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DANIELA MAZO CALLE

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EFFECTS OF SPATIAL FOREST HARVESTING PRACTICES ON EFFICIENCY THROUGH A BENCHMARKING APPROACH

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DANIELA MAZO CALLE

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RÉSUMÉ

L'exploitation forestière dans le premier maillon de la chaîne d'approvisionnement en bois et est l'activité responsable de l'extraction et du transport du bois de la forêt vers les autres industries. La planification se fait par le biais de la gestion forestière qui, au Québec, a une approche écosystémique. Les stratégies de gestion forestière qui sont appliquées s'inspirent donc des perturbations naturelles qui se produisent dans chaque type de forêt, y compris l'organisation spatiale des récoltes et la pratique de la récolte qui suit un gradient nord-sud. Les perturbations naturelles les plus fréquentes dans le sud sont caractérisées par de petites brèches créées par les chablis et les chutes d'arbres. Le principal agent de perturbation au nord est le feu qui couvre de grandes surfaces du territoire.

L'objectif de cette étude est de comparer les stratégies d'aménagement forestier actuelles axées sur l'organisation spatiale de la récolte effectuée dans les différentes unités d'aménagement forestier (latitudes) de l'ouest du Québec, en se basant sur une méthode de mesure de l'efficacité appelée *Data Envelopement Analysis* (DEA), et en mettant l'accent sur l'efficacité. Les stratégies d'aménagement forestier ont été décrites en termes de variables spatiales telles que la superficie, la forme des sites de récolte et la dispersion des peuplements récoltés, de variables non spatiales telles que les pratiques de récolte (coupe partielle ou coupe à blanc) et le volume récolté par espèce, et d'autres variables associées au secteur forestier telles que les kilomètres de routes construites, entre autres. L'efficacité du régime de gestion sera évaluée en fonction du coût de l'approvisionnement en bois ($\$/m^3$). Plus précisément, 1) nous documentons et sélectionnons des variables non spatiales et d'autres variables associées (intrants) qui affectent l'efficience (par exemple, le coût d'approvisionnement en bois); 2) nous identifions les variables spatiales (par exemple, l'indice de forme, la taille des parcelles, la juxtaposition) sur la base des empreintes spatiales des pratiques forestières sur un an dans un gradient nord-sud; et 3) nous identifions les variables qui affectent l'efficience dans le cadre du gradient.

Les résultats montrent 3 valeurs d'efficacité calculées pour 50 sites de récolte dans l'est du Canada. La valeur d'efficacité globale ou agrégée est de 72% avec une variation élevée de (±23%), tandis que pour la pure efficacité technique la valeur est de 89% (±9%), et pour l'efficacité à l'échelle elle est de 79% (±19%), valeurs similaires à celles rapportées dans la littérature pour la province de Québec. Il a été prouvé que les variables spatiales sont importantes pour déterminer l'efficacité de la récolte de bois à faible coût, parmi les variables évaluées, celles liées aux chemins forestiers (distance aux usines et kilomètres de routes construites) et la dispersion (indice de proximité) des sites de récolte se sont avérées les plus importantes. D'après nos résultats, nous pouvons voir à la fois des sites efficaces et inefficaces dans tout le gradient de données, les zones de récolte ne présentant pas un schéma unique en fonction de la latitude dans laquelle elles se trouvent comme le suggère la gestion écosystémique des forêts. Pour cette raison, l'efficacité n'est pas déterminée par la localisation de la forêt, mais par les variables spatiales associées à chaque site de récolte. Lorsque l'efficacité est divisée en fonction des différentes latitudes, il y a une tendance à des valeurs plus élevées dans le sud mais avec plus de variation des mesures en fonction de la valeur commerciale du bois, de la densification du réseau routier de la zone, et des taxes. Enfin, la méthode permet d'identifier des objectifs de réduction dans chacune des variables afin que les unités inefficaces atteignent un niveau efficace. Pour la variable des routes construites, il y a une réduction de 37%, ce qui représente 2.8 km de moins de nouveaux chemins, pour la distance aux usines de transformation de 29% (41 km), et la dispersion (indice de proximité) de 21%.

Mots clés: Fragstats, DEA, indice spatial, efficacité

ABSTRACT

Forest harvesting in the first link of the wood supply chain, which is the sector that is responsible for extraction and transportation of wood from the forest for processing by other industries. Planning of this activity in the Province of Quebec is conducted through forest management that uses an ecosystem-based approach. Forest management strategies that are applied are therefore inspired by natural disturbances that occur in each type of forest including the spatial organization of harvests and the harvesting practice that follows a north-to-south latitudinal gradient. Natural disturbance that is more frequent in the south is characterized by small-sized gaps created by windthrows and by tree falls. The principal agent of disturbance in the north are fires, which cover large areas of the territory.

The objective of this study is to compare the forest management strategies in the different forest management units (latitudes) in western Quebec, focus on the spatial organization of the harvest activity through the efficiency, based on a benchmarking method of efficiency measure called Data Envelopment Analysis (DEA). The forest management strategies were described in terms of spatial variables such as the size area, shape of harvested sites and dispersion of harvested stands, and non-spatial variables of forest management such as harvest practices (partial cut or clear-cutting) and volume harvested per species, and other variables associated with the forest sector such as constructed kilometres of roads, among others. The efficiency of the management regime will be evaluated according to the wood procurement cost ($/m3). Specifically, 1) we document and select non-spatial variables and other associated variables (input) that affect efficiency (e.g., wood procurement cost and profit margin) 2) Identify spatial variables (e.g., shape index, patch size, juxtaposition) based on spatial footprints of forest practices over one year within a north-south gradient, and 3) Identify variables that affect the performance within the gradient.

The results show 3 efficiency values calculated for 50 harvested sites in eastern Canada. The overall or aggregate efficiency is 72% with a high variation of ±23%, for the pure technical efficiency is 89% (± 9%) and for the scale efficiency it is 79% (±19%). It was proved that spatial variables are important to determine the efficiency of harvesting wood at a low cost, among the variables evaluated those related to the forest roads (distance to the mills and kilometres constructed roads) and the dispersion (proximity index) of the harvested sites showed to be the most important. From our results, we show both efficient and inefficient sites in the latitudinal gradient, harvesting sites do not present a single pattern depending on the latitude in which they are found as suggested by ecosystem forest management. When the efficiency was dividing according to the different latitudes, there is a tendency of higher efficiency values in the south but with more variation on the commercial value of the wood, the higher road density of the zone, and the taxes. Finally, the method allows the identification of reduction targets in each of the variables so that inefficient units could reach an efficient level. Globally, a reduction of an average of 2.8 km for road construction could increase efficiency by 37%, a reduction of 41 km to the mill by 29%, and a reduction of the dispersion (proximity index) by 21%.

Key words**:** Fragstats, DEA, spatial index**,** efficiency.

CHAPTER I

GENERAL INTRODUCTION

1.1 Statement of the Problem

Forest management is the process of planning and implementing activities for the stewardship and use of forests, based upon legal, technical, scientific and social regulations to achieve specific environmental, economic, social and cultural objectives (FAO, 2018). Forests provide different goods and services for society, such as wood products. These goods and services also include biodiversity protection, cycle regulation, and recreational opportunities. Twenty percent of Canada's boreal forests lie within the Province of Quebec. These provincial forests, in turn, are 92% publically owned, administered and managed by the Government of Quebec through the "Sustainable Forest Management Act" (*loi sur l'aménagement durable du Territoire Forestier,* LADTF) (Chapter A 18-1, (Légis Québec, 2013). This law promotes the implementation of Ecosystem Forest Management (EFM) that aims to maintain the health and resilience of forest ecosystems by focusing on reductions in the differences between natural and managed landscapes to maintain ecosystem functions, as well as social and economic benefits to society (Gauthier *et al.*, 2008).

Quebec's forests display differences in structure and vegetation composition that are associated with variation in the physical environment (i.e., soil deposits, slopes, and drainage), climate and natural disturbances. Together, these natural conditions have created bioclimatic domains that divide the territory and describe the balance between climate and potential vegetation (MRN, 2003). In the North, conifers dominate the spruce-feather moss domain. In the South, broadleaves dominate the sugar maple domain. Mixed wood stands lie between these extremes, and include the balsam fir-white birch and balsam fir-yellow birch domains (MRN, 2013). Natural disturbance regimes in boreal forests consist mainly of catastrophic wildfires and secondary disturbances such as insect outbreaks, windfalls, and forest gap dynamics (MRN, 2013). In Quebec, these disturbances vary in their extent and intensity along a north-to-south gradients, following the bioclimatic domains. For example, in the North, the fire regime has shorter cycles, and greater frequency, severity and extent. In the South, fire cycles are longer with lower severity and smaller areas. Historically, these natural disturbances have been the promoters of biodiversity and ecosystems are adapted and resilient to them (Gauthier *et al.*, 2008).

EFM is inspired by natural disturbances and uses the toolbox of available harvesting practices to emulate post-disturbance stands and the landscape. EFM further attempts to maintain these stands within the limits of their natural variability (Bergeron *et al.*, 1999). To fulfill both EFM and financial objectives, current forest harvesting practices are modulated according to species composition, natural disturbance regimes, and wood demand. The interplay between these factors results in different forest management strategies, which involve different spatial organizations of the harvest-blocks within the territory. For example, clear-cut harvesting is implemented most commonly in the north to emulate fire disturbance, whereas partial cutting and shelter-wood cuts are used mainly in the south to emulate windfalls and forest gap dynamics (Bergeron *et al.*, 1999). Therefore, forest management strategies will yield different efficiencies depending upon spatial variables, such as road construction and maintenance, transport distances between cut-blocks and sawmills, size of stands and mean cutting area, the spatial distribution of harvested units, and non-spatial variables such as silvicultural treatment, timber surveys, machinery, contractor teams, and available species.

Evaluating performance is important for maintaining competitiveness in the current environment, and for improving productivity (Drolet et LeBel, 2010). Generally, forest harvest performance has been based upon financial results, such as increasing productivity, reducing costs per unit and improving profits, or increasing operational and technical efficiency. The use of efficiency indicators helps companies achieve their goals, notice faults or shortcomings, and take corrective actions. Wood procurement costs and profitability are frequently used as financial indicators in the forest product industry. Evaluation of efficiency using benchmarking techniques (Rolstadås, 1995), particularly within the forestry sector in Quebec, has focused on pulp and paper production and the wood-processing industry, with limited use in the forest harvesting industry (Hailu et Veeman, 2003). Indeed, identifying differences in efficiency following forest management strategies that are distributed across the bioclimatic domains of western Quebec would allow us to establish best management practices that are currently being carried out and better understand the influence of spatial variables. Therefore, business practices that include benchmarking could help improve efficiency throughout western Quebec.

1.2 State of Knowledge

1.2.1 Spatial organization

Forest management planning involves the integration of silvicultural treatments, economic concepts, and ecological and social objectives that are present in an ecosystem. Planning is done hierarchically from coarse to fine scales through space and time, divided into strategic, tactical and operational levels. The objective is to predict the future amount of harvest, optimize the use of resources, and maintain and develop current habitats (Bettinger *et al.*, 2009). Strategic planning focuses upon the long-term and the landscape level. The landscape is defined as a spatial mosaic of arbitrary boundaries containing different areas that interact functionally (Turner, 1989). Tactical and operational planning is conducted over the short-term and at small scales, where spatial organization is being integrated into the process. Spatial restrictions are necessary for the development of forestry activities, to meet ecological and environmental objectives that can only be achieved through spatial monitoring

(Baskent, Emin Z. et Keles, 2005). The spatial organization that is defined in the planning process determines the structure of the landscape, which refers to the relative spatial arrangement of harvested sites and the interconnections between them (Baskent, Emin Z. et Jordan, 1995).

Spatial organization is a key process in the management of environmental, social and economic aspects of today's forests (Baskent, Emin Z. et Keles, 2005). Spatial forest planning has emerged as the study of patterns and trends in the landscape that is focused upon forestry and natural resource management activities (Bettinger et Sessions, 2003). The distribution of harvest sites deals with environmental protection areas, habitats of species of interest or loss of connectivity, and the influence of profitability for the forestry industry. The study of spatial forest planning has recognized economic benefits that can be brought to forest businesses (Baskent, Emin Z. et Keles, 2005), such as the reduction of road construction and operational costs with logistic controls (Baskent, E.Z. et Jordan, 1991; Öhman et Eriksson, 2010) and seasonal effects (D'Amours *et al.*, 2008). Many optimization programs have been developed to integrate spatial variables into the planning process (Favreau et Ristea, 2016; Weintraub *et al.*, 2007).

Quantifying spatial organization requires a method of describing and representing variability in space and time (Gustafson et Crow, 1998). Spatial pattern organization can be described and measured at the scale of the minimum management unit or that of their relationships in the landscape. The range of measurement indices includes size, shape, juxtaposition and distribution of management units (harvest areas, corridors, protected areas), minimum and maximum limits of harvesting on- site, adjacency (regeneration delay), restrictions, fragmentation, and aggregation and dispersion (Baskent, Emin Z. et Keles, 2005). Spatial statistics can be used directly to calculate the spatial distribution of cut-blocks (Baskent, Emin Z. et Jordan, 1995).

1.2.2 Spatial organization in Quebec

The Canadian forest industry provides a wide range of social, economic and environmental benefits (Mobtaker *et al.*, 2017). Canada has 7.7% of the world's forest cover and the Province of Quebec encompasses around 25% of the Canadian forest (MFFP, 2017). To manage this resource, the Quebec Ministry of Forests, Wildlife and Parks (*Ministère des Forêts, de la Faune et des Parcs*, MFFP) implemented the Sustainable Forest Management Act in 2013 - Chapter A 18-1 - (Légis Québec, 2013). This act provides wood supply guarantees that are based upon processing mill capacity and available species on each Forest Management Unit (FMU), which represent spatial divisions of the territory under management of forest activities.

The Act establishes the planning process to be carried out through the integrated forest management plan. The operational plan includes the spatial forest organization, where the areas of forest interventions or harvest blocks are established geographically for one to two years with the measures to reduce negative effects of the harvest. Planning is performed for potentially harvestable areas by watershed, which represent twice what is required for the harvest of the year. With this wide range of options, companies make their selections and develop their activities according to their economic and transformation requirements. Based upon the plan, the areas that are finally selected are presented in the annual forest management activities program (PRAN), with yearly details of blocks within the harvest sites, their locations, sizes and shapes, harvesting practices, and infrastructure (roads).

In the context of annual preparation and programming, companies within the territory agree upon which available sectors will be harvested in the coming year; the MFFP ensures that their selections respect the strategy and harvesting permits that specify volume and species requirements. Spatial determination of harvest blocks serves as the main resource from which companies create their logistical work-steps. This procedure must include transportation schedules, road construction and maintenance programs, and wood flow between forest and the mills. It considers the weather affecting harvest operations in terms of accessibility of both roads and harvest areas and makes sure that these factors fulfill the demand (Karlsson *et al.*, 2003). After harvesting, companies are required to submit a complete annual report that includes all activities that were performed in public forests, including harvest sites, silvicultural activities such as planting, and infrastructure construction. This report facilitates MFFP monitoring prior and following forest activity (Légis Québec, 2013).

1.3 Ecosystem Management in Quebec

Forest planning in Quebec, as defined by the new legislation (Chapter A 18-1, Légis Québec 2013), has established and ecosystem forest management (EFM) of publicly owned forests. This multi-objective approach implements sustainable forest management by ensuring responsible stewardship of the territory's resources, ensuring the supply of wood to processing companies, and directing forest protection activities. The objective is to reduce the differences between natural and managed forests, as inspired by the natural dynamics of the forest (Ministère des Forêts de la Faune et des Parcs, 2015). Natural disturbances promote biodiversity within ecosystems because they change structural and functional resource conditions, thereby allowing regeneration and release of suppressed trees (Attiwill, 1994). By knowing the disturbance's characteristics (severity, size, frequency), it is possible to establish the natural dynamics of the forest in each region and define the harvesting practices that would subsequently imitate natural spatial patterns, together with the irregular shapes and sizes of the disturbances (Bergeron *et al.*, 1999; Gauthier *et al.*, 2008; Latrémouille *et al.*, 2013).

Bioclimatic domains represent a higher level in the hierarchical ecological land classification system of western Quebec, which is used as a tool for planning forest operations and management. The bioclimatic domains represent the combination of the potential vegetation and physical characteristics of the territory (MRN, 2003). These follow a gradient running from North to South, moving from the dominance of coniferous species to that of broadleaves, to describe different forest compositions and dynamics.

Natural disturbances and harvesting practices are closely related to the north-to-south gradient in Quebec's bioclimatic domains (Bergeron *et al.*, 1999). Natural disturbances can be divided at the stand level in those that affect the forest overstory (e.g., insect epidemics, windthrow, and tree falls), which are more common in southern domains, and those that affect the tree canopy, soil layers and natural regeneration (e.g., catastrophic wildfire), which occur in northern domains. Fire disturbance variability is characterized by a combination of size, frequency and severity (Bergeron *et al.*, 2002). Harvesting practices differ between bioclimatic domains in western Quebec, as described by Moulin (2018), who further noted that clear-cutting is the most common harvest practice in the north domain while partial cuts are more commonly found in the south domain.

The spruce-feather moss domain is present in the North and is characterized by mono-specific coniferous populations of black spruce (*Picea mariana* [Miller] BSP). Together with balsam fir (*Abies balsamea* [L.] Miller) and jack pine (*Pinus banksiana* Lambert), this species represents 88-94% of stand volume. The fire regime is characterized by high frequency and severity and covers extensive areas, making wildfire the most common natural disturbance. Hence, the harvest practice that is used to imitate it is clear-cutting, which is characterized by agglomerated and greater areas. Conditions for clear-cutting harvest areas in the spruce-feather moss domain specify agglomerations of areas that are less than or equal to 150 hectares (MRN, 2013).

The balsam fir-white birch and balsam fir-yellow birch domains represent the transition between the spruce-feather moss forests in the northern zone and the broadleaf forest in the temperate zone. These are characterized by mixed forests that are composed of birches and poplars, together with black spruce, jack pine and firs, which constitute around 60% of stand volume (MRN, 2013). The fire regime in these domains is characterized by lower severity and recurrence. Thus, agglomerated, large areas of clear-cuts are replaced with harvesting in small and scattered areas. In the balsam fir, white or paper birch (*Betula papyrifera* Marshall), and yellow birch (*B. alleghaniensis* Britton) domains, clear-cuts are created with respective restrictions of 50, 100 and 150 hectares. These restrictions depend upon the percentage area being harvested (70%, 90% or 100%), and the species that are present in the stand (mainly conifers). The balsam fir-white birch and balsam fir-yellow birch domains could also be affected by disturbances, such as wind throw and insect epidemics; therefore, the harvest practice that is typically used to imitate these disturbances is partial cutting (MRN, 2003).

The sugar maple (*Acer saccharum* Marshall) domain is a mixed forest that exhibits a greater diversity of species, a greater presence of broadleaves (57 to 67% occupation) and always includes maple species (MRN, 2013). Natural disturbance dynamics are dominated by the occurrence of wind throws (minor areas) and single tree falls of old individuals, which generate small canopy- gap dynamics in the forest (MRN, 2003; Vepakomma *et al.*, 2008). The harvesting practices that have been applied to imitate these disturbances are selective and shelter-wood cutting (Légis Québec, 2013). In the sugar maple domain, the clear-cuts are created with area restrictions of 25, 50 or 100 ha, depending upon the percentage area being harvested (70, 90 or 100%) and the harvest practice that is being applied. In this domain, more dispersed harvest patches are created due the nature of the forest (Gouvernement Québec, 2017).

1.4 Performance

The concept of performance refers to the accomplishment of a task that is measured against levels of accuracy, completeness, cost and speed (Shannon, 1998). Given that performance is mostly based upon perceptions, it must be defined in terms of setting tangible goals, developing key performance indicators, then defining, tracking and measuring their suitable metrics, and making managerial adjustments that anticipate the expected results (Drolet et LeBel, 2010; Vom Brocke et Rosemann, 2010).

The importance of measuring performance is identifying possible elements for improvement and be competitive. This is especially important in the forest industry in Canada because the nation has the largest trades balance at the world level (data from 2013) yielding $19.3 billion annually. In 2017, the sector accounted for 7.2% of national exports (Natural Resources Canada, 2018). In the Province of Quebec, there are 287 primary processing companies and nearly 1500 secondary and tertiary processing companies, which generate around 90 000 direct jobs in wood products, furniture and paper manufacturing, together with printing, forestry and exploitation (MFFP, 2017).

Performance could be measured using non-efficiency indicators, such as product quality or client satisfaction, which are practices that emerged recently to integrate the different dimensions of the business. Traditional performance has been measured by financial indicators, which often have greater importance at strategic planning levels (Gunasekaran *et al.*, 2001). Using financial measures of performance is advantageous because they represent elements of evaluation that will help to manage effective and efficient operations. Moreover, they are used as a mechanism of control and motivation. Efficiency is thus the major objective of any business organization, including the logging sector (Austin, 2002). In the forestry sector, the indicators that are often used to measure performance are cost per unit measurement, profitability, revenues, wood procurement costs, and net present value (Borges *et al.*, 2017; Holmesa *et al.*, 2002). Profits and wood procurement costs are the simplest measures that can be directly obtained from the activity.

Performance can also be measured through the evaluation of efficiency, which assesses how revenues in the forest harvesting process are translated into outputs, e.g., tonnes of wood that are produced. This method allows us to not only examine performance on a cost basis, but also to examine components of the forest activity. Measurements of the effectiveness of transforming the inputs of the forest harvesting process into outputs translate into a measure that can be used by management to identify factors and conditions that positively or negatively affect performance (Drolet et LeBel, 2010; LeBel et Stuart, 1998).

Components of forest harvesting can be divided into two categories, i.e., those that are associated with the operational activity of harvesting (non-spatial variables) and those that are derived from the spatial patterns of the harvesting units (spatial variables). Within the first category, we can include direct variables of harvesting, such as machinery, and the silvicultural treatment (thinning, total or partial cutting), administrative costs, staff, contractor teams, transport of wood (types of vehicles, capacity, fuel), and number of companies and their employees (Béland *et al.*, 2009; Groupe Del Degan Massé, 2016).

The variables that are associated with the spatial organization of harvest sites are average size, distribution and agglomeration. How merchantable and economically harvestable wood quantities are geographically located relative to one another determines their cost of extraction from roadside to mill (Baskent, E.Z. et Jordan, 1991). The literature reports that widely distributed patches would be more expensive (road cost per cubic metre) than those that are geographically concentrated (Baskent, E.Z. et Jordan, 1991). Thus, roads are one of the largest and most crucial elements of the harvest activity; literally and figuratively, roads link together all activities on the site. The industry is dependent upon an efficient road network to provide access to harvest areas. Transportation is a major part of forest operations, constituting up to 40% of operational costs (D'Amours *et al.*, 2008). Planning of roads involves both their construction and maintenance. The costs depend directly upon the length of roads and the average volume of wood conveyed per kilometre of road (Béland *et al.*, 2009). The road maintenance costs vary according to the season when the road is used. For the winter roads, additional machinery is needed for maintenance and removal of snow, in contrast to summer roads. Machinery on summer roads requires constant monitoring to reduce its impacts on the soil and, thus, maintenance costs are higher (Grenier *et al.*, 2010). Due to the different patterns of harvest throughout the bioclimatic domains of Quebec, forest companies must create strategies to deal with a given spatial organization and to make the business profitable.

1.4.1 Benchmark method

For any organization, including forestry companies, continuous improvements in the levels of performance will make the company more competitive (Shannon, 1998). Comparisons have emerged as an administrative and managerial tool, which allows the organization to compare its performance with peers. Thus, the Benchmarking technique has arisen. Benchmarking is a process of searching and implementing best practices at the best cost, based upon collaboration among several organizations where the principle is to identify a point of comparison that is referred to a benchmark (Ettorchi -Tardy *et al.*, 2012). This benchmark can be defined as a reference measurement standard, which is identified as the best achievement in its class (Lema et Price, 1995). Benchmarking is, therefore, a management and evaluation tool where a given organization’s practices are compared with those that are used by the best representatives of the field in question. This comparison does not have a formalized methodology. It is carried out with the specific objective of developing recommendations that would identify and improve good practices, thereby achieving greater performance (Pitarelli et Monnier, 2000). The objective of benchmarking ensures that the best practices are being applied through an ongoing process of planning, analysis, integration, and action. This tool allows proposals to be generated that result in concrete actions, creates strategy and policy recommendations, and gives managers the ability to operate effectively (Pitarelli et Monnier, 2000).

There are two core types of benchmarking (Rolstadås, 1995). Benchmarking can be a process that is internal to an organization, or an one that arises externally through comparison and competition with other organizations (Lema et Price, 1995). Whether internal or external, the steps are benchmarking are implemented in terms of focusing on process, strategy or performance.

In the forest industry, a competitive comparison is often used among companies and regions. When the best representatives of the field are defined, this establishes a model with which the organization can be compared; this model will be the standard for determining differences in performance among companies (Bruno, 2008). Within the forest sciences, benchmarking has been used in different ways, i.e., to establish benchmarks of forest characteristics or to perform analyses of the forest industry. Spinelli *et al.* (2010) inventoried different effects of traditional harvesting systems in Mediterranean forests of central and southern Italy to create the benchmark value. Hoover *et al.* (2012) defined benchmark values of carbon that was stored in different compartments of old-growth New England forests (United States). Other studies have focused upon the pulp and paper industry in comparisons of energy consumption (Rogers *et al.*, 2018), or on competitiveness of harvesting costs and operations at a global scale (Di Fulvio *et al.*, 2017).

The different statistical techniques that are used for performing efficiency measures and benchmarking comparisons can be either parametric, such as the stochastic frontier approach (LeBel et Stuart, 1998), or nonparametric. Nonparametric analyses have fewer restrictions in their underlying assumptions, do not require prejudgments values of relative importance of the variables, making them easy to apply. This analysis is performed through Data Envelopment Analysis or DEA (Salehirad et Sowlati, 2005).

1.4.2 Data Envelopment Analysis

DEA is a tool for managers and has been used in different fields (Hollingsworth, 2013; Liang *et al.*, 2018; Macpherson *et al.*, 2013; Quintanilha et Ho, 2006; Zhu *et al.*, 2018). A key characteristic that makes DEA appropriate for benchmark activities is that it extends the concept of productivity and efficiency to cases with multiple incomes and multiple outputs. Inefficiency that is detected and quantified by the analysis is the measure of distance from the production frontier of best practices that would be used as the benchmark. These estimates permit low-performance values that are based upon aggregate information of the activity to be identified. Since this information is relatively easy to obtain, the DEA method results in low-cost acquisition of pertinent information (Homburg, 2001).

DEA was first presented by Charnes *et al.* (1978) as a linear programming method for comparing the performance of a set of entities. The entities are referred to as Decision-Making Units (DMUs), which convert multiple inputs into multiple outputs. Within the realm of forest activities, the DMU may represent the contractor team, forestry companies or spatial units, such as regions or sectors. The inputs can cover different classes of variables, including those that are easy to measure (e.g., number of employees, or machinery used) to more complex variables, such as time that is invested by employees in a certain activity. The outputs are generally values of volume of wood and financial indicators, such as wood procurement costs (Charnes *et al.*, 1978). A line is formed in the solution space that connects the most efficient observations, or DMUs. This line forms a shell or envelope, which bounds the observations in the data set. The efficiency of observations is then determined by measuring their distance from the best practice frontier formed by the line (LeBel et Stuart, 1998). In Figure 1.1, the simplest case is exemplified with one input and one output; the line that intersects the DMU_2 unit is the production frontier of best practices that the DEA model establishes through comparisons among the observed DMUs. All other DMUs are inefficient because they are not at the production boundary; their distances to the production boundary suggest where future improvements can be focused and made (Homburg, 2001).

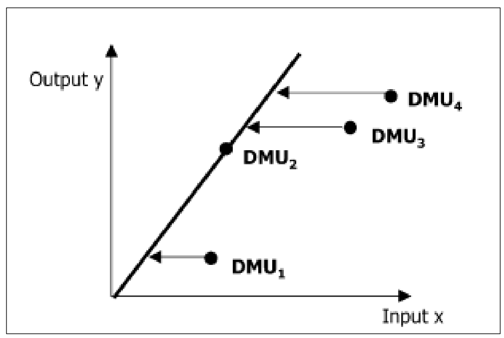


Figure 1.1 Data Envelopment Analysis (DEA) case of one input and one output presented by Homburg (2001).

The original model of the DEA assumed a constant return to scale (CRS), meaning that each increase in the inputs also generates a proportional increase in the outputs, i.e., aggregate efficiency. When variable return to scale (VRS) is assumed, the model changes and the measure is called pure technical efficiency, which is defined as the ability of a DMU to utilize its limited inputs to produce the desired outputs. This ability is influenced by technology and equipment. The ratio of these two efficiencies is scale efficiency, which reflects the inefficiency due to the DMU scale of operations and size (Salehirad et Sowlati, 2007).

The use of DEA is desirable for several reasons. First, DEA is capable of incorporating multiple inputs and multiple outputs as a result of linear programming. Second, there is no need to assign weights to the different inputs and outputs. Last, the measurement units of the different inputs and outputs do not need to be in the same category (Mohammad S *et al.*, 2010). Another feature of DEA is its ability to calculate potential improvements for inefficient units; DEA constructs efficient targets for inefficient units according to the performance of their peers. This is an essential tool for improving policymaking and for benchmarking a set of units (Salehirad et Sowlati, 2006).

In the forest industry sector, DEA is frequently used in surveys of sawmill efficiency from Brazil (Macpherson *et al.*, 2009), the United States (Helvoigt et Adams, 2008), and Canada (Salehirad et Sowlati, 2005; Upadhyay *et al.*, 2012). Also, DEA has been used in the pulp and paper sector (Alfredsson *et al.*, 2016; Hailu et Veeman, 2001; Jauhar *et al.*, 2015; Lee, 2005; Rogers *et al.*, 2018). Other studies have shown comparisons of the forestry industry across European nations to evaluate the performance of the Slovak sector (Kovalčík, 2018), harvesting and marketing activities in Iranian forest (Limaei, 2013), and log contractor efficiencies in the southern United States (LeBel et Stuart, 1998). In Canada, only one study of the harvest sector using DEA analysis was performed at the level of the country. Hailu et al. (2003) had examined the logging industry for the period 1977-1995 based upon technical efficiency, technical change and productivity growth for six provinces with operations in the boreal forest. The scale of the analysis was broad and only road distances were the spatial characteristics that were evaluated. Distance exerted a negative effect on overall efficiency, indicating that spatial variables could have an important effect on the efficiency of the harvest sector.

1.5 General objectives

The objective of this study is to compare actual forest management strategies, focusing upon the spatial organization of the harvests that are performed in different forest management units (latitudes) in western Quebec. The comparison is based upon a benchmarking method that focuses on efficiency. The forest management strategies are described in terms of spatial variables such as the area and shape of harvested sites and dispersion of harvested stands, together with non-spatial variables of forest management, including harvest practices (partial cut or clear-cutting), wood volume harvested per species, and other variables that are associated with the forest sector, such as kilometres of constructed roads. Efficiency of the management regime is evaluated according to the wood procurement cost ($\$/m^3$).

1.5.1 Specific objectives

- Documenting and selecting non-spatial variables and other associated variables (input) that affect efficiency (e.g., wood procurement costs)
- Identifying spatial variables (e.g., shape index, patch size, juxtaposition) that affect efficiency (e.g., wood procurement costs and profit margins), based upon spatial footprints of forest practices over one year along a North-South gradient in western Quebec.
- Creating a correlation matrix to select the most relevant spatial and non-spatial variables.
- Determining relationships between non-spatial and spatial variables to perform a benchmarking analysis along the North-South gradient in western Quebec.
- Identifying practices that affect efficiency in one region along the gradient and developing recommendations to generate an action plan that would improve performance in another region.

CHAPTER II

EFFECTS OF SPATIAL BOREAL FOREST HARVESTING PRACTICES ON EFFICIENCY THROUGH A BENCHMARKING APPROACH IN EASTERN CANADA

2.1 Abstract

In eastern Canada, harvesting practices and spatial organization of harvested sites are modulated according to ecosystem forest management objectives. We determined how spatial organization affects efficiency by evaluating wood procurement costs. A comparative analysis of benchmarking was presented using a non-parametric technique, i.e., data envelopment analysis (DEA), which allows multiple variable analyses of different factors. A database of 50 harvested sites during the periods 2015-2016 and 2017-2018, located along a North-South latitudinal (46° to 50°) gradient, was constructed with variables describing spatial organization (roads and dispersion of patches) and operational aspects (wood procurement costs). The evaluated efficiencies show high values greater than 70%. Efficient and inefficient units were observed in all sites along the latitudinal gradient, where causes of inefficiency were dispersion of the patches (proximity index), distance to the mill, and the number of kilometres of built roads. Harvesting areas exhibit a wide range of spatial organization patterns. When efficiency values were arranged by latitudinal location, northern sites exhibited a lower value of overall and scale efficiency due to the nature of the wood value harvested, and developed road density of the zone.

Key words: Fragstats, DEA, spatial index, efficiency.

2.2 Introduction

Forests provide a wide range of social, environmental, and economic benefits to society (Mobtaker *et al.*, 2017). Canada has 7.7% of the world's forests and is the world's largest exporter of forest products (Natural Resources Canada, 2018). Timber harvesting is the first link in the wood supply chain for other branches of the industry and is the sector that is responsible for field activities, wood extraction and transport. This operation directly affects the cost and supply of raw materials to the wood product manufacturing industry (Obi et Visser, 2017b).

Within a given harvest area, forest management is the process by which the planning and implementation of the activity are carried out based upon legal, social, and technical regulations (FAO, 2018). In eastern Canada, particularly within the province of Quebec, ecosystem-based forest management set into law in 2013 (Légis Québec, 2013). Quebec contains 25% of Canada’s forests; in turn, 92% of the provincial forest areas is in the public domain. Ecosystem forest management (EFM) is an approach that aims to maintain the health and resilience of forest ecosystems by focusing upon the reduction of gaps between natural and managed landscapes that maintain ecosystem functions as well as social and economic benefits to society (Gauthier *et al.*, 2008). To meet this aims as well as financial objectives, current forest harvesting practices are modulated according to species composition, natural disturbance regimes and timber demand (Bergeron *et al.*, 1999). Ecosystem management results in the application of different forest management strategies, according to the development of the forest that is eventually being harvested. In northern areas, the forest is dominated by conifers, specifically black spruce (*Picea mariana* [Mill] B.S.P.), and while southern forest is dominated by broadleaf trees, mainly maple sugar tree (*Acer saccharum* Marshall). Mixed forests lie between these two groups (MRN, 2013). Silvicultural treatment depends upon the natural disturbances that characterize each forest type: clear-cutting is more common in the north, emulating fire disturbances, while partial- and shelterwood-cutting are mainly used in the south to emulate small-scale disturbances typical of this area and forest gap dynamics (Bergeron *et al.*, 1999).

Spatial organization refers to the arrangement of harvested patches and their interconnections, thereby determining the structure of the landscape (Baskent, Emin Z. et Jordan, 1995). Spatial organization can be measured using a range of indices. These focus on the patches in terms of their average size and shape, and relationships among the patches, including inter-patch distance and their degrees of aggregation or dispersion (Baskent, Emin Z. et Keles, 2005).

The distribution of patches within the harvested site must deal with environmental concerns, together with their influence on the profitability of the forest industry. Spatial planning is recognized for the economic benefits that it can bring to the forest business (Baskent, Emin Z. et Keles, 2005), such as reduced road construction and reduced operating costs (Baskent, E.Z. et Jordan, 1991; Öhman et Eriksson, 2010). Cost reduction is the main objective of any business organization and can used as a financial indicator (Austin, 2002). Constant evaluation of financial indicators are required to determine how well the industry (in this case, the forest industry) is performing that would make it both more competitive in the market and in strategic planning (Gunasekaran *et al.*, 2001). Spatial planning is especially important in Quebec, where the provincial government is responsible for forest management across a very large land surface (about 828,000 km^2).

"Benchmarking" is a management tool that is frequently used to evaluate performance and efficiency through comparisons. Benchmarking is an evaluation technique where practices implemented by a particular organization are compared with those that are used by the best representatives in the field in question, i.e., the Benchmark (Ettorchi - Tardy *et al.*, 2012). The objective of benchmarking is to ensure that the best practices are being applied throughout a process that is undergoing constant change and evaluation (Pitarelli et Monnier, 2000). There are different statistical techniques to calculate efficiency measures and to perform benchmarking comparisons, which can be parametric (Chen *et al.*, 2020) or non-parametric methods. The most frequently used non-parametric method is Data Envelopment Analysis, i.e., DEA. This is a low-cost information method (Homburg, 2001). Further, DEA is appropriate for comparisons, given that it extends the concept of productivity and efficiency to cases with multiple inputs and multiple outputs from different nature. Moreover, it is a linear programming method that produces a metric that can be used by management to identify factors and conditions that positively or negatively affect efficiency (Drolet et LeBel, 2010; LeBel et Stuart, 1998). DEA, allows identifying the opportunities for improvement in the process being evaluated and according to the resources being studied, based upon the performance of their peers. DEA evaluates a set of entities that are referred to as the "decision making units" (DMUs) that perform the same task, after which a comparison is made among them to find the best performing unit among those being evaluated. The model provides a relative efficiency by assigning a maximum value of 100% to the most efficient one (Limaei, 2013). Increasing efficiency must be implemented through the use of technologies and management decisions to reach optimum levels of the inputs. This a significant tool for improving policymaking (Salehirad et Sowlati, 2006).

DEA has been used in forestry harvesting sector for performance comparisons among countries (Kovalčík, 2018), evaluations of harvesting and marketing activities (Limaei, 2013), forest resources allocation (Li *et al.*, 2017), and log yards evaluation (Trzcianowska *et al.*, 2019). The most cited studies are for contractor's team activity (Bonhomme et LeBel, 2003; LeBel et Stuart, 1998; Obi et Visser, 2017a, 2017b). In Canada, a study of the harvest sector using DEA analysis was performed at the level of the country by Hailu et Veeman (2003), they examined the logging industry from 1977 to 1995, based upon technical efficiency, technical change and productivity growth among six Canadian provinces with forestry operations in the boreal biome. The scale of the analysis was broad and only road distances were evaluated as a spatial variable.

These distances exerted a negative effect on overall efficiency. This indicated that spatial variables could have an important effect on the efficiency of the harvest sector and that could be identified using the DEA analysis.

In this study, we aim to measure the efficiency of forest harvesting activities based on a spatial organization of harvested sites, here in after DMUs, among the latitudinal gradient, and the financial and non spatial variables by a non-parametric benchmarking approach (DEA). For the purpose of this study the DMUs are define as a cluster of several blocks during the planning of the activity, and which can be characterized by spatial and managerial variables. We hypothesised that the efficiency of the northern harvested site will be higher because the EFM allows larger and aggregate clear-cuts that will produce lower operational cost and therefore a better financial result. Based on the results we will able to suggest potential adjustments to increase the efficiency of forest activities, especially in the eastern Canadian boreal forest. DEA is a relevant approach that could be more widely adopted by forest managers and government decision-makers both locally and nationally.

2.3 Materials and Methods

The study area encompasses different forest compositions along a North-South gradient, covering the latitudes from 46°N to 51°N. With black spruce as the dominant conifers in the north, while different broadleaf species, including maple sugar, dominate in the south. The study was located in three administrative regions of Quebec: Abitibi-Temiscamingue, Nord-du-Quebec, and Outaouais (Figure 2.1). Within 50 DMUs between 2015 and 2018 (11,159 ha), spatial and non-spatial variables were measured to describe the most representative year of activities in this territory among the five-year plan. Specialized plans, such as salvage logging following natural disturbances (fires and windthrow sites) were avoided. These 50 DMUs were chosen due to the availability of initial data, ensuring that all latitudes had a minimum number for comparisons, DMUs smaller than 100 ha were eliminated.

