Some idea of the R&D and capital costs that might be required to do this can be gained from the historical development of Parallam. MacMillan Bloedel Co. (1998), who were the original developers of Parallam, have published some details about the costs. The key assumptions used in the following analysis are summarized in table 2.5.
Table 2.5 Key Assumptions in Financial Analysis of New Engineered Product

These assumptions were incorporated in model V shown in figure 2.20. The model was run under the assumption of a linear fall in lumber demand of 6% over the 25-year period and a steady rise in residual price of 30% from the starting value of $160/mbf. The value of 30% was chosen arbitrarily at this point as it had been shown to restore profitability in the previous analysis. When the majority of the capital for the new product plant has been expended the “lost” lumber demand at that point becomes production of the new product. This assumes that the 6% lost lumber sales are all converted into 180,000mbf of engineered lumber sales by year 25. The “Total NPV” for the combined investment in process and product R&D under these conditions is about $12M. This is shown in figure 2.19.

![Graph for TOTAL NPV](image)

Figure 2.19 NPV of the Combined Investment in Process and Product R&D.
It should be pointed out in this scenario that the NPV for just the new product portion of the investment is close to zero ($0.6M) under these assumptions. Most of the $12M NPV derives from the new process R&D investment. However, as has been shown, the new process investment is NOT worth undertaking in the absence of the increase in residual price brought about by the new product. In this sense the two investments can be said to be synergistic and mutually dependent. The assumption that the price of residuals rises by 30%, driven by the high value market for them created by the new product, is a key contribution to the profitability of this scenario. This scenario has also assumed that 100% of the lost lumber demand has transferred to the new engineered product. How reasonable are these assumptions and how sensitive are the results to changes in them?

The assumption of a 30% increase in price of residuals appears to be an order of magnitude too high when one considers the following. It seems reasonable that the most the new product plant would be prepared to pay for raw material would be the current price of saw logs, i.e. $250/mbf. At year 25 the demand for raw material for the engineered product is 180,000mbf. This is only 6.3% of the rate of lumber production (2.86Mmbf/year) at that time. Since the recovery factor at year 25 is 0.47 there are 2.86M*((1-0.47)/0.47) = 3.23Mmbf of residuals available. Thus the expected or average price of residuals would be given by 180,000mbf sold at $250/mbf plus (3.23M-180,000)mbf sold at $160/mbf. This works out to an expected price of only $165/mbf. This is only 3% above the baseline price of $160/mbf and not the optimistic assumption of 30%. When this 3% rise in price over a 25-year period is entered into model IV the profitability of the operation is NOT maintained and the NPV of the combined investment is negative (~$11M).

Relaxing (lowering) the assumption of capturing 100% of the lost lumber market will of course only make the situation worse.

It is now appropriate to reconsider an assumption that was stated at the start of section 2.4. The above analysis was carried out under the condition that all firms take the same action at the same time. Whilst this is reasonable in the case of new process developments (especially when they are purchased from vendors) it appears incorrect for new products. New product development requires very large and sustained R&D and capital expenditures as shown in table 2.5. Only those firms of sufficiently large size will be able to make such investment. This has an important implication in terms of the supply of engineered wood products. Stated simply, any firm who has made the engineered lumber investment is likely to have a proportion of market share in engineered lumber that is considerably greater than their share of the conventional lumber
market. If it is assumed that only 1/10th of firms in the industry (representing 1/10th of the industry lumber capacity) decide to invest in engineered lumber then the demand for engineered product that our hypothetical firm will experience will be increased 10 fold at any point in time. This of course will not effect the average price that the engineered lumber division will be willing to pay for residuals (it will remain at rising steadily to $165/mbf over the 25-year period) since they can go “outside” to buy residuals if they wish. Embedding this 10-fold increase in demand for the product (with a limit of 180,000mbf still in effect to represent the assumed capacity of the plant) yields a new NPV for the new product investment of some $25M. This NPV is unaffected even by reducing the demand increase to 5-fold (to simulate the effect of engineered lumber only capturing half of the “lost lumber” market) because by the time the plant becomes available there is considerable “pent-up” demand. The NPV of the new product investment is still positive at ca. $6M even if the profitability of the new product is eroded (linearly) from $108/mbf to reach only ca. $6/mbf (the current value for lumber) after 25 years. This is a consequence of the fact that the NPV derives more value from revenues in the earlier years.

The final assumption of model V that should be challenged is that of the time it takes to bring a new product R&D project to completion. To this point it has been assumed that the project can be completed in about 5 years (spending $5M/year to reach the “critical mass” of $20M). It was stated in section 2.3 that the concept of a “critical mass” of R&D expenditure includes an assumption that there are no “bottlenecks” in the system i.e. the faster you spend the faster the R&D objective is reached. This is a reasonable assumption for process technology improvements. In the case of new structural products, regulatory agencies have to be involved in the final stages of product testing in order to certify the safety and suitability of the materials. This could add another 1-3 years to the development cycle before revenues could be derived. To explore the implications of this a 1.5-year delay was added to the 5-year development time before “approval” to use the product is granted and any revenues are derived. This reduces the NPV of the new product to about $ zero, i.e. the engineered product investment just earns the cost of capital. This scenario includes the linear profitability erosion from $108/mbf (year 0) to $6/mbf at year 25.

2.6.3 Model Stage V: Interim Summary

In summary it can be stated that judicious investment in engineered lumber R&D (but not process R&D) has a reasonable chance of earning the cost of capital and should be considered as part of the technology strategy of larger firms within the lumber industry.
Figure 2.20 Model Stage V. New Product R&D vs. New Process R&D
3. Technology Strategy in other Commodity Industries

3.1 Background to Case Histories

As described in the introduction (section 1.1) the latter portion of this thesis will examine, from a historical perspective, the technology strategies of other commodity industries. The goal is to compare and challenge the “analytical” conclusions of the modeling (section 2) with some real world examples. Of particular relevance are those commodity industries that have features in common with the lumber industry. Examples include other raw material and resource industries and those that have faced (or are facing) similar transitions in their businesses. Other industries that can be said to have reached a “commoditized” state are also of interest. Whilst the basis for comparison in some of these cases may seem remote it is posited that interesting insights can be gained from such cross-industry analyses.

3.2 The Steel Industry – Strategic Groups

The steel and lumber industries have much in common. Both are traditional enterprises that convert a natural raw material into a variety of dimensioned products. Steel, like lumber, has been in a state of overcapacity for some time. Data for 1996 show that installed world steel capacity exceeds demand by some 22% (Edington, 1998).

Oster (1994) has written about strategic changes that have occurred in the US steel industry over the last 40 years. In the early 60’s the US industry began to feel the effects of imported steel which by 1984 accounted for more than 25% of US consumption. Competition from material substitution such as aluminum in packaging and a long-term downward trend of steel use in lightweight (more fuel-efficient) vehicles have also contributed to overcapacity. Technological advances such as the electric arc furnace and its use in scrap processing in minimills has led to more intense price pressure especially at the low quality end of the market. Edington (1998) provides data showing that the ratio of steel price to cost fell by nearly 65% of its value over the period 1960 to 1996.

Faced with challenges such as these Oster (1994) has described how US steel firms have made the decision of whether “to invest further in new productive capacity ...or put their capital into other industries.” This is equivalent to the “new process vs. new product” decision that has been
discussed for the lumber industry. Steel makers had to decide whether to invest in new technologies such as the basic oxygen furnace and continuous caster or to invest in new steel products or other industries. Oster shows how different firms took different routes down this decision path and how groups of firms have come to lie at “opposite ends of the strategic map”. An important point here is that there were no firms that ended up occupying the “middle ground” but rather two quite polarized or extreme “strategic groups” developed. All of the firms survive today (although some have merged) and are categorized by Oster as having either “high diversification and old capital equipment” or “low diversification and new capital equipment”. Whilst this suggests that there is no “right” answer to this puzzle it does imply that a firm must chose between discrete options and not attempt to combine them. In Oster’s examples there are no precedents for “middle-ground” approaches. This finding further supports the assertion made in section 1.3 that describing a technology strategy aggregated at the national level is not a very useful concept. Individual firms are more interested in the trade-offs that must be made in adopting discrete choices of strategy.

Oster (1994) shows that the cause of the differences between the firms’ choice of strategic group lies partly in their history i.e. that to some extent the future is determined by the past. Oster cites the example that firms who had been traditionally organized functionally (with separate firm-wide groups for marketing, research etc) were less likely to diversify than those that had been organized in separate product divisions. Historical composition of the board of directors was also seen as an important factor. Boards with directors from outside the steel industry were more likely to embrace the idea of moving into new products earlier in their strategic transition and presumably were better equipped to make this transition a success. The point of introducing this last example is to show that technology strategy may involve important factors that would not be considered in a financial or purely numerical analysis.

The case of British Steel illustrates an interesting strategy that goes beyond the examples described by Oster. Facing the same basic pressures as the US firms British Steel would probably be described in Oster’s nomenclature as belonging to the “low diversification, new capital” grouping. It has not diversified outside of steel. As described by Edington (1998) however British Steel is attempting to supplement this strategy with an emphasis on a high level of augmentation of the basic product. This augmentation is based on both technology and service. For example, British Steel has been a pioneer in the development of new high strength and polymer coated steels for lightweight cars that do not require painting. They have also hired a number of
automotive engineers to work closely with their customers on steels for new stamping processes. British Steel has also been active in extending the use of steel in commercial construction. Their approach however has gone well beyond that of viewing construction as a mature market for I-beams. They have developed a proprietary steel flooring system called “Slimdek” that saves space in a multi-story building to allow an additional floor(s) to be installed without raising the height of the building. This type strategy is of great relevance to the lumber case. It illustrates how a company can diversify into assembled products that use their basic raw material as a structural component.

British Steel has also incorporated environmental considerations as an integral part of its technology strategy. It has participated in an industry wide study or “Life Cycle Analysis” of steel that examines the environmental costs and benefits of steel using a “cradle to grave” methodology. The steel industry in general has promoted the recyclable nature of steel as being a key benefit. A key disadvantage of steel has been its high energy consumption. This is also an important factor in the production cost for steel. Energy use has been a point of focus for process R&D in the industry in much the same way that recovery factor has been for the lumber industry. Considerable progress has been made in this area by the steel industry. In the long run however energy use is likely to continue to be a strategic “boat anchor” for steel. The current worldwide debate on global warming and CO₂ emissions is likely to produce policy that will favor materials and construction methods with low embodied energy.

3.3 The Disk Drive Industry – Leadership vs. Following

Christensen (1997) has carried out an extensive study of the disk drive industry. At first sight this may seem an unlikely candidate as a commodity industry case. Christensen points out that the disk drive industry has such a rapid pace of change that multiple generations of products were introduced, became commodities and made obsolete in the space of a few years. Some 83 companies have participated in this fast moving field. Disk drives only appear to avoid “commoditization” by being made obsolete so quickly. VanBree (1995) studied the commoditization of the semiconductor industry and DRAM chips in particular. This is another fast moving industry that, despite its pace, has many structural characteristics in common with slow moving industries. As stated by Christensen, one of the reasons to study such fast paced industries is for the opportunity it affords to look for patterns that emerge over multiple
generations of product. These patterns and learnings may then be applied to make inferences about the future of slow moving industries for which historical data simply does not exist. Christensen points to an analogy of studying fruit flies to learn and make inferences about human genetics.

One of the many interesting questions that Christensen studied was whether there is any advantage to be gained from being a leader in technological change vs. a follower. From his studies of the disk drive industry Christensen found that the answer depended upon a critical distinction. For what Christensen termed “sustaining technologies” (incremental improvements to either process or product that enhance the firm along the current measure(s) of performance) it was found that no advantage existed for technology leaders. This was true for either market share gained or “learning curve” effects (technology leaders for one innovation were no more likely to be the genesis of the next). In contrast, for what was termed “disruptive technologies” (advances in either process or product that redefined the measures of performance) he found that there was a very marked and sustainable benefit to being a leader. Christensen’s study of disk drives and several other industries also showed that leadership in disruptive technologies was most effectively carried out by small organizations. He showed small firms were much better able to serve the initially modest markets for these ideas. Christensen did provide examples of large firms that had successfully exploited disruptive technologies. He showed however that they had only been able to do this by either setting up an independent company to develop and market the early phase of the technology or through making a strategic acquisition of a small firm.

The particular details of these various cases are not important here but it is of interest to apply these findings to the lumber industry. In this case the “sustaining technology” would be the process technology aimed at enhancing recovery factor. If the disk drive results were transferable they would support the findings of the lumber modeling study which suggested that process technology improvements should be sought principally from vendors. In other words, a prudent strategy would aim to be a rapid “follower” of developments made by vendor firms. Before dismissing the idea of conducting internal R&D on process technology it is reasonable to ask if any benefit might be gained from the lead-time or “head start” that this might afford over the rest of the industry. The monetary value of a head start would be easy to model. In essence such an analysis is the reverse of that done for tying R&D spending to profitability (section 2.4.1) in which the small delay in reaching the critical mass expenditure was shown to slow down the timing of the expected returns. Providing a head start, in terms of profitability compared to the
rest of the industry, would slightly accelerate the payback from the investment. The head start however would also have to compensate for the increased discount rate that must be applied to these higher risk R&D investments as described in the “make vs. buy” analysis of section 2.3.2. The evidence of the disk drive study does not directly address the question of short-run profitability of the firms that were leaders in sustaining technologies. This subject is taken up again in section 3.5 in terms of the historical precedent in the lumber industry.

The disk drive example does however address the issue of market share and suggests no benefit in this area for leader firms. The issue of market share in the lumber industry is somewhat of a mute point. There are over 7500 firms in the industry with the largest share of any individual firm being less than 10% (Lenard, 1977). A firm’s ability to influence market share by, for example, aggressive pricing (enabled in the short-run by a temporary advantage in recovery factor) is extremely limited. In the short-run (before new capacity can be built or acquired) the firm can only hope to capture that portion of the market that it is capable of supplying. This severely limits the advance it can make in market share for each advance in process technology that it brings to bear. The limit is set by the degree of underutilized capacity in the firm. Furthermore, given the finding in the disk drive industry of no correlation between leadership and the genesis of the next innovation there is little prospect of a string of successful innovations arising from a single firm. This precludes the possibility of a steady step-wise gain in market share by an aggressive “technology enabled” pricing strategy.

For “disruptive technologies”, applying the disk drive learning to the lumber case would imply that the new “disruptive” technology of engineered lumber products will provide benefit to the leader in this field. Christensen’s findings are remarkably consistent with the recent history of the case of Parallam (described briefly in section 2.6.1). Parallam was developed by the large integrated forest products company MacMillan Bloedel. In order to bring this product to market MacMillan formed a joint venture company with TrusJoist who were already engaged in a number of other engineered lumber businesses. The joint venture (TrusJoist MacMillan, TJM) has been developing the manufacturing technology further and expanding the market (TJM, 1988). An interesting issue is if the “parent” company will bring the technology back into their own divisions? MacMillan Bloedel has recently announced its intent to “enhance the value of its partnership” with TJM and “focus on the building materials business” as part of a restructuring plan (Canadian Newswire, 1998). Interestingly they announced at the same time that they will close their entire corporate R&D facility.
The idea of “closing R&D” raises the important question of what level of internal technical competence is needed in the parent company to manage the selection and implementation of technologies (sustaining or disruptive) that are either purchased from outside the company or developed in a joint venture. Intuitively it seems reasonable that a company must have *some* level of activity focussed in this area. To rely wholly on vendors to supply this expertise seems an unrealistic proposition. The most obvious example of this is that nearly all large companies maintain an IT (information technology) department with responsibility for the selection and implementation of business critical IT investments. This is true even for corporations that have “outsourced” all of their IT supply needs. It is intuitive that other outsourced business critical technologies would still require a “technology implementation” department.

### 3.4 Rubber Tires – Innovation in Assembled Commodities

The modern tire industry is a mature commodity business with a history of over 100 years (the pneumatic tire was invented by Dunlop in 1888). Many large companies worldwide provide products with this same basic function. Despite the long history of the industry Goodyear Tire and Rubber Co. (1998) recently announced its intent to introduce a completely redesigned manufacturing process as part of their technology strategy for the next several years. It is claimed that this new process will cut production times by 70%, material use by 15% and labor by 35% and result in substantial savings. This opportunity for drastic change may seem surprising for such a mature industry. It illustrates however the flexibility and choices available in manufacturing of assembled products. The modern tire may contain upwards of 40 parts (Kinnamon, 1998) which creates many possible permutations and combinations as to how they can be assembled and thus how companies can differentiate themselves to remain competitive. This case illustrates a fundamental reason why assembled or engineered wood products are attractive alternatives to simple lumber. Their more complex nature increases the possibilities for deriving competitive advantage.

Assembled products are also interesting because they are subject to advances made independently in the raw materials from which they are made. The historical impact of rayon, polyester and more recently high tensile steel on tire manufacture provides evidence of this effect in preventing the “stagnation” of technology and profits.
In the case of engineered lumber it is speculated that advances in adhesive technology (a large cost element) will be an important source of change and competitive advantage. It is postulated however such an advantage will only come to those companies who maintain an adhesives business or a strong adhesives R&D department. The recent history of the oriented strand board (OSB) market provides an interesting example. Over the last 5-years there has been a shift from the use of formaldehyde based adhesives to those based on isocyanates for reasons of performance. It is probable that any lasting advantage will go to the adhesives suppliers since all OSB producers have access to the same technology at the same time. Technology strategy then should also consider how far one should be integrated into raw materials manufacture or research.

3.5 The Lumber Industry – History as a Guide to the Future

Mead (1966) (citing Zivnuska) writes that the lumber industry “might warm the heart of Adam Smith but it would break the heart of any industrial research director”. Mead is making reference to the intensely competitive nature of the industry and to the fact that its history of innovation is one of “open” exchange of ideas and technology. Mead describes how most of the process innovations arose from “tinkering” by small and medium sized operators. The innovations were adopted by the equipment manufacturers who made them available to the rest of the industry. This view is fully supported by Zaremba (1963) who gives details of the extremely low level of R&D expenditure in lumber firms compared to virtually all other industries. Zaremba believes that the low level of R&D is a direct consequence of the economic structure of the industry and the lack of any concentration in market share. Zaremba states that “virtually no lumber producer has any immediate incentive to invest in research and development”.

Mead (1966) described a study in which he attempted to track the genesis of innovations in the lumber industry. He found it a “sobering experience” and reported that “it is virtually impossible to assign originality and to separate invention and innovation from improvement in design”. In this regard Zaremba (1963) cites the specific example of the “chipper” (the chipping headrig of section 2.6.1) and states “Rapid spread of technology dampens the incentive for technical development because the innovator at best is left with only the temporary rewards of a head start”. These observations are fully consistent with the results of the modeling study, which suggest strong economic incentive to buy process technology from vendors over conducting internal process R&D.
Zaremba (1963) provides an interesting discussion of the scarcity of advertising in the lumber industry. He shows that for lumber, the benefit from advertising, where it exists at all, usually accrues to the industry in general rather than the individual firm. Zaremba describes how other commodity industries (e.g. agriculture, bituminous coal and textiles) have formed industry associations or have involved trade unions to stimulate innovation and interest in their products. Zaremba points to the almost complete lack of product differentiation as being a limiting factor in the effectiveness of such promotional activities for lumber. As stated in section 2.2.2 a key component of a technology strategy could therefore involve a quest for some modest, but sustainable (patented), product differentiation. The differentiation should be both useful to the consumer and easily visible. The latter feature would make patent infringement easy to detect (in contrast, patents on process improvements are difficult to police) and would provide brand recognition for the customer.

Mead (1966) has considered the effect of lumber industry innovations on log producers. He describes how log price (or “stumpage”) increased when the valuable new product technology of plywood came on the market and drove up demand for quality logs and how the advent of the chain saw reduced the cost of log production. Both innovations enhanced the log producer’s profit. Mead also describes some negative effects of innovation. In a particularly relevant example he states that...

"A technological improvement that increases the physical output of lumber per unit of physical log input reduces the value of stumpage. This follows from the conclusion that the demand for lumber is inelastic. Thus a technological innovation that substantially reduces saw kerf will bring about greater lumber output per unit of log input. The decline in lumber price will be greater than the corresponding increase in quantity of lumber sold. Therefore, the residual value accruing to the timber resource owner will decline."

Mead’s example is consistent with the workings of the model under the conditions that were described at the end of section 2.4.2. In section 2.4.2 it was shown that allowing the “extra” lumber produced by an advance in the recovery factor onto the market merely depresses the price and results in lower total revenue (i.e. the price reduction is not compensated by the extra lumber sold). The assumptions of the “preferred” model differ however from those implied by Mead’s statement above. When the model operates with the “classical” price determining structure of figure 2.12 the amount of lumber supplied is not determined by how much can be supplied, as Meads’ statement implies. Price is determined by the level of inventory on hand and the desire to increase or reduce it as dictated by the models decision rules. Despite this subtle distinction the
implication of both the model and Mead’s description is clear. In a firm that is backwards integrated into log production the effect of any innovation on log price must be considered.

4. Summary and Conclusions

4.1 Technology Strategy for the Lumber Firm

The combined effort of modeling and an examination of the strategies of other commodity industries supports the following suggested technology strategy for the hypothetical lumber firm. The following list is in order of increasing importance or emphasis (top to bottom)...

- **No money should be spent on exploratory process R&D whose focus is the improvement of recovery factor or other moderate leverage production technologies.**

- **A small but dedicated group of technologists should be maintained to evaluate vendor and industry derived process technologies for lumber manufacture. The NPV of investment in such technologies should only be evaluated using a model that embeds the “opportunity cost” of having less to spend/invest in other aspects of the strategy (below).**

- **Some exploration of ideas for adding incremental value to lumber should be undertaken. Only projects where the innovation is patentable and the patent easy to enforce should be considered.**

- **For firms that are backwards integrated into log production some further exploration into the issue of log cost and the log cost - log quality trade off should be made.**

- **The majority of R&D spending (80-100%) should be devoted to the exploration of future opportunities in engineered lumber and assembled construction products derived from wood.**

As stated in section 2.1 this modeling exercise has been didactic. Further work could be directed at converting the model into a strategic or forecasting model for a specific firm or set of products. Emphasis should be given to some of the “loose ends” in this analysis. These include a more detailed consideration of feedbacks involving log cost and exogenous demand (housing starts). The historical analysis of specific forest products companies and engineered wood products could also be expanded. A full strategic analysis should include linkages to the firms other divisions.
4.2 General Conclusions for Technology Strategy in Commodity Industries

The following is a list of general considerations that would seem to be relevant to commodity firms wishing to develop technology strategies. The list is arranged in sequence of how an analysis might be structured...

- A thorough understanding of the important costs in the product(s) and the linkages (interdependencies) between them.

- An analysis of external change factors and threats/opportunities faced by the industry.

- An explicit consideration of the benefit/cost of process improvement and the “opportunity costs” involved.

- A consideration of the structure of the industry and the sources of new technology.

- An analysis of the mechanism(s) by which supply, demand and price are determined.

- The impact of substitute products/materials and the drivers behind the substitution.

- A comparison of any intended strategy with relevant historical precedents.

In developing an analysis of this type it is important to consider the particular stage of “development” of the industry. Based on observations of commodity industries such as petroleum refining, Weil (1998) has developed a 5-stage chronology of process technology emphasis. The chronology describes what types of technology are likely to be of greatest value at different stages of “commoditization”. In the earliest phase, technologies which improve “value added” (e.g. gasoline per barrel of crude oil, or lumber per log) are likely to be emphasized. In stage two the focus switches to direct operating costs such as energy, labor and maintenance. In stage three, overcapacity forces minimization of capital expenditure and in stage four the operational “flexibility” of capacity (ability to switch the mix of outputs or to operate economically across a broad range of output volumes) becomes particularly important. In the final stage or “end game”, lowering of “barriers to exit” becomes an important strategy and focus of R&D (the high environmental cost to close a petroleum refinery or clean up a wood preservative treatment plant provide examples of this situation). Weil’s chronology and the analysis of this thesis suggest the lumber industry to be in the fourth stage. In this stage there is little to be gained from emphasizing the “value added” technology of recovery factor and much to be gained from the inclusion of engineered lumber or assembled construction products in the mix of outputs.
Returning “full circle”, the question asked at the start (p13) of the thesis (what is “technology strategy in commodity industries”?) can be re-examined. First, commodity industries have some significant characteristics that must be considered. These include cyclical profit margins, price as the basis for competition, mature technology and a desire for some form of differentiation. These features affect both the process of determining a technology strategy and the specifics of what makes one effective. The strategy process for a commodity firm should be multi-disciplinary, drawing on cost accounting and finance (to deal with the cyclical nature of profits), sales and marketing (to address price issues) and the sourcing of technology (to break from the “mature” tradition). An effective strategy will target the commodity characteristics to accomplish the following objectives; reduce the cyclicality of price and profit, extend the life of mature technologies and nurture the existing business while differentiation evolves over time.

Regardless of the industry under consideration it is believed that the joint use of system dynamics and case histories can be of great value in combining the above factors to derive a technology strategy.
Appendices

I: References


Weil, H.B. (1998). Personal communication. Weil has conducted research in this area for private companies. He is at the MIT Sloan School of Management.


II: Model Documentation

(001) "$\% \text{ of R&D Spending on Process} = 0.166667$
Units: dimensionless
This is the proportion of the annual R&D budget that is spent on process R&D. It is set at 0.16 when the Total R&D Spending Rate is at $6M/yr. This diverts $1M/yr. to process R&D.

(002) Accumulated Capital Requirement = ("Effect of R&D Spending on Accumulated CAPX"("Accumulated R&D Spending"/"Critical Mass for Process R&D"))*CAPX per. Process R&D Project * Number of Mills
Units: $
This is the accumulated amount of capital required to implement the process improvements at all mills.

Units: $
This is the accumulated amount of capital required to implement the new product.

(004) Accumulated Depreciation for New Product = INTEG (Depreciation Rate from CAPX for New Product,0)
Units: $
This is the accumulated amount of depreciation resulting from the investment in the new product.

(005) "Accumulated R&D Spending for New Product" = INTEG ("Rate of R&D Spending for New Product",0)
Units: $
This is the cumulative amount of money which has been spent on the new product.

(006) "Accumulated R&D Spending" = INTEG ("Rate of R&D Spending",0)
Units: $
This is the cumulative amount of money which has been spent on process improvement.

(007) Addition to Recovery Factor = ("Effect of R&D Spending on Recovery Factor"("Accumulated R&D Spending"/"Critical Mass for Process R&D"))*CAPX Ratio
Units: dimensionless
This is the amount by which the recovery factor has improved as a result of process improvements.

(008) Annual Log Harvesting Rate = 6.25e+006
Units: MBF/Year
This is the baseline rate at which logs are harvested to supply the mills.

(009) "Annual Lumber Production Rate with R&D" = Annual Log Harvesting Rate * "Recovery Factor with R&D"
Units: MBF/Year
This is the rate at which lumber can be produced when process improvements resulting from R&D expenditure are installed at the mills.

(010) "Annual Lumber Production Rate without R&D" = Annual Log Harvesting Rate * "Recovery Factor with No R&D"
Units: MBF/Year
This is the rate at which lumber can be produced when no process improvements have occurred.
(011) **Basis for Discount Rate** = 1  
Units: Year  
This is the length of time over which the discount rate applies.

(012) **CAPX Annual Depreciation Rate** = 0.04  
Units: 1/Year  
This is the annual rate of depreciation of capital. It is set at 4% based on the assumption of straight line depreciation over a 25 year period.

(013) "**CAPX per Process R&D Project**" = 1e+006  
Units: $/mill  
This is the assumed capital requirement to install each new process improvement at one mill.

(014) **CAPX Rate** = Current Capital Requirement/time constant  
Units: $/Year  
This is the rate of capital expenditure on process improvements.

(015) **CAPX Rate for New Product** = Current Capital Requirement for New Product/Time Constant for New Product  
Units: $/Year  
This is the rate of capital expenditure on new product facilities.

(016) **CAPX Ratio** = ZIDZ (Cumulative Capital Spent , Accumulated Capital Requirement)  
Units: dimensionless  
This is the ratio of how much capital has been spent to what needs to be spent to install the process improvements at all mills. It represents the degree to which the new process has been adopted.

(017) **Change in Price** =((Desired Price)-Price)/Price Change Delay  
Units: ($/MBF)/Year  
This is the rate at which price is changing.

(018) "**Change in Price with R&D"**=(("Desired Price with R&D")-"Price with R&D")/Price Change Delay  
Units: $/(MBF * Year)  
This is the rate at which price is changing when money is being spent on process R&D.

(019) **Cost of Logs** = 250  
Units: $/MBF  
This is the cost of logs i.e. the price which the sawmill pays for its raw material.

(020) "**Critical Mass for New Product R&D**" = 2e+007  
Units: $  
This is the amount of money it takes to develop a new engineered lumber product.

(021) "**Critical Mass for Process R&D**" = 5e+006  
Units: $  
This is the amount of money it takes to develop a new process to improve recovery factor.

(022) **Cumulative Capital Spent** = INTEG (CAPX Rate,0)  
Units: $  
This is the cumulative amount of capital that has been spent on process improvements.

(023) **Cumulative New Product Capital Spent** = INTEG (CAPX Rate for New Product,0)  
Units: $  
This is the cumulative amount of capital that has been spent on new product manufacturing facilities.
(024) **Current Capital Requirement** = Accumulated Capital Requirement-Cumulative Capital Spent
Units: $  
This is the current or remaining capital requirement for new process equipment.

(025) **Current Capital Requirement for New Product** = Accumulated Capital Requirement for New Product-Cumulative New Product Capital Spent
Units: $  
This is the current or remaining capital requirement for new product manufacturing facilities.

(026) **Demand** = Demand Price Schedule (Price) + Demand Shock
Units: MBF/Year  
This is the assumed demand for lumber for a firm of our capacity.

(027) **Demand Price Schedule** = \(((0,2e+006)-(1000,4e+006)),(0,3,5e+006),(400,3e+006),(800,2.5e+006),(1000,2.25e+006))
Units: MBF/Year  
This is the rate at which customers demand lumber based on the price in the market.

(028) **Demand Shock** = (-7200*Time)
Units: MBF/Year  
This is a "shock" or change in the external demand for lumber. Here demand is set to fall steadily as a function of time by having the demand shock become increasingly more negative with time.

(029) "*Demand with R&D*" = Demand Price Schedule ("Price with R&D") + Demand Shock
Units: MBF/Year  
This is the assumed demand for lumber for a firm of our capacity operating with spending on process R&D.

(030) **Depreciation from CAPX** = (Accumulated Capital Requirement * CAPX Annual Depreciation Rate)/"Annual Lumber Production Rate with R&D"
Units: $/MBF  
This is rate of depreciation of capital expenditure for process improvement expressed on the basis of expenditure per. mbf of lumber produced.

(031) **Depreciation Rate from CAPX for New Product** = IF THEN ELSE (Accumulated Depreciation for New Product < Accumulated Capital Requirement for New Product, Accumulated Capital Requirement for New Product * CAPX Annual Depreciation Rate, 0)
Units: $/Year  
This is rate of depreciation of capital expenditure for new products expressed as expenditure per. year.

(032) **Desired Inventory** = Demand * Desired Inventory Coverage
Units: MBF  
This is how much inventory the firm wants to have on hand in order to meet the expected demand.

(033) **Desired Inventory Coverage** = 0.07692
Units: Year  
This is how many years of inventory at the expected demand rate that the firm wants to keep in stock. It is set at 0.076 years or 4 weeks.

(034) "*Desired Inventory with R&D*" = "Demand with R&D" * Desired Inventory Coverage
Units: MBF  
This is how much inventory the firm wants to have on hand in order to meet the expected demand when operating with process R&D expenditure.
(035) **Desired Price** = Effect on Price (Inventory Ratio)*Price
Units: $/MBF
This is the equilibrium price as set by the inventory ratio. The actual price will reach this value after a delay specified by the price change delay.

(036) **"Desired Price with R&D"** = Effect on Price ("Inventory Ratio with R&D")**"Price with R&D"
Units: $/MBF
This is the equilibrium price as set by the inventory ratio when the firm is spending money on process R&D. The actual price will reach this value after a delay specified by the price change delay.

(037) **Discount Rate** = 0.19
Units: dimensionless
This is the annual discount rate for process R&D projects.

(038) **"EBIAT due to R&D"** = ("EBIT due to R&D"**(1-Tax Rate))+"R&D Tax Shield"
Units: $/Year
This is the rate of earnings before interest after tax that are due to the process R&D improvements.

(039) **EBIAT for New Product** = (Profit Rate From New Product**(1-Tax Rate))+"R&D Tax Shield from New Product"
Units: $/Year
This is the rate of earnings before interest after tax that are due to the new product.

(040) **"EBIT due to R&D"** = "EBIT with R&D"-"EBIT without R&D"
Units: $/Year
This is the rate of earnings before interest and tax due to the new process.

(041) **"EBIT with R&D"** = ("Shipments with R&D"/"Recovery Factor with R&D")**"Profitability with R&D"
Units: $/Year
This is the rate of earnings before interest and tax in the business with the new process running.

(042) **"EBIT without R&D"** = (Shipments/"Recovery Factor with No R&D")**"Profitability with No R&D"
Units: $/Year
This is the rate of earnings before interest and tax in the business without the new process running.

(043) **"Effect of R&D Spending on Accumulated CAPX"**([(0,0)-
(11,10)],(0,0),(1,0),(1.001,1),(2,1),(2.001,2),(3,2),(3.001,3),(4,3),(4.001,4),(5,4),(5.001,5),(6,5),(6.01,
6),(7,6),(7.001,7),(8,7),(8.001,8),(9,8),(9.001,9),(10,9),(10.01,10),(100,10))
Units: dimensionless
This lookup table says that for each unit of process R&D money spent the accumulated requirement for capital expenditure goes up by one unit per. mill, i.e. it is a LINEAR growth.

