Assessing the impact of policies and regulations on log supply: A British Columbia case study

by

Mahsa Mojahednia

B.A., Isfahan University, 2007
M.A., Isfahan Payam-E-Noor University, 2011

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Abstract

British Columbia is one of the major log producers in Canada and is somewhat unique compared to the rest of the world since the majority of its forests are publicly owned. Log supply is the key underlying economic driver in the performance of British Columbia’s wood-products industry. Despite its importance, little work has been done recently to analyze it. Moreover, there have been significant changes in markets and policies in the past decade that needs to be addressed in these analysis. This research investigates the impacts of government policies and market changes on British Columbia’s log supply.

The objectives of this research are (1) to develop a log supply model for British Columbia regions (coast and interior) and (2) to identify relationships between government and market factors and log supply. Monthly time-series data from 2000 to 2013 were used to develop regional regression models for log supply. These models take into account differences in log quality as well as log prices, cost of labour, seasonality, and policy. The methodology used in this research is based on developing simultaneous equations models where the price is endogenously determined at the intersection of the demand and supply models. Two Stage Least Square (2SLS) method is used to estimate the models.

The results showed that log supply is elastic in the coast region and inelastic in the interior. Own price elasticity was significant in all regions with respect to different grades except for the low grade logs in the interior. Changes in policy impacted the log supply and harvest levels in BC. These changes in the policy included the elimination of minimum harvest levels and introducing take or pay policy. Costs and other market factors such as wage and log export price impacted log supply but the effect differs based on the region and log quality. Seasonality is the other factor impacting log supply in all regions and for all log types.
Preface

This thesis includes literature review, data gathering, developing econometric models and analyzing the results that were carried out by the author, Mahsa Mojahednia, under the supervision of her research supervisor Dr. Harry Nelson.

Literature review was written by the author with inputs from Dr. Nelson and Dr. Gaston.

The method was adopted from Mutanen and Toppinen (2005) and Sun et al. (2015). These models were then developed and modified based on the current research case study by the author with inputs from Dr. Nelson and Dr. Niquidet.

The results presented in chapter four are in preparation to be published in a peer reviