The Forest Sector: Important Innovations

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Discussion Paper 97-42

August 1997

RESOURCES FOR THE FUTURE
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This paper is one of a series of studies on "Understanding Productivity Change in Natural Resource Industries" undertaken by Resources for the Future with the assistance of a grant from the Alfred P. Sloan Foundation. Titles in this series are:

- PRODUCTIVITY CHANGE IN U.S. COAL MINING, by Joel Darmstadter with the Assistance of Brian Kropp, RFF Discussion Paper 97-40;

- PRODUCTIVITY GROWTH AND THE SURVIVAL OF THE U.S. COPPER INDUSTRY, by John E. Tilton and Hans H. Landsberg, RFF Discussion Paper 97-41 (forthcoming);

- THE FOREST SECTOR: IMPORTANT INNOVATIONS, by Roger A. Sedjo, RFF Discussion Paper 97-42;

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and

- UNDERSTANDING PRODUCTIVITY CHANGE IN NATURAL RESOURCE INDUSTRIES, edited by R. David Simpson, a book from Resources for the Future (forthcoming).

The Forest Sector: Important Innovations*

Roger A. Sedjo

Abstract

Unlike other resources such as petroleum, coal, and copper, forests are renewable. Yet, in many respects forests historically have been treated as a nonrenewable resource in that forest stocks were depleted or "mined" and loggers moved on to exploit other "deposits." The lands were often put to other uses, typically agricultural, or allowed to regenerate naturally.

This paper looks at technical change in forest extraction, i.e., logging under a number of different conditions. It finds that, on average, labor productivity has been increasing in recent decades. However, total factor productivity in the US has declined in recent years. In addition, the study examines the tree-growing potential of plantation forestry. It finds that there is underway a substantial shift away from the harvesting of old-growth forests and toward intensive forest plantations. Plantations allow for high productivity in tree growing and are being used to offset decreased wood availability due to the inaccessibility and high costs of many old- and second-growth forests. The decreased accessibility reflects not only the impacts of past logging but, perhaps more importantly, the increase in forests in protected area set-asides. Additionally, natural forests face increasingly stringent regulations on logging and forest management activities. High-yield intensively managed forests, on well located, high productivity sites, offer the potential of obtaining high yields while using relatively small land areas by allowing the near full output potential of practices including species selection, fertilization and pest control. Finally, tree planting creates the opportunity to apply genetic improvements to the tree stock thereby further increasing growth productivity and allowing for control of tree characteristics.

Key Words: productivity, resources, forests, timber, technology, innovations, plantations, logging, genetics, extraction

JEL Classification Nos.: O31, O32, O50, O51, Q23

* This study was funded largely by the Sloan Foundation.

Acknowledgments

The author would like to acknowledge the assistance of a large number of individuals and organizations in a number of countries that provided information and insights which allowed this study to be completed. In many cases field trips to relevant operations were involved. These included a visit to a logging operation near Joensuu, Finland and discussions of Nordic logging with Bjorne Hagglund, and later correspondence with Hans Troedsson, both of Stora Skog, Sweden; a visit to a logging training operation with the latest equipment on the Olympic Peninsula in Washington state and related conversations with Peter Schiess, of the University of Washington; and visits and discussions regarding logging and forestry with employees of MacMillan Bloedel in Vancouver, B.C., including Bill Caferata, Neil Brett-Davies, Rob Prinz., Bill Beese, Brett Gildner, G.B. Dunsworth, S.M. Northway, N.J. Smith, and others. Also very helpful were the discussions with almost a dozen members of the Forest Engineering Research Institute of Canada, in Vancouver B.C., led by A.W.J. Sinclair and including Ernst T. Stjernberg; Marv Clark; Raymond K. Krag; Ingrid B. Henin; and others. Also, Clark Binkley, Dean of the Faculty of Forestry at the University of British Columbia, provided useful comments.

Discussions and comments regarding logging in the South were provided by William Stuart and William Hyde, of VPI, Fred Cubbage of NCS and Cam Carte of the AF&PA. Visits and discussions on plantation forestry and forest genetics were undertaken with Robert Rogers and others at MacMillan Bloedel and Rex McCullough and Chris Dean of Weyerhaeuser Co., Tacoma, WA. A field trip of hybrid poplar fiber plots in Washington State was undertaken with Toby Bradshaw, a University of Washington molecular geneticist, who provided much useful information of fiber plantations and the role of genetic improvement. William Baughman, VP and Timberlands Division Manager, Westvaco, Summerville, SC, and his staff provided a very useful discussion on a range of relevant issues including logging, new forest practices and genetics. Participants included Brian Fiacco; Gene Kodama; Ed Owens; John Thurmes; Leland Gauron; Dave Gerhardt; Dave Canavera; Dick Dainiels; and Clifford Schneider. Finally, David Duncan and Lisa Drake of Monsanto provided useful information on genetics and pesticide/herbicide use.

Finally, I would like to thank Neil Brett-Davies, Sharon Friedman, William Hyde, Cliff Schneider and William Stuart for their participation and comments at a workshop that examined an earlier draft of this paper, and their comments on still earlier drafts of this paper.

Roger A. Sedjo
August 6, 1997

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Roger A. Sedjo[1]

I. INTRODUCTION

Background

This paper looks at innovation and technical change in logging, primarily in North America. It is part of a larger project on factors influencing productivity in selected natural resource industries. Unlike the other resources examined in this study -- petroleum, coal, and copper -- forests are renewable. The renewable aspect is also examined in the form of the innovation of intensively managed forest plantations and their productivity, achieved and anticipated. Superimposed over the analysis is the effect of the increasing stringent regulation of forest practices being experienced in recent years, especially since the UNCED Rio meeting of 1992.

In many respects forests historically have been treated as a nonrenewable resource in that few provisions were made for regeneration. Traditionally, forest stocks were depleted, "mined," and the loggers moved on to exploit other "deposits." The lands were often put to other uses, typically agricultural, or ignored. When ignored, the forests commonly regenerated through natural processes and often were "mined" once again decades or centuries later. Today, vast areas of forest are being managed for the production of industrial wood resources, as well as other outputs including recreation and environmental outputs. And, the emphasis on forest regeneration, growth and management is increasing. In the US the vast majority of our harvested wood comes from forests receiving some management, and the proportion is rising.

Study Focus and Conclusions

This study examines an important subset of innovations and technologies that are impacting the forest extraction (logging) and tree-growing industry. Although many technological innovations have taken the form of the development of new products using wood and wood fiber and new technologies for processing wood and wood fiber, the focus of this study is directed at the raw resource itself and on important innovations in harvesting and growing industrial wood fiber. Figure 1 (below), *Wood Flows and Uses*, describes the flows from the raw wood resource. Some of the wood succumbs to various forms of natural mortality such as fire and infestation. Humans harvest wood for use both for fuel and for industrial wood, i.e., wood that is processed into wood materials and woodpulp for paper. This study is concerned with the approximately 50 percent of raw wood that is harvested worldwide for use as industrial wood.

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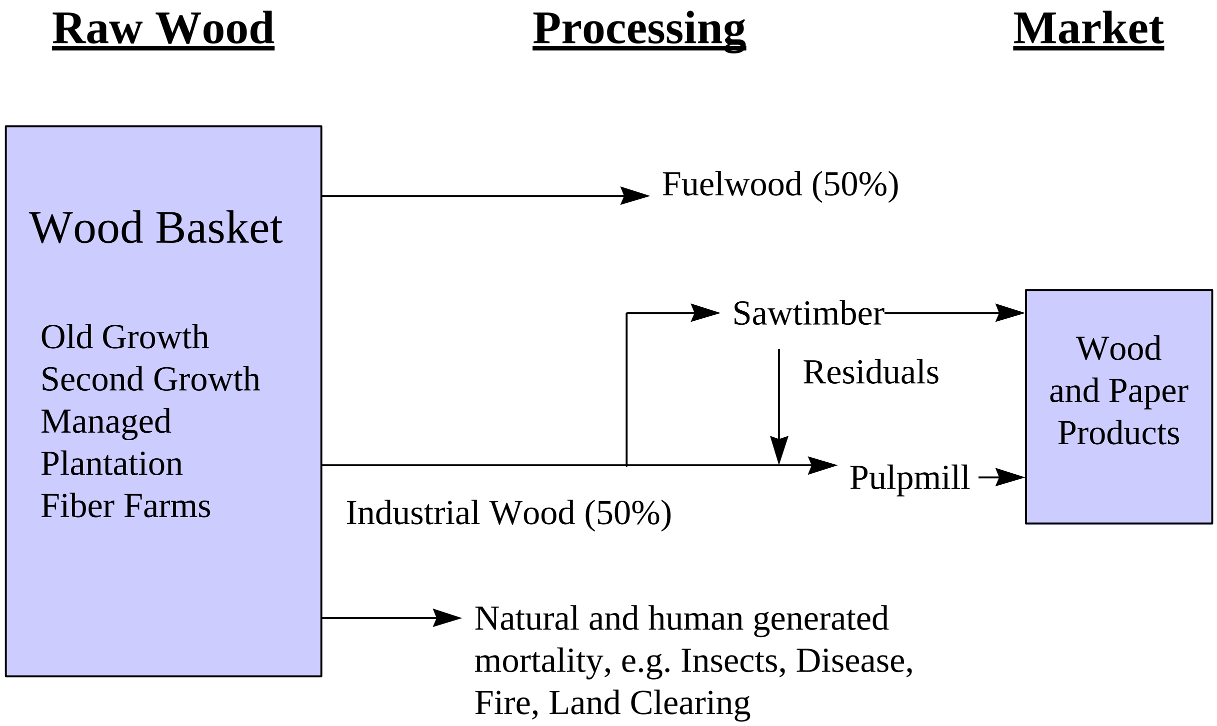
Figure 1. Wood Flows and Uses



Industrial Wood Uses

Industrial wood has two major uses, for building materials such as those used in construction, furniture and the like, and fiber products, typically various types of paper and paperboard used for writing, printing and packaging (Figure 1). Although wood for construction and materials has been used for millennia, the use of wood fiber for paper production has only been common for about the last century.[2] Traditionally, hardwood and conifer has been used to produce quite different types of products. Initially, paper was quite limited in its use of species due to concerns about both wood fiber characteristics and wood resins. For example, due to the nature of pine resin, it was not until the post-WW II era that southern pine was commonly used to produce newsprint. Additionally, the length of the fiber is important to the strength in paper and conifer was preferred for its long fiber. Thus, short-fiber hardwood had only limited uses in paper production.

While for some construction purposes various types of wood were interchanged, there were still preferences based on milling and nailing characteristics, surface characteristics and visual features. Also, with the advent of plywood and other panel materials, certain types of woods had advantages for the production of certain products. Also, gradually, the short fiber

[2] Previously paper was made out of plant and animal fibers, much from old cloth.

of various deciduous species was mixed into the process both to impart the paper with a smoother surface more amenable to writing and printing and also as a less expensive "filler" material. Today, many pulpmills face scarce supplies of certain short fibers due in part to new packaging approaches that require more printing on the package surface[3] and also because much of the hardwood resource exists in less accessible, often wetter, areas.

In recent years, however, fiber products have come to include not only paper products, but also a host of solid materials that have been produced by the composition of wood fibers. These include various types of reconstituted fiberboard and engineered wood products. Often, the species is important and historically certain species have physical characteristics that allow their use for producing specific products. However, through time technology has allowed increasing degrees of flexibility in utilizing substitute species.[4]

Study Focus

The study focuses on two important innovations in forest resources. These are a) technological innovation in wood extraction (logging), and b) technological and institutional innovations in tree growing with the focus being on intensive management of plantation forests. The examination takes place within the context of changing societal attitudes toward forests as reflected in changing regulations and laws regarding logging and forest practices.

The focus is on technological innovations including those related to genetic improvement of the growing stock and conditions necessary to allow for the introduction of genetically improved seedlings. The study examines these innovations in the context of recent land use policies that have and are affecting industrial forestry and the production of industrial wood. The perspective is primarily that of North America, the dominant wood-producing region of the world, however, not all the examples are from North America. Examples of changes in logging include the US South, the Pacific Northwest, British Columbia in Canada and the Nordic countries. The forest management focus is on prospects in the US, both with traditional intensive forest management and the even more intensive "fiber farming."

Although the study looks in some detail at the nature of the logging operation in four different regions - two in the US - the estimates of logging productivity in the US are developed in a companion study and are derived from national data. Thus, regional differences are lost in the averaging. The study concludes that logging labor productivity in the US has increased over the past three decades by about 20 percent, suggesting that technology and other inputs have somewhat more than offset harvestable resource depletion, some caused by environmental constraints and forest set-asides. The single dominant innovation within the forest industry in recent decades is the shift to intensively managed forest plantations and fiber farms. This trend

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[3] More items are being packaged in containers that have promotional writing on the surface. This requires a surface more amenable to printing which calls for the greater use of short fiber.

[4] Until recently tropical hardwoods were used rarely in paper production. However, recent technological innovations allow for the use of mixed tropical hardwood in the production of low quality paper. Modern technology is allowing a large degree of inter-species substitutability.

is driven by a number of forces and considerations that suggest that high rates of return on investments in plantation forests are obtainable. In a competitive market one would expect the returns to return to competitive levels over time as investment opportunities are exploited. The advantages of plantations relate to control of species and resources location, as well as the prospects for the introduction of genetic improvements that increase tree growth and allow for control of the quality of tree and the tree fiber.

The opportunities at the intensive margin, e.g., intensively managed forest plantations, have been demonstrated to be especially favorable on high biological sites, which can support rapid tree growth, in locations with access to processing facilities and to markets, both at home and abroad. Foreign competitors, e.g., Brazil, Chile and New Zealand, as well as plantations in the US South have demonstrated that financial returns to plantation forestry can be substantial. Furthermore, the threat for the 21st century to established producers in traditional wood-producing regions posed by low-cost regions moving into plantation forestry, such as Indonesia, is being taken very seriously.

Also, the ability of intensive forest management to increase yields 5-10 times[5] the growth rates experienced in nonmanaged forests has provided firms with the opportunity to conserve their expenditures on land ownership and focus their forestland holdings into a smaller, more productive area. This approach also improves the logistics of operations providing economies in management and harvesting, as well as in the application of intensive management, including planting. Furthermore, tree planting provides the opportunity for the benefits of genetic research to be applied to forestry. With widespread tree planting the returns to plantation forestry activities can be captured through increased yields and shorter rotations. The recent development of the fiber produced by fiber farms reflects what is perhaps the most advanced form of intensive tree management, rivaling that of much of agricultural cropping.

The basic trend towards an expansion of investments in intensively managed plantations is being accelerated by changing land use policies, which preclude harvests on some lands and raise costs on others. Obtaining wood from the extensive margin, (i.e., from old-growth forest) is becoming increasingly difficult, costly and uncertain. Old-growth forests are becoming inaccessible due not only to the decreasing physical availability of old-growth timber as the more accessible sites are logged, but also due to the increasing pressures being applied by the environmental community that have resulted in policies that have taken large areas of old-growth forest out of production and that have put in place more stringent and expensive logging requirements.[6] Of course, these phenomena are probably related in that as old-growth forests become scarcer they become socially more valuable at the margin. These changes in land use policy are viewed as an important force for change that is likely to continue.

In harvesting, this study found that there has been a stream of new equipment and techniques that were being applied in most of the regions examined. However, there has been

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[5] The actual increases realized thus far are probably in the 2 to 4 fold range.

[6] Of the four regions examined closely, only the Canadian Coastal forests has substantial volumes of available and assessable old-growth.

no single large innovation that dominates the forest industry. Rather, there are a number of small gradual innovations, changes in harvesting that are maintaining a stable labor productivity. These innovations, however, in the aggregate barely keep pace with factors increasing harvest cost, including poorer accessibility of old-growth forests. This stability of productivity may hide the large variability in technologies used in harvesting, even within a region. For example, in the South relatively inefficient logging operations are being used at the same time efficient operations are also underway, thereby resulting in an average that may be well below what is obtainable with the best technology. This probably reflects season employment, where labor opportunity costs are low, and the willingness of some small loggers to work at lower financial returns in return for the rewards of self-employment.

Furthermore, policies that impose more stringent forest practices and logging requirements and have withdrawn some prime timberlands from production may have offset cost advantages provided by new technology, especially in the west. Here, logging costs will likely rise due to increasing inaccessibility of some sites and due to more stringent logging regulations. In response to this and other forces, industrial wood production in North America is shifting to intensively managed forest plantations and fiber farms[7] where economies in harvesting and returns from management, e.g., planting genetically improved growing stock can be captured by the producer. The transition to intensive wood management has been underway for only a few decades. Nevertheless, the process has now become well developed, and plantation management accounts for an estimated one-third of global industrial wood production.[8] However, not all plantations are intensively managed, even in regions of higher productivity. The advantages of intensively managed plantation forestry appear substantial and the process is likely to continue in the US indefinitely.

The balance of the study takes the following form. First, a broad overview background is presented. Then, there is a discussion of innovations in logging and in tree planting, including the introduction of recent genetic innovations as applied to forestry. Additionally, a section examines the changing forest and land use laws and regulations that affect forestry and forest practices. Finally, the implications of the innovations are brought together and their implications on US and North American forestry are examined and the conclusions of the study are presented.

Historical Perspective

Wood has been an important construction medium for millennia. One of the first recorded accounts of a seagoing voyage documents the delivery of forty shiploads of cedar from Lebanon to Egypt about the year 2600 BC (Herm 1975). However, logging has

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[7] Although many "non-tree" species, e.g., wheat straw, knaff, hemp and bamboo, can be substituted for wood fiber in some uses, this paper examines the forest sector only and the term "fiber farm" refers to very intensively managed forests.

[8] See Table 2. The transition is likely to involve not only shifts within a region to more intensive forestry modes, but also interregional shifts in forestry operations out of regions poorly suited to plantations into regions that have a comparative advantage in intensive plantation forestry (See Sedjo and Lyon 1983).

traditionally been a painstaking and difficult task and timber was typically only useful if it could be used close to its origin in the forest.

Earliest human uses no doubt included wood use for fuel, for weapons and for building materials. The source of those early materials was the natural forest where humans simply drew upon the stock of forest resources provided by nature. Today, in many respects, human use of forest resources continues to be the utilization of the natural resources provided by nature. In much of the world -- Canada, Russia, Indonesia and Malaysia, parts of the Amazon, and elsewhere -- humans still draw from stocks of the wood natural resource provided by nature. In the US much of the industrial wood supplied through the late 1980s was drawn from natural stocks, although with the recent dramatic reduction on harvests from federal lands, especially in the Pacific Northwest, a much higher portion of US harvests involves second-growth and planted forests.

One can view the globe as being in a transition in the provision of its industrial wood resource needs away from a gathering and foraging mode in natural forests to an agricultural mode of husbandry and cropping. This trend is driven by financial considerations. As natural forests become increasingly inaccessible financial decisions at the margin are shifting increasingly to investments in intensive management and plantation forests, which can generate positive financial returns. This trend has been accelerated by both decreased availability of natural old-growth and technological change which increases yields and lowers costs to plantation forests. Furthermore, this transition is accelerated by society's changing view of the forest and its role, which has had the effect of decreasing the forest industry's access to natural forest and increasing its harvesting costs.

Industrial wood has the rather unique characteristic of having become increasingly costly over a long period of time. In a study of the long-term availability of natural resources, Potter and Christy (1962) found that the only natural resource (with fisheries) that has been experiencing increasing economic scarcity was industrial wood. In a follow-on study, Robert Manthy (1978) confirmed the increasing real price trend prior to 1950 but found that after the early 1950s, the increasing scarcity of industrial wood appeared to cease. The basic approach used by these researchers was to examine the long-term trend in real price, inflation-adjusted price, of the raw resource to determine if any long-term increases were observable. In the case of industrial wood, Potter and Christy found that there was a long-term upward trend in sawlogs, but not pulpwood. Manthy confirmed these trends, but demonstrated that the long-term upward price of sawlogs disappeared between the early 1950s and the early 1970s.

In more recent work, Sedjo and Lyon (1990) found that real price of sawlogs and pulpwood rose in the 1970s, but fell back almost to their pre-1970s prices in the 1980s, thus exhibiting only a very modest long-term trend.[9] However, in the decade of the 1990s,

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[9] The data referred to here are log prices delivered to the mill. It should be noted that industrial wood prices are sometimes reported as stumpage prices, i.e., the price of the right to harvest the tree, and sometimes as wood at roadside and sometime as logs delivered to the mill. These prices will differ and the trends may differ. For example, stumpage and delivered logs price trends may different systematically if transport costs from the forest to the mill are falling, due, for example, to cost-reducing technical change in log transport.

beginning in 1992, real delivered log prices once again exhibited a rise.[10] Since wood resource prices are influenced by the business cycle and exhibit a high amount of variability, care must be taken in interpreting recent price trends. These may capture temporary short-term trends, which are not sustained.

One explanation for the reduced rates of real price increases in recent decades has been the host of technological innovations impacting the forest products industry. Although the forest products industry is often thought of as traditional and stodgy, in fact it has been characterized by an array of technological innovations that have profoundly changed the nature of the industry. These innovations have primarily been driven by the desire to increase the effective availability of the raw material. The technological changes have been characterized as a) wood saving; b) wood extending; and c) wood increasing (see Sedjo and Lyon 1990). Examples of wood-saving technologies are found, for example, in new pulp production processes such as chemi-thermolmechanical pulp (CTMP) that reduce the wood required per ton of pulp production. Wood-extending technologies include the development of oriented strand board (OSB), which uses low quality wood (e.g., Lake State aspen), to produce a product that is a substitute for a product typically requiring high quality wood, e.g., plywood. Waste paper recycling is also an example of a wood-extending technology since it allows a wood fiber to be utilized more than once. Wood-increasing technologies refer to tree-growing and forest management activities that increase the growth rate of the commercial forest and thus increase the supply availability of industrial wood. In this category are included artificial regeneration, forest plantations and fiber farms.[11] In this study we focus largely on wood-extending technological changes.

Forest Exploitation and Extraction

Historically, humans have drawn their wood needs from the natural forests provided by nature. Generally, the wood was utilized near its source since the transport costs tended to be prohibitive over long distances and other materials were substituted for wood in areas where wood was dear, e.g., tents or sod dwellings were substituted for wooden structures on the plains and deserts. Nevertheless, in many parts of Europe and Asia, as well as the New World, wood played a critical role as a major construction material. Through much of human history and prehistory local wood resources were adequate to local needs, especially given the regenerative capacity of the forest. In much of the world it is only in recent centuries that

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[10] In North America the real price rise appears to be associated with the large reductions in timber harvests from public forests.

[11] Generically the difference between intensively managed forest plantations and a fiber farm growing trees is perhaps artificial and, at best, one of degree. Some states and provinces make a distinction on the basis of the length of the growing rotation, e.g., a rotation of less then 10 years constitutes a fiber farm in Washington State and thereby receives a different and more favorable tax treatment. Also, the term fiber farm is often used when referring to very intensively managed tree plantations growing on lands that traditionally would be in agriculture. Finally, the industry appears to favor the term fiber farm since harvesting "farm" products is accepted as more politically correct than harvesting trees.

major human-generated land-use changes occurred, which necessitated the opening of new forest areas for timber production.[12] Furthermore, as more sophisticated transport networks made large-scale wood transport feasible, human-constructed transport systems supplemented natural routes such as those provided by rivers.

Until recent decades humans could move on to new forested areas, as the areas exploited earlier become unavailable. In the US forest resources were drawn first from New England, the mid-Atlantic States, and parts of the southeastern coastal plain; then from the Ohio Valley, the Lake States and the South Central, and finally from the Pacific Northwest. Canals and later railroads added to the natural transport network provided by rivers. The US forest frontier was gradually extended into Canada, and Canadian wood became an increasingly large component of US consumption.[13]

Worldwide, new sources of wood have been developed as traditional sources became depleted or the forestland was converted to other uses. The natural tropical forests of the Philippines, Malaysia and then Indonesia became the leading suppliers of tropical hardwoods for world markets only in the post-WW II period, and for Indonesia only since the 1970s. Thus, the forests of Japan were complemented by wood from the Asia-Pacific as well as North America and Russia. The vast forest of Russia in the Soviet Union was an important source of industrial wood for the centrally planned economies as well as portions of the Pacific Basin and European markets until the Soviet Union's political break-up in 1989 and the early 1990s led to disruptions which have adversely affected timber harvests. Similarly, harvests from Canada's natural forest have expanded as world markets grew and Canada has become the world's largest industrial wood exporter.

In many respects, however, the exploitation of the last of the major "frontier" forests of the world with their huge inventories of natural mature forest has already been undertaken. Globally, there are few new native forests that can be developed or exploited. The largest remaining forest areas that have not been developed for large-scale commercial logging are found in the Amazon and in interior Asian Russia.

This area, however, is unlikely to be utilized as a major source of industrial wood given current technology since the species are so diverse and varied that large-scale commercial logging of the native forest has not been economically feasible.[14] The deforestation occurring in the Amazon is largely driven by forest conversion to agricultural uses and little of the wood is utilized as industrial wood.

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[12] There are clearly exceptions to this and local wood scarcity caused by overharvesting and land-use conversion was found, for example, in the Mediterranean region and in China.

[13] Today, almost 40 percent of US consumption of softwood lumber is imported from Canada. One and two decades ago it was below 30 percent.

[14] Not all wood is identical for industrial wood purposes. Where forests are very heterogeneous, as in many tropical forests, most of the species do not have ready markets.

The Current Situation: Industrial Wood Sources

The industrial wood resource comes from a host of regions around the globe. Table 1 provides a global overview of industrial wood production in a recent year. The data reveal that although North America is an important supplier of industrial wood accounting for over 37 percent of global production, there are also many other important suppliers.

Table 1. World Industrial Wood Production, 1993

Country	Volume, cubic meters	Percent Total
USA	402,500	26.3
Canada	173,133	11.3
Europe, excluding Nordic	169,036	11.1
Nordic	103,213	6.7
Russian Federation	172,955	11.3
Japan	32,209	2.1
Indonesia/Malaysia	84,011	5.4
China/India	125,275	8.2
Other	-	17.6
Total World	1,529,000	100.0

Source: FAO *Forest Yearbook*, 1995

The globe can be viewed as being in a transition in the provision of its industrial wood resource needs away from a gathering and foraging mode in natural forests to an agricultural mode of husbandry and cropping. Today a variety of sources make up the world's wood basket. Virgin forests are the primary source of industrial wood supplies in almost all of the Canadian West and much of the East. Much of the Russian harvest is drawn from virgin forests, especially in Siberia and the Russian Far East.

Although vast forests remain in Siberia, they are unlikely to provide a major source of industrial wood in the foreseeable future due to their economic inaccessibility. Under the old Soviet system these forests could be exploited, since the huge transport costs to market were subsidized. However, it is problematical whether significant volumes of Siberian industrial wood can be transported economically to major world markets if the price must fully bear the transport costs.

Having indicated the limits to new "frontier" suppliers of industrial wood it should be noted that some natural areas that are now being exploited still have vast natural forest, which in principle, could continue to provide large volumes of industrial wood into the indefinite future. Much of northern Canada remains unexploited. Large areas of native forest remain in European Russia and in the Russian Far East.[15]

[15] The Russian Far East and Siberia are often confused. Whereas the Siberian forests are generally thought of as those of the Lake Baykal region, well over 1000 miles from the Pacific, the Russian Far East consists of the coastal and adjacent areas north of Korea and to the east and north of Manchuria. These forests have generally good access to the Pacific Basin markets.

However, there are environmental pressures to limit or modify logging practices in many of these regions. Even as the Russian harvest fell to about 50 percent of its level during the Soviet era, many in the West are concerned lest the Russians overexploit Siberia and the Russian Far East. Concern also is expressed about Canadian and US forests with new practices going into effect in the Pacific Northwest and British Columbia.

Industrial wood from tropical forests accounts for less than 25 percent of the world's industrial wood production and comes largely from logged areas of older forests, with Southeast Asia and the Asia-Pacific region being a major tropical wood source. The largest stock of tropical forest is in the Amazon. This area, however, is unlikely to be utilized as a major source of industrial wood given current technology since the species are so diverse and varied that large-scale commercial logging of the native forest has not been economically feasible.[16] The deforestation occurring in the Amazon is largely driven by forest conversion to agricultural uses and little of the wood is utilized as industrial wood.

Due to the limited number of commercial species found in most tropical forests, commercial logging in tropical forests almost always takes the form of selective logging whereby only a relatively modest portion of the trees are felled and removed.[17] In much of Europe and the US the timber harvests are drawn from second-growth forests. In Europe the forests have often been replanted to ensure regeneration, while in much of the US the harvests are drawn from areas that were logged-over and have regenerated naturally or areas that were formerly agricultural lands that had been neglected and were naturally regenerated in forests.

In addition, a growing portion of the world's industrial wood is being supplied from plantation forests. Although many of these are in traditional forest areas including parts of Europe and the US South, a growing portion of the world's industrial wood basket is coming from plantations in nontraditional wood-producing regions. These regions include several countries in South America, including Brazil, Chile, Venezuela, Uruguay and Argentina; as well as countries such as New Zealand, Australia, South Africa, Spain Portugal, Indonesia, Thailand and China. All of these countries have important industrial tree-growing activities and several have become major wood producers, not only for their domestic markets, but for international markets as well.

Finally, a new source of wood fiber is being developed in the form of the "fiber farm." The fiber farm takes plantation forestry to its logical extension in that fiber is grown as an agricultural crop in very intensively managed short rotations on sites that typically until recently were used for agricultural crops. Where water is lacking, it is provided through "drip irrigation" and where nutrients are lacking they are provided through appropriate fertilization.[18] Although this form of

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[16] Not all wood is identical for industrial wood purposes. Where forests are very heterogeneous, as in many tropical forests, most of the species do not have ready markets.

[17] Deforestation in the tropics is driven largely by land conversion to nonforest uses, primarily agricultural uses (see UNFAO 1987).

[18] Fiber farms are a subset of intensively managed plantations and differ only in the degree of the intensity of management.

plantation is still in its fledgling stages of development, probably occupying less than 40,000 ha currently in the US, this type of activity has increased substantially in the past decade.

A crude disaggregation of the types of forests from which current timber harvests are supplied is provided in Table 2. This table suggests that approximately 30 percent of current timber harvests come from old-growth forests; 10 percent from exotic plantations; and 62 percent from second-growth forests, most with some degree of management.

Table 2. Global Harvests by Forest Management Condition

Forest Situation	Percent of Global Industrial Wood Harvest
- Old-growth	30
- Second-growth, minimal management	14
- Indigenous second-growth, managed	22
- Industrial plantations, indigenous	24
- Industrial plantations, exotic	10

Source: Personal estimate drawing one-country production levels provided by the FAO (see notes).

Notes - Table 2:
Old-growth includes: Canada, Russia, Indonesia/Malaysia
Second-growth, minimal management: parts of the US and Canada, Russia
Indigenous second growth, managed: residual
Industrial plantations, indigenous: Nordic, most of Europe, a large but minor portion of US, Japan, and some from China and India.
Industrial exotic plantations: Sedjo 1994
Second-growth, minimal management: the residual

The trend toward managed and intensively managed plantation forests is driven primarily by financial considerations and concerns about future supplies. As natural forests become increasingly inaccessible, plantation forests generate improved positive financial returns. This tendency is promoted by industry concerns over environmental legislation that may further restrict harvests on old-growth forests.

A Brief History of Forests in the US

In colonial America the forest provided an obstacle to the use of land for agriculture and much of the logging was undertaken to clear land for agriculture. In many cases the large trees were not felled but simply girdled to cause their death. The defoliated trees were left standing with the underlying crop receiving adequate sunlight through the bare branches (Hawke 1988). Historically, in many cases, the larger more difficult trees to fell were left in the forest and only smaller trees were taken. However, the forests were valuable in providing materials for fences, log buildings, and so forth, as well as fuelwood, which could readily be extracted from the smaller trees.

Despite the impediment of the forest, iron axes, together with the power of oxen and horses, gradually made logging more feasible. Also, water and water power could be harnessed and sawmills began to proliferate along streams and rivers. Also, most logging took place near to settlements or near waterways, which considerably eased the problems of transport.

In the US, as the frontier expanded and the railroad developed, logging too was a beneficiary of improving technology. Steam-powered railroads made the transport of logs easier and steam-powered mills replaced the need for location near water power. Although the forest was gradually giving way to clearing for agriculture use in the East, this process had begun to abate even before the Civil War as the railroad made the bounty of the highly fertile prairies available in the East. However, the industrialization of the post-Civil War period set in motion widespread logging to fuel the nation's wood needs. By the latter decades of the 19th century, the forests of the Lake States were rapidly falling to the ax of the lumber jack as they supplied the materials which built the rapidly growing cities of the Midwest.

In the South some regions had been cleared and converted to agriculture since settlement. However, at the beginning of the 1880s there were still remaining vast areas of virgin forest as before then most logging took place along rivers and rail-lines. Until 1880 large areas of forest remained untouched by lumbermen in the pine forests of Florida, Georgia, Alabama, Mississippi, Louisiana, Arkansas, and East Texas (Clark 1984). However, the years between 1880 and the end of WW I saw frantic logging in parts of the South, as in the Lake States. By the 1920s there was the realization that excessive rates of logging could extract a high cost on the lands. The purpose was not simply to log the timber, but it was also to clear the land making it available for the next wave of immigrants and settlers. Thus, reforestation issues were simply not relevant. By the second decade of the 20th century, the forests of the Lake States were largely gone and the timber industry moved west and continued in the South. However, forests being renewable, this was not the end but rather the beginning of a new phase.

The forests of the West and South provided the nation with most of its timber during World War I and the interwar period, although the opening of the Panama Canal in the first decade of the century did provide a means for west coast timber to reach eastern markets. Additionally, Canadian wood fiber products increasingly found their way into US markets, especially newsprint produced from fiber from eastern Canadian forests.

The interwar period was one of economic stagnation and depression in the US. Thus, the demands on the forest for industrial wood were relatively modest. In addition, many of the logged-over areas of the US experienced natural reforestation. In the South and East many cleared agricultural fields and pastures were neglected for agriculture. These lands became reforested in what was called "old-field pine" for the pine that had regenerated in the "old-fields." Additionally, the depression of the 1930s brought into being the Civilian Conservation Corps (CCC), which undertook a host of land renovation and reforestation activities. Finally, the depression saw the abandonment of marginal agriculture[19] in the South, Lake States and

[19] The use of the term "abandoned of marginal agriculture" is used here to refer to the cessation of agricultural activities such as cropping or active pasture and not the literal abandonment of the land. Many lands that continue to be in private ownership but where agricultural activities were abandoned reverted to forest. Also, some lands were literally abandoned and reverted to the state due to failure to pay taxes.

East. These fields, naturally regenerated, would become valuable timber resources three to five decades later.

With the end of WW II, however, the forests of the West, and especially the Pacific Northwest, became major wood fiber suppliers nationally and globally. Harvesting technology saw the advent of the chain saw as well as improved roading abilities into previously inaccessible forests of the Cascade Mountains of Washington and Oregon. The chain saw and the logging truck now replaced the long-saw and the spur lines of rail. In steep terrain, "high lead" logging made it possible to retrieve logs felled hundreds of yards from the road.

In the South the forest industry began anew on forests which had sprung up as the lands which were abandoned from agricultural and logged-over lands regenerated and moved toward maturity. In the Lake States, the reemergence of a large forest industry would require another couple of decades. The reemerging forest consisted largely of little utilized species, particularly Aspen. However, by the 1970s a new product had been developed, oriented strand board (OSB), which utilized the tree fibers to make a wood panel that substituted for plywood in many uses and was perfectly suited to the Aspen resources of the region.

II. LOGGING

Timber extraction or logging practices vary depending upon the species, tree size, location and terrain. Old-growth forests are old usually because of their inaccessibility or due to the lack of commercial value of much of their forest.[20] The trees of the old-growth forests are often large, in part because they are relatively mature, and the terrain is difficult reflecting the reality that most of the easily accessible "large tree" forests on less difficult terrain have already been logged. Hence, old-growth logging tends to involve large trees in less accessible, often difficult terrain and typically requires expensive road construction and management techniques to reduce the need to build expensive roads, e.g., aerial systems. Furthermore, much of the heavy equipment that increases productivity cannot be used on steep terrain and logging systems for steep slopes typically involve cable logging. Helicopter logging appears increasingly financially feasible as helicopter costs decrease. However, helicopter logging is still rare.

Worldwide, logging in old-growth forest occurs in the difficult terrain of the coastal mountains of British Columbia; the less accessible northern forest areas of Canada; in the more inaccessible parts of Russia; and in the less accessible regions of tropical forests in Malaysia, Indonesia and parts of South America and Africa.

Second-growth unmanaged stands usually reflect an opportunistic situation where an original old-growth forest harvest had occurred, and perhaps was followed by subsequent harvests on the regenerated growth or a secondary species that became valuable over time. However, the unmanaged nature of the forest indicates that no attempts were made to manage to reestablish the forest nor to convert the land to other uses. Vincent (1994) has referred to

[20] The forest of the Amazon would probably have been logged decades ago if the wood had been less heterogeneous and of more valuable commercial species.

these situations as "pulse" harvests. Examples would include: selection harvesting (harvesting only selected trees) as is common in most tropical forests, and second-growth forests that occurred by natural forest regeneration after the abandonment of agricultural lands throughout the US and Canadian East.

Second-growth managed forests tend to consist of indigenous species that have been both naturally and artificially regenerated as in the US South and much of Europe. Typically these sites are reasonably accessible, having been harvested before, with small- to medium-size trees. Often management is applied after the harvest of second-growth timber and the unmanaged second-growth forest is converted into a managed forest.

Exotic plantation forests are the result of a conscious human decision to establish a forest, usually for the purposes of future industrial wood supplies. The trees, being exotic (non-indigenous) species, are planted in tree plantations that are chosen for their productivity and their accessibility. Harvesting usually involves relatively high volumes of small but very homogeneous trees. Examples include the tree plantations of South America, which feature imported pines or eucalyptus; Oceania with its radiata pine; and increasingly, parts of the Asia/Pacific, with a variety of introduced species.

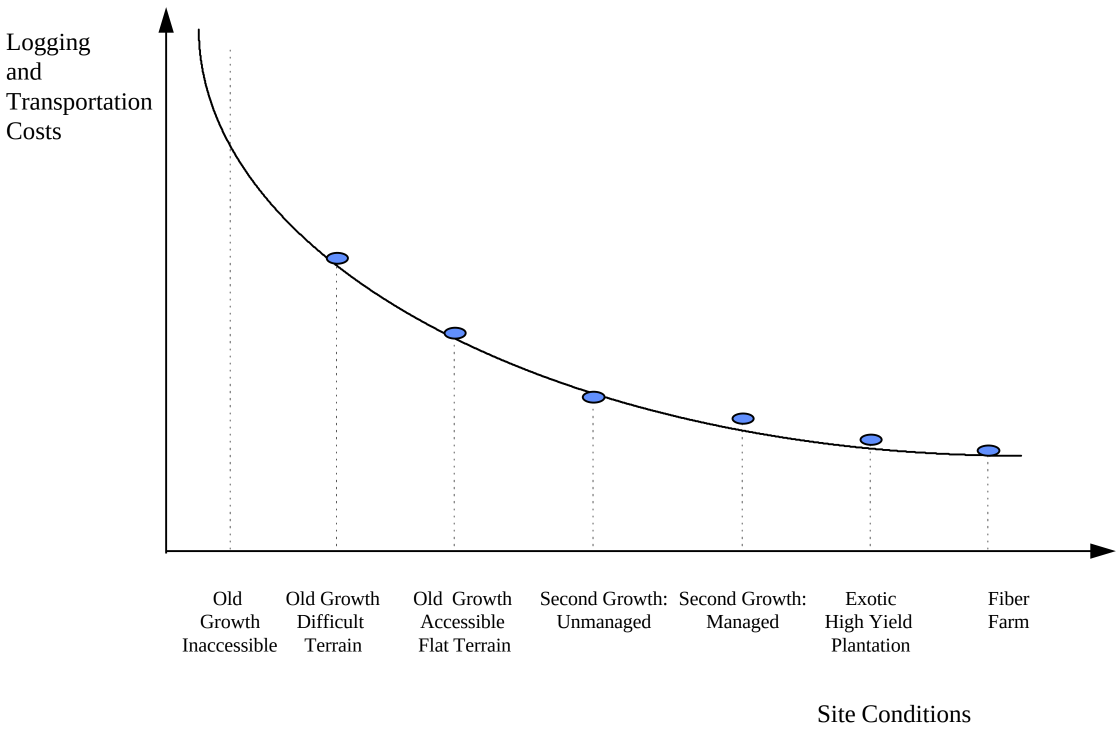
Exotic plantations are established in accessible sites in part because of the characteristics of the site that make planting and harvesting low cost and make the wood accessible to markets. Plantations very often are established on former agriculture lands. These commonly have a transport infrastructure already in place and have terrain conducive to mechanized planting and harvesting. In fact, forest plantations can be thought of as simply the application of cropping techniques to the growing of wood fiber. Although the trees tend to be small, full stocking allows for large volumes per unit of land area harvested. Such a situation provides opportunities for mechanized low-cost timber harvesting.

However, while harvesting costs for plantations may be lower, some difficult old-growth forest continue to be economically competitive because old-growth trees often have characteristics that warrant high market prices. For example, higher harvest cost old-growth coastal British Columbia timber is used for the high-price decorative wood market while commodity grade dimensioned lumber is produced from the lower harvest cost interior forest. More generally, most wood from the low-harvest-cost plantations is used for low-price fiber for pulp and paper.

Features of the forest discussed above suggest different logging approaches. Figure 2 (below) provides a schematic of alternative logging situations and provides an estimate of the relative logging costs likely to be experienced for the various forest situations discussed above. As the figure shows, in general, it would be expected that logging costs would be highest in old-growth forests in difficult terrain and lowest in intensively managed plantations. Not only is terrain important, but stand homogeneity and volumes of timber per unit of land area also are significant influences. Thus, plantations and fiber farms would be expected to have the lowest harvesting costs. An advantage of forest management is that it can influence growth so as to generate high volumes of homogeneous trees on accessible sites on easy terrain.

Figure 2

Hypothetical Logging Costs: Alternative Site Conditions



Historical Innovations in Logging [21]

Perhaps the most important post-WW II innovation in logging was the chain saw, which substituted mechanical power for human muscle in driving the saw to fell and cut the tree. This was accompanied by the development of increasingly more sophisticated power equipment (which replaced draft animals) in removing the logs from the forest.

In the last several decades there does not appear to be any single dominant technological innovation in logging that has had the impact of the chain saw. Rather in many forests the chain saw has been replaced by mechanical tree fellers and other power equipment that have subsequently been replaced by the second, third and fourth generations of improved power equipment. In general, the changes reflect not only site conditions and tree sizes, but also the relationship between the processing functions that are done in the mill vis-a-vis those done in the forest. For example, in the Nordic countries logs are often debarked and bucked in the field providing a feedstock that can readily be consumed by local mills, which process shorter logs.

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[21] Ruttan (1982, p237) gives the following definitions for technical change: Technical change (a) is the substitution of "inexpensive and abundant resources for scarce and expensive resources," (b) is "the substitution of knowledge for resources," and (c) "releases the constraints on growth imposed by inelastic resources supplies."

By contrast, in the US South where many mills are designed to utilize longwood the harvesting is focused on minimizing the processing in the field and delivering the longwood to the mill chipper where the first steps of processing are undertaken.[22] For example, some newer techniques in the South bypass the field delimbing operation entirely and deliver the stems to the chipper, limbs and all. This approach enhances logging productivity by reducing the number of operations. However, shortwood is still common in the US South and driven largely by the limitations on the ability of local mills to use longwood. This example demonstrates the need for systems integration from the forest to the mill to enhance efficiency.

The use of mechanical tree fellers is most effective on flat terrain and where the trees are of relatively similar size. Thus mechanical fellers are uncommon in the rough steep terrain of Coastal BC and the chain saw is still the dominant cutting tool, as it is in much of tropical forest logging, where only a small fraction of the forest is logged and where tree sizes may vary greatly.

Variations in Logging Innovations across Countries[23]

The logging industry has evolved different harvesting styles in Canada, the US and Sweden. Although some of these differences, no doubt, reflect different site, climate and locational conditions for logging, the path also reflects different histories and social forces. In the Nordic countries the earlier post-WW II period was one when attempts to maintain populations in the rural northern area were breaking down. Labor was no longer willing to endure the hardship of the logging camp. The decline of the small farm further reduced the labor force available for harvesting, even for seasonal employment in the winter months. In this context government policy directed the development of mechanization which performed the same tasks as had been done in labor-intensive systems. Expensive labor-saving equipment, developed by the government, included innovations tending to mimic earlier human activities such as felling, bucking, forwarding the wood to the pick-up point, etc. Equipment with "booms," which could reach out for the tree, was required since glacial detritus often precluded driving to the tree and the orientation was to deliver the wood to the primitive roads that existed. Forwarders were developed to mimic crude equipment used by forester-farmers. Furthermore, due to national decisions as to wood needs for a current year, Swedish harvesters produced for annual targets and did not have to vary the pace of the harvest to respond to changing market conditions and the expensive equipment experienced little down time.[24]

Canada, too, had difficulty recruiting labor in areas far from urban centers. However, the major transport to mills was via water routes, often at a substantial distance from the

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[22] The Nordic system of short logs may be dictated by the roadside wood collection operation, in which smaller wood is more easily handled.

[23] I am indebted to William P. Stuart of Virginia Polytechnical Institute for enlightening me as to the role social forces have played in the development of technologies in the various regions and I have borrowed heavily from his suggestions.

[24] Nordic mills have provisions for the build-up of very large wood inventories.

logging. A system of manual felling and tree-length skidding to rivers was used where water transport was available. Gradually, trucks replaced water transport, except on the Pacific Coast.

The US South, by contrast to the Nordic countries and Canada, had large numbers of rural communities. Logging provided attractive off-season employment to the essentially agrarian labor force. Thus, labor in the South was not the constraint that it was in Canada or the Nordic area. Technical requirements for logging were minimal, requiring a saw, a farm tractor and a light truck. There was no need for wood-consuming firms to invest in harvesting, as numerous small contractors would provide the service of buying, harvesting and delivering the wood to a pick-up point, often a rail siding, or directly to the mill. Since the mill's wood requirements could vary week to week depending upon market changes, logging contractors might find themselves very busy one week and without mill demand the next. Thus, the southern contract system has developed an "idle capacity" feature, where wood inventories at the mill are typically small and wood flows are "just-in-time." By contrast, the Swedish harvester has little excess capacity since its annual harvests are predetermined and its specialized equipment provides a continuous flow of wood to the mill, which may accumulate substantial inventories (Laestadius 1990).

As the post-WW II period continued, logging in North America, and especially the South, has been modified with the demise of the small family farm and the large-scale migration to urban areas. In recent periods many, if not most of the innovations, have taken the form of labor-saving technology (see Stier 1982, Cubbage and Carter 1994). This is not surprising given that labor has become the scarce factor and real wages have been increasing in the South as well as in most industrial wood-producing countries, while the delivered resource real price has been relatively stable. Nevertheless, the contract logger continues to dominate and opportunities exist for small logging operations staffed by seasonal employees.

Technical Change in Logging: Some Case Studies

Below we examine modern logging technology in four regions with very different conditions, running the gamut from flat terrain and small trees to steep terrain and large trees. The cases are the Nordic countries, Pacific Northwest of the US, coastal British Columbia and US South. The Nordic forests examined are characterized by relatively flat terrain, small trees, and long periods of frozen soil, which allows for ease of logging. The area of the Pacific Northwest examined was one of naturally regenerated second-growth forest, largely hemlock, moderate size trees, relatively flat terrain and high levels of precipitation. Precipitation creates soils that are wet for large portions of the year making logging more difficult, in part due to greater soil damage associated with logging on wet soils. The coastal forests of BC are characterized by steep terrain, wet weather, and relatively large old-growth trees. Finally, the US South is characterized as having large areas of flat terrain, moderate size trees, and substantial periods of the year with wet soils.

For an old-growth forest there is typically a single harvest with the logs going into the production of solidwood products, such as lumber, and the wood residues being used for pulpwood. For managed second-growth forests there are commonly two types of harvest. First, is a thinning harvest that occurs sometime during the stand growing cycle and is designed both to obtain wood and to "open the stand" so as to allow the remaining trees to increase their growth. Sometimes there are a series of thinnings -- up to three -- that occur during the stand's growth cycle. A thinning typically removes 10-30 percent of the stand's biomass. The thinning volumes are commonly used for pulpwood. Finally, there is the final harvest in which the mature trees are felled and transported from the site. This is typically followed by regeneration of the forest, often by tree planting. Often the second-growth forest that is regenerated is managed to promote its growth and influence the type of forest that is regenerated.

The Nordic Countries: Finland and Sweden. In the last several decades timber harvesting technology in the Nordic countries has taken the form of the substitution of capital equipment and technology for labor. This result has been a dramatic reduction in the labor required for harvesting. Stora Skog, a major Swedish forest products firm, states that their logging employment has fallen from about 20,000 four decades ago to about 1200 currently, while the harvest levels have remained essentially the same.

Modern logging in the Nordic countries uses two important pieces of equipment, the processor and the forwarder.[25] This equipment costs about $450,000 per machine and each can be run by a single operator. The harvesting systems are essentially the same for thinnings and for final harvests except that larger machines may be required for the final harvest if the trees are substantially larger. The processor is designed to fell the tree, remove the limbs, cut the trunk (bolt) into desired lengths, and to stack the wood in small piles. The processor has a "boom" with a grasping arm and a cutting arm. The grasping arm holds the tree trunk about 10 feet above the ground while the cutting arm cuts the trunk slightly above the ground with either a "pinching" or sawing mechanism. The grasping arm then maintains the stem in a vertical position as it moves it to a spot for piling.[26] This configuration allows the felling at some distance from the tree, a feature useful where glacial detritus precludes driving to the tree. Simultaneously the processor removes the branches with rollers which effectively strip off the branches and cuts (bucks) the stem or bolt into a prescribed length as it neatly piles the logs. The processor's computer can automatically keep track of the number of logs and their cumulative volume as these are measured in the bucking process.

The forwarder is designed to move the logs from the pile to the road or a pick-up "deck" via an operation that places the logs into a bin on the forwarder. Since a forwarder is used, the logs need to be bucked (cut into smaller lengths) to allow the forwarder to transport them. At the pick-up point the logs can be transported directly onto trucks for transport to the mill.

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[25] The system described below represents what might be the coming generation of logging techniques in the Nordic countries. Current harvesting practices in Sweden and Finland are very similar to the "ideal" system discussed below for the PNW (Hans Troedsson, Stora Skog AB, personal communication February 5, 1997).

[26] Obviously, equipment will vary to some degree depending upon the vintage of the equipment and the peculiarities of various sites.

The total labor crew required is only one person per machine. Typically, the crews work in teams of 2-3 for 2 shifts daily, with a machine operator limited to a 5 hour shift. When not operating the equipment, the crew will plan the next day's harvest by reconnoitering the site and making a preliminary determination of the path that the equipment should take.

The equipment is designed to minimize its impact on the soil with wide tires, and the limbs and tree parts that remain in the forest are used to cushion the soil as the equipment drives over the land. Logging in the Nordic countries is largely confined to the winter months when the ground is frozen and less subject to damage. Additionally, the equipment has spotlights for night operations and an enclosed cab for safety and to protect the operator from weather extremes.

The Pacific Northwest. Until recently, harvesting in the PNW was very similar to that of Coastal BC (below) with harvests focused on old-growth forests on fairly difficult terrain. Field activities consist of hand felling, limbing and bucking, with cable yarding to bring the logs from the field to the loading deck. For second-growth forests on relatively flat terrain, however, the cable system is being displaced by a system with equipment similar to that used in the Nordic countries and discussed above. On second-growth forests in the PNW on relatively flat terrain, an emerging approach eliminates the cable and relies on the use of a feller-buncher to fell and situate the logs, and a skidder to deliver the logs to the deck. However, the system differs somewhat in that the trees are larger and require a larger type of harvester-processor in the PNW than that used in the Nordic countries. In addition, where the terrain in the PNW is steep and more difficult, the use of cable logging systems is sometimes required (see the discussion on coastal BC). Also, access into some stands is difficult due to obstacles created by the remaining very large stumps from the old-growth harvests 50 years earlier; however, a "boom" arrangement overcomes some of these problems.

On relatively flat terrain, the most technologically updated system in the PNW uses a wide-wheel "harvester" designed to handle the second-growth thinnings.[27] The harvester has a long arm which allows it to reach and fell trees from a distance of perhaps up to 20 feet. Thus the machine need not disturb much of the ground where felling occurs, thereby reducing soil damage. The tree is felled by the arm grasping the tree's trunk some above the ground as the trunk is encircled by a clamp with internal saws and cut at a point just above the ground. The grasping arm controls the fall of the tree (but cannot maintain it in a vertical position like a Nordic processor) and drags it to the desired spot to be piled for pick-up. As with the Nordic processor, as the log is being moved it is also being delimbed by a grasping clamp and cut to a predetermined length. As with the Nordic equipment, the harvester's computer can automatically keep track of the number of logs and their cumulative volume. The harvester can fell up to 60 trees per hour, compared with about 60 per day with a worker and chain saw.[28]

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[27] In the PNW three thinnings are often viewed as ideal. First is a precommercial thinning, at a stand age of 10-15 years, from which none of the wood is used commercially. This thinning is designed to select the best trees and remove the others from competition. This is followed by commercial thinnings at age 20-25 years and 30-35 years. The wood removed is used largely as pulpwood. The final harvest typically occurs at stand age 50-60 years.

[28] Observation by former logger at a site on the Olympic Peninsula, Washington State.

As in the Nordic countries, the forwarder moves the log piles onto the machine and to a loading deck, although a skidder may be used instead. Here the logs can be moved directly to the trucks to be transported to the mill. The total labor crew required is only one person per machine.

The equipment used in the Pacific Northwest is similar in price to that of the Nordic countries, in the range of $430,000 per machine. As with the Nordic equipment the crew is small but operating the machine effectively requires skill and experience. A training program for operators costs about $15,000.[29]

For final felling the equipment used would depend on the terrain and the size of the trees. The processor can handle trees up to 18-20 inches in diameter (DBH), which is about the size achieved in a 50-60 year rotation cycle. Larger trees may require larger equipment or hand felling. As with both the Nordic and PNW systems discussed above, the equipment is designed to minimize the impact on the soil. The tires are wide to distribute the weight. The equipment has "arms" which can reach out some distance, thus minimizing the need to move the equipment. Additionally, as in the Nordic countries, there is a growing practice, not only to leave the limbs in the forest, thus providing nutrients for future growth, but to distribute the limbs over the paths taken by the equipment to further reduce the impact on the soil.

For final harvests in second-growth forests, however, individual tree felling is common and the bucking and delimbing are also done by an individual with a chain saw. Skidders are typically used to drag the larger logs to the deck, where cranes are used for loading. In steep terrain cable logging may be used for second-growth harvests similar to that described below for logging in coastal BC.

Logging in British Columbia. Logging in British Columbia occurs in two distinct areas: the coastal mountain range and the provincial interior. The coastal region is characterized by rugged mountains and old-growth forests with large size trees. Historically, logging has proceeded from the earlier most accessible areas to the difficult and increasingly inaccessible areas. Logging in the interior forest began at a later date and has been geared to the production of commodity dimension lumber for the US market. In an earlier period the logs of the BC coast were used for producing commodity-grade lumber, much of which was marketed in the US, with the residues used for pulp and paper production. In recent decades, however, commodity-grade lumber has been obtained from interior BC, which is the lower cost harvesting region. As the US market for lumber imports has increased, the interior harvests have expanded to accommodate that market. The logs of the coastal forests, which are larger and of a higher quality, have been used primarily for high quality decorative wood products and cedar shake. A large portion of the products of this forest are marketed in Japan, whose market places a higher value on its features, with the high-value cedar shake being exported to the United States.

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29 Information provided by Peter Schiess of the University of Washington.

Logging Volumes and Costs: The logging costs for the coastal and interior BC forests are presented in Figure 3 and Table 3. The cost data for the period 1965 to 1996 reveal a rising long-run real cost trend for both regions.[30] Although costs are substantially lower for the interior, logging costs appear to have been increasing slightly more rapidly in the interior. The net logging costs (net of stumpage fees, royalties, depreciation, and a normal return on logging capital) increased by two-thirds on the coast from about C$35 per cubic meter in 1965 to about C$58 per cubic meter in 1996 (all in 1995 prices). This upward logging cost trend has included, however, an 18-year period from 1975 to 1993 during which real logging costs showed no increase. The periods before 1975 and after 1993 both were characterized as having rising logging costs. For the interior, logging costs rose somewhat more rapidly, 75 percent in 29 years.

Figure 3

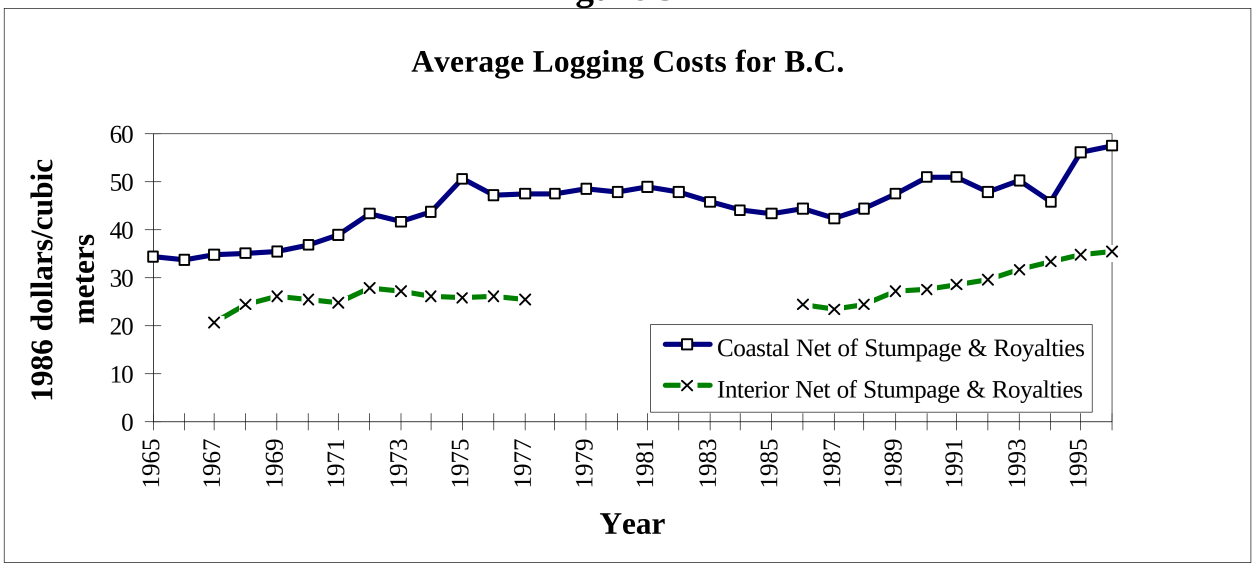

Table 3. Recent Total Forestry and Logging Costs Before Stumpage and Royalties ($/m3)

	1992	1993	1994	1995	1996
Coast	52.48	56.89	64.71	72.33	77.04
Interior	32.46	35.28	39.99	44.77	47.41

Source: Coast Forest and Lumber Association (CFLA) n.d.

Much of this cost increase occurs in two subperiods, during the 1970s and after 1987. Local observers attribute the 1970s run-up to union pressures which raised labor compensation rates. After the mid-1970s costs declined modestly, presumably due to labor-saving technological change that offset some of the wage increases. The cost increases after

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[30] The data were drawn from information provided by MacMillan Bloedel and the B.C. Council of Forest Industries (COFI), and Price Waterhouse.

1987 are attributed to the imposition of increasingly severe environmental regulations, which have increased harvesting costs. The cost increase initially appears to have been offset in the coastal region, perhaps due to the stronger yen to Canadian dollar relationship.[31] However, as shown in the figure and in Table 3, after 1993 this upward trend has been renewed.

After 1987, the cost trends of interior BC, which has much less difficult terrain than the coast, are similar to those of the coastal region, except that the total percentage cost rise over the period is somewhat less in the interior than on the coast. Harvesting costs in the interior rose steadily after 1987 and both regions also experienced about 46-47 percent cost increases between 1992 and 1996.

Harvest volumes for the coast and the interior are shown in Figure 4. Harvests on the coast show no trend and remain at roughly 25 million cubic meters, with some interannual variability, throughout the three-decade period. By contrast, harvests in the interior show a substantial upward trend rising from about 20 million cubic meters in 1965 to about 50 million in 1996. All of the considerable increase in the BC harvest over the period is due to expanded harvests in the interior.