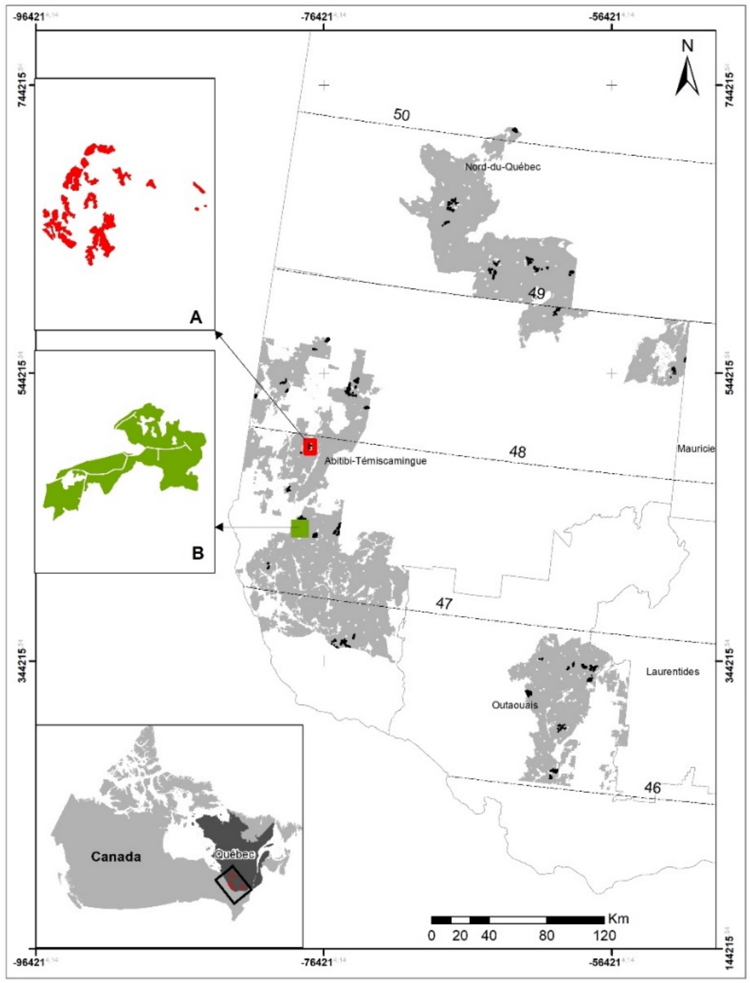


Figure 2.1 Localization of the DMUs in eastern Canadian boreal forest along a North-South gradient (46° to 50°N). Enlarged inset areas 1.a) and 1.b) respectively refer to dispersed DMUs and agglomerated DMUs.

Spatial and non-spatial variables were computed for each DMU. Provincial government forestry agency data describing harvest volume and species volume potential, wood procurement costs, product values, and spatial characteristics were used to construct the database. Fourteen spatial variables (Table 2.1), which quantify the spatial configuration and composition of each DMU, were calculated using the spatial pattern analysis program Fragstats version 4.2 (McGarigal, 2015). Distance to the closest mill also was calculated, (D'Amours *et al.*, 2008), together with the number of road construction (km) that was reported by DMU, due to the importance of hauling costs and forest roads. Thirteen non-spatial variables included administration costs, harvest costs, product values, taxes, hauling costs, and the total volume that was harvested by species groups (conifers and broadleaf) and by treatment (total or partial cut) (Cost are detailed in Appendix E).

In Figure 2.2, we show the distribution of the mean area of the patches inside the DMU (AREA_MN) with 13 ha, ranges from 3 ha to 35 ha, with an extreme value of 68 ha. Total area (Area total) averages 223 ha and varies from 20 ha to 600 ha. The number of patches (NP) varies from 2 to 55, with a mean of 22. The density of patches per hectare (PD) has a mean value of 11 patches per hectare. The landscape shape index (LSI) is dimensionless; if its values are higher, there is greater disaggregation; it varies from 2 to 14, with a mean value of 9. Nearest-neighbour (Euclidean) (ENN MN) distance varies from 0 to 300 m, with a mean of 89 m. For non-spatial variables, the mean value of total volume (Volume) per DMU that was harvested is 27,000 m^3 (range: 1,400 m^3 to 67,500 m^3). The percentage of conifers (% Conifers) varies from 0 to 100%; across the DMUs, mean conifer cover is 67%. The percentage of clear-cut area (% Clear-cut) also varies from 0 to 100% based upon overall area per DMU, with a mean value of 77%. Taxes average \$7/m^3 (range: \$3/m^3 - \$14/m^3). Product values of the wood on the DMUs average \$64.4/m^3 (range: \$57.9/m^3 - \$79.9/m^3).

Table 2.1 Description of the spatial and non-spatial variables for the study area.

Variables		Description
Inputs		
Spatial	**CODE**	
area Indices *	AREA_MN	Mean area of harvest patches (ha) by DMU.
	Area Total	Total area of the DMU (ha).
	NP	Number of patches.
	PD	The number of patches in 100 ha; defined as patch density.
	LPI **(X5)**	Largest patch in the DMUs, expressed as a percentage and measuring dominance.
Shape index*	LSI	Landscape shape index, a measure of complexity and dispersion in the landscape.
	SHAPE_MN	Average shape index of patches; measures complexity of patch shape compared to that of a square
Indices of juxtaposit io n and dispersion *	PROX_CV **(X4)**	Coefficient of variation of the proximity index, measures distance between patches; if the DMUs are heterogeneous, the variation is high.
	ENN_MN	Nearest-neighbour mean (Euclidean) distance; shortest straight-line distance between patches.
	CONNEC	Connectivity index, the number of functional unions among patches as a percentage; 0% when it is 1 patch and 100% when all patches are connected.
	CONTIG_MN	Mean contiguity index, average of spatial contiguity of cells in patches.
	MESH	Mesh index, area of patches to reach the split level, related to index below (ha)
	SPLIT	Split index is the number of patches with a constant area that represent the level of separation in the landscape.

Table 2.1 Continuation

Variables		**Description**
Distance to mill	Distance to mill (X3)	Distance (km) between the harvest block and mill that consumes most of the wood in the zone.
Constructed roads	Constructed roads **(X2)**	Total Road construction kilometres by DMUs.
Non-Spatial		
Bioclimatic domain	Domain	The location of the DMUs in the ecological classification reference system of Quebec
Volume	Volume	Total volume of harvested wood in cubic metres (m^3)
Type of harvest practice	% Clear-cut	Proportion of Clear-cut by DMUs as a percentage
Stand type	% Conifers	Type of dominant species in the DMUs (coniferous and broadleaf) in percentage
Wood volume per hectare harvest	Wood volume per hectare harvest **(X1)**	Cubic metres of wood harvested by hectare in each DMU (average) (m^3/ha)
Wood value	Product value	Wood product value presented in the DMUs (\$/m^3)
Taxes	Taxes	Stumpage cost for public forests (\$/m^3)
Harvested cost	Harvest cost	Cost of cubic metre by harvesting activities (\$/m^3)
Cost of roads	Roads cost	Construction and maintenance cost of roads used to extract the wood during a period (\$/m^3)
Cost of transport	Transportation cost	Hauling cost by cubic metre (\$/m^3)
Profits	Profits	Financial expected advantage after reducing total wood procurement cost of wood's values (\$/m^3)
Output		
Total wood procurement cost	Total Cost	Sum of harvest cost, other cost, taxes, cost of roads and cost of transport to the mill by DMU (\$/m^3)
Transformed total wood procurement cost	**Y**	Transformed of the total wood procurement cost transformed was a subtraction operation 100 \$ - total wood procurement cost (\$/m^3).

Note: * more details are available in McGarigal (2015).

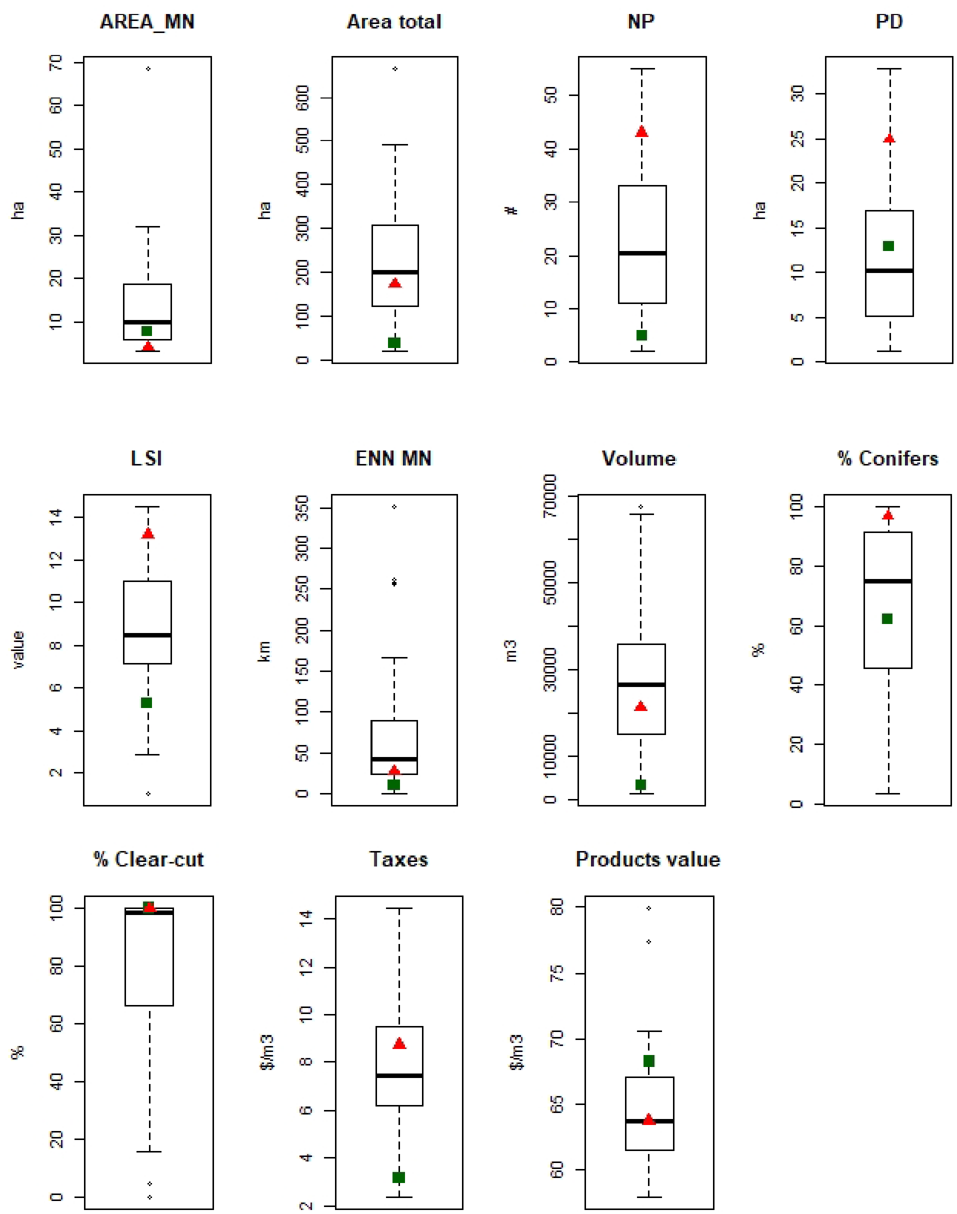


Figure 2.2 Box plots of variables for the 50 DMUs (for more details, see Table 2.1). The thick line represent the median (50th percentile). The square represents the data among the 25th and 75th percentile presenting the 50% of data are located in this range. The extended lines are the variability outside the upper and lower percentiles. The points are extreme values. The example from figure 2.1 is presented as the red triangle showing the dispersed DMU (Figure 1a) and the green square the agglomerated DMU (Figure 1 b).

2.3.1 DEA analysis

Two measures are available in the DEA. One presented by Charnes, Cooper and Rhodes (1978) that assume a constant return to scale (CRS); for each unit increase in the inputs, a proportional increase in the outputs is generated. This measure is called aggregate or overall efficiency, which represents the ratio of potential work and actual work that is integrated into the process of wood procurement activities (Kleiner et Powell, 2017). The second is when variable return to scale (VRS) is assumed, which means that the response of the outputs could be less than proportional (decreasing returns of scale) or greater than proportional (increasing returns of scale) (Boussofiane *et al.*, 1991). This measure is called pure technical efficiency, as defined by Banker, Charnes and Cooper (1984), as the ability of a DMU to utilize its limited inputs to produce the desired outputs under the influence of technology and equipment. The ratio between these two efficiencies is the scale efficiency, which reflects the inefficiency due to the DMU scale of operations and size, relative unit size, or input transformations that are ineffective with respect to attaining the desired outputs (Salehirad et Sowlati, 2005; Trzcianowska *et al.*, 2019).

An output-oriented DEA model was used in this study to measure the current relative efficiency level. Using available inputs, this efficiency identifies which DMU can maximize the output; in other words, which DMU can achieve a better financial outcome using current spatial organization. The free version of the spreadsheet-based software DEASOLVER LV 8.01 from Saitech Inc available in http://www.saitech-inc.com, was used for the efficiency assessments. This software also provides input targets for inefficient DMUs, represented as slacks of a unit when have input excess. Slacks are related to a unit's capacity to utilize inputs in optimal proportions.

We examined homogeneity within DMUs to determine whether the following DEA assumptions were respected: (1) DMUs are engaged in the same process; (2) the same inputs and outputs are applied to each DMU; and (3) DMUs are operating under the same conditions (Haas et Murphy, 2003). The first and second conditions are satisfied, but the third is not, given that the DMUs of the sample are from different forests. To compensate for non-homogeneity among DMUs, we employ a method that was proposed by Sexton, Sleeper and Taggart (1994). This method incorporates regional characteristics that measure operating conditions external to the process, such as percentage conifers or taxes, which are expected to account for efficiency differences that are not attributable to management. The SST method consists of stepwise, multiple regression on the initial efficiency scores using variables that describe the regional characteristics. Variable outputs are then adjusted using the ratio between the initial values against the predicted, after which a second DEA is run to produce a new set of efficiency scores. These final scores focus upon the relationship between non-homogeneity and true efficiency (Haas et Murphy, 2003; Sexton *et al.*, 1994).

2.3.2 Selection of DEA Variables

Selection of input and output variables is critical because they are constrained by the availability and accuracy of data, the relative independence and correlation of the inputs and outputs, the latter relationship's practical meaning, and fulfilling the objective of the study (Yan, 2019). A Pearson correlation matrix (r) was constructed to eliminate redundant variables. Inputs that were strongly correlated with the output variable were preferable due to their significant influence (Sundberg et Silversides, 1988); linear regression was performed to evaluate the relationships between the inputs and outputs.

Our selected output variable total wood procurement cost was a transformed, using a subtraction operation (100 $ - total wood procurement cost). By managing the variable in this way, we have a variable with positive values. DMUs with lower wood procurement cost value will have higher positive values of this transformed variable.

Reducing costs is one of several important objectives of the forest industry, and it is also a common indicator that is often used as a performance measure that leads to improving profits (Hailu et Veeman, 2003). DEA evaluations should include the factors that globally characterize the production process; in this case, we focus on how spatial organization of the DMU affect the efficiency of financial forest activity. The variables that were included in this analysis reflect aspects related to spatial organization and wood procurement activities. We evaluate the quantity of extracted wood from each DMU and spatial distributions among patches within the DMU, which are reflected in associated road construction and the distance to the mill.

From the Pearson correlation matrix, we selected the variables that exhibited moderate correlations ($r > 0.3$) between the input and output variables (Damanik, 2017; Kao *et al.*, 1993). These variables were; wood volume per hectare, constructed roads, distance, LPI, and PROX CV (Table 2.2) The variables wood volume per hectare (X1) and transformed total wood procurement cost (Y) show the strongest correlation ($r = 0.53$, $p = 0.0001$), if the DMUs have a greater wood volume harvest per hectare, then a higher transformed total wood procurement cost would result. Distance (X2) and constructed roads (X3) are moderate negatively correlated with transformed total wood procurement costs, greater distance and higher road construction costs create a lower value of transformed total wood procurement costs. PROX_CV (X4) and LPI (X5) also exhibit a moderate negative relationship with the transformed total wood procurement costs. The higher the values of PROX CV, the greater the dispersion between patches and the lower transformed total wood procurement costs will be. Based upon multiple regression, the selected variables explain 58% of the transformed total wood procurement costs (Adjusted $R^2 = 0.58$, $p < 0.05$). The number of final variables that were required to run the model follows recommendations, where the number of DMUs should be at least twice the number of inputs and outputs (Kao *et al.*, 1993).

Table 2.2 Pearson correlation coefficients (p-values) for inputs (X1 = Wood volume per hectare [m^3/ha], X2 = distance [km], X3 = constructed roads [km], X4 = PROX_CV [%], X5 = LPI [%]) and outputs Y = Transformed total wood procurement cost ($/m3) among selected DEA variables (see Table 2.1 for details).

	X1	X2	X3	X4	X5	Y1
X1	1					
X2	0.12 (0.417)	1				
X3	0.05 (0.721)	0.06 (0.695)	1			
X4	0.10 (0.493)	0.11 (0.447)	**0.42** (0.0025)	1		
X5	**-0.31** (0.029)	0.01 (0.9305)	**-0.35** (0.012)	**-0.46** (0.0007)	1	
Y	**0.53** (0.00001)	**-0.37** (0.0014)	-0.26 (0.066)	-0.17 (0.232)	**-0.28** (0.048)	1

Note: Correlations significant at p = 0.05 are shown in boldface type.

The distributions of the selected variables for the DEA model are in

Figure 2.3 wood volume per hectare (X1) ranges from 24 m^3/ha for partial cutting to 200 m^3/ha from total clear-cut, with an average of 124 m^3. Distance (X2) ranges from 42 km to 283 km, the highest value belongs to DMU in the north of the study area. Constructed roads (X3) range from 0 km to 17.3 km, with an average of 6 km. The coefficient of variation for the proximity index (X4) ranges from 0% to 246%, with an average of 127%; lower values represent connected patches. LPI (large patch index, X5) varies from 2% to 87%, with a mean value of 29%. The spatial variables were evaluated with the Anova test to verify if they presented differences between latitudes. The results presented in Table 2.3, show that there are no significant differences in these variables.

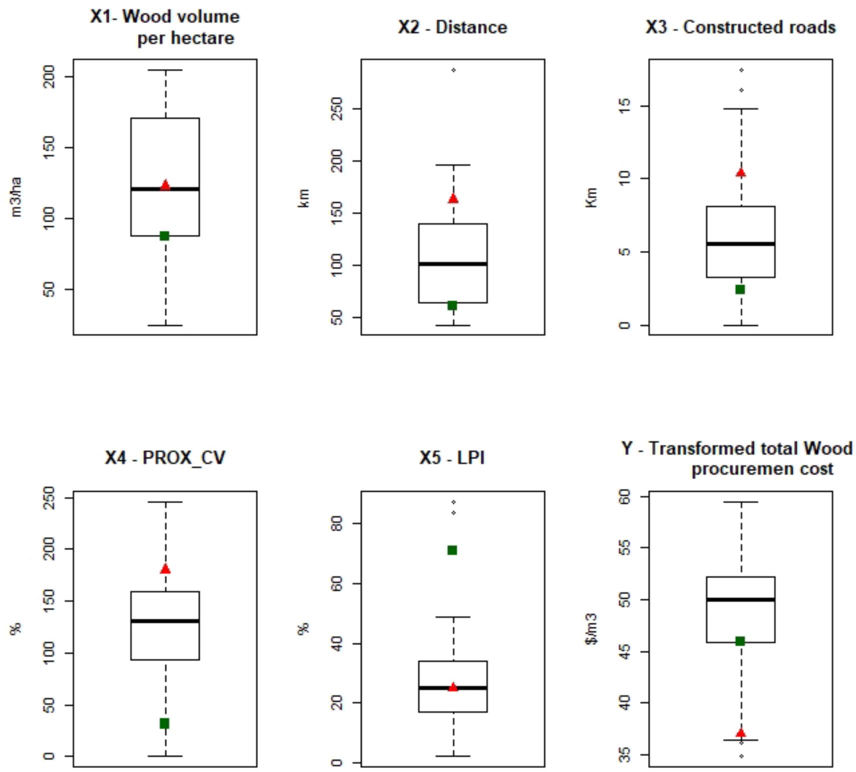


Figure 2.3 Boxplots of selected input variables: X1 = Wood volume per hectare (m3/ha), X2 = distance (km), X3 = constructed roads (km), X4 = PROX_CV (%), X5 = LPI (%), and output total wood procurement cost (Y) used in the data envelopment analysis (DEA). The points show the values from the DMU examples of dispersed DMU (Figure 1a), which are presented as red triangles and agglomerated DMUs (Figure 1b), which are as green squares. Boxplots follow the description detailed in Figure 2.2.

Table 2.3. P values from ANOVA test for the spatial variables among the location of the different latitude evaluated.

Variable	F value	P value
LPI	0.759	0.532
PROX_CV	1.295	0.287
distance to mill	0.622	0.605
constructed roads (km)	1.866	0.149

2.3.3 Compensating for Non-Homogeneity

Before applying the SST method to compensate for non-homogeneity in the DMUs, their efficiency scores according to their latitude range of locations divided from 46°-47°, 47°- 48°, 48°- 49° and 49° - 51° N, was tested with the Kruskal-Wallis test, a non-parametric rank-based alternative to ANOVA (Vargha et Delaney, 1998). The difference among the four groups was significant ($p = 0.025$) for aggregate efficiency (CCR), with a lower value in the north (51° to 49°N) in contrast with the other tree located in the south (from 49° to 46°N). For pure technical efficiency (BCC model), there were no differences among DMUs that were located at different latitudes. Differences in scale efficiency were significant ($p = 0.0004$) and followed the same trend as those for aggregate efficiency.

The aggregate and scale efficiency values were adjusted to compensate for the non-homogeneity prior to implementing the SST method. For adjusting the DMUs to the same conditions, environment variables that describe regional characteristics external to the process were used to explain the differences. From our initial database, the variables that differentiate the characteristics between the forests were percentage clear-cut, taxes, and percentage conifers that present significant differences tested with Kruskal-Wallis ANOVA among DMUs latitudinal locations. The percentage of conifers, percentage of clear-cuts, and taxes show a gradient decreasing from north to south (Figure 2.4). After testing several models using these three variables, the best model that was used to correct the score for the aggregate efficiency (CCR) was a model using the percentage of harvested conifers that depended upon the availability of these species in the territory and a location variable (latitude), which explains 19% of the efficiency score ($p = 0.02$). The two other variables were strongly correlated with the percentage of conifers. A greater percentage of conifers permits more clear-cutting ($r = 0.66$, $p < 0.0001$) and taxes also depend upon the quantity of conifers, species that are more greatly desired by industry and, hence, more valuable ($r = 0.62$, $p < 0.0001$)

(Cayford, 1990). Since the scale efficiency is the ratio of the aggregate efficiency and the pure technique, it was recalculated with the corrected aggregate efficiency values.

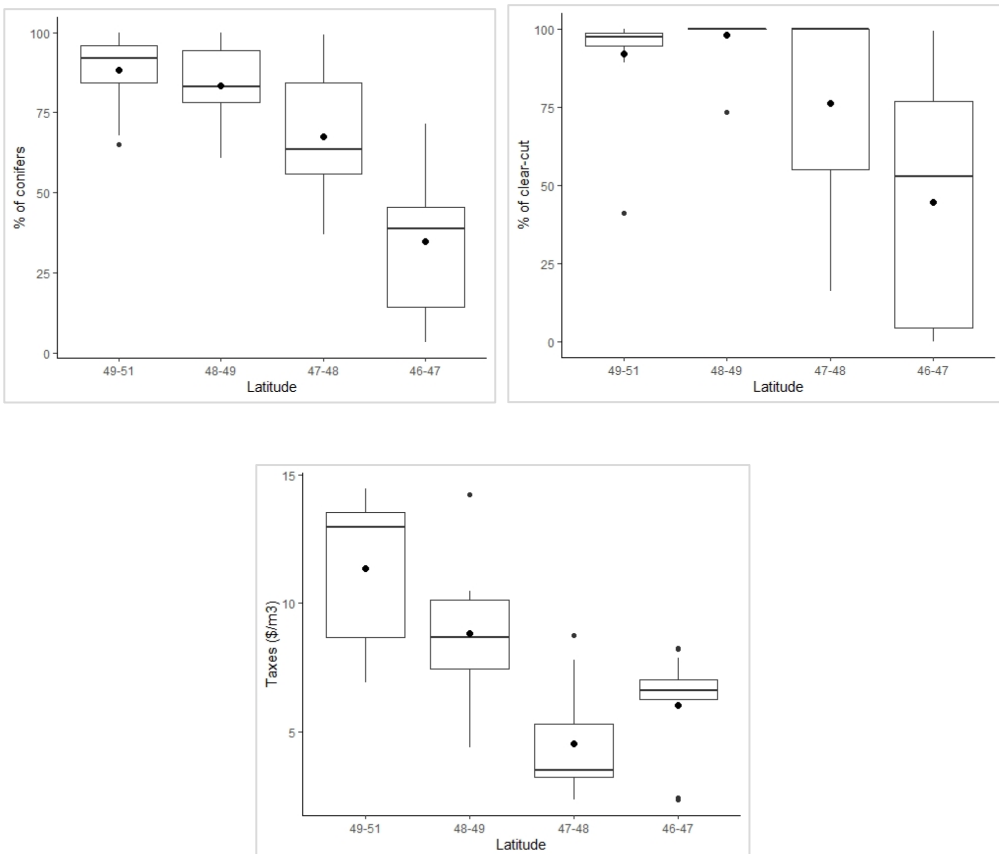


Figure 2.4. Boxplots of variables (% conifers, % clear-cut and taxes $\$/m^3$) used in the adjustment of the data envelopment analysis (DEA) by latitude. Dots present the mean value. Boxplots follow the description detailed in Figure 2.2.

2.4 Results

Results presented in Figure 2.5 summarize the mean values for the aggregate, pure technical and scale efficiencies that were calculated for the 50 DMUs in eastern Canada. They reflect efficiencies of the DMUs under the same operational conditions after integration of the compensating for Non-Homogeneity.

The aggregate or overall efficiency (CCR) has an average (± SD) of 72% ± 23% (median: 69%). Thirteen of the 50 (26%) DMUs are complete efficient (100%), while inefficient DMUs have values of ranging between 97% and 30%.

For pure technical efficiency (BCC), the mean (± SD) is 89% ± 9% (median, 89%); 14 sites (28%) are considered efficient. This efficiency measures the extent to which DMUs can decrease the inputs to produce the desired transformed total wood procurement cost, but having taken into consideration the equipment and technology that are used in the process. Scale efficiency represents the level of efficiency that is only due to the scale of operations, i.e., the relationship between aggregate and pure technical efficiency. The value of scale efficiency is 79%, with a standard deviation of 19% (median 78%); 36 of 50 DMUs are operating below optimal scales. This means that the source of inefficiency on the size of operations is the ability to transform the current inputs (spatial configuration of the DMUs) effectively to a lower transformed total wood procurement cost.

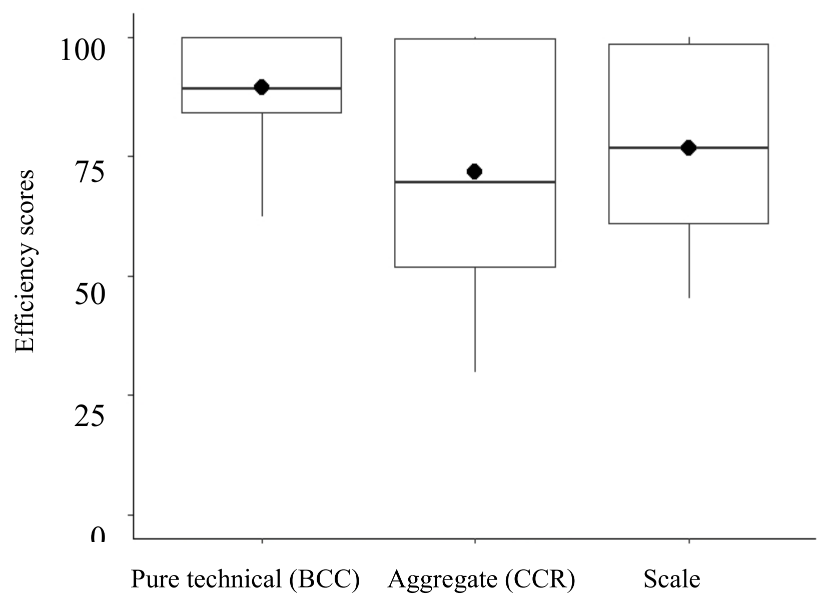


Figure 2.5 Efficiency scores of the DMUs that were examined. Black dots present the mean value. Boxplots follow the description detailed in Figure 2.2.

When we differentiate efficiency values by latitudinal location, they display a tendency of lower values for the DMUs that are in the northern area with higher values towards the DMUs located in the southern forests. In

, we present the final values of efficiency. The values for pure technical efficiency (BCC) do not differ among locations; they vary from 88% to 92%, with more variation for DMUs that are located in the south. After compensating for non-homogeneity in aggregate efficiency (CCR), the mean value for aggregate efficiency in the DMUs that are located at latitudes above 49°N is 60% (± 25%) compared to the rest of DMUs below latitude 49°N where values range between 74% and 75%. Variation is greater for DMUs that are located between 47°N and 48°N (± 28 %), where values of efficiency have a greater range (100% to 29%). Finally, for scale efficiency, the value for DMUs that are above 49°N has a mean value of 68% compared to DMUs below 49°N, where the values are around 80%. Figure 2.6 presents average target reductions for the complete set of DMUs, based upon inefficient DMUs. Targets were established using the BCC model given that it best expresses the use of technology and managerial tools. It was estimated that the variable distance to the mill (X2) it's more efficient with lower values, 29% less than average, which equates to 41 km (range: 2 km - 243 km). Our results suggest that a 37% reduction of the kilometers of constructed roads (X3) would allow an optimal efficiency, equivalent to an average decrease of 2.8 km (range: 1 km - 13 km). The target reduction level for PROX_CV (X4) is a decrease of 21%, which means a final value of 34% for the index (range of diminution: 0.4% - 132%). For LPI, the target is 3% on average for dominance by a bigger patch (range: 0.2% - 16%).

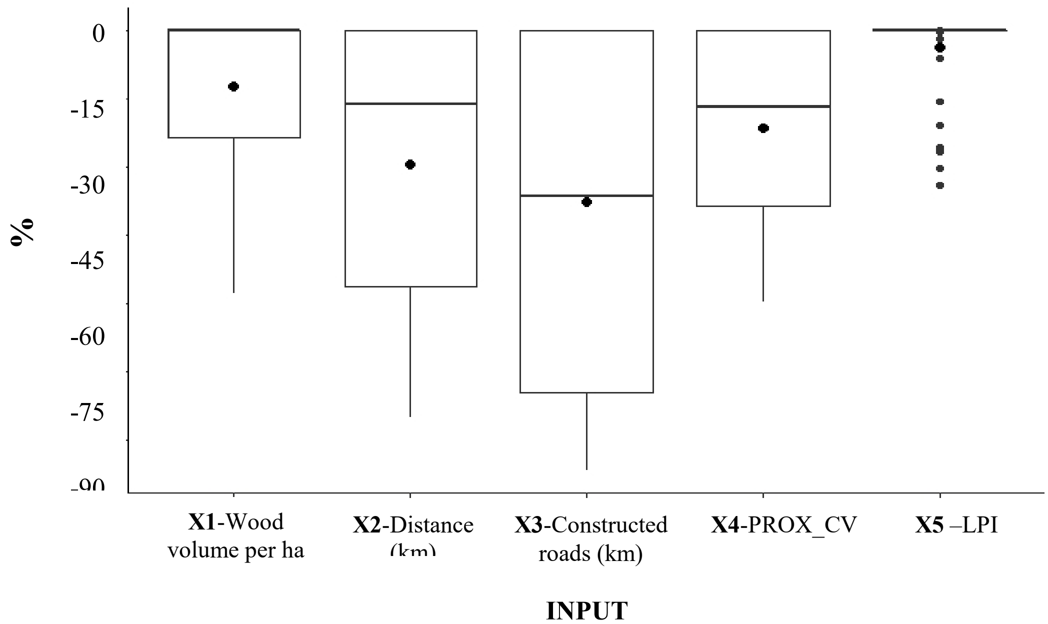


Figure 2.6 Target projections reductions for each input variable according to DEA analysis. Black dots present the mean value. Boxplots follow the description detailed in Figure 2.2.

According to DEA results, constant returns of scale (CRS) are prevalent, with 41 DMUs operating below this scale, this represent there is not need to increase or lower the size and quantity of inputs used in the process. Three DMUs were under decreasing returns of scale; the ability to manage inputs decreases if the quantity of inputs increases. Six DMUs were observed under increasing returns to scale, where output could be maintained at same level by increasing the scale of operations; these do not necessarily refer to the size of inputs, but to the use of more inputs (DEA model output-oriented).

2.5 Discussion

The results show high values of efficiency on average in the DMUs studied, the harvested sites in eastern Canada, the efficiency expressed in how well the current the spatial configuration allow them to maximize the financial outcome in the context of ecosystem management rules. The pure technical efficiency (BCC) have an average of 89% and a low degree of variation (9%). Because this efficiency describes the intrinsic technology of the process, the high value among all the latitudinal location studied shows the advantages of the use of technology and management strategies, which help reduce differences in the territory. The overall or aggregate efficiency (CCR) was of 72% (mean value), which is considered a good value. However, this efficiency has greater variation (±23) and the 74% of the DMUs (37/50) are not able to use the available inputs in transformed total wood procurement in a cost-efficient manner. The reason of that forest industry in eastern Canada creates a year-round balance for planning for harvest sites, where access to remote sites is balanced by nearby sites to compensate for the disadvantages and extra costs of the former, and the availability of mature stands limits the possibility to operate at high efficiency everywhere. From our results, we can see both efficient and inefficient sites across the gradient of sites.

There was no significant difference in spatial variables that were evaluated of the different types of DMUs that were examined in the study (Table 2.3). Harvesting areas do not exhibit a single pattern that depended upon the latitude and ecosystem in which they are found, as have been suggested by EFM. We found areas with concentrated patches as dispersed along the north-south gradient, as also small and bigger areas. There is no tendency for areas harvested at any specific latitude to share a single pattern of spatial organization.

The spatial variables have great importance in determining the efficiency of forest harvesting at lower costs. Despite the great range of variables that were considered, those that were related to roads and to the dispersion of the patches were of greatest importance. Roads represent almost 40% of procurement costs and are essential for providing site access for timber harvesting (Baskent, Emin Z. et Keles, 2005; D'Amours *et al.*, 2008). From our data, road costs stem from construction and distance to the mill; indeed, these costs are the major components of the wood procurement cost. This was corroborated by LeBel et Stuart (1998), who showed that hauling distance was one of the factors that explained efficiency values for contractors in the United States. Road construction (km) depends directly upon the distribution and number of patches. We obtained a highly positive correlation ($r = 0.57$, $p < 0.0001$) between the number of patches and the kilometers of constructed roads within the harvested site, and also moderate with PROX_CV and LPI (Table 2.2). Efficiency is affected by road construction (km) showing a direct relationship with cost (Appendices 2 and 3). Dispersion of the patches is represented by the index PROX_CV; large values mean greater variation in the distances between patches, thereby making the areas more disperse. Dispersion has a clear relationship with the DMUs that have the lowest efficiency values (Appendices 2 and 3). Evidence that aggregating harvesting areas is recognized as a means of reducing the costs of road construction and maintenance (Mathey *et al.*, 2009; Öhman et Eriksson, 2010). The large patch index represents the percentage cover of the large patch that means number patches. This variable shows a positive relationship with wood procurement costs; the bigger, the LPI the more efficient are the DMUs. As expected, larger areas would translate to lower wood procurement cost (Appendices 2 and 3). In Figure 2.1, we present an example of the two extreme cases of DMUs. DMU1 (a) has the lowest efficiency values, with an aggregate efficiency of 48% and pure technical efficiency of 68%. The variables that describe it were the number of 10 km lengths of constructed roads, the distance to the mill is 163 km, the LPI is 24%, and the PROX_CV index is 179. DMU 2 (b) has 100% for both efficiencies, with a value of 2 km length of constructed roads, the distance to the mill is 60 km, the LPI is 70%, and the PROX_CV index is 31.3.

About 19% of aggregate or overall efficiency is explained in by the variable percentage Conifers when we performed the compensation of non-homogeneity with the regression of SST method. The variables taxes, % of clear-cut and % of conifers express the differences between latitudes and help to explain the efficiency values that have been reported. Percentage Conifers that were harvested depend upon the dominant forest type and latitude, with coniferous dominating north, broadleaf dominated the south and mixed wood in between. Taxes change depending upon location according to regulations set out by the Province of Quebec, where the value depends upon the level of infrastructure in the zone and the potential species to be harvested, with higher values in areas with more conifers. Further, the percentage of clear-cut is predominant in the north where conifers are dominant, and where the application of partial cuts is not mandatory is optional (Gouvernement Québec, 2017).

When we examined efficiencies according to different latitudes, there is a tendency for higher efficiency values in the south forest. Yet, it should be noted that efficient DMUs occurred in all forest types across the range of latitudes. While mean efficiency is higher at lower latitudes, these values were accompanied by a higher degree of variation (± SD range: 22% – 28%). Thus, we can find inefficient DMUs among the efficient units in these areas, for example disperse DMU (Figure 2.1a) show a lower value of efficiency of the complete dataset and is found between 47° and 48°N. Southern areas may be more efficient for several reasons. First, the wood extracted have greater commercial value and larger diameters (third forestry inventory) compared to the latter cuts, which is directly related to the % of conifers at that latitude. In the North, the activity is based on extracting greater quantities of wood, but the quality of the wood is lower from trees with smaller diameters (average DBH: 16 cm; (Pamerleau-Couture *et al.*, 2015) compared to tree further south (average DBH: 28 cm; (Angers *et al.*, 2005). Second, the road network is more developed in the south resulting in a smaller number of roads being built; northern areas often must open new roads. Also, distances to the mill tend to be shorter in the south, which makes them more efficient in producing wood with a lower cost. The issues of the volume ratio of wood harvested per km of road, which affects the profitability of opening and maintaining roads (Gharbi, 2014), is lower in this area. Finally, higher taxes in northern areas also give a disadvantage compare to the lower taxes in the southern areas.

