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Productivity in the Forest Products Sector: A Review of the Literature

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Introduction

The objective of this literature review is to gather and synthesize all the studies on productivity levels and trends in the forest products sector from around the world. However, the research has been limited to papers published in English. Therefore, the result is that most but not all of the studies listed and summarized in this review are on the Canadian and American forest products sectors, since those two countries are the major forest products producing English speaking countries. The majority of the reviewed studies are published either in books, industrial publications or scientific journals. All the wood products industry sectors are covered, some more than others.

The studies have been regrouped in sections: (1) general, (2) logging, (3) saw milling, lumber and wood products, and (4) pulp and paper studies. The first section contains studies concerned with the forest sector as a whole while the other three are about specific sub sectors. Each section is then subdivided by country and the studies are ordered by publication date. Each study has been summarized in order to present the main research results. When it has been possible, the authors' interpretation or explanations are also included in the summaries. The summaries are then followed by a synthesis of the major findings.

There are two basic approaches to the empirical study of productivity. The index number or non-parametric approach develops indexes of inputs and output from data on employment, hours worked, capital stock and real output to directly calculate partial and total factor productivity estimates. The parametric approach, on the other hand, uses econometric techniques to develop productivity estimates based on indexes of inputs and output. The two approaches are complementary, with both having advantages and disadvantages (Hulten, 2001). About one half of the studies surveyed use the index number approach and one half the econometric approach.

1. General Studies

1.1 Canadian studies

Michael Sandoe and Morris Wayman (1977) studied the evolution of both labour and capital productivity in the Canadian forest products industries (lumber and pulp and paper) between 1965 and 1972. They found no upward trend in capital productivity, but there were important changes from one year to another, depending on the annual level of investment by firms. This was because capital productivity tends to decrease after a rise in capital stock. As in the American case, the Canadian forest product industries experienced labour productivity growth. The average annual growth rate was as high as 9 per cent in the plywood sector and as low as 2.8 per cent in the pulp and paper sector. Economies of scale and substitution of labour for capital explained the labour productivity growth. The average size of production facilities rose and automated machines replaced unskilled labour in this period.

Pierre Mohnen, from the Université du Quèbec à Montréal (UQAM), Romain Jacques from the Canadian Forest Service and Jean-Sebastien Gallant, former M.A. student in UQAM (1996) analyzed the effect of R&D on the trend in total factor productivity (TFP) in the pulp and paper and wood products sectors in Canada. After calculating the rate of return on R&D investments, which was relatively low compared to other manufacturing industries, the authors concluded that R&D did not contribute significantly to TFP growth in either the lumber or pulp and paper industries. In fact, they believed that the TFP growth observed between 1963 and 1988 was the result of positive returns to scale rather than of technological innovation. The authors concluded that fiscal incentives for R&D investment to increase productivity in the forest products sector may therefore be ineffective.

1.2 American studies

H. F. Kaiser (1971) considered the evolution of labour productivity in all forest products sectors in the United States. His study provided estimates of the rate of change in output per unit of labour for the period of 1947 to 1967. He found that labour productivity rose in all forest products sectors at an average annual rate of 3.4 per cent. Saw milling, lumber and pulp and paper had the highest labour productivity growth. The author explained that the rise in labour productivity in the saw milling and lumber sectors (particularly in plywood mills) was due to the automation of the production process. At the same time, the total number of producers in the American saw milling and lumber sectors dropped by half while output rose by 50 per cent. Similarly, Kaiser explained that the trend in labour productivity in pulp and paper industry was due to increased research and development which led to better automated processing. In most forest products sectors, the average wage rates went up as the number of skilled workers employed grew.

The study by Gregory Horvath (1980) was similar to the one by Kaiser except the period covered was longer, from 1947 to 1977. All U.S. forest product sectors experienced labour productivity growth, but some more than others (2.6 per cent on average annually in the saw mill industry and 4.6 per cent on average annually in the plywood industry). The author also explained labour productivity growth by a combination of automation and economies of scale.

The study by Greber (1982) considered the rise of the capital-labour ratio in the American lumber and wood products industries between 1951 and 1973. This was a result of factor substitution from technical change. During the period under study, the number of firms in the wood products industries decreased (and the average size increased). At the same time, heavy machinery and automation became the norm. Technical change was biased towards capital, which triggered the rise in labour productivity observed in that period.

In their study of Maine's wood industry, Lloyd Irland and Joel Maxcy, both from the Irland Group (1991) used value-added per worker as a measure of labour productivity. The authors produced a descriptive study, providing numbers yet avoiding the explanation of the underlying causes of their findings. Labour productivity was calculated for each wood product industry (lumber, logging, saw mills, flooring mills, millwork, furniture and fixtures). For the 1982-1987 period, the logging industry had the highest labour productivity level while the furniture industry had the lowest. The authors found that higher wage rates were associated with higher levels of labour productivity. Their calculations also showed an inverse relationship between labour productivity and labour intensity (the ratio of wages divided by value added). Compared to the national U.S. average, Maine's wood industries were less productive except in logging and flooring mills. A similar situation was observable for the wage rates. Transformed wood products sectors such as flooring and millwork showed a higher level of value-added intensity (ratio of value-added to value of shipment) than the national average.

2. Logging Studies

2.1 Canadian studies

The study by Shashi Kant and Jagdish Nautiyal (1997), both from the University of Toronto, was the only one concerned with the Canadian logging sector exclusively. The authors were interested, among other things, in the total factor productivity growth of this sector from 1964 to 1992. They were able to decompose total factor productivity growth into two components, the scale effect and the technical change effect using a translog cost function. The authors found that technical change led to labour and capital saving while increasing material and energy usage over the period studied. They also found a continuously negative technical change effect that pulled down total factor productivity growth, which was positive only nine of the 28 years. But this does not mean that technology is deteriorating. The authors explained this result the same way Sedjo (1997) did for the American logging industry (see page 4). Over the years, harvesting conditions have changed, as the exploitation sites shifted to more hostile and hard to reach terrain, reducing the overall productivity of logging activities. Technology was probably not as adapted as it should have been to the new harvesting context. The estimated scale effect was positive more often but insufficient to compensate for the negative technical change effect. The authors found that most of the positive TFP growth occurred in the 1960s and 1970s, a period when exploitation sites were relatively more accessible. The Kant and Nautiyal concluded that TFP growth was especially important in the logging sector because it provided the wood inputs for all the downstream wood products industries. Logging technology improvements should therefore be a priority for all concerned parties.

2.2 Studies on countries other than Canada

The study by Frederick Cubbage from the United States Department of Agriculture (USDA) and Douglas Carter from the University of Florida (1994) on Southern US pulpwood producers was a technical one. The authors surveyed producers and found that the pulpwood harvesting industry was much more capital intensive in 1987 than in 1979 and that the predominant harvesting technology had changed from short wood harvesting systems to long wood systems. They also found that average production (they used cords per week instead of cords per hour per week) rose 24 per cent over 8 years. During the same period, the total number of loggers decreased by 30 per cent (but not necessarily the total number of hours used in the industry). The productivity growth was explained by the new harvesting technology and by its high cost, which led to better managers running the harvesting companies.

David Wear from the USDA (1994) used an index number approach to estimate total factor productivity growth of the U.S. South’s timber production over the 1962-1985 period. He studied timber production on industry-owned timberland and, separately, on privately owned timberland. He found an average annual total factor productivity growth rate of 0.45 per cent for the 1962-1985 period with near zero growth rates after 1977 on industry-owned timberland. The average annual TFP growth rate on privately owned timberland was considerably higher at 2.5 per cent with an equivalent growth rate for the 1977-1985 period. Although the results for industry's TFP growth seemed reasonable on the basis of related forest productivity studies, one should be cautious with the findings for the private timber activities. The findings could have been the result of a problem with the measurement of the assets used in timber activities. The author also warned that one should not necessarily equate TFP growth with technological change since environmental factors (temperature, rain, etc.) affect timber growth and therefore TFP. Climate effects can lead to an underestimate or an overestimate of technological change.

Roger Sedjo from Resources for the Future Inc. (1997) was interested in logging and innovations in this sector. He summarized the technical progress that has occurred in various regions of the world over the last 50 years. The introduction of the chainsaw in the 1950s was a turning point in the evolution of logging activities because it was the beginning of the mechanization of wood harvesting. Since then, various machines have been designed to further reduce the number of loggers and the physical effort needed to harvest trees. The evolution of logging technology has varied depending on the physical characteristics of a region (climate, topography, type of soil, etc.) and on its social context. In Sweden, for example, the difficulty in recruiting loggers led to an early development of heavy machinery to replace labour input. The machinery was adapted to relatively small trees and frozen soil. This, of course, led to labour productivity growth. Today, a single trained operator can fell a tree, strip away its branches and cut it in pieces of determined length without having it touch the ground. Similar machinery was used in the Pacific Northwest region of the U.S but it was designed for larger trees. Heavy machinery was not used in Southern U.S. until the 1970s. Until then, logging was an off-season activity for agricultural workers, who used chainsaws and light trucks. But the size of this labour force declined with the migration of rural workers to cities. This led to substitution of capital for labour and the introduction of heavy machinery. Smaller logging activities without heavy machinery have not totally disappeared since they are more adapted to soft wet terrain or smaller logging sites, such as private forests.

On the Canadian B.C. Coast, where the terrain is steep, there have been a number of technical innovations since the 1960s. On steep terrain, trees have to be moved above the ground from the logging site to the road or river using a cable fixed to a spar. A more efficient steel spar was introduced in the 1960s while the grapple yarder (making the attachment of the log to the cable easier) was introduced in the 1970s. More recently, helicopter logging has been used on terrain with high price logs. Sedjo also provided total factor productivity estimates which showed a downward trend for the American logging industry from 1970 to 1993, while labour productivity rose slightly during the same period (20 per cent over the period). His conclusion was that although new technology permitted labour productivity growth, its introduction was not enough to offset the effect of reduced accessibility of the resource because exploitation has moved over the years from easy access sites to more difficult ones.

Paulo Barreto, Paulo Amaral, Edson Vidal and Christopher Uhl (1998), all from the *Instituto do Homem e Meio Ambiente da Amazonia* in Brazil, studied the impact of forest management on productivity and the cost of logging in the Amazonian region. The objective was to show the economic benefits of planned logging activities compared to unplanned ones.

The authors estimated three measures of productivity: labour productivity (volume of wood extracted per person hour), productivity of road making machines (machine hour per volume of wood extracted) and the productivity of skidders (volume of wood per machine hour). They found that the labour productivity level was 18 per cent lower in a planned logging operation than in an unplanned one when the crew size was the same (two workers per crew). Labour productivity was lower in the planned operation because the crew tried to minimize the damage to other trees. Labour productivity rose when a worker was added to the crew, because of division of labour rather than planning. Road making machine productivity benefited significantly from planning since 37 per cent less time per m^3 of wood extracted was necessary to build planned roads compared to unplanned roads. Planning led to lower road and landing area (where the logs are regrouped for pickup) density. Skidder productivity was also higher (27 per cent) in planned logging operations than in unplanned ones. Planning permitted the skidder operator to move more quickly from one logging site to another because of marked skid trails. In the short run, the reduction in cost from higher productivity did not compensate for the additional planning cost, but the additional revenue from the reduction in wasted wood does.

Dale Greene, Ben Jackson and Jack Culpepper from the University of Georgia (2001) studied Georgia loggers over a 10-year period from 1987 to 1997. This period was characterized by heavy investments in mechanization as capital per firm rose 102 per cent in 10 years. Capital productivity was steady, with a 2 per cent rise in ten years while labour productivity rose by 79 per cent. Heavy investment led to financial difficulties for Georgia's logging firms.

3. Saw Milling, Lumber and Wood Products Studies

3.1 Canadian and comparative studies

B.K. Singh and J. C. Nautiyal (1986) used a translog cost model to study factor demands and productivity trends in the Canadian lumber industry from 1955 to 1982. They found that the lumber industry experienced economies of scale over the time period but their model could not capture any significant technological progress. Either their model was faulty or there actually was not significant technological progress. Economies of scale were responsible for the observed productivity growth. Labour productivity rose during the period while capital, round wood and energy productivities went down (2.9 per cent, -6.1 per cent, -0.5 per cent and –5.7 per cent on average annually respectively). Using their theoretical model, the authors found that the rate of growth for the productivity of labour could have been as high as 3.65 per cent a year (assuming the input mix is always optimal) instead of the observed 2.9 per cent. In the same way, the negative growth rates of capital, round wood and energy could have been weaker (-4.6 per cent, -0.5 per cent and –4.9 per cent respectively) if the industry had adapted faster to the short run fluctuations in the economic context and therefore avoided input misallocation. The positive growth of labour productivity was the result of investments by lumber firms in automated machinery, which was the conclusion reached by Sandoe and Wayman in 1977.

Jamie Meil of JKM Associates, B. K. Singh and J. C. Nautiyal (1988) used a translog variable cost function to estimate single factor productivities (for labour, material and energy) in the absence of an adjustment period following fluctuations in input price or output demand.

They studied the British Columbia interior softwood lumber industry for the 1950-1983 time period. Single factor productivity average annual growth rates had the same sign as the least-cost annual growth rates but they were systematically lower: labour (3.8 per cent versus 4.7 per cent), material (-0.45 per cent versus –0.19 per cent) and energy (-0.86 per cent versus –0.54 per cent). The deviations from the least cost estimates were a sign of difficulty in adapting rapidly to changing market conditions. It is noteworthy that the B.C. interior softwood labour productivity growth was higher than that for the Canadian saw milling industry. The drop in energy productivity was also weaker than in the Canadian saw milling industry. The authors also found that the B.C. interior softwood lumber sector experienced technological change over the years. Although technological change was labour saving, it also was wood-using which could become a problem in a context of limited availability of wood resources (because of government regulation or resource depletion).

Luis Constantino from the University of Alberta and David Haley from the University of British Columbia (1989) compared total factor productivity in the saw milling industries of British Columbia in Canada and the Pacific Northwest region of the U.S. over the period from 1957 through 1982. They also controled for wood quality. The authors found that when wood quality was ignored, the saw milling industry in the Pacific Northwest was, on average, 10 per cent more productive than its B.C. competitor. But when the poorer quality of B.C. wood was taken into account, the B.C. industry was in fact more productive on average. Although the B.C. industry had a higher level of total factor productivity, its TFP growth was lower than in the Pacific Northwest. That region's saw milling industry therefore caught up with B.C.'s industry total factor productivity in the early 1980s.

Asghedom Ghebremicheal, Don Roberts and Michael Tretheway, from the University of British Columbia (1990) studied productivity trends in the Canadian lumber industry over the 1962-1985 time period. They calculated single as well as total factor productivities for BC, coastal and interior, Ontario and Quebec using a multilateral index number approach. Of all the single factor productivities, labour and capital productivities grew the fastest in the four regions over the 1962-1985 period (see Table 1). The authors explained this result by the faster rise in labour and capital prices relative to other input prices. But the average annual rate of capital productivity on the B.C. coast was significantly lower than in other regions. The authors explained this difference by their use of volume based productivity measures because it did not correctly account for the specific nature of capital on the B.C. coast. The machinery used in that region produces higher value products rather than a larger volume of products. In 1985, the two B.C. region's total factor productivity levels were 10 per cent higher than Ontario's TFP level and 20 per cent higher than Quebec's TFP level. However, Ontario and Quebec were able to reduce the productivity gap over the 1962-1985 period because of larger average annual TFP growth rates (see table 2). After 1980, the Quebec and B.C. interior regions had the greatest total factor productivity gains. In B.C. this was the result of higher labour, energy, capital and material productivity growth rates than in other regions. In Quebec, higher labour, energy and wood productivity growth rates were the main causes. Ontario and the B.C. interior benefited the most from economies of scale.

Jeffrey Bernstein from Carleton University (1994) used a dynamic model including price cost margins to evaluate and decompose the Canadian softwood lumber industry's total factor productivity growth for the 1963-1987 period and three sub-periods. Since certain studies have shown that price-cost margins affect TFP growth measures, he included those margins in his model. In doing so, he found an average total factor productivity growth rate over the 1963-1987 period of 3.24 per cent annually. The total factor productivity growth was also decomposed to show the effects of scale, technological change and capital adjustment. Technological change alone would induce a 2.35 per cent total factor productivity growth (over 70 per cent of the TFP) while returns to scale account for about 1.5 per cent of growth. Capital adjustments reduced the total factor productivity growth by almost 0.7 per cent a year on average.

Robert Abt from North Carolina State University, Jamie Brunet from Forestry Canada, Brian Murray from the USDA Forest Service and Don Roberts (1994) produced a comparative study of the saw milling industry in North America, using a non-parametric superlative index method. They calculated the single factor productivity growth for labour, wood, and capital in 6 North American regions: Ontario, Quebec, B.C. Interior, B.C. Coast, U.S. West and U.S. South over the 1965-1988 period. There were single factor productivity growth differences across regions and sub-periods. Labour productivity growth was positive for all regions and especially high after 1980 everywhere, except in Ontario. The relatively higher growth of wage rates could explain the substitution of labour for capital. The authors found that capital productivity growth was negative for most of the regions, which was the result of investment in capital over the time period. Only Ontario experienced positive capital productivity growth before 1980. After the 1980 recession, capital productivity rose as capital stock growth fell everywhere in North America. Although there were single factor productivity differences across regions, when comparing total factor productivity growth, the authors found that the growth rates were similar, between 1.2 per cent and 1.6 per cent annually except on the B.C. coast (see Table 2). The authors took this result to be a sign of competitive regional markets. If there had been great divergence in total factor productivity growth rates, there would have been an incentive to reallocate resources from one region to another.

<u>3.2 American studies</u>

John Duke and Clyde Huffstutler (1977) of the Bureau of Labor Statistics calculated labour productivity estimates for years 1958 to 1975 in the saw milling sector. The average annual rate of growth in labour productivity was equal to that of manufacturing in general in the U.S., at 2.7 per cent. Labour productivity growth was higher than average before 1965 and then lower until 1970. Labour productivity tended to fluctuate with output, which in turn fluctuated with the demand for lumber for housing. As noted in other studies, new technology was responsible for the growth. The number of unskilled jobs dropped at the same time, especially in lumber handling.

The study of the veneer and plywood industry between 1958 and 1976 by Mary Farris (1978) of the Bureau of Labor Statistics comes to the exact same conclusion as Kaiser (see page 2). Labour productivity grew at an average annual rate of 4.5 per cent over the time period. This above average growth rate was partly the consequence of an expansion of demand and therefore output arising from housing needs. Technical innovations permitting the use of different tree species of various sizes and reducing the amount of unskilled labour needed in the production process by automation also contributed to labour productivity growth. Plywood plants tended to be larger on average in 1976 than in 1958.

Jack Veigle and Horst Brand (1982) from the Bureau of Labor Statistics conducted a study of the American millwork industry (window frames, doors, mouldings, etc.). They were interested in the progression of labour productivity between 1958 and 1980 in the U.S. For the time interval of 1958 to 1972, the growth was positive with an average of 2.6 per cent annually and then negative at -1.4 per cent annually from 1972 to 1980. Labour productivity varied greatly from year to year depending on the respective growth of output and labour. The period of 1972 to 1980 was characterized by lower demand from residential housing. The authors explained the low labour productivity growth by a lack of investment in new technology. The relatively small size of the typical millwork plant compared to other manufacturing sectors could have explained the lack of investment in automation of the production processes, because of too small a volume of production.

Wood containers are essentially wood pallets and boxes. James York (1992) from the Bureau of Labor Statistics studied the labour productivity growth of the wood containers sector for the years 1977 to 1989. The average annual growth was higher until 1984 (2.2 per cent) and has dropped subsequently (to 0.9 per cent). The growth was the result of mechanization and automation, especially by the bigger producers that had the production volume to make it profitable.

4. Pulp and Paper Studies

4.1 Canadian studies

Nautiyal and Singh (1986) studied the evolution of the single factor productivities in the Canadian pulp and paper industry over the 1956-1982 period. They used a translog cost function to determine the least cost long run combinations of inputs from which they derive the hypothetical long run single factor productivities. They observed that labour and capital productivity average annual growth rates were positive (1.8 per cent and 0.8 per cent respectively) while the ones for material and energy were negative (-1.4 per cent and –0.6 per cent respectively). These growth rates were smaller than the long run rates estimated by the authors because the adjustments to new levels of output and factor prices took time and caused temporary misallocation of inputs. In fact, the difference between long run and observed productivities was higher in recessions. The authors explained the slowdown in the various productivity growth rates in the 1970s and early 1980s by cyclical factors.

David Frank, Asghedom Ghebremichael, Tae Oum and Michael Tretheway (1990), all from the University of British Columbia, studied productivity trends in the Canadian pulp and paper industry for the 1963-1984 period. They estimated total and single factor productivities using a non-parametric method. Labour, energy and material average annual productivity growth rates were positive over the 1963-1984 period (2.5 per cent, 2.2 per cent and 1.1 per cent respectively). Since the average annual capital productivity growth rate was negative (-0.6 per cent) for the same period, this was a sign that the variable inputs productivities probably grew because of investment in capital. Furthermore, there were signs that the capital input growth was not optimal, implying excess capacity in the industry. The authors estimated the average annual total factor productivity growth rate to be 1.2 per cent. They decomposed their TFP measure using translog total and variable cost functions. Most of the TFP growth resulted from economies of scale (0.88 of the 1.2 percentage points) while technical change accounted for 0.32 of the 1.2 percentage points.

Jamie Brunet (1993) from Forestry Canada studied productivity levels and trends in the Canadian pulp and paper industry over the 1964-1988 period. He constructed indices of TFP levels for Ontario, Quebec, B.C. and the rest of Canada (R.O.C.) using a superlative index number approach. In 1964, the pulp and paper industries of Ontario, Quebec and R.O.C. were all more productive (TFP) than B.C.'s industry (4.1 per cent, 10.3 per cent and 10.1 per cent respectively). Over the years, B.C.'s industry caught up with its competitors and eventually surpassed them. Using regression analysis, Brunet estimated the following average annual TFP growth rates – B.C.: 0.9 per cent, Ontario: 0.1 per cent, Quebec: -0.2 per cent, R.O.C.: 0.5 per cent (see Table 3). According to Brunet, the regional differences in TFP growth rates could have been the result of different capital productivity trends. The annual average capital productivity growth rates for Quebec, Ontario and R.O.C. were negative over the 1964-1988 period (-2.4 per cent, -2.3 per cent and -0.4 per cent respectively) while it was positive for B.C. (2.2 per cent). When Brunet used a variable factor productivity measure (from which capital inputs are excluded), the interregional differences in productivity growth are smaller, which suggested that capital productivity growth was in part responsible for TFP growth rate differences across regions.

Brunet also estimated labour, energy, wood and other materials single factor productivity average annual growth rates (see Table3). The rates were positive in all regions for labour and energy while they were negative in all regions for wood and other materials. He also found that single factor productivity was affected by output mix. Labour and energy productivity levels were higher in B.C. and R.O.C. than in Quebec and Ontario because in B.C. and R.O.C the main product was pulp and the production of this product required less labour and energy. Another important result in Brunet's study was the volatility of TFP growth over time. The author found that periods of productivity decline would be followed by periods of productivity advance and so on. He explained that this finding was due to the existence of excess productive capacity in the industry.

Atakelty Hailu and Terrence Veeman (2000a, 2000b, 2001), both from the University of Alberta, produced a series of studies on productivity trends in the Canadian pulp and paper industry. The first one (2000a) used a parametric input distance function as well as a Tornqvist index method to estimate total factor productivity growth over the 1959-1994 period. On average, using the input distance function, the annual productivity growth rate was 0.19 per cent but with some annual variations over the time interval. The authors found that there was negative productivity growth during the 1960s and 1970s (-1.55 per cent and -0.74 per cent annually respectively). Productivity growth was positive on average since the 1980-82 recession (0.99 per cent) and especially high since 1990 (3.95 per cent). The authors had difficulty explaining the negative growth of the 1960s but they attributed the negative growth of the 1970s to the two oil crises and their effect on output and to the environmental constraints introduced in that decade. The especially high productivity growth rate of the 1990s was due to the addition of several new mills equipped with modern production installations. At the same time, some of the older mills with outdated technology exited the market. A similar TFP growth trend was found using the Malmquist index measure, derived from the Tornqvist index method, but with an average annual growth rate of 0.41 per cent. When the authors controlled for the effect of output expansion, they found a negative growth rate (-0.15 per cent). Therefore, the TFP growth was mostly attributable to scale effect rather than to technological progress.

The second study by Hailu and Veeman (2000b) complemented the first one by using a productivity measure sensitive to improvements in environmental quality. Their measure was affected positively by the reduction of undesirable outputs, i.e. pollutants, so that the cost of pollution abatement was compensated for by an improved environmental quality. The authors used a parametric input distance function with both desirable and undesirable outputs. They created a Malmquist index of productivity growth for 1959-1994, the same period they analyzed in their other study. In doing so, the authors found that total factor productivity rose by a total of 42 per cent over the 1959-1994 time interval (1.0 per cent annually on average) rather than the smaller 7 per cent (0.19 per cent annually on average) found when they ignored the reduction in undesirable outputs in their first study. Their conclusion was therefore that traditional measures of TFP growth underestimated TFP improvement. The authors also found that the industry seemed technically efficient, except in periods of recession and oil crises.

The third study by Hailu and Veeman (2001) was similar to the second one. Their objective was the same, to show that traditional measures of TFP growth underestimate the true growth, but the methodology they used to achieve this was different. The authors constructed productivity measures with a non-parametric approach (they called it the Chavas-Cox approach). Their results differed in part from their previous studies. Instead of declining throughout the 1960s and 1970s, TFP growth was positive for most of those two decades (2.0 per cent and 0.3 per cent respectively). The growth was again especially high since 1990 but with a higher growth rate of 6.1 per cent. Again, the mill composition was the cause of the rapid TFP growth of the 1990s and the unfavourable economic context of the 1970s was responsible for the slow TFP growth rate of that decade. Over the 1959-1994 period, the average annual total factor productivity growth was 1.8 per cent instead of 0.19 per cent found when the effect of the reduction in undesirable output was ignored. When the model included the effect of reduction in undesirable output, the average annual TFP growth rate was 2.1 per cent instead of 1.0 per cent. Although the difference between the average annual TFP growth rate with and without the effect of environmental constraints was smaller, the traditional measure understated TFP growth.

4.2 Studies on countries other than Canada

Bruno De Borger from the University of Antwerp, and Joseph Buongiorno from the University of Wisconsin (1985) estimated the total factor productivity growth rate for the American paper and paperboard industries for the years between 1957 and 1981. To do so they used a variable cost function from which they derived two different versions of total factor productivity growth estimates for each industry. The total factor productivity annual growth rate was positive for all years. There was an upward trend from 1957 to 1973 and a downward trend subsequently. These results were observed in both industries. Depending on which version of

TFP growth was used, the average annual growth rate was 2.89 per cent or 4.54 per cent in the paper sector while the average annual growth rate was smaller at around 1.0 per cent for both versions of TFP in the paperboard sector. The authors suggested two reasons for this rather large difference in TFP growth rates. The first one was that the paperboard industry was more energy intensive and that the rise in energy prices after 1973 affected it more than the paper industry. Yet, the TFP growth rate for the paper industry has been systematically two percentage points higher than the paperboard industry TFP growth rate since 1957. The second reason was the faster labour productivity total growth in the paper industry compared to the paperboard industry (150 per cent and 130 per cent respectively).

Oum et al. (1991) compared single factor and total factor productivities in the pulp and paper industries of Canada, the U.S. and Sweden over the 1970s. The authors used an index number approach in order to decompose total factor productivity growth into capacity utilization, output scale and technical efficiency change effects, the last effect calculated residually as the TFP growth rate minus the first two effects. In the evolution of the average capital productivity growth over the 1970-1980 period, Sweden and the U.S. had a negative average annual growth rate (-2 per cent and -0.54 per cent respectively) while Canada had a positive one (1.05 per cent). Conversely, the average labour productivity growth rate was higher in Sweden and in the U.S. than in Canada at 3.51 per cent, 2.97 per cent and 2.58 per cent respectively (see Table 4). These different rates were partly the result of different investment trends in each country. The annual capital input increase in Sweden was higher than in the U.S. and Canada (3.7 per cent, 2.8 per cent and 2.1 per cent respectively). The average total factor productivity growth rate was highest in Canada, followed by the U.S. and Sweden at1.88 per cent, 1.7 per cent and 0.67 per cent respectively (see Table 5).

The U.S. industry benefited the most from technical change (1.22 of the 1.7 percentage points) followed by Canada (0.51 of the 1.88 percentage points) and Sweden (-0.27 percentage points). The large U.S. technical change effect came from technical innovations in the use of material inputs. These innovations had an important effect on TFP because material inputs account for 50 per cent of total input cost. Material input productivity growth was also especially high in the U.S. industry. The Canadian industry benefited the most from the scale effect (1.34 of the 1.88 percentage points), followed by the U.S. (0.77 of the 1.7 percentage points) and Sweden (0.70 of the 0.67 percentage points). The capacity utilization effect accounted for 0.61 percentage points in the U.S., 0.24 percentage points in Sweden and 0.03 percentage points in Canada. The fact that Canada TFP growth did not benefit from capacity utilization indicated that the Canadian industry had a utilization rate near optimum. The higher capacity utilization in Canada was the result of a high output growth due to a favourable exchange rate with the U.S. The positive results for the capacity utilization effect came from the use of a dynamic model of capital stock adjustments rather than a static variable cost model.

The comparative study on the American and Canadian pulp and paper industries by Oum and Tretheway (1992) builds on Oum et al. (1991) and on Frank et al. (1990). The authors estimated the average annual single factor productivity growth rates for the 1963-1984 time period using a Tornqvist methodology, a non-parametric approach (see Table 6). The growth rates of labour, material and capital productivity were higher in the U.S. than in Canada (3.5 per cent against 2.6 per cent for labour, 2.8 per cent against 1.1 per cent for material, and 1.3 per cent against 0.6 per cent for capital respectively) while the energy productivity growth rate was higher in Canada (2.6 per cent against 0.6 per cent). The authors calculated that capital inputs in the Canadian industry rose by 130 per cent during the period while they only grew 49 per cent in the American industry. Despite the far greater volume of investments in the Canadian industry, the U.S. industry led the way in all single factor productivity growth rates with the exception of energy productivity.

From a cost perspective, a higher energy productivity growth rate is not as important as other single factor productivity growth rates because energy accounts for less than 10 per cent of the total cost. Therefore, the investment by Canadian firms in energy-saving installations could not improve total factor productivity in a significant way. The authors suggested that the U.S. investment programs were more effective than the Canadian ones. The total growth of total factor productivity was 44 per cent over the period in the U.S. and 29 per cent in Canada. Put another way, the average annual TFP growth rate was 1.75 per cent in the U.S. and 1.2 per cent in Canada. Therefore, the Canadian industry became relatively less cost effective than its American competitors. Most of the TFP growth in the U.S. occurred after 1980 (27 of the 44 percentage points) while most of the Canadian TFP growth occurred before 1974 (26 of the 29 percentages points). The periods of high TFP growth in each country coincided with periods of high investment by their respective industries. The data the authors used also show that the Canadian industry had more difficulty than the American industry in adjusting its input mix to changes in the economic context. This could have negatively affected the overall productivity level of the Canadian industry.

Jiing-Shyang Hseu from the University of Wisconsin and Buongiorno (1994) studied the evolution of total factor productivity in Canada and the U.S. from 1961-1984 using three different non-parametric methods: the Tornqvist-Theil index and two linear programming techniques (translating hypothesis and distance function). The total factor productivity trends estimated using the Tornqvist and distance function approach gave similar results. The TFP fluctuations from year to year were much more accentuated with the translating hypothesis. The authors found that the average annual total factor productivity growth rates for Canada and the U.S. were almost the same, at 0.5 per cent, with a small advantage for the U.S. The authors did not try to interpret their results or suggest the causes of the trends they observed.

Belton Fleisher of Ohio State University, Keyong Dong of Renmin University of China and Yunhua Liu of the Nanyang Technological University (1996) studied the effect of education and enterprise organization on labour productivity in the Chinese paper industry. They estimated that the average annual labour productivity growth rate was 6.4 per cent between 1985 and 1990. When comparing different profit distribution methods, they found that none of them contributed more to labour productivity growth. However, the authors did find that the level of ownership had an impact on labour productivity. They suggested that ownership at a lower level of government (municipal versus provincial) induced more effort by workers since surpluses go to regional authorities.

The Indian pulp and paper industry was studied by Katja Schumacher and Jayant Sathaye, both from the Ernest Orlando Lawrence Berkeley National Laboratory at the University of California (1999). Single as well as total factor productivities were estimated. The authors used three types of estimates (translog, Solow and Kendrick index) to evaluate total factor productivity growth rates from 1973 to 1993. Overall, the single input productivity average annual growth rates were negative except for labour (capital at -2.31 per cent, energy at -2.68 per cent, materialat -0.82 per cent and labour at 3.14 per cent). But these averages did not give a good perspective on growth trends. The 1970s saw negative growth rates for all inputs while the 1980s saw strong positive growth for both labour and capital. These trends were the result of a particular national context. India suffered a paper shortage in the early 1970s that led the government to create a large number of small paper mills equipped with outdated capital from developed countries to end the crisis. Machinery decay over the years led to the negative single factor productivity growth rates. But in the 1980s, the equipment was modernized and larger paper mills benefiting from economies of scale were created, explaining the positive growth rates for capital and labour. Over the time period studied by the authors, the average annual TFP growth rate was negative (translog at -2.2 per cent, Solow at -3.6 per cent, Kendrick at -3.4 per cent). All three TFP estimates followed a similar time trend. The 1990s were a difficult time for the Indian paper industry since the TFP growth rate was between -13.3 per cent and -13.4 per cent. The unstable economic context, the scarcity of wood resources and environmental regulations could have explained the size of the decrease in productivity growth.

Synthesis

The present literature review is an attempt to gather and summarize the extent of our knowledge of the productivity trends and levels in the forest products sector. We consider single factor as well as total factor productivity definitions. The present section will synthesize the review along two lines: (1) the overall productivity growth trends in Canada and other countries and a comparison between forest products sectors in Canada and the United States and (2) the determinants of productivity growth.

(1) Overall productivity growth trends and comparisons

The overall productivity trends vary from one sector to another. The American logging industry experienced slow labour productivity growth, at least since the 1970s (20 per cent over the 1970-1993 period). Since we did not find a Canadian study that reported labour productivity in logging, a comparison will be impossible. On the other hand, we have TFP growth estimates for both the Canadian and the American logging industry. TFP increased in Canada in the 1960s while in both countries, it decreased since the 1970s.

The Canadian lumber industry experienced labour productivity growth from the 1950s to the 1980s and the B.C. region did better than the Canadian industry as a whole. The evolution of capital productivity is more problematic. Ghebremichael et al. reported positive growth rates for capital productivity in all the Canadian regions for 1962-1985 while Abt et al. reported negative growth rates in all Canadian regions for the 1965-1988 period (see Table 2). Nautiyal and Singh reported a negative growth rate for capital productivity in the Canadian industry as a whole for the 1955-1982 period. Abt and Ghebremichael both used an index number approach while Singh and Nautiyal used a translog cost function. Ghebremichael and Singh found decreasing energy productivity for all the regions and for Canada as a whole. Regional average annual TFP growth rates were similar and positive in Abt and Ghebremichael. The only exception was the B.C. coast. Bernstein also estimated TFP growth but he used a dynamic model that controls for price-cost margins. He found the Canadian softwood lumber industry as a whole had a significantly higher average annual TFP growth rate of 3.24 per cent for the 1963-1987 period.

The American lumber industry also experienced labour productivity growth since the 1950s. Duke et al. reported a 2.7 per cent average annual labour productivity growth rate for the American industry as a whole for the 1958-1977 period while Abt et al. reported a much higher rate for the U.S. West region. We do not have capital productivity nor TFP growth rate estimates for the American industry as a whole but Abt et al. provided estimates for the U.S. West and South regions for the 1965-1988 period (see Table 2). The average annual TFP growth rates were respectively 1.6 per cent and 1.3 per cent while the capital productivity growth rates were negative. If the estimates for TFP growth in U.S. South and West can be extended to the entire American lumber industry, then the American industry probably became more productive relative to the Canadian industry between 1965 and 1988. This is consistent with the study by Constantino who showed that the Pacific Northwest industry narrowed its TFP gap with B.C. over the 1957-1982 period.

As for the other forest products sectors, the Canadian pulp and paper industry experienced labour productivity growth from the 1950s to the 1980s. Oum et al. reported an average annual labour productivity growth of 2.57 per cent for the 1963-1984 period while Singh and Nautiyal reported a smaller rate of 1.8 per cent for the 1956-1982 period. On a regional basis, Ontario and the R.O.C had the highest average annual labour productivity growth rates (see Table 3). The average annual capital and energy productivity growth rates estimated by Oum and Tretheway were different from the estimates reported by Singh and Nautiyal. This is probably the result of relatively different study periods. The regional estimates reported by Brunet are consistent with national estimates by Oum and Tretheway. As for the national level, average annual capital productivity growth rates were negative, except in B.C. and average annual energy productivity growth rates were positive. There is variation from one TFP growth measure to another. Hailu and Veeman reported different average annual TFP growth rates for the 1959-1994 period depending on the method used: 0.19 per cent a year with an input distance function and 1.8 per cent with the Chavas-Cox approach. Oum and Tretheway reported an average annual TFP growth rate of 1.2 per cent for the 1963-1984 period while Hseu and Buongiorno reported a smaller one, 0.5 per cent a year for the 1962-1984 period using a similar methodology. Hseu and Buongiorno suggested that definitional differences between the studies could explain the different results. The regional average annual TFP growth rate estimates reported by Brunet seem to be more consistent with the results of Hseu and Buongiorno. They suggest an absence of growth in Ontario and Quebec, while Brunet’s estimates suggested modest growth in B.C. and the R.O.C.

The study by Oum and Tretheway was the only one to provide estimates of single factor productivity growth rates for the American industry. The American industry experienced labour, capital and energy productivity growth between 1963-1984, with average annual growth rates higher than the ones for Canada (see Table 6). TFP growth estimates were provided by Oum and Tretheway, Hseu and Buongiorno, and by DeBorger and Buongiorno. The first set of authors found an average annual TFP growth rate of 1.7 per cent for the 1963-1984 period, the second set found a 0.6 per cent annual rate for the 1961-1984 period and the third found a higher annual rate for the paper industry (2.9 per cent or 4.5 per cent depending on the method) and a more modest one of 1.0 per cent per year for the paperboard industry for the 1958-1981 period. The difference between Oum and Tretheway, and Hseu and Buongiorno estimates is probably one of definition as mentioned above but both estimates for the American industry are higher than the estimates for the Canadian industry. Although the gap between the Canadian and American estimates in the study by Hseu and Buongiorno was quite small, both studies show that TFP grew faster in the U.S. pulp and paper industry in the 1960s trough the 1980s. The study by DeBorger and Buongiorno is not useful for international comparisons since the estimates do not include the pulp sector. A comparison with Sweden over the same time period would have been instructive but due to a lack of data, Oum and Tretheway were only able to compare the American, Canadian and Swedish industries from 1970 to 1980. They found that TFP growth in that period was much lower in Sweden than in the other two countries (see Table 4). India experienced negative overall TFP growth between 1970 and 1993 while China experienced labour productivity growth between 1985 and 1990.

(2) Determinants of productivity growth

Technical and organizational changes, along with economies of scale, are the two main sources of total factor productivity growth. The Canadian logging industry benefited from economies of scale. The effect on TFP growth limited the impact of a negative technical change effect since the 1970s because of the increasing difficulty in harvesting associated with new logging sites. The American logging industry experienced a similar decrease in TFP for the same reason. This indicates the importance of improving logging technology to keep up with the changing nature of new logging sites. In the Canadian lumber sector, Nautiyal and Singh did not report any technical change for the 1955-1982 period but they did report the impact of economies of scale on productivity and so did Ghebremichael et al. for the 1962-1985 period. Bernstein also reported economies of scale in the Canadian lumber industry. However, he found an important technical change effect that accounted for 72 per cent of the average annual TFP growth rate estimate (3.24 per cent) he reported for the 1963-1987 period.

There is more consensus on the respective impact of technical change and scale effects on TFP growth in the pulp and paper industry. Hailu and Veeman found that the strong TFP growth of the 1990s in the Canadian pulp and paper industry was the result of technical change, but for the 1959-1994 period as a whole, economies of scale were responsible for most of TFP growth. Frank et al. reported a similar result. They estimated that the scale effect accounted for two-thirds of the average annual TFP growth rate for the 1963-1984 period while technical change accounted for one-third. Oum et al. estimated the share of the scale effect of the average annual TFP growth rate to be slightly higher than 70 per cent in the 1970s (see Table 5). Mohnen et al. also estimated that TFP growth was the result of economies of scale rather than technical change for the 1963-1988 period for both the lumber and the pulp and paper industry. On the other hand, according to Oum et al., the technical change effect accounted for 70 per cent of the average annual TFP growth rate in the American pulp and paper industry for the same decade, following innovations in the use of material inputs. It therefore seems that most of the TFP growth in all the Canadian forest products sectors is mainly the result of economies of scale and that very little technical change has occurred since the 1960s.

Single factor productivity growth can be the consequence of economies of scale. When all the single factor productivities rise because of a proportional increase of all inputs, so does TFP as discussed above. Single factor productivity growth can also be the result of factor substitution. This usually happens following a change in relative input prices. For example, because of rising wage rates, logging firms invested in labour saving felling and skidding machinery that required fewer workers. The lumber industry benefited from reduced material handling in saw mills with the labour saving capital investment in automation of the production process. The Canadian pulp and paper industry also saw increased energy productivity after energy prices rose. But productivity growth for one or more inputs usually comes at the expense of a decrease in another input's productivity, typically capital, because other inputs are often substituted for it. This was the case in the lumber industry where labour productivity rose while capital productivity declined across all American and Canadian regions. Only Ghebremichael et al. estimated positive capital productivity growth. Most of the authors reported an overall declining capital productivity since the 1960s while labour, energy, and material productivities went up in both the Canadian and American pulp and paper industries. Only Oum and Tretheway reported rising capital productivity. The impact on TFP of factor substitution will depend on the relative importance of each input in total cost.