Figure 4

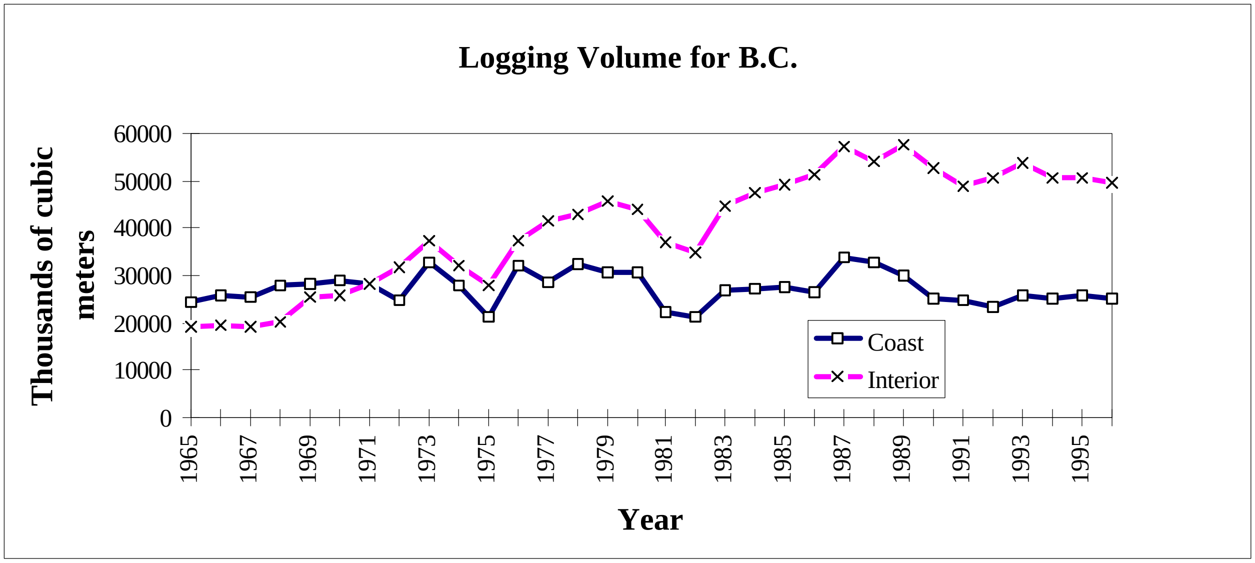
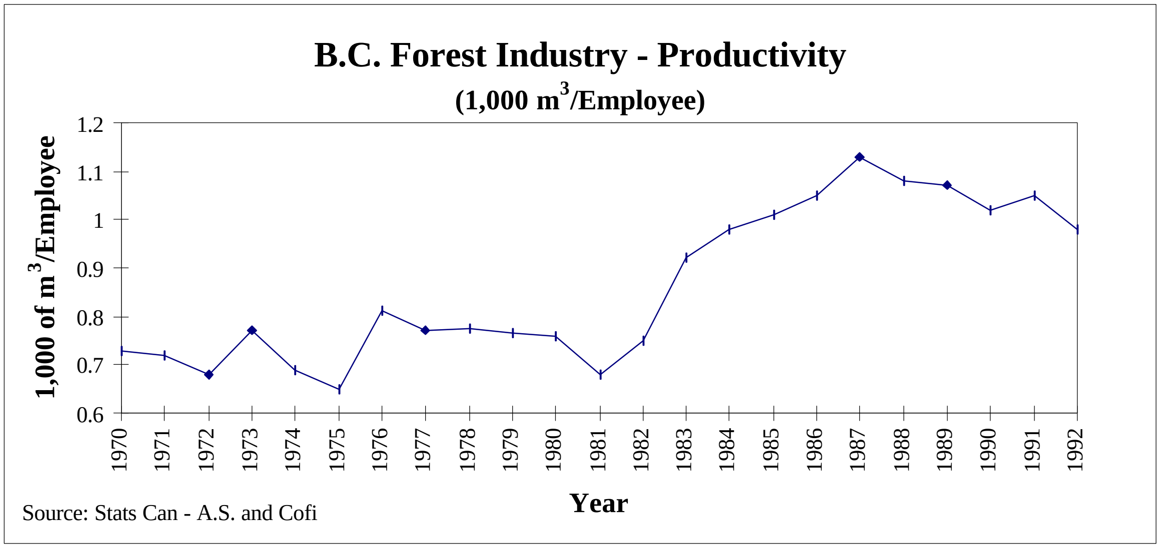


Figure 5 (below) presents the labor productivity of the entire BC forest industry, coastal and interior. These data, however, have significant limitations for examining labor productivity in logging since they include labor in sawmilling and pulp production, as well as labor in secondary wood manufacturing and government regulatory employees in the Ministry of

31 This explanation was suggested by Neil Brett-Davies.

Forestry. Given that caveat, the period 1970 to 1992 saw about a one-third increase in labor productivity. Essentially all of the labor productivity increase occurred over the period 1981 to 1987. After 1987 until 1992, the last year for which productivity data are available, labor productivity declined about 10 percent.

Figure 5[32]



Productivity on the Coastal Range of British Columbia: The coastal region of BC was chosen for this study because it embodies many of the characteristics common to logging in old-growth forests in difficult terrain. In many respects the situation and problems found in coastal BC are replicated in other temperate and boreal mountain forests such as those of the Pacific Northwest of the US and the forests of the Russian Far East. However, in regions such as those just mentioned, the difficulties are offset to some extent by the large volumes of merchantable species (conifer) which generate acceptable average logging costs per unit volume. Also, the large log sizes and high wood quality tend to generate relatively high market prices per unit volume. Nevertheless, logging costs under these conditions are among the highest experienced worldwide. The forests of the coastal range of BC are characterized by steep slopes and rugged terrain, which is rich in old-growth conifer timber resources. Logging has been underway in this region since the 19th century and has moved from the more accessible flat sites near populated areas into the less accessible and rugged terrain.

A typical logging operation in the BC coastal range includes felling, bucking, yarding (moving the tree to a place and position where it can be loaded for transport), loading and hauling, initially to tidewater and then to the mill. The process has remained the same for nearly a century. Once at the beach the logs are dumped, sorted and boomed (placed into their

32 Data presented include more than logging - see text for explanation.

respective processing streams). In order to obtain access to the trees, roads must be constructed and maintained (at least for some period). A common system in rough terrain is that of "high lead" logging whereby a cable is situated above the area to be logged and the logs are attached to the cable and moved to the loading deck. This approach requires that a road be built to a point from which a cable is extended into the timber stand, sometimes for several thousand feet. Where possible, the cable is situated so the logs are partially or wholly elevated above the ground thereby minimizing the ground disturbance and soil damage. The trees are felled by chain saw and attached to the cable and drawn up the slope. They are then moved to the mill by trucks and water transport, e.g., barges.

During the post-1960 period a number of logging innovations were introduced which contributed to holding down the costs. In the earlier 1960s the steel spar was introduced as a substitute for the wood spar (originally made from an existing standing tree) to which the cable was attached. This approach reduced costs in that the steel spar was easier to rig (set-up) and allowed for faster yarding. Also, by the early 1960s the chain saw had entirely replaced the hand saw, again contributing to logging productivity.

The traditional approach of logging in the coastal forest is fairly labor intensive using manually attached chokers to tie the log to the cable. This required labor in the forest not only to fell the trees but also to attach the trees to the cable. In the early 1970s the grapple yarder was introduced which allowed for the attachment of the log to the cable in a manner that substantially reduced the labor required. This innovation is in the form of a "grappling" approach whereby the log can be attached to the cable by positioning the grapple over the log and closing the arm to attach the log to the cable. This approach reduced the number of workers from 6-7 to about 3 per cable team and is generally lower cost.[33] Thus overall labor in moving (yarding) the logs from the forest to the road (deck) for loading was reduced. However, for effective operation the cable must be shorter and thus cannot cover the same amount of territory as a traditional cable. This means that less area can be covered from a given position and thus more cable set-ups are required and, for them, more roads. Although reduced labor in yarding was offset by additional roading costs, in many instances the grapple-yarder enhanced productivity.

Helicopter logging, also, has found a place in BC coastal logging as the costs of helicopter operations decline and the value of the high quality logs rises. However, this logging approach is only financially viable if the terrain with the high priced logs is near efficient transportation routes to mills (usually water).

New Harvesting Regulations: In the 1990s, the use of some of these innovations was limited by new requirements on logging practices. A major element of the new practices is stricter standards on logging road construction and maintenance. This will preclude building more roads within an area to precarious sites where high lead grapple logging can be

[33] Information provided by Peter Schiess of the University of Washington and Neil Brett-Davies of MacMillan Bloedel Ltd.

practiced. Limiting roads in these areas will necessitate the return to the less efficient, more labor intensive long-line cable systems, since the use of the labor-saving grappling approach must be reduced. The effect, within a given area, will be fewer roads and greater labor requirements, thereby increasing logging costs on some sites.

The more stringent regulations also limit the immediate harvest on sites adjacent to recent logging so that one area is not excessively harvested at a given time.[34] This effect will be to limit harvests within a given area. However, these stricter regulations are likely to promote incentives for the building more roads to inaccessible areas within BC to gain access to new, previously unlogged sites, from which to make up the declines in the total harvest. The implication is that more roads will be built into previously inaccessible areas and higher costs will be incurred in expanding and maintaining a larger road network. This will contribute to higher average logging costs.

Productivity Implications of Improved Logging Technologies: The BC data suggest that labor productivity in forest logging in BC has been increasing.[35] Furthermore, BC's harvest mix is changing so as to provide in aggregate, a bias toward increasing productivity, as the production shifts to the higher productivity interior forests from the lower productivity coastal region. Thus, at least some of the productivity increase for all of BC reflects the changing share from the lower labor productivity coastal forests to the higher productivity interior.

Furthermore, these data also demonstrate that, despite rising labor productivity, the real costs of harvesting have been rising over the past three decades. Over the period since the 1960s the real costs of harvesting have increased in the coastal region of BC by about 100 percent despite the introduction of new labor-saving technologies. Presumably, the logging cost increases reflect the fact that the increased costs of harvest associated with the increasingly difficult access and terrain, the additional roading requirements and higher environmental standards were not wholly offset by substituting nonlabor inputs and the introduction of technological innovations.[36] The implication is that the improvements in productivity due to technological change have been insufficient to offset the increased costs associated with more difficult sites and regulations.

The US South. The US South is one of the world's major industrial wood baskets, with production that exceeds that of Canada or that of all of the Nordic countries. The South produces about 15 percent of total world production. Although known for its pine production, the South also produces large volumes of hardwoods.

Logging in the US South: The mechanized system now in place in Southern logging began to take form in the latter 1970s. It was then that chain saws and cable skidders, began

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[34] For example, a mature forest may not be harvested if adjacent areas have been harvested within the past, e.g., two decades.

[35] This is also the case for the US data as developed by Parry (1997) and discussed below.

[36] In addition, more stringent forest practices regulations are discussed below as a source of higher costs.

to be replaced. The chain saw was replaced by a felling machine and the system whereby logs were attached to cables attached to a "tractor" and removed from the forest was replaced by a "grapple-skidder." In much of the South where pulpwood is the principal output, clearcutting is practiced. Early in the harvesting process the sawlogs are commonly separated from the pulpwood and transported to a sawmill. The residues of the sawmilling process become by-products that are used as feedstock for pulpmills.

Logging on managed pine forests in the South consists first of felling the trees using a feller-buncher, which "grabs" the tree and then fells it, using either a saw or a shear, and moves the whole tree onto a pile. Where longwood logging is practiced, the pile or "bunch" is later transported to the loading area or deck using a skidder. En route the trees are delimbed by pushing the limbs through a screen that breaks off the branches. At the deck the sawtimber is separated from the pulplogs for later transport to separate mills. The logs are loaded onto a truck for transport to the mill.

Unlike the processor used in the Nordic countries, the feller-buncher typically does not delimb, cut the stem into shorter lengths, nor keep track of the volume felled. Also different is transport from the ground to the deck. In the South the forwarder has not come into common use since its advantages are with shortwood that has been bucked in the field. Rather longwood logging is growing in importance and lends itself to transport to the deck via a skidder, which is used to move "bunches" of whole trees to the loading area. Longwood logging is feasible where the mills have undertaken the investments to provide them with the capacity to chip whole trees. The whole-tree approach eliminates the need to cut logs to shorter lengths thus reducing log "processing" activities and costs.

On wet soils "shovel logging" is beginning to be practiced in the South. Although somewhat more expensive, it increases the number of days of logging in bad weather. This system uses equipment that moves the logs by a series of short motions using a portable platform that minimizes disturbance of the soil.

The equipment used in the South is, in general, different and less expensive than that of Sweden. For example, the feller-buncher will cost $150,000-250,000 and the skidder $100,000-125,000. For thinning operations on plantations a similar system is used with smaller equipment. For example, a three-wheel feller used in thinning may cost $75,000-100,000. However, the equipment is well adapted to the conditions of the South, especially where logging operations are integrated into mill operations, as with longwood operations. An important innovation is the transport of longwood (whole tree stems), thereby eliminating the need to cut the stems into shorter pieces (shortwood) for transport. The transition to whole-tree logging is not yet complete since the use of the longwood, requires a chipping mill engineered to handle longwood (see Cubbage and Carter 1994).

Although much of the current logging in the South fits the description given above, there are a host of alternative logging systems in common use. The broad ownership of forestlands, many of these being owned by small private owners, suggests that there is latitude for a mix of logging techniques. These approaches range from labor-intensive, very small logging operations, to the more capital intensive techniques discussed above. The choice of approach, no doubt, depends on the size of the harvest, the nature of the terrain, wetness of the soil, and so forth. The more capital-intensive techniques would be expected on larger, flat, dry sites.[37] Alternative logging systems, perhaps involving part-time or seasonal loggers with minimal types of equipment, may find opportunities for certain sites, particularly at peaks in the business cycle that are reflected in high log prices. Thus, estimates of region-wide logging labor productivity will tend to estimate an average of both highly productive and lower productivity loggers.

The Work Force: Associated with the introduction of more expensive and sophisticated equipment has been a tendency, across the regions investigated, to move toward a better trained and more dependable labor force. For many decades logging has been done in the US by contractors hired by the landowner or industrial forest product firm. This reflects the prevalence in earlier periods of a large agricultural population with "seasonal" availability for nonagricultural employment. These laborers were the labor force of earlier contractors and often had the characteristics of "day labor" or temporary labor. Thus harvesting in the South depended upon available labor and equipment drawn from agriculture, e.g., a farm tractor and a light truck. During the post-WW II period, however, agriculture in the South declined, labor became less available and the equipment became more specialized. And contractors are now making substantial investments in equipment. Today, long periods of non-use are now financially unacceptable. Nevertheless, even today a significant portion of logging in the South is done by small contractors, often working on a seasonal basis with fairly nonspecialized equipment, particularly in some of the upland forests where the terrain is more difficult.

Aggregate Productivity Growth in Logging

Anecdotal evidence from all of the regions examined suggests that in recent periods labor has generally been the scarce factor and other inputs, e.g., capital and labor-saving technology, were being substituted for labor. This interpretation is consistent with rising real wages which have been occurring in each of the regions in the post-WW II period.

In a survey piece Stier and Bengston (1992) review technical change in the North American forestry sector. Although they mention a large number of studies and discuss in detail 24 studies that examine total factor productivity, most of these studies examine some part of the wood-processing activity, e.g., lumber milling or pulp and paper making. Only one of these, (Stier 1982) focuses on logging and wood extraction. Stier's 1982 study is consistent with the anecdotal evidence. He found that wages in North America increased threefold and the capital-labor ratio more than doubled over the 1950-1974 period examined, indicating the large substitution of capital for labor. Furthermore he concludes that the "substitution away from labor has taken place primarily through changes in technology in the form of new labor-saving equipment" (p. 265).

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[37] The international trade literature has demonstrated that quite different technologies and mix of productive factors can both be consistent with least-cost production in a single country in the presence of "factor reversals."