The advantage of measuring efficiency is the capability of identifying opportunities for improvements. Input projections are calculated by the data envelopment analysis determine the reduction targets of DMUs with an excess inputs, thereby allowing them to reach efficiency based upon the peers being evaluated (DMU). Because we calculate two types of efficiency, the reduction of targets using aggregate efficiency (CCR) evaluates the process as a whole, which in some cases can reach 77% reduction. Yet, reduction targets that are based on CCR are often a result of scale inefficiency. Improvements that can be achieved through managerial means are better presented by the targets in the BCC model (Trzcianowska *et al.*, 2019). The goal and strategy of the forest industry is identifying the possible variables that could be important for improving the efficiency of producing wood at a lower the cost (Hansen *et al.*, 2006). From Figure 2.6, we can observe the improvements projected by the analysis of the variables. The main variable to improve is road construction (km), efforts need to be made in reducing 37% fewer kilometers on average. Forestry roads are closely monitored and controlled in forest planning. They are thus one of the main topics of study facing the forest industry (FP innovations, 2020). Reduction of constructed roads can be helped by reducing patch dispersion (PROX_CV), which has been targeted at -21%, together with the number of kilometres within the harvested sites. Distance to the mill is also an important factor to be reduced because it directly influences the cost per kilometre of road to maintain and the cost of transport, this could be a point of improvement as previously mentioned if there is greater coordination among contractors sharing the same territory and considering a short and long term planning will lower the wood procurement cost (Béland *et al.*, 2009). Both targets could be addressed from the perspective of the technology if it is impossible to reduce the distance or the number of kilometres to build, together with options such as vehicles that more fuel-efficient, greater capacity of trucks, and improvement in the materials and load capacity of roads.

Evidence regarding the nature of returns to scale in the logging industry is mixed. Here, we find that our DMUs worked under a constant return of scale (CRS), as has been mentioned by Boussofiane *et al.* (1991). If the unit already operates in the CRS region, it usually is not a good idea to change its operating scale, given this alteration would decrease scale efficiency. Increasing returns to scale in the logging sector have been reported by practicing foresters in a survey of contractors in New Zealand and the United States by Stuart *et al.* (2010). Our study focusses upon the spatial configuration of the harvested sites and not on the contractors, we presented a more general view of the process. This may explain the disparity between our results and reports in the literature.

The empirical results that are presented in this paper are an estimate of the efficiency of the harvest in Quebec according to the spatial organization and based on average and official values provided by government agencies. By no means can claim to be representative of the forest harvesting industry in Quebec and Canada. Some limitations of the study were the quality of available data that could be considered as a simplification of reality, and may not represent the complete complexity of the regions, because some information may have been excluded from the analysis. We cannot extrapolate to regions under different conditions, since the data cover only five management units of a single harvest year. The economic values that have been estimated here may not express reality because the harvested sites offered by the minister are often treating in different managerial ways and not necessarily follow the initial limits and the profitability may be calculated on another scale, but nevertheless the exercise provides some insight into the advantages of this type of comparative study in forestry. The DEA analysis allowed us to include different types of variables and to easily understand efficiency, and through the measure of targets projections, how to improve the performance.

In conclusion, the forest harvest evaluated at the scale of the harvested sites demonstrates the importance of spatial variables for determining efficiency values, given that they are mainly related to the dispersion of the patches, the roads that have been build, and distance of transport from site to mill. Also, we can conclude that harvested sites do not represent a single pattern that depends upon the latitude and forest composition in which they are found, as has been suggested by EFM directives that are currently applied in eastern Canada.

CHAPTER III

GENERAL CONCLUSION

The results presented in this study show the relative efficiency of 50 harvested sites in eastern Canada measured based on the wood procurement cost and focused on spatial characteristics. The spatial variables are kilometres of roads that have been built, distance to the mill, a dispersion index (PROX_CV), and a dominance index (LPI). Aggregate efficiency of harvested sites is 72% on average (± 23%). which represents the overall process. For pure technical efficiency, the value is 89% (± 9%) and it considers the technology and machinery that are used in the process. The average scale efficiency of 79% (± 19%) shows that the DMUs have margin to increase their efficiency especially if the size of the operations increases. The level of efficiency for the region is high and is like previous studies that have been conducted in the region. Despite the wide variety of initial variables that available for the analysis, our results confirmed that variables related to forest roads and dispersion of the patches were the most important ones when harvesting at a low wood procurement cost.

Our initial hypothesis posited that northern areas would be more efficient because, following the rules of EFM, the areas should be larger and more agglomerated. Which would result in less road construction and shorter distances traveled within the harvested site, generating lower costs of timber extraction. Also, the dominant treatment in that area is clear-cut, which is less costly than partial cut. The results show that there is a great variety of spatial distributions and sizes of the patches to be harvested and that these do not belong to a region or forest type in specific. There are harvested sites that are dispersed and clustered across the entire North-South gradient as well as sites with large and small patch sizes. Therefore, it cannot be concluded from the spatial organization data that there is one region that is more efficient than another. This study shows that the southern areas tend to have better values in terms of both efficiencies; after homogenization of aggregate efficiency. The differences among harvest site latitudes were not significant, but a tendency for lower values was retained in the north. Aggregate efficiency is 60% for DMU's that are located above 49°N and for DMUs below 49°N latitude, values vary between 74 and 75%. For pure technical efficiency, values across locations vary from 88 to 92%. The scale efficiency follows the trend of aggregate efficiency with a lower value for DMUs located above 49°N, with a value of 68%. Compared to DMUs below this latitude, with a value of around 80%. Several reasons may explain why southern areas are more efficient. First, they extract wood with greater commercial value and of larger diameters, which is inversely related to the conifer percentage of the forest type, these forests have a lower proportion of conifers and the species that dominate are the broadleaved characterized for greater growth in diameters and the wood has more commercial value because have several uses as furniture. In the north, the activity is based upon extracting greater quantities of wood, but the quality of the wood comes from trees with smaller diameters. Second, the road network is more developed in the south, generating a smaller number of roads to be built, while northern areas often must open new roads. Also, the distances to the mill tend to be shorter in the south latitudes, which makes them more efficient in producing wood at a lower cost. Finally, higher taxes in the northern areas prove to be a disadvantage compared to southern areas.

Based upon pure technical efficiency, which indicates the improvements that can be achieved through administrative means and the use of technology, the variables that would have to be reduced to achieve efficiency are focused on the spatial variables. The analysis suggests that the efficiency of the forest operations will increase reducing the construction of the roads (optimal target -37%), the dispersion of the forest patches and the distance to the mill. Based upon these target reductions, forest managers can focus on strategies and decisions to decrease these variables, or technological measures that can counteract the negative consequences of not being able to change these variables, as has been done in recent years. For example, more durable forest routes, improvement in truck capacity and improvement in the form of transportation would be such solutions.

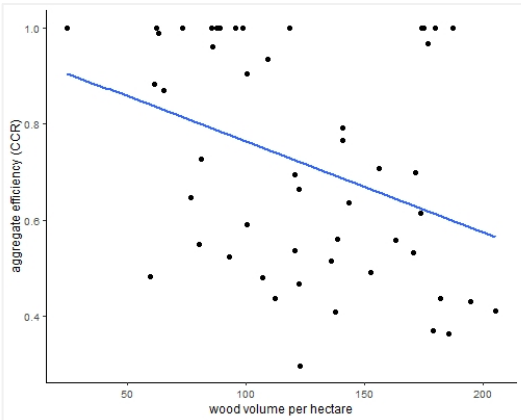
Comparative studies of benchmarking with the non-parametric methods of DEA analysis demonstrate their usefulness when carrying out efficiency studies, as they allow us to compare variables of different types and understand the relationships among them. The importance of the quality of the data to be used and the definition of the variables that are used should be highlighted since they affect the results which are relative to the sample being studied.

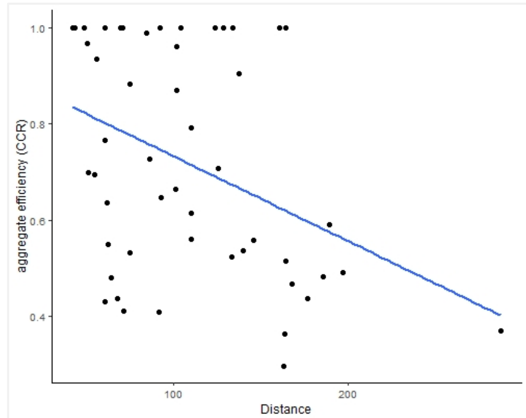
APPENDICES

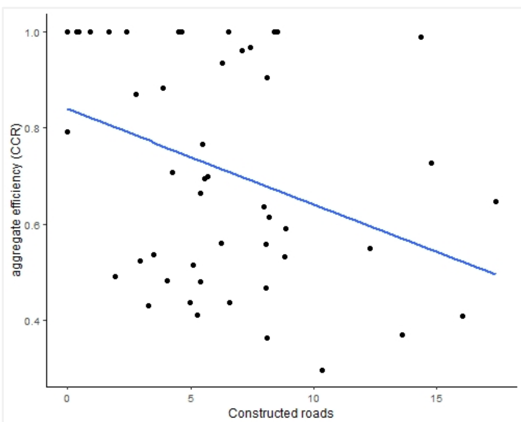
Appendix A Efficiency values for each Decision making unit

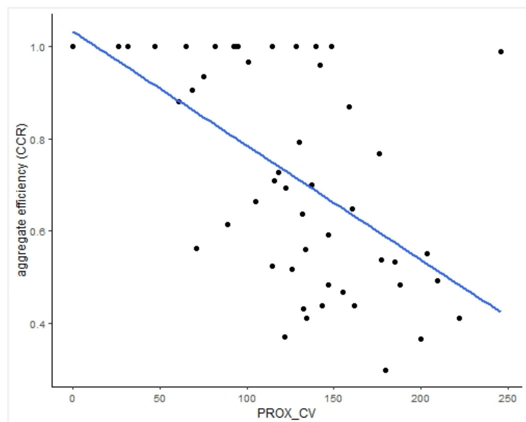
DMU's	CCR	BCC	Scale efficiency	DMU's	CCR	BCC	Scale efficiency
ARNTFIELD	0.56	0.82	0.68	HUBBARD	0.77	0.92	0.83
ARTHUR	1.00	1.00	1.00	JOS	0.65	1.00	0.65
BARTON	0.99	1.00	0.99	KALM_SE	1.00	1.00	1.00
BASSERODE	0.30	0.62	0.48	KESSIK_NORD	0.47	0.79	0.59
Beaumesnil	1.00	1.00	1.00	LA PAUSE	0.54	0.82	0.66
BIGAT-EST	0.90	1.00	0.90	LA PAUSE EST	1.00	1.00	1.00
Bigniba-Nord	1.00	1.00	1.00	LA PAUSE NORD	0.79	0.89	0.89
BLONDEAU	1.00	1.00	1.00	LA PAUSE OUEST	1.00	1.00	1.00
BOISSONAULT	0.43	0.89	0.49	LATULIPE	0.41	0.85	0.48
CAVELIER	0.36	0.80	0.45	MILLET	0.37	0.78	0.48
CHERRIER_NE	0.49	0.82	0.60	MINOMING	0.55	0.70	0.79
COUPAL	0.69	0.85	0.81	MONTBRUN-EST	0.61	0.88	0.70
CRAMOLET	0.56	0.91	0.61	PINE	0.96	0.98	0.98
CRAMOLET_SO	1.00	0.89	1.12	POIRIER	0.87	0.95	0.92
DASSERAT	0.52	0.85	0.62	POMBERT	1.00	1.00	1.00
DEGUIRE	1.00	1.00	1.00	Poularies Nord	0.93	1.00	0.93
Desjardins SO	0.53	0.88	0.60	RAZILLY	0.71	0.91	0.78
FLAVRIAN	1.00	1.00	1.00	SOUFFLOT	1.00	0.97	1.03
FRANQUET_NE	0.41	0.84	0.49	SQUARE	0.59	0.78	0.76
FRANQUET_NO	0.97	0.96	1.01	TELFER	0.88	1.00	0.88
GIBSON	1.00	1.00	1.00	TRUDEL	0.48	0.73	0.66
GIRARD	0.73	0.89	0.82	VEZZA	0.44	0.85	0.52
Grevet	0.44	0.77	0.57	vezza_bmmb	0.52	0.85	0.61
HOLMES_SUD	0.70	0.91	0.77	VICTOR	0.66	0.88	0.76
HOWARD	0.64	0.89	0.71	Villars Sud	0.48	0.70	0.69

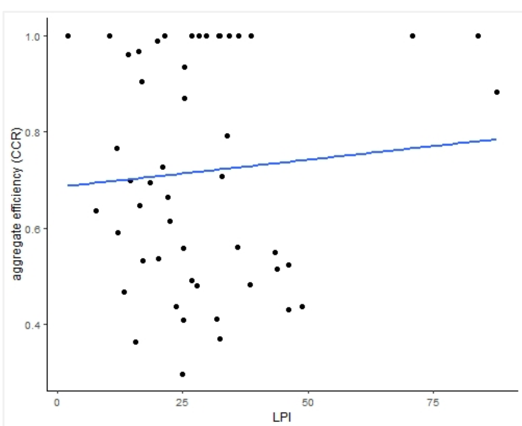
Appendix B CCR efficiency trends for each input variable.