It is also important to note that excess capacity and input misallocation are negative determinants of productivity in the sense that they reduce the SFP and TFP levels the forest products industries would have experienced had the firms been able to rapidly adjust their input mix to changing market conditions.

This survey has three key conclusions. First, there have been a considerable number of studies on productivity trends in the forest product sector in Canada, at least compared to other sectors. Consequently, there are a number of Canadian economists with expertise in the area of forest products sector productivity, including T.H. Oum and M.W. Tretheway at the University of British Columbia and T.S. Veeman at the University of Alberta. Second, many of these studies however, are highly technical and dependent on unrealistic assumptions about firm behaviour, which limits their relevance for policy discussion. Finally, there appear to be no studies which examine productivity developments in recent years, which is the period most relevant to the current policy debate.

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Tables

Table 1
Average annual single factor productivity (SFP) growth rates in lumber industry by region, 1962-1985

	B.C. Coast	B.C. Interior	Ontario	Quebec
SFP Labour	2.10 per cent	3.20 per cent	4.00 per cent	3.90 per cent
SFP Wood	0.30 per cent	0 per cent	0.90 per cent	0.30 per cent
SFP Materials	-3.10 per cent	-1.00 per cent	0.90 per cent	0.80 per cent
SFP Energy	-2.50 per cent	-0.50 per cent	-0.50 per cent	-1.10 per cent
SFP Capital	1.20 per cent	2.40 per cent	2.80 per cent	2.50 per cent

Source: Ghebremichael et al. (1990) *Productivity in the Canadian Lumber Industry, an Inter-regional Comparison*. Forestry Canada Information Report O-X-411, p.39.

Table 2
Average annual TFP growth rates by region in Lumber industry

	Sawmilling industry (Abt and al. 1994) 1965-1988	Lumber industry (Ghebremichael and al. 1990) 1962-1985
B.C. Coast	-0.10 per cent	0.40 per cent
B.C. Interior	1.20 per cent	0.90 per cent
Ontario	1.30 per cent	1.80 per cent
Quebec	1.30 per cent	1.50 per cent
U.S. South	1.30 per cent	N/A
U.S. West	1.60 per cent	N/A

Source: Ghebremichael et al. (1990) *Productivity in the Canadian Lumber Industry, an Inter-regional Comparison.* Forestry Canada Information Report O-X-411, p.45
and Abt et al. (1994) "Productivity Growth and Price Trends in the North American Saw Milling Industries: an Inter-regional Comparison". *Canadian Journal of Forest Research.* 24(1), p.143

Table 3
Average annual single factor productivity (SFP) and TFP growth rates in the Canadian pulp and paper industry (as calculated by regression) 1964-1988

	B.C.	Ont.	Que.	R.O.C.
SFP Wood	-0.10 per cent	-0.40 per cent	-0.30 per cent	-0.40 per cent
SFP Materials	-0.50 per cent	-1.10 per cent	-1.30 per cent	-0.50 per cent
SFP Energy	1.00 per cent	1.50 per cent	0.80 per cent	0.90 per cent
SFP Labour	1.60 per cent	2.10 per cent	1.40 per cent	2.50 per cent
SFP Capital	2.20 per cent	-2.30 per cent	-2.40 per cent	-0.40 per cent
TFP	0.90 per cent	0.10 per cent	-0.20 per cent	0.50 per cent

Source: Brunet (1993) *Productivity in Canada's Pulp and Paper Industry: an Inter-Regional Comparison*. Working Paper. Policy and Economics Directorate, Forestry Canada, 4th Floor, Fuller Building, 75 Albert Street, Ottawa, ON K1A 1G5, Canada. p. 20.

Table 4
Average annual single factor productivity (SFP) and TFP growth rates in the pulp and paper industry by country, 1970-1980

	Canada	United States	Sweden
SFP Labour	2.58 per cent	2.97 per cent	3.51 per cent
SFP Capital	1.05 per cent	-0.54 per cent	-2 per cent
SFP Energy	3.76 per cent	1.37 per cent	2.89 per cent
SFP Materials	1.06 per cent	3.76 per cent	-0.43 per cent
TFP	1.88 per cent	1.70 per cent	0.67 per cent

Source: Oum et al. (1991) *Productivity Measurement, Decomposition and Efficiency Comparison of the Pulp and Paper Industry*: *Canada, the U.S and Sweden*. UBC, Forest Economics and Policy Analysis, Working Paper 159 : p. 28-30

Table 5
Average annual TFP growth rate decomposition in the pulp and paper industry by country, 1970-1980

	Canada	United States	Sweden
Due to changes in:			
Output scale	1.34 per cent	0.77 per cent	0.70 per cent
Capacity Utilization	0.03 per cent	0.61 per cent	0.24 per cent
Efficiency (Residual)	0.51 per cent	1.22 per cent	-0.27 per cent
TFP growth rate	1.88 per cent	1.70 per cent	0.67 per cent

Source: Oum et al. (1991) *Productivity Measurement, Decomposition and Efficiency Comparison of the Pulp and Paper Industry: Canada, the U.S and Sweden*. UBC, Forest Economics and Policy Analysis, Working Paper 159 : p.33.

Table 6
Average annual single factor productivity (SFP) and TFP growth rates in the pulp and paper industry by country, 1963-1984

	Canada	United States
SFP Labour	2.57 per cent	3.49 per cent
SFP Capital	-0.61 per cent	1.26 per cent
SFP Energy	2.26 per cent	0.56 per cent
SFP Materials	1.13 per cent	2.76 per cent
TFP	1.21 per cent	1.75 per cent

Source:Oum and Tretheway (1992) *A Comparison of the Productivity Performance of the U.S and Canadian Pulp and Paper Industries*. in Nemetz, P. ed. *Emerging issues in forest policy*. Vancouver, UBC Press: p. 226.

Synthesis Tables

General Studies

Authors	Country	Period	Methodology	Major Findings
Sandoe Wayman (1977)	Canada	1965-1972	Output/input ratios	No trends in capital productivity but annual variations. As a result of economies of scale and automation, labour productivity is up in all forest products sectors.
Mohnen Jacques Gallant (1996)	Canada	1963-1988	Tornqvist index	The rate of return on R&D investment is low and does not contribute significantly to TFP growth. TFP growth is the result of economies of scale.
Kaiser (1971)	U.S.	1947-1967	Output/input ratios	Labour productivity is up in all forest products sectors, with a parallel rise in wages. Automation and economies of scale are accountable for both trends.
Horvath (1980)	U.S.	1947-1977	Output/input ratios	Same conclusion as Kaiser but for a wider time period.
Greber White (1982)	U.S.	1951-1973	Econometrics (following Sato-Batavia)	Labour-capital ratios were down in all forest products sectors. Technical change was biased towards capital and led to labour productivity rise.
Irland Maxcy (1991)	U.S. (Maine)	1982-1987	Value-added ratios	In forest product sectors, higher wages are associated with higher labour productivity. There is an inverse relationship between labour productivity and labour intensity.