(044) **"Effect of R&D Spending on Recovery Factor"**([(0,0)-
(15,0.1)],(0,0),(1,0),(1.001,0.018),(2,0.018),(2.001,0.035),(3,0.035),(3.001,0.049),(4,0.049),(4.001,
0.062),(5,0.062),(5.001,0.073),(6,0.073),(6.001,0.082),(7,0.082),(7.001,0.089),(8,0.089),(8.001,0.09),
(9,0.095),(9.001,0.098),(10,0.098),(10.01,1),(100,1))
Units: dimensionless
This lookup table incorporates the "law of diminishing returns". It says that for each unit of process R&D expenditure the "return" in terms of recovery factor boost gets smaller by 10% each time.
(045) \textbf{Effect on Price} \(([(0.5,0),(1.5,2)],(0.5,2),(0.6,1.8),(0.7,1.55),(0.8,1.35),(0.9,1.15),(1.0,0.875),(1.2,0.75),(1.3,0.65),(1.4,0.55),(1.5,0.5))]\)  
Units: dimensionless  
This lookup table regulates the price change. When the inventory > desired inventory then the inventory ratio is >1 and the price must be reduced. When the inventory ratio is <1, price must be increased.

(046) "\textbf{FCF due to R\&D}" = "EBIAT due to R\&D" + Total Depreciation Rate-CAPX Rate-'Rate of R\&D Spending"  
Units: $/Year  
This is the free cash flow due to the improvements resulting from process R\&D.

(047) \textbf{FCF for New Product} = EBIAT for New Product + Depreciation Rate from CAPX for New Product-CAPX Rate for New Product-'Rate of R\&D Spending for New Product"  
Units: $/Year  
This is the free cash flow for the business operating with the new product.

(048) \textbf{FINAL TIME} = 25  
Units: Year  
The final time for the simulation.

(049) "\textbf{Initial Rate of R\&D Spending for New Product}" = "Total R\&D Spending Rate"*(1-'% of R\&D Spending on Process")  
Units: $/Year  
This is the initial rate at which money is spent on new product R\&D.

(050) "\textbf{Initial Rate of R\&D Spending}" = "Total R\&D Spending Rate" * "% of R\&D Spending on Process"  
Units: $/Year  
This is the initial rate at which money is spent on new process R\&D.

(051) \textbf{Initial Recovery Factor} = 0.48  
Units: dimensionless  
This is the recovery factor at the start of the simulation.

(052) \textbf{INITIAL TIME} = 0  
Units: Year  
The initial time for the simulation.

(053) \textbf{Inventory} = \text{INTEG (+Supply- Shipments , Desired Inventory)}  
Units: MBF  
This is the inventory of lumber in stock.

(054) \textbf{Inventory Ratio} = Inventory/Desired Inventory  
Units: dimensionless  
This is the ratio of inventory to desired inventory.

(055) "\textbf{Inventory Ratio with R\&D}" = "Inventory with R\&D"/"Desired Inventory with R\&D"  
Units: dimensionless  
This is the ratio of inventory to desired inventory when the company is spending money on process R\&D.
(056) "Inventory with R&D" = INTEG (+"Supply with R&D"-"Shipments with R&D", "Desired Inventory with R&D")
Units: MBF
This is the inventory of lumber in stock when the company is spending money on process R&D.

(057) Log Quality = Log Quality Data (Time)
Units: dimensionless
This is the log quality as a function of time. It falls with time from 0.6 to 0.5 over the 25-year period.

(058) Log Quality Data (([0,0)-(200,1)],(0,0.6),(26,0.5),(100,0.5))
Units: dimensionless
This is an index of log quality as explained in section 2.2 of the thesis. It is the ratio of annual log volume going to the sawmills divided by the annual volume of roundwood harvested.

(059) New Product Discount Rate = IF THEN ELSE(Time<7,0.19,0.13)
Units: dimensionless
This is the discount rate for the new product. It is set at two levels. It starts out at 19% and then falls to 13% after 7 years when the new product plant has been operational for about two years. This reflects the reduction of risk as the technology becomes proven.

(060) New Product Plant CAPX = 4e+007
Units: $
This is the capital cost of building the new product plant.

(061) NPV of New Product = INTEG (PV of FCF for New Product,0)
Units: $
This is the net present value of the new product investment.

(062) "NPV of R&D Projects" = INTEG (PV of FCF,0)
Units: $
This is the net present value of the investment in new process equipment.

(063) "Number of Completed R&D Projects" = Accumulated Capital Requirement/("CAPX per. Process R&D Project" * Number of Mills)
Units: dimensionless
This is the number of process R&D projects which have been completed.

(064) Number of Mills = 30
Units: mill
This is the number of lumber mills in the hypothetical firm.

(065) Other Production Costs = 40
Units: $/MBF
These are other costs that include labor, maintenance, overhead and energy.

(066) Price = INTEG (Change in Price,400)
Units: $/MBF
This is the current price of lumber.

(067) Price Change Delay = 0.01923
Units: Year
This describes how long it takes for prices to be adjusted. It is currently set at 0.019 years or 1 week.
(068) **Price of Lumber** = Price
Units: $/MBF
This is also the price of lumber.

(069) "**Price of Lumber with R&D**" = "Price with R&D"
Units: $/MBF
This is the price of lumber when the firm is spending money on process R&D.

(070) **Price of Residuals** = 160+(Production Rate of New Product/180000)*0.03*160
Units: $/MBF
This is the price of residuals.

(071) "**Price with R&D**" = INTG ("Change in Price with R&D", 400)
Units: $/MBF
This is the price of lumber when the firm is spending money on process R&D.

(072) "**Production Costs with No R&D**" = (Cost of Logs/"Recovery Factor with No R&D") + Other Production Costs
Units: $/MBF
This is the production cost of lumber when nothing is spent on process R&D.

(073) "**Production Costs with R&D**" = ((Cost of Logs)/"Recovery Factor with R&D") + Other Production Costs + Depreciation from CAPX
Units: $/MBF
This is the production cost of lumber when the firm is spending money on process R&D.

(074) **Production Rate of New Product** = MIN (IF THEN ELSE(Cumulative New Product Capital Spent<0.8*New Product Plant CAPX,0,-Demand Shock*5),180000)
Units: MBF/Year
This is the rate at which the new product is being produced.