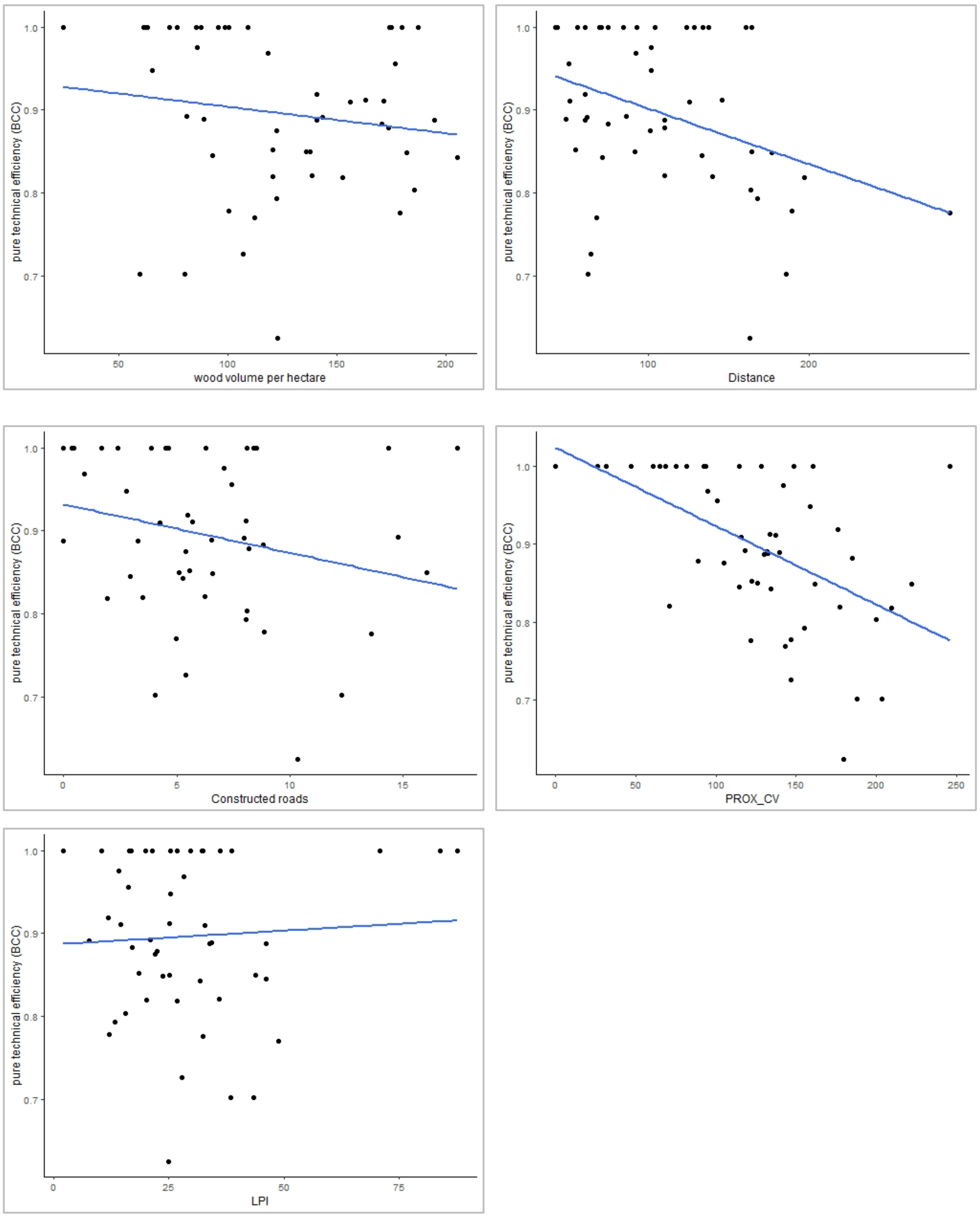




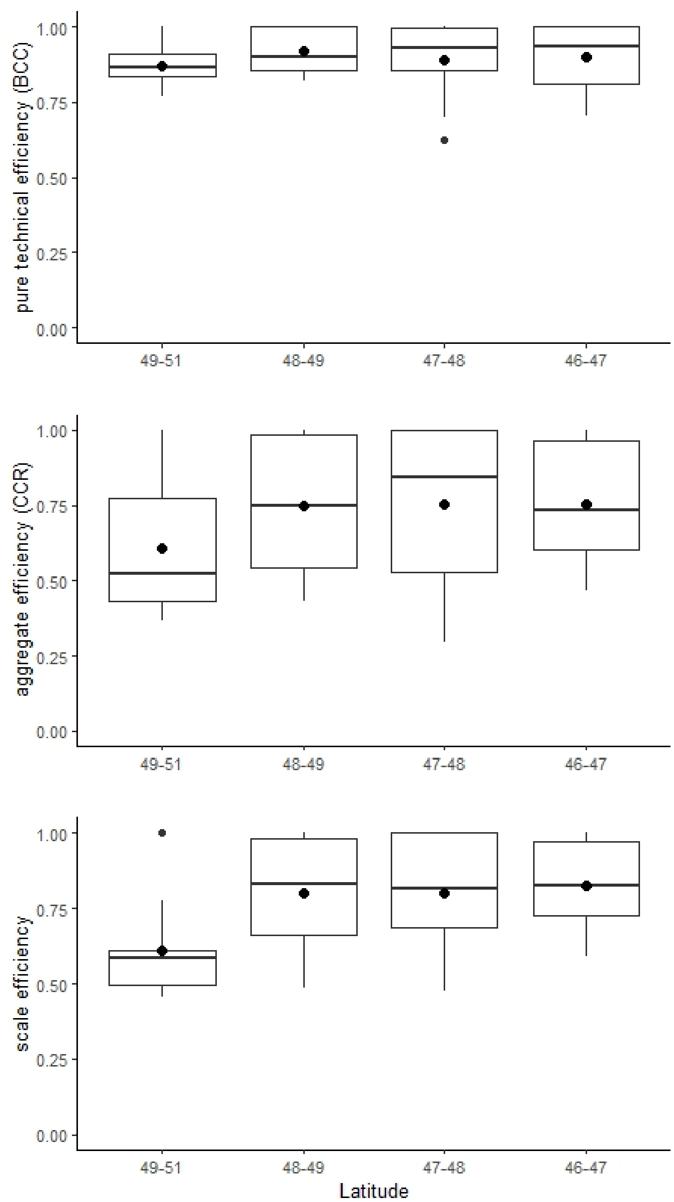




Appendix C BCC efficiency trends for each input variable.



Appendix D Aggregate, pure technical and scale efficiency values by latitude (degres). Black dots present the mean value. Boxplots follow the description detailed in Figure 2.2.



Appendix E Information use for the calculation of wood procurement cost of the harvest activity source forest minister (MFFP) per cubic meter:
1. Harvest cost by method **2.** other cost involve in the harvest activity by tarif zone**. 3.** Products value per cubic meter type of product and per species. **4.** Taxes by tarif zone, quality and species. **5.** cost of roads and cost of transport to the mill by DMU ($/m^3).

1. Harvest ($/m^3)

m^3 Stem	Partial cut broadleaves low removal	Partial cut broadleaves high removal	Partial cut conifers low removal	Partial cut conifers high removal	CPRS
0.05	50.96 $	45.73 $	36.78 $	32.51 $	28.99 $
0.1	42.72 $	38.77 $	30.05 $	26.82 $	24.17 $
0.15	38.87 $	35.52 $	26.91 $	24.16 $	21.91 $
0.2	36.50 $	33.51 $	24.97 $	22.53 $	20.52 $
0.25	34.84 $	32.11 $	23.61 $	21.38 $	19.55 $
0.3	33.59 $	31.06 $	22.59 $	20.52 $	18.82 $
0.35	32.61 $	30.23 $	21.79 $	19.84 $	18.24 $

2. Other costs

Tarif zone	transport machine ($/m^3)	Lodging ($/m^3)	Measure ($/m^3)	admin ($/m^3)	Loading ($/m^3)	Unloading ($/m^3)
755	0.98	0.67	0.77	4.55	1.89	1.34
852	0.98	1.21	0.77	4.55	1.89	1.34
853	0.98	1.25	0.77	4.55	1.89	1.34
855	0.98	0.06	0.77	4.55	1.89	1.34
856	0.98	1.17	0.77	4.55	1.89	1.34
857	0.98	0.88	0.77	4.55	1.89	1.34
858	0.98	0.33	0.77	4.55	1.89	1.34
859	0.98	0.27	0.77	4.55	1.89	1.34
868	0.98	1.13	0.77	4.55	1.89	1.34
871	0.98	0.56	0.77	4.55	1.89	1.34
886	0.98	0.79	0.77	4.55	1.89	1.34
887	0.98	0.88	0.77	4.55	1.89	1.34

3. Products value by Species ($/m^3)

CODE		BOJ	BOP	CHN	ER	PE
Name	other broadleaves	*Betulla alleghaniensis*	*Betula papyfera*	*Quercus*	*Acer*	*Populus*
Broadleaf veneer	$ 172.9	$ 192.7	$ 160.4	$ 204.8		$ 105.9
Pasta	$ 61.7	$ 59.1	$ 59.1	$ 65.8	$ 45.5	$ 42.5
Poles						
Sawing	$ 103.0	$ 97.5	$ 84.0	$ 107.0	$ 54.4	$ 75.6
clapboard						
Panels	$ 61.7	$ 59.1	$ 59.1	$ 65.8	$ 45.5	$ 42.5

CODE	PIB	PIR	PRU	THO	**Sawing SEPM**
Scientific name	*Pinus strobus*	*Pinus resinosa*	*Tsuga canadensis*	*Thuja occidnetalis*	*Ables balsamea, Picea sp, Pinus sp and Larix sp*
Coniferous veneer					DBH 18
Pasta	$ 42.0	$ 42.0	$ 38.4	$ 31.2	$ 69.7
Poles		$ 138.0			DBH 16
Sawing	$ 52.2	$ 51.9	$ 62.3	$ 74.0	$ 64.4
clapboard				$ 74.3	DBH 14
Panels	$ 32.1	$ 38.0			$ 64.4

4. Taxes ($/m3)

		Tarif zone											
		2016										2018	
Sp	**Quality**	**755**	**852**	**853**	**855**	**856**	**857**	**858**	**859**	**868**	**871**	**886**	**887**
AUF	**B**	10.4	0.4	0.4	0.4	7.8	8.1	8.6	8.3	8.0	9.4	8.7	8.7
	C	6.5	0.8	0.8	0.8	1.1	1.1	1.1	1.1	1.1	1.1	0.9	1.4
	D	2.0	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
BOJ	**A**	48.2	27.9	27.9	35.1	31.4	31.4	31.4	31.4	31.4	31.4	27.9	27.9
	B	18.0	13.9	13.9	13.9	12.2	13.1	13.5	13.2	12.6	13.4	13.9	13.9
	C	9.9	3.0	3.5	3.3	1.7	1.7	1.7	1.7	1.7	1.7	1.4	2.3
BOP	**A**	39.4	28.1	28.6	28.9	29.3	29.9	30.1	29.3	27.8	30.3	26.7	28.3
	B	9.1	6.7	6.7	6.7	5.6	6.2	6.4	6.2	4.1	6.5	4.8	6.5
	C	2.0	0.7	0.7	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.7	0.7
CHN	**A**	55.4	31.6	31.6	40.3	34.9	34.9	34.9	34.9	34.9	34.9	31.6	31.6
	B	20.4	15.3	15.3	15.5	17.8	18.6	19.5	19.1	15.2	18.0	15.3	15.3
	C	10.7	3.6	4.2	3.9	2.4	2.4	2.4	2.4	2.4	2.4	1.7	2.7
ER	**A**	56.2	39.5	39.5	39.5	40.1	37.8	37.4	41.0	34.2	34.2	30.1	30.1
	B	15.4	12.5	12.5	12.5	15.2	16.1	16.4	15.6	13.9	16.8	9.4	11.4
	C	6.3	4.6	4.3	4.6	2.2	2.2	2.2	2.2	2.2	2.2	4.6	4.6
PIB	**G**	38.2	21.0	17.9	19.9	10.7	10.7	10.7	10.7	10.7	10.7	11.7	12.2
	H	18.3	9.1	7.9	8.5	3.9	3.9	3.9	3.9	3.9	3.9	7.1	6.7
	I	10.2	2.2	2.2	2.2	1.7	1.7	1.7	1.7	1.7	1.7	2.2	2.2
PIR	**F**	46.1	43.1	37.8	41.2	29.9	28.6	29.9	28.3	15.1	15.9	25.1	24.5
	G	31.3	18.6	16.3	17.8	10.3	10.3	10.3	10.3	10.3	10.3	11.7	12.2
	H	14.9	5.6	4.7	5.1	3.8	3.8	3.8	3.8	3.8	3.8	5.1	5.6
	I	10.1	2.2	2.2	2.2	1.7	1.7	1.7	1.7	1.7	1.7	2.2	2.2
SEPM	**B**	14.2	4.6	6.1	10.2	8.6	13.3	15.2	15.6	14.9	19.9	13.9	17.0
	C	1.9	1.4	1.4	1.4	1.7	2.7	3.6	3.9	3.4	6.3	4.5	7.3
HEG		2.1	8.7	8.7	8.7	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4
PE	**B**	1.3	1.9	2.2	2.0	0.5	1.3	1.3	2.3	0.5	0.5	0.8	0.9
THO	**B**	6.3	2.4	1.9	2.1	0.9	1.4	1.6	1.4	0.9	0.9	1.6	1.6
	C	2.8	1.0	1.0	1.0	0.6	0.6	0.6	0.6	0.6	0.6	1.0	1.2

5. Cost of roads and cost of transport to the mill by DMU ($/m^3)

	$/km		
Type of work and road	**summer**	**winter**	**maintenance**
Construction class 3	36,000		
Construction class 4/5	20,000	10,000	1,000
Refraction	3,000		

Road class	**Speed without charge**	**Speed with charge**	**Rolling rate**	**Volume transport per truck**
Asphalt	85	75		
1	65	60		
2	50	40	100 $/kmh	42 ton
3	40	30		
4/5	30	20		

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