Logging Studies

Authors	Country	Period	Methodology	Major Findings
Kant Nautiyal (1997)	Canada	1964-1992	Translog cost function	Technical change was labour and capital saving but used energy and material. The technical change effect was systematically negative. The annual TFP growth rates were therefore rarely positive. This could be a consequence of changing harvesting site conditions.
Wear (1994)	U.S. (South)	1962-1988	Index number approach	The TFP average annual growth rate was much lower on industry owned land than on privately owned land. This could be the result of difficulty in measuring assets. One should not necessarily equate TFP and technological change in the timber industry because of the effect of climate.
Cubbage Carter (1994)	U.S. (South)	1979-1987	Survey	The industry was much more capital intensive in 1987 than in 1979. Average weekly production rose during the period. Predominant technology has changed from short to long wood systems.
Sedjo (1997)	U.S.	1970-1993		Technology has led to rising labour productivity. But that was not enough to compensate for the negative effect on productivity of the reduced accessibility of wood resources over the years.
Barreto Amaral Vidal Uhl (1998)	Brazil	N/A	Output/input ratios.	Labour productivity was lower in planned logging operations because loggers minimized damage to other trees. However, capital productivity was higher in planned logging operations because of reduced time loss and wood waste.
Greene Jackson Culpepper (2001)	U.S.	1987-1997	Survey	The period was characterized by heavy investments. Capital productivity was almost steady while labour productivity rose almost 80 per cent.

Lumber and Saw Milling Studies

Authors	Country	Period	Methodology	Major Findings
Singh Nautiyal (1986)	Canada	1955-1982	Translog cost function	There were no signs of technological progress. Only the labour productivity growth rate was positive There was input misallocation because of slow adaptation by firms.
Meil Singh Nautiyal (1988)	Canada (B.C. Interior)	1950-1983	Translog variable cost function	Labour productivity was up while material and energy productivity were down during the period. There were deviations from the least-cost paths, therefore showing input misallocations. B.C.'s labour productivity growth rate was higher than Canada's.
Constantino Haley (1989)	Comparative study of Canada (B.C.) and the U.S. (Pacific Northwest)	1957-1982	Index number approach	When controlling for wood quality, B.C.'s industry was more productive. But the Pacific northwest industry narrowed the productivity gap over the years.
Ghebremichael Roberts Tretheway (1990)	Canada (Comparative study of Ont., Que., B.C. Coast, B.C. Interior)	1962-1985	Index number approach	Labour and capital productivities grew the fastest. The two B.C. regions had a productivity advantage but the gap has diminished since 1962. After 1980, Quebec and B.C. Interior had the greatest productivity gains.
Bernstein (1994)	Canada	1963-1987	Dynamic model of multiple output production and investment.	The model controls for price-cost margins. The average annual TFP growth rate was relatively high. Technological change accounts for almost 70 per cent of the TFP growth rate.
Abt Brunet Murray Roberts (1994)	Comparative study of Canada (B.C. Interior, B.C. West, Ont., Que.) and the U.S. (U.S. South, U.S. West)	1965-1988	Non-parametric superlative index method.	Labour productivity was positive for most regions and especially high in the 1980s. Although there were high single factor productivity growth rates differences, the TFP measures were similar between regions, a sign of regional competitive markets.
Duke Huffstutler (1977)	U.S.	1958-1975	Output/input ratios	Labour productivity for the period was equal to the average of the manufacturing sector a whole. New technology explains the labour productivity growth.
Farris (1978)	U.S.	1958-1976	Output/input ratios	Labour productivity growth rate was relatively high compared to other sectors. Technological innovation and rapidly expanding demand were responsible for the higher labour productivity growth rate.

Wood Products Studies

Authors	Country	Period	Methodology	Major Findings
Veigle Horst (1982)	U.S.	1958-1980	Output/input ratios	Labour productivity was lower than in other forest product sectors because of declining demand. There also have been fewer investments in automation.
York (1992)	U.S.	1977-1989	Output/input ratios	Labour productivity was up, faster before 1984. Investments in automation by larger producers are the main cause of the labour productivity rise.

Pulp and Paper Studies

Authors	Country	Period	Methodology	Major Findings
Nautiyal Singh (1986)	Canada	1956-1982	Translog cost function.	Labour and capital productivity were up but material and energy productivity were down. The observed productivities diverged from their least-cost paths, especially in recession periods, which suggest input misallocation.
Frank Ghebremichael Oum Tretheway (1990)	Canada	1963-1984	Non-parametric method.	Because of investments, all single input productivity growth rates were up except for capital. Most of the TFP growth was the result of economies of scale.
Brunet (1993)	Canada (Comparative study of B.C., Ont., Que., Rest of Canada)	1964-1988	Superlative index number approach	B.C. had a higher TFP growth rate than competitors and gained a productivity advantage over its Canadian competitors, probably because of its positive capital productivity growth rate. Excess capacity could explain the volatile TFP growth.
Hailu Veeman (2000a)	Canada	1959-1994	Parametric input distance function. Tornqvist index.	There was a negative TFP growth rate in the 1960s and 1970s but a positive one in the 1980s and 1990s. Most of the TFP growth is a result of the output scale effect. The oil crises are responsible for negative growth in the 1970s and mill composition is responsible for positive growth in the 1990s.
Hailu Veeman (2000b)	Canada	1959-1994	Parametric input distance functions	Traditional measures of TFP growth underestimate productivity improvements because they ignore the reduction in undesirable outputs.

Authors	**Country**	**Period**	**Methodology**	**Major Findings**
Hailu Veeman (2001)	Canada	1959-1994	Non parametric approach (Chavas-Cox)	Contrary to their 2000a results, TFP growth was not negative, but practically zero in the 1970s and positive in the 1960s. Again, traditional measures underestimate productivity growth.
DeBorger Buongiorno (1985)	U.S.	1957-1981	Variable cost function	The paper and paperboard industries enjoyed positive productivity growth, but the paper industry's growth rate was higher. A larger labour productivity growth rate and less energy intensity for the paper industry could explain in part the result.
Oum Tretheway Zhang (1991)	Comparative study of Canada, the U.S. and Sweden	1970-1980	Index number approach	Sweden had the highest capital growth and labour productivity growth rates, but the U.S. had the highest TFP growth rate and Sweden the lowest. The U.S. also experienced more technological change while Canada benefited most from the scale effect.
Oum Tretheway (1992)	Comparative study of Canada and the U.S.	1963-1984	Non-parametric approach (Tornqvist approach)	The TFP growth rate was higher in the U.S. despite a much lower capital input growth rate. Most of the U.S. growth occurred after 1980 while most of the Canadian growth occurred before 1974. Canadian industry had more trouble adjusting input mix.
Hseu Buongiorno (1994)	Comparative study of Canada and the U.S.	1961-1984	Non parametric methods (2 linear programming methods and a Tornqvist index)	The Canadian and American industries experienced very similar TFP growth rates with two of the models. The model with the translating hypothesis produced much more yearly fluctuations.
Fleisher Dong Liu (1996)	China	1985-1990	Translog production function.	Labour productivity was up for the period. Profit distribution does not affect labour productivity but the level of ownership does.
Schumacher Sathaye (1999)	India	1973-1993	Translog index, Solow index, Kendrick index.	TFP growth was negative in the 1970s, but positive in the 1980s with the creation of larger and more modern installations. TFP growth was once again negative in the 1990s.