A separate study related to wood extraction, reported by Cubbage and Carter (1994), examined the changing costs over time associated with shortwood and longwood[38] pulpwood harvesting systems in the South. They found that the costs of the shortwood harvesting systems generally increased while those of the longwood harvesting systems declined. They concluded that they "believe that productivity increases in longwood systems, as well as the greatly increased use of longwood systems, caused decreased average costs for the industry" (p. 89).

Parry (1997) examines total factor productivity growth for the US in the natural resources industries between 1970 and 1994 using aggregative data. For US logging Parry finds that labor productivity rises about 20 percent from 1970 to 1993 (Figure 6, below).[39] This compares with the estimated 33 percent increase in labor productivity in coastal BC for the forest industry (including activities other than extraction, and estimated labor productivity growth in US manufacturing over that same period of about 34 percent (Parry 1997). However, an examination of multifactor productivity gives a different picture. During the period 1970-1993, Parry finds that multifactor productivity in US forestry declined about 20 percent (Figure 7, below).

These results suggest that labor productivity grew due to the introduction of nonlabor inputs into forestry production and their substitution for the labor inputs. These results suggest that labor productivity grew due to the introduction of nonlabor inputs into forestry production and their substitution for the labor inputs. However, the results also indicate that the overall increase in productivity from the introduction of improved technology has not been adequate,[40] overall, to offset the decline in the accessibility[41] and the quality of the resource.[42]

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[38] As already noted, longwood harvesting systems are those in which the entire tree stem (bolt) remains intact to be processed at the mill. The shortwood harvesting systems involve cutting the bolt into shorter pieces (bucking) in the field and transporting these shorter pieces to the mill. The longwood system avoids the bucking process thereby reducing processing in the field. It also provides economies in that it reduces the number of pieces to be handled in transport. The longwood system is preferred if the mill has the capability to process the longer wood.

[39] The concept of aggregate labor productivity obviously hides a great deal of regional and firm specific data and tells us little about the characteristics of the "highest" and "lowest" productivity operations. Clearly regions and firms will different in their productivity for a variety of reasons.

[40] With a constant quality and accessibility of the resource, technological improvements would be reflected in declining delivered resource prices. Where the quality/accessibility of the resource is declining, improved technology must first offset the higher real costs of the delivery.

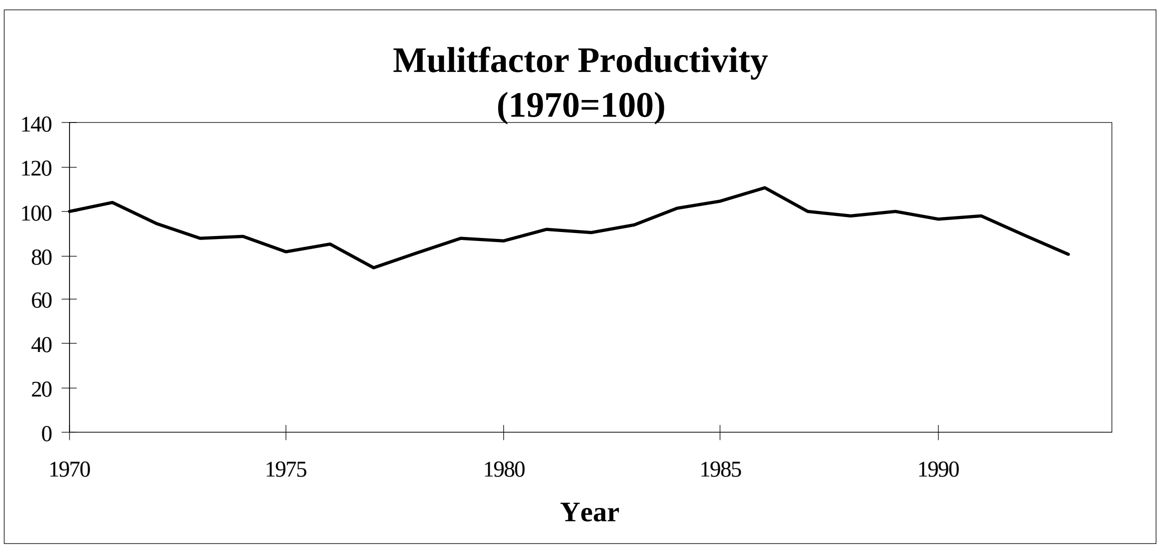
[41] Access to old-growth in the Pacific Northwest region has become more difficult as logging moved from the flat coastal plain into the rugged interior mountains.

[42] Quality attributes include log size, absence of knots, species type, etc. Sawlog size in the South, for example, had declined steadily during the post-WW II period. Sedjo and Lyon (1990, chapter 6) suggest that declines in wood quality have been offset by technological improvement in processing.

Figure 6

Source: Parry 1997.

Figure 7



Source: Parry 1997.

III. PLANTATIONS AND INTENSIVE MANAGEMENT

The Trend toward Tree Plantations

At the margin total timber production can be expanded by a) increasing harvests from native forests; b) increasing forest management in second-growth and other forests; c) expanding the area of tree planting and plantation forest; or d) increased intensity of forest management on plantation forest.

In most parts of the world trees will regenerate naturally unless prohibited from doing so by land-use changes, such as to cropping or pasture, or excessive and continuous land disturbances. Although the history of planting trees and forest management goes back millennia, it is only within the past few decades that industrial tree planting has become an important economic activity. Much of the tree planting that occurred earlier in North America represented environmental concerns and the creation of protection forests for water shed purposes, to prevent avalanches, as part of land rehabilitation schemes as with the Civilian Conservation Corps during the Depression years. Elsewhere most tree planting was also associated with environmental concerns and land reclamation, e.g., as in the Netherlands.

Beginning during the 1960s, however, major industrial tree plantation activities began to be undertaken in a number of regions of the world including the Pacific Northwest and the southern US, as well is in other regions such as New Zealand, Chile, Brazil and South Africa. In the southern US and the PNW, where natural regeneration often resulted in the growth of less commercially valuable hardwood species, tree planting selected the desired species as well as assuring rapid and complete forest regeneration.

Advantages of Plantations

The advantages of industrial forest plantations are similar to the advantages of cropping agriculture over foraging. For example, tree planting and intensive management allow for the control of inputs to achieve higher growth rates even without genetic improvements.[43] Additionally, control over the location of the plantation allows for the choice of lands where a) the terrain is favorable to planting and harvesting activities, b) soil and climate are conducive to higher biological productivity, c) species can be chosen to fit the site conditions, and d) the area is accessible to mills and markets. As in agricultural cropping, uniformity in product as well as other favorable conditions associated with the site, allow harvesting costs to be lower than in most natural forests.

Furthermore, tree planting, *per se*, allows for the introduction of fast-growing species, that may not occur on that site in nature. For example, various types of pine have been introduced into South America, New Zealand, and Australia -- areas that do not have indigenous pine. In many cases the growth of pine in its new environment has been excellent and pine plantations are now common in many parts of these regions. Similarly, eucalyptus,

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[43] Farnum et al. (1983) showed that theoretical maximum biological timber yields were 5 to 10 times natural yields.

an Australian genus, has been adopted and flourishes in many regions while exhibiting excellent growth characteristics. A recent study (Sedjo 1994) observed that the share of the industrial wood production from plantations in the tropics and sub-tropics, using almost entirely exotic (non-indigenous) species, has roughly doubled in the 15 year period from 1977 to 1992, from about 5 to 10 percent of the world's total production.[44] Also, planting allows for intensive management, e.g., fertilization, pest control, thinning, to be undertaken throughout the growth cycle to promote high yields and desired characteristics.[45] As in agriculture, evidence suggests that high intensity management generates the most favorable financial returns on the high productivity sites and relatively lower returns on less favorable sites (e.g. see Sedjo and Lyon 1990). Furthermore, the "fiber farm," the most intensive forestry operations to date, have come upon the scene in only the last decade and already have well over 100,000 acres[46] established in the PNW, BC and the South.

Finally, as with agriculture, planting allows for the introduction of genetic improvement through the selection of seed and seedlings from superior trees, hybridization and so forth. Without planting, investments in genetic tree improvement have no commercial applications.

IV. GROWTH, BIOTECHNOLOGY AND GENETICS[47]

Some Research Findings

In an assessment of the effects of research on the productivity of the forestry sector, Hyde, Newman and Seldon (1992) corroborated the work of earlier researchers reviewed by Stier and Bengston (1991) when they found substantial economic returns to a number of research activities related to the development of new products and new technologies in wood processing. In their study, Hyde et al. also assessed the benefits of research in wood growing, e.g., timber growth and forest management, on softwood timber production in the US South. Newman (1987) had estimated that aggregate productivity in a southern composite of softwood forest inventory plus removal increased at an average of 0.5 percent to 1.0 percent annually over the period 1935-1980. He estimated that about 40 percent of the increase in forest inventory was attributable to increased forestland productivity, presumably due to management. Hyde et al., however, found little positive economic return even though aggregate productivity of the forest was increasing and they conclude that "Net present value and the internal rate of return estimates are uniformly poor. . . ." They continue, "Apparently, research benefits in southern softwood growth and management have not led to large social gains" (p. 192).

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[44] This does not treat as plantation production the wood of the US South or most of Europe.

[45] For a discussion of the advantage of industrial plantations, see Sedjo (1983).

[46] This estimate provided by Bob Rogers of MacMillan Bloedel Ldt.

[47] Much of the information reported in this section about fiber farms was provided by Toby Bradshaw of the University of Washington.

One reason given by Hyde et al. (p. 218) for the lack of apparent net economic benefits to forest management and tree planting was the large overhang of old-growth forests elsewhere in North America and the reality that technological improvement in southern pine is probably justified only on a subset of industrial lands. Alternatively stated, it makes little sense to invest in activities that produce more rapidly growing trees when there are large volumes of mature timber that are available for the cost of the logging. This explanation is similar to the findings of Hayami and Ruttan (1971, see p. 115) where they found that, for agriculture in the US, investments in yield-improving technologies were not forthcoming until essentially all of the potentially usable agricultural land was in agricultural use. Until all of the land available for cropping was in use, investments in equipment designed to extend the area of land that could be cropped generated the highest returns. However, once the frontier had disappeared and new crop land was not readily available, returns to research investments that increased agricultural yields began to be substantial.

There is now some anecdotal evidence, found in the behavior of forest firms in recent periods, that this threshold may have been passed. Many forest product firms are investing substantial sums in tree-growing research efforts and biotechnology research is common in many intermediate to large firms. Additionally, many industrial forest products firms appear to have a long-term policy of consolidation of the best lands for tree growing combined with an active genetic improvement research program. For example, Westvaco Corporation has as its explicit long-term strategy the objective of consolidating its land holdings to those of highest productivity and then managing intensively, including genetic tree improvement. Thus, a major segment of the market is behaving as if it believes that the long-term returns to research in areas designed to increase returns to intensive management are substantial.

This interpretation applied to forestry suggests that as the old-growth forest becomes less available (due to political considerations) and experiences higher costs due to access problems, the high-return investments would be expected to be found in research that generates yield-increasing technologies. Similarly, it also suggests that historically, higher returns were likely to be associated with innovations that reduced the costs of logging and transport to the mill. Thus, perhaps the findings of Hyde et al., that research in tree improvement found little support, are not surprising since, until recently, those improvements could not be introduced into wood fiber production in a major way.

Anecdotal evidence suggests that the US, indeed the global forest industry, is moving through a transition from primary reliance for meeting industrial wood needs on naturally generated forests to increased reliance on planted forests. One might view plantation forests as providing the technological "backstop" which constrains the price growth of industrial wood as wood "scarcity" can be offset by investments[48] in plantation forests. To the extent that the real price of industrial wood continues to rise, the returns to investments in forest plantations increase.

Further enhancing returns to recent genetic innovation is the fact that in recent decades the wood fiber from natural forests has become even more inaccessible since the remaining

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[48] See Solow (1974).

unlogged forests are increasingly being set-aside due to the desire to increase the area of protected forests in the form of National Parks and wildland reserves. This change should simultaneously increase the attractiveness of several yield-increasing activities including: forest management; industrial forest plantations; and genetic improvements that increase tree growth, yields, and desirable tree and fiber characteristics.

Biotechnology and Genetics

Biotechnology comprises any technique that uses living organisms to make or modify a product, to improve plants or animals or to develop micro-organisms for specific use (Haines 1994, 1994a). In the tree-growing industry genetic research takes two forms. First is the use of traditional breeding techniques that utilize the variation in the natural population to breed trees with desired traits. These techniques would also include hybridization techniques, which have provided more robust offspring, by bringing together populations that do not normally mix in nature. These techniques have proved very successful in agriculture and appear to have huge promise in forestry. One problem with traditional approaches in tree breeding, however, is the long growth cycles, which make this process very slow. Techniques that can help identify trees with desired genes, such as molecular biology and genetic marking, can enhance the productivity of this approach. The second form of biotechnological research is the utilization of genetic engineering approaches whereby genes with desired traits are introduced into the tree through artificial means. This approach is better developed in agriculture but is still in its very early stages. Nevertheless, the potential for application to forestry appears great.

The success of genetic approaches for increasing yields and generating desired modifications in plants is unquestioned in agriculture. Traditional breeding techniques have resulted in the development of a large array of "improved seeds" that have generated yield increases in a host of agriculture products. Furthermore, applications of genetic engineering in agriculture have been successful in transferring to agricultural crops desired traits, such as resistance to disease and herbicides, resistance to cold, and to forth. The same possibilities are available for trees and it is only a question of refining the application of the techniques to trees.

Tree Improvement Programs

With the planting of trees come the incentives for tree improvements. Tree improvements can take many forms (Figure 8, below). The most common emphases of tree improvement programs are increased growth, disease resistance, and wood quality. Growth typically refers to wood volume growth or yields. Disease and pest resistance is usually oriented to specific problems common in a particular species. Wood quality includes a variety of characteristics including tree form and wood fiber quality. Form can include the straightness of the trunk, the absence of large or excessive branching, the amount of taper in the trunk and so forth. These features are related to the usefulness of the wood in the production of products either in the final output, e.g., straightness facilitates production of boards, or in some stage of the processing, e.g., paper fiber needs adequate strength to allow paper sheets to be produced on high-speed machines. Desired fiber characteristics may relate to ease in processing, e.g., in the breakdown of wood fibers in chemical processing, reduced lignin which provides more desired pulping properties, and the extent and ease with which the wood can be converted into woodpulp and paper products with desired characteristics or desired properties of products such as paper tear strength, surface texture, whiteness, and so forth. In addition, wood fiber is increasingly being processed into structural products such as strand board, fiber board, and engineered wood products, which have their own set of desired fiber characteristics.

Figure 8. Tree Improvement Programs

Important Attributes:

- **Growth Rates**
- **Disease and pest resistance**
- **Tree form and wood fiber quality**: straightness of the trunk, the absence of large or excessive branching, the amount of taper in the trunk and so forth.
- **Desired fiber characteristics may relate to ease in processing,** e.g., the break-down of wood fibers in chemical processing.

In recent years pulp producers have begun to move away from simply producing a standardized "commodity" pulp and are producing specialized pulp for targeted markets. Aracruz, a Brazilian pulp company, has asserted that it can customize its tree fibers to the requirements of individual customers. This requires increased control over the mix and types of wood fibers used. Customized products require customized raw materials.

Genetic Techniques

As in agricultural products, tree hybrids are often a means to improved growth and other desired characteristics. As noted, there are two general approaches to genetic improvement. The first is using classical breeding and testing approaches to select superior trees. Tree improvements can be developed in a number of ways. The classical procedures may be as crude as simply selecting trees in the forest that have desired characteristics such as size or straightness and introducing these into the tree seed orchard and subsequently selecting the offspring on the basis of their desired traits. The second is genetic engineering to modify the tree in the characteristics that are desired.