(075) **Profit Rate From New Product** = IF THEN ELSE (Time<0,0,Production Rate of New Product *Profitability of New Product)
Units: $/Year
This is the rate of profit generation (before tax) from the new product. It is currently set to fall at a steady linear rate over the 25-year period.

(076) **Profitability of New Product** = 108-4*(Time)
Units: $/MBF
This is the profitability (before tax) of the new product. It is currently set to fall linearly from 108 $/mbf to ca. 8 $/mbf over the 25 year period.

(077) "**Profitability with No R&D**" = MAX (0,(Price of Lumber * "Recovery Factor with No R&D")+(Price of Residuals * (1-"Recovery Factor with No R&D")("Production Costs with No R&D" * "Recovery Factor with No R&D"))
Units: $/MBF
This is the profitability of the operation without any spending on process R&D. It is expressed as profit before tax per. mbf of log converted to lumber.

(078) "**Profitability with R&D**" = MAX (0,("Price of Lumber with R&D" * "Recovery Factor with R&D")+(Price of Residuals*(1-"Recovery Factor with R&D")-("Production Costs with R&D"* "Recovery Factor with R&D"))
Units: $/MBF
This is the profitability of the operation with spending on process R&D. It is expressed as profit before tax per. mbf of log converted to lumber.
(079) \( PV_{\text{of FCF}} = \frac{\text{"FCF due to R&D"}}{(1 + \text{Discount Rate})^{(\text{Time/Basis for Discount Rate})}} \)
Units: $/Year
This is the present value of the free cash flow resulting from the new process investment.

(080) \( PV_{\text{of FCF for New Product}} = \frac{\text{FCF for New Product}}{(1 + \text{New Product Discount Rate})^{(\text{Time/Basis for Discount Rate})}} \)
Units: $/Year
This is the present value of the free cash flow resulting from the new product investment.

(081) \( "\text{R&D Tax Shield from New Product"} = \text{IF THEN ELSE} (\"\text{Profitability with R&D"}>0,\"\text{Rate of R&D Spending for New Product"} \times \text{Tax Rate},0) \)
Units: $/Year
This is the tax shield which results from the expenditure on new product R&D.

(082) \( "\text{R&D Tax Shield"} = \text{IF THEN ELSE} (\"\text{Profitability with R&D"}>0,\"\text{Rate of R&D Spending"} \times \text{Tax Rate},0) \)
Units: $/Year
This is the tax shield which results from spending on new process R&D.

(083) \( "\text{Rate of R&D Spending for New Product"} = \text{IF THEN ELSE} (\"\text{Accumulated R&D Spending for New Product"}<\"\text{Critical Mass for New Product R&D"}, \"\text{Initial Rate of R&D Spending for New Product"},0) \)
Units: $/Year
This is the rate of spending on R&D for the new product. It is set to fall to zero when the "critical mass" has been reached.

(084) \( "\text{Rate of R&D Spending"} = \text{IF THEN ELSE} (\text{Addition to Recovery Factor}<0.1, \"\text{Initial Rate of R&D Spending"},0) \)
Units: $/Year
This is the rate of R&D spending on new processes. It is set to fall to zero when the addition to the recovery factor is \( = \) or \( > 0.1 \).

(085) \( "\text{Recovery Factor with No R&D"} = (\text{Initial Recovery Factor} \times \text{Log Quality}/0.6) \)
Units: dimensionless
This is the recovery factor with no spending on process R&D.

(086) \( "\text{Recovery Factor with R&D"} = (\text{MIN} (\text{Initial Recovery Factor}, ((\text{Initial Recovery Factor} \times \text{Log Quality}/0.6) + \text{Addition to Recovery Factor}))) \)
Units: dimensionless
This is the recovery factor with spending on process R&D.

(087) \( \text{SAVEPER} = \text{TIME STEP} \)
Units: Year
The frequency with which output is stored.

(088) \( \text{Shipments} = \text{Demand} \)
Units: MBF/Year
The rate at which lumber is shipped.

(089) \( "\text{Shipments with R&D"} = "\text{Demand with R&D"} \)
Units: MBF/Year
The rate at which lumber is shipped when the firm is spending on process R&D.
(090) **Supply** = Supply Price Schedule (Price)
Units: MBF/Year
The rate at which lumber is produced based on the price of lumber in the market.

(091) **Supply Price Schedule** ([0,0]-
(1000,4e+006),(0,0),(100,0),(200,2e+006),(400,3e+006),(800,3.5e+006),(1000,3.75e+006))
Units: MBF/Year
This lookup table sets the rate at which the firm will produce lumber based on the price in the market.

(092) "**Supply with R&D**" = Supply Price Schedule ("Price with R&D")
Units: MBF/Year
The rate at which lumber is produced based on the price of lumber in the market when the firm is spending on process R&D.

(093) **Tax Rate** = 0.4
Units: dimensionless
This is the rate of taxation on corporate profits. It is set at 40%.

(094) **Time constant** = 0.5
Units: Year
This sets the time over which the capital expenditure on new process technology is made. With a time constant of 0.5 year it takes about 2 years for all 30 plants to get the latest "upgrade" in recovery enhancing technology.

(095) **Time Constant for New Product** = 0.5
Units: Year
This sets the time over which the capital expenditure on new product technology is made. With a time constant of 0.5 year it takes about 2 years for the capital for the new plant to be fully paid out.

(096) **TIME STEP** = 0.0078125
Units: Year
The time step for the simulation. It needs to be smaller than the smallest time constant to avoid numerical integration errors.

(097) **Total Depreciation Rate** = Depreciation from CAPX * "Annual Lumber Production Rate with R&D"
Units: $/Year
This is the annual rate of depreciation of the new process capital.

(098) **TOTAL NPV**=NPV of New Product + "NPV of R&D Projects"
Units: $
This is the combined net present value of both the new process and new product investments.

(099) "**Total R&D Spending Rate**" = 6e+006
Units: $/Year
This is the total annual rate of spending on R&D for both new process and new product development.
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