In recent years molecular approaches to tree selection and breeding have shown great promise. The molecular approach typically involves genetic material being identified, collected, bred and tested over a wide range of sites. Rather then simply choosing specific tree phenotypes on the basis of their characteristics, the molecular approach identifies the chromosomes that are associated with the desired traits. "Markers" are then used to identify these genes in the collection/screening process. This approach allows for exploitation of the abundant genetic variation found in natural populations. When a particular gene or set of genes has been found to be associated with a desired trait, the use of molecular markers and screening techniques allows for the examination of the DNA of thousands of individual trees to identify the few, perhaps less than a dozen, with the optimal mix of genes. These techniques are currently being applied to the development of improved poplar in the US and eucalyptus in Brazil.[49]

Where elite genetic material is available, in vitro plant propagation (through various tissue and cell culture techniques micropropagation) has the ability to multiply clonal material very rapidly, which can be used to produce the seedlings for future tree farms. In other cases cloning approaches are limited, and more traditional approaches must be used.[50] Using modern cloning techniques, thousand of clones with the desired traits can be produced for later establishment in tree or fiber farms. However, for various technical reasons cloning is more difficult with conifers than with deciduous trees.

As in agriculture, hybrids are often developed in forestry. Hybridization crosses trees that are unlikely to breed in nature, often where parents do not occur together in sympatric populations. These crosses often exhibit growth and other characteristics that neither of the parent species alone can match. In the US, for example, hybrid poplar have shown remarkable growth rates exceeding that found in the parent populations.[51] Pitch pine-loblolly pine hybrids exhibit the cold hardiness found in pitch pine and the rapid growth of loblolly pine.

Recent work using molecular genetics on hybrid poplar in the Pacific Northwest has shown a 20 percent increase in yields in plantations and an additional 20 percent on dry sites, where irrigation can be applied (east of the Cascade Mountains).[52] Also, improvements in the yield continue.[53] Growth rates with these plantations are impressive with yields about 7 tons per acre, or about 50 cubic meters per ha. These growth rates are about three times the growth rates on typical pine plantations in the South. In some cases, as in Aracruz in Brazil, yields of hybrid eucalyptus are reported to have more than doubled.

Finally, research is underway to examine the potential of using genetic engineering for producing superior trees. Genetic engineering allows novel genes to be transferred among species that cannot be transferred in nature or else the modification of existing genes through manipulation of the DNA molecule. Currently, there are discussions underway to introduce a gene into plantation trees that creates a resistance to the herbicide glyphosate (trademark as Vison, Accord or Roundup). This approach, now practiced in some agriculture, would allow

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[49] Personal conversation with Toby Bradshaw, Director of the Poplar Molecular Genetic Cooperative at the University of Washington, Seattle. Also see Westvaco 1997.

[50] Such as the use of seed orchards and conventional breeding techniques.

[51] Growth in hybrid poplar stands is 5-10 times the rate experienced in native forest growth rates (Bradshaw personal communication, January 8, 1997).

[52] Personal communication: Toby Bradshaw.

[53] Withrow-Robinson et al. (1995), p 13.

for the planted area to be sprayed with the herbicide without damage to the tree, thus ensuring a fast and successful start to tree growth.[54]

As the ability to introduce meaningful tree improvements increases, the economics of plantations improves vis-a-vis those of natural forest harvesting, especially as the old-growth overhang is reduced. In general, traditional breeding approaches have been shown to produce substantial yield improvements. For example, an orchard mix of first-generation open-pollinated seed can be expected to generate an 8 percent per generation improvement in the desired characteristic, e.g., yield. Other seed collection and deployment techniques, such as choosing the best mothers (Family Block), can result in an 11 percent increase in yield, while mass-control pollination techniques, which control for both male and female genes, has increased yield up to 21 percent.[55]

Table 4: Gains from Various Traditional Breeding Approaches

Technique	Effect
Orchard Mix, open pollination, first generation	8% increase in yields
Family Block, best mothers	11%
Mass Pollination (control for both male and female)	21%

Source: Westvaco Corporation

Clonal Applications

One approach for transferring genetic traits and developing large numbers of improved seedlings is through "tissue culture." Tissue culture can produce multiple copies of an elite genotype as well as provide a means of introducing novel genes. In one approach, called organogenesis, plant tissue is placed on a nutrient medium and buds are initiated on the plant tissue. From these buds plants are developed. Tissue culture techniques provide the tools to produce genetically engineered plants and to regenerate trees with desired traits quickly, without having to wait for the trees to reach sexual maturity (Westvaco 1996, pp. 8-9).

The development of clonal approaches to propagation is important to the broad utilization and dissemination of genetically improved stock. With tree planting often involving over 500 seedlings per acre,[56] large-scale planting of improved stock requires some method of generating literally many millions of seedlings, at relatively low cost, which embody the genetic upgrading. The costs of the improved seedlings are important in a financial sense since the benefits of the improved genetics are delayed until the harvest. With harvests often being 20 years or more after

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[54] In addition to being a very effective herbicide, glyphosate has the desirable properties of decomposing quickly on the site and so avoiding residual and downstream damages Monsanto n.d. and personal conversation David Duncan, Monsanto Company.

[55] Source: Conversation with Westvaco researchers, Summerville, SC, December 17, 1996.

[56] It is estimated that 4 to 5 million trees are planted in the US *every day*.

planting, large costs for improved seed are difficult to justify financially. On the other hand, if the costs of plantings are going to be incurred, the incremental costs associated with planting improved genetic stock are likely to modest and thus more likely to be financially justified.

The Effect of Genetics on Fiber Production

Thus far, tree improvement programs have probably had relatively little effect on fiber production in North America since there is a lag between the introduction of an improved seedling and the capture of that increased productivity in a harvested tree. In the US most genetically improved trees that were planted during the 1980s will not be harvested until after 2000. However, the advent of fiber farms brings the possibility of a much faster impact on production since rotations are as short as 6 years. Similarly, industrial forest plantations in the semi-tropics, using eucalyptus, often have rotation periods as short as 6-7 years. With short rotations the impacts of new genetic technology embodied in seedlings will have a much more rapid effect on industrial wood volumes.

An anecdote that indicates that tree growers believe that technological improvement in seed stock is important is reflected in the fact that in some places where eucalyptus has been planted, they have been replanted after harvest. The original expectation had been that the single planting would generate 3 harvests through the natural process of coppicing, a characteristic exhibited by many deciduous tree species whereby the stump of a felled tree will react by sprouting new limbs, which can grow into trees. Initially the plan was to rely on coppicing in order to save the costs of replanting. However, in fact, this has rarely been done. Rather, the stumps are treated and new genetically superior stock is planted. The rationale for the replanting is often because the genetic improvement is viewed as justifying the planting of the superior stock, rather than relying on the genetics of the existing tree.

Fiber Farms

In the past decade or so fiber farms have been introduced in the US and Canada. Fiber farms differ from plantation forests in the degree of management intensity. In the Pacific Northwest they are often established on prime agricultural lands or on irrigated arid or semi-arid lands east of the Cascades, but typically not on recently logged land or on marginal agricultural lands that have simply been neglected. In the Pacific Northwest and British Columbia forest products firms have established 20,000 to 25,000 ha, largely in hybrid poplar,[57] with rotations of 7-12 years. One advantage of the short rotations is that if they are 10 years or less, state law in Washington and Oregon treats the operation as agriculture rather than forestry and the regulations applying to agriculture are typically less stringent than those applying to forestry. In BC the legal requirement for agricultural treatment of a fiber farm is a rotation of 12 years or less. Poplar plantations are common in Europe; however, they tend to occur in small plantings and with longer (15-25 year) rotations.

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[57] The hybrid poplar is using a cross of black and eastern poplar.

In areas of high precipitation, as west of the Cascades in the PNW, hybrid poplar tend to be planted on river bottoms and require no irrigation. In dry regions, such as east of the Cascades, the poplar are planted on lands formerly in irrigated agricultural crops. In dry regions drip irrigation is common. Yields are in the 40-50 cubic meters per hectare range on irrigated sites and 30-40 cubic meters on non-irrigated sites. It is estimated that there are 20,000 to 25,000 hectares of fiber farms in the PNW and BC, with plans for continued increased plantings.[58]

Fiber farms are also being established in the US South and East motivated by the growing local scarcity of short fiber. Hardwood is increasingly coming into short supply due, in part, to the fact that much of it is located on more inaccessible wetter sites. Fiber farms are being located especially on deep, well-drained sandy soil, often along rivers. Westvaco, for example, has a cottonwood fiber farm in Missouri, which grows hardwood using "fertigation" to increase their growth. Fertigation is a process that delivers precise amounts of water and fertilizer through a drip irrigation system. The anticipated rotation period is as short as 5 years (Withrow-Robinson 1995).

The reasons for North American fiber farms appear to be twofold. First, they have been created to meet an anticipated shortage of short fiber over the next decade or two. Second, they are viewed as a possible approach to dealing with the competition expected to come from tropical plantations over the next several decades. Experience from South America and especially Aracruz in Brazil has demonstrated that improving the resource can dramatically increase growth and yields.

V. CHANGING FOREST AND LAND USE LAWS AND REGULATIONS THAT AFFECT FORESTRY AND FOREST PRACTICES

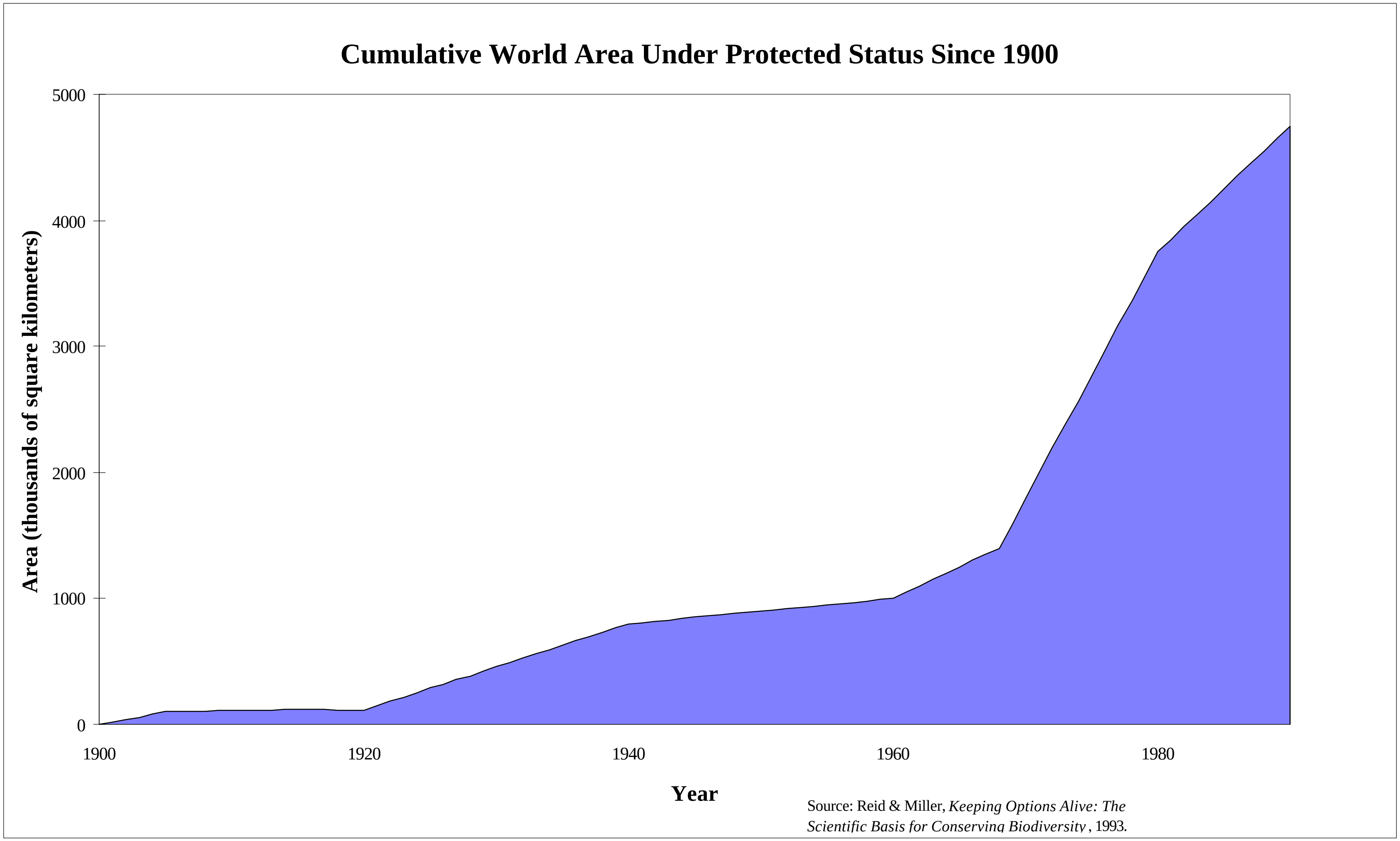
Perhaps one of the most important changes affecting forest productivity is the advent of a host of new forest policies, practices and regulations that have been instituted in a number of countries, literally across the globe. These consist of both land set-asides in the form of parks and forest preserves, which preclude timber harvests, as well as changes in policies and logging practices which reduce the amount of timber which can be removed from a site and also changes in various logging and management practices thereby increasing the costs of logging operations. This section discusses the nature of some of these changes and their impacts on forest harvest productivity.

Recent Trends

Recent decades have seen a burgeoning of protected areas worldwide. Figure 9 shows the cumulative areas under protected status since 1900. Although it took until 1960, sixty years, for the first million square kilometers to receive protected status, the second million

[58] For example, MacMillan Bloedel is planning to plant about 1000 ha annually beginning in 1997. (Personal communication Neil Brett-Davies; memo from S.L. Tisdale 6/18/97).

Figure 9


Cumulative World Area Under Protected Status Since 1900
Area (thousands of square kilometers)
5000
4000
3000
2000
1000
0
1900
1920
1940
1960
1980
Year
Source: Reid & Miller, *Keeping Options Alive: The Scientific Basis for Conserving Biodiversity*, 1993.

took only about ten years. By 1990 nearly 5 million square kilometers were in protected status, about 3 million square kilometers of which were placed into protected status in the most recent 15-year period for which data are available, 1975-1990 (Reid and Miller 1993). In recent years the US has seen substantial changes, which have reduced significantly the harvests from public forests. However, reduced harvests from public lands translate into higher prices for the timber that is harvested from private lands. For years there were disputes over the harvest levels that should be taken from federal forestlands, especially from the heavily forested areas of the West. Although the harvest-level determinations were ostensibly made by the Forest Service on the basis of professional considerations, in many years harvest levels were dictated by Congress on the basis of political considerations.

In the latter part of the 1980s and early 1990s public harvest levels in some regions, especially the Pacific Northwest, were being tied up by court injunctions related to the Endangered Species Act and the spotted owl. Many of those issues were resolved, at least for the time being, by the Forest Ecosystem Management Assessment Team (1993). In the last couple of years harvest decisions on federal forests in the US have fallen substantially, reflecting new political realities.

The 1990s have also seen a tightening of forest practices on private sector forests. First, many states have forest practices codes that are legally binding. These provide standards for logging and forestry within those states. These standards, which include restrictions on riparian zones, roads, etc., generally raise costs and reduce allowable harvest from any individual site. Additionally, the forest industry in the US is voluntarily undertaking a "sustainable forestry initiative" whereby the firms commit to certain forest practices and to meeting certain standards. These voluntary standards are estimated to increase industry delivered wood costs by about 7 percent (Michaelis 1996).

Despite these factors, or perhaps because of them, worldwide timber harvests in 1994 were almost identical to harvests ten years earlier in 1984. In North America US timber harvests have been maintained at close to peak levels. In 1994 harvests were almost 400 million cubic meters, down only slightly from the peak of 427 million in 1990, albeit at somewhat higher overall prices. Furthermore, the Canadian harvest reached its historical peak in 1994 at 181 million cubic meters, an increase of 8 million over 1990.[59] The maintenance of these high harvest levels despite timberland withdraws and more stringent forest harvest regulation is due, in the US, to increased harvests on private lands in the PNW and elsewhere in the US in response to higher prices. In addition, concerns that future harvest restrictions could become even tighter are said to have accelerated the private harvest on some lands.[60] In addition, some of the US short-falls relative to domestic demand have been met by increased imports from Canada and from reduced wood exports abroad.

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[59] Source: FAO *Forest Products Yearbook 1994*, Rome.

[60] It is common to hear of private owners who rush to harvest in areas of unoccupied spotted-owl habitat due to concerns that, if not harvested, spotted owls may find nesting within the area thus precluding future harvest.

Furthermore, the rate of forest set-aside is increasing. In the US harvests from US public lands have decreased dramatically over the past few years as forest lands have been, de facto, withdrawn from the timber base. For example, harvests on US Forest Service land fell from 12 billion board feet in 1989 (about 60 million cubic meters) to 3.7 billion board feet in 1995 (about 18.5 million cubic meters), or to less than one-third its 1989 level and only about 6 percent of total US production. In the Pacific Northwest the decline was even more dramatic with federal harvests being reduced from 5.4 billion board feet in 1989 to 0.9 billion board feet in 1994, or about 17 percent of its previous level. These declines have little to do with the physical availability of native forest, since forest stocks on federal lands are expanding. Rather, most of these declines are the result of policies which reduced logging on public forests. Furthermore, harvest reductions of this type are not limited to the US. In Canada, British Columbia's new forest practices code calls for harvest reductions of 5 to 15 percent overall.

Sustainable Forestry and Certification

Coming out of the UNCED meeting in Rio in 1992 have been a host of forestry initiatives designed to limit deforestation and/or improve forest management and logging practices so as to reduce environmental damage and maintain traditional forest ecosystems. Included among these are efforts to reduce harvests on native old-growth forests, as discussed above, and to move forestry practices toward what is being called sustainable forestry. Sustainable forestry is different from the more traditional concept of sustained-yield forestry in that the concept is designed to "sustain" not only timber yields, but also a host of other forest outputs and ecological services including such outputs as biodiversity.

The follow-through to the initiative is proceeding on three levels. At the international level most governments in the industrial world have been engaged in one of the ongoing international dialogues. These have included the Helsinki ministerial meeting (involving the European countries), the Montreal process (involving largely non-European industrial countries) and the Santiago Declaration (which was a continuation of the Montreal process). These meetings have been examining ways for the industrial countries to move toward agreements of mutually acceptable approaches toward the management of their forests. In general, the process has been difficult since the forest ownership patterns vary considerably among countries, e.g., almost 90 percent of Canadian forests are publicly owned while in the US about 80 percent of the forests are privately owned.

At the national government level, most countries are modifying their forest policies and forest practices codes to reflect international concerns. Finally, at the private and nongovernmental level, changes are occurring. Where forestland is privately owned, owners are concerned as to the nature of any new policies that may emerge. Where forestland is publicly owned but the industry privately owned, the industry is concerned as to how policy changes might affect their wood supplies. In many countries the industry is taking initiatives to modify forest practices. These private actions are also interacting with the activities of some NGOs, which have environmentalist agendas calling for formal third-party certification.

In the US, for example, major elements of the US industry have established their Sustainable Forestry Initiative (SFI) which calls for commitment to a minimum standard of forest practices. Although most of the large forest products firms have committed to meet these standards, the industry also is generally resisting efforts at third-party certification of their forest practices. Additionally, in the US almost 60 percent of the forestland is owned by nonindustrial private forest landowners (NIPFs). These ownerships, by definition, have no processing capacity and are for the most part small individual forestland holdings. However, most large forest products firms, which own most of the processing capacity, are dependent on these large number of small forest owners for the majority of their wood supply.

Many of the NIPFs are small and undertake little if any forest management. Many of the major firms, which purchase wood from the NIPFs to be processed, are considering ways to induce the NIPFs to introduce sustainable forestry practices in their forest management. One approach is to train loggers in the use of new less invasive logging techniques.

Costs of Forest Practices: Some Estimates

Sustainable forestry often involves the introduction of new management techniques. Typically, costs are increased due to the set-aside of larger areas for riparian zones, the retention of some of the trees, and other practices that increase costs. Firms in the US have commonly estimated the increased costs to be of the order of 5 to 10 percent. In a recent paper Greene et al. (reported in Michaelis 1996) estimate the reduction in harvest for the Pacific Coast region of the US due to regulations to be from 5 to 14 percent. Some additional estimates are presented in Table 5.

Table 5. Some Cost Estimates of Increased Environmental Standards

Country	Study	Cost Increase
USA	Greene et al. (1995)	5-14% cost increase
Finland	Tikkanen (1997)	12% decrease in net income to meet new biodiversity standards
Finland	Kajanus and Karjalainen (1996)	18 % decreased net income to meet certification standards
Canada	van Kooten (1994)	$3 cost increase/cubic meter
Canada	Haley (1996)	$8 cost increase/cubic meter (about 15% cost increase) + other costs

In BC a host of different studies have been done to estimate the effects of the new forestry code. An early study estimated increased harvest costs at about $220 million annually (van Kooten 1994). A more recent assessment in BC of the cost of the BC Forest Practices Code (Haley 1996) estimates that the Code's implementation would increase total annual costs by about $1.5 billion dollars. This consists of increased harvest costs of about $7.50 per cubic meter, which based on the pre-Code harvest of 72.7 million cubic meters results in an increase in harvest costs of at least $440 million annually and rising. In addition, other costs such as retraining, additional administration and research were identified and included in the total cost estimate. In a separate study using a general equilibrium model, Binkley et al. (1994) estimated the annual losses to provincial GNP due to the Forest Practices Code at over $1 billion annually or 1.54 percent of annual Gross Domestic Product (GDP), an estimate not too different from Haley's. In still another study Binkley (1995) estimates the effects of the current policy regime will result in about a 23.5 percent long-term reduction in total harvest levels in BC. Additionally, since the policy changes are focused on reducing the impacts on harvested areas, an implication is that the harvest will necessarily be spread over a larger area if harvest levels are to be maintained.[61] In sum, these studies suggest that the costs of the Code are likely to be substantial, both in dollar terms and as a portion of the income or GDP of the province.[62]

More generally, environmental pressures are resulting in modified logging and other forest practices throughout much of the world. In the Nordic countries of Finland and Sweden, for example, new forest policies have placed biodiversity on an equal footing with industrial wood production. The result has been modified logging practices that, among other changes, reduce the area eligible for harvest and leave more standing trees on harvested areas. For many situations, the new harvest policy is estimated to increase costs 5-10 percent. However, a recent study by Kajanus and Karjalainen (1996) for the Nordic countries found that the costs can rise as much as 30 or 40 percent for certain land conditions. This was largely because those practices required to achieve an ecolabel certification would reduce harvests due to set-asides. Also, costs would rise due to restoration targets and the alteration of certain management methods. They estimated that the average net effect would be to reduce income per hectare by about 18 percent.

VI. CONCLUSIONS AND IMPLICATIONS

Conclusions

Above, three sets of innovations in forestry have been discussed. These are 1) new logging technologies; 2) tree growing innovations and organizational changes as reflected in forest plantations, with a focus also on technical change in the form of genetic improvements; and 3) the expanding array of environmentally motivated restrictions on logging and forest practices, including the large areas being designated as forest set-asides.

The study concludes that the dominant innovation within the industry is the move to plantation management. This trend is driven by a number of forces and considerations, many

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[61] BC has projected lower harvests, however, the fiscal implications for the province of the reduced revenues are estimated to reduce provincial revenues by about $1.5 billion.

[62] This result should not be surprising, given the large role forestry plays in the economic life of BC. However, to the extent that higher costs can be passed to consumers in higher prices, the negative local economic effects may be offset. Since most of the major wood-producing countries are implementing higher cost sustainable practices, many of the costs are likely to be passed on. However, countries that have higher than average costs of meeting the standard are likely to be competitively disadvantaged.

of which relate to the other topics examined including harvesting productivity, genetic improvements in tree growing and changing land-use policies, which importantly impact forestry.

Traditionally, most of a region's, and indeed the world's, industrial wood has come from the harvest of forests that were established by natural processes. Thus, the social costs were viewed as primarily the extraction costs. This study examined harvesting modes in four regions: coastal BC; the PNW; the US South and the Nordic countries. The type of logging undertaken depends upon the terrain, size of trees, and size and shape of the wood as it is received by the mill.

All regions examined have been introducing new techniques and technologies in their logging efforts, however, the study concludes that there is no single dominating new technology in logging and that productivity levels have, at best, grown modestly. In harvesting, this study found that the cost reductions were not uniform. Technology seems to provide lower costs on flat accessible sites and fewer cost advantages on steep difficult terrain. However, innovations are barely keeping pace with cost-increasing factors in harvesting including poorer accessibility of old-growth forests. Data on extraction in the US developed by Parry (1997) indicate that, although labor productivity in timber extraction increased during the 1970-1992 period, total factor productivity declined modestly, as factor inputs grew somewhat more rapidly than total industrial wood output.

While traditionally, most of the nation's industrial wood came from the harvest of natural forests, humans possess the knowledge and expertise to create forests for the production of industrial wood and/or other outputs. Unlike other natural resources examined in the suite of RFF productivity studies, the forest resource is renewable. In recent decades investments in man-made forests have been expanding rapidly and humans are apparently on a transition away from relying on natural forests for industrial wood to utilizing wood produced by conscious human investments. The costs of producing forest resources today are no longer limited to the costs of extraction but increasingly include planting, growing and harvesting costs. However, studies suggest that the financial returns to tree growing can be substantial under the right conditions. Also, the rapid expansion of tree planting and the growing share of global production coming from plantation wood suggests that there can be favorable financial returns.

The development of tree planting not only allows for control of planting, growing and management, but it also allows for the selection of species. Additionally, planting allows for the possibility of controlling the choice of species and the introduction of genetically improved trees into the forest. Forest resource firms are investing substantial sums in research to improve the genetic stock of the trees planted in managed forests, expecting to emulate the productivity gains experienced in agriculture during the past 50 years. The financial returns to investments in genetic improvements have yet to be realized in most of North America, since the benefits require a substantial gestation period dictated by the harvest rotation. However, for some forestry operations and in some regions of the world, where rotations are short, the financial benefits are already being captured.[63]

[63] For example, with the current genetic improved tree stock, Aracruz in Brazil is experiencing growth rates that are over twice those of two decades ago.

This paper also examined the effects on the timber industry of public policy that imposes more stringent and expensive harvesting practices and that withdraws timberlands from the industrial forest land base. The perspective is that of North America, the dominant wood-producing region of the world. The public policy aspect of this analysis suggests that timberland set-asides will increase the value of the remaining timberlands. Also, the high prices will provide financial incentives to invest in plantation forests, on the assumption that investors believe that they will be allowed to harvest the forests that they plant.

The above considerations imply that: a) obtaining wood from the extensive margin (i.e., from old-growth forest) is becoming increasingly difficult and uncertain as old-growth forests are becoming increasingly inaccessible and difficult and costly to harvest; b) the opportunities at the intensive margin, e.g., intensively managed forest plantations, have been demonstrated to be especially favorable on high biological sites in locations with access to processing facilities and to markets, both at home and abroad; c) the ability of intensive forest management on selected species to increase yields 5-10 times the growth rates experienced in nonmanaged forests have provided firms with the opportunity to conserve their capital and focus their forestland holdings into a smaller more productive area, which improves the logistics of the operations, providing economies in management and harvesting, as well as in the application of intensive management, including planting; and d) planting provides the opportunity for the benefits of genetic research to be applied to forestry.

In summary, due to both financial considerations and as a reaction to public policy, industrial wood production appears to be shifting to intensively managed forest plantations and fiber farms where returns from genetically improved growing stock can be captured by the producer. The transition to intensive wood management has been underway for only a few decades. Nevertheless, the process has now become well developed, and plantation management now accounts for an estimated one-third of global industrial wood production. However, the potential for further innovation and expansion, as well as the potential for major advances in genetic improvements appear vast and, compared with agriculture, the process has just begun.

Implications for North American Comparative Advantage

North America has held a comparative advantage in industrial wood production based largely on the existence of a huge native forest covering much of the US and Canada. The stock of old-growth is essentially gone in the US, with most of the remaining old-growth forest having been set aside in protected areas. Canada, however, still retains large volumes of native forests on relatively accessible areas throughout the country. Canada has been able to maintain its share of the US lumber market, as well as exporting widely outside of North America, by harvesting heavily from its flat accessible areas. In the difficult coastal area of BC, however, the forest harvest has been maintained at more or less the same levels for a considerable period only because it has a unique market, e.g., the high price Japanese wood market.

While Canada can be expected to continue to draw from its native forests, the US will surely find an increasing share of its production coming from intensively managed forests. The US is likely to continue to develop the large land areas that are well suited to plantation forestry. These areas, mostly in the South, are very accessible, well located vis-a-vis markets, and have relatively flat terrain, which lends itself to planting, management and harvests. In addition, these areas have conditions that allow high biological growth rates for trees, although still less favorable growing than some of the very favorable areas for high growth rates such as are found in parts of South America and other places in the semi-tropics.

In the global market, North America has been the world's dominant producer throughout the post-WW II period largely by virtue of the comparative advantage imparted by its huge stock of natural forest suitable for commercial wood needs. In the future, however, North America will be increasingly unable to rely on its vast natural forest to ensure its competitive dominance, due to the decline of that natural forest usable for commercial harvests. Since the old-growth set-asides in the PNW, the US has found itself producing industrial wood from its second-growth and plantations forests. Over time, these forests may find themselves under increasing competition from the plantation forest that is rapidly developing in the Southern Hemisphere.[64] With the demise of the previous basis of the US comparative advantage, old-growth, future forest resource production will be dependent on the tree-growing potential of the US.

Although many parts of the US have climate, soils, etc., suitable to very effective intensive forestry, so too do large areas of South America, South and Southeast Asia and Africa. Thus, the US has no monopoly on favorable timber-growing conditions and its plantations, while competitive, are unlikely to be the low-cost producers worldwide. However, while some regions have the necessary prerequisites to provide them with the basis for a comparative advantage in wood production in a world where an increasing share of the industrial wood supply will be coming from plantation forests,[65] not all of these regions have the necessary political, social and cultural prerequisites for successfully developing a sustainable forest production industry.[66]

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[64] For a more formal analysis see Sedjo and Lyon (1983).

[65] Brazil, for example, reversed a $500 million pulp and paper trade deficit to an almost $1.5 billion trade surplus in less than 20 years (Sedjo 1994).

[66] Although many regions may not have the political prerequisites to allow for long-term investments as required in forestry, many regions obviously do since the role of the nontraditional producer in tropical and subtropical regions is growing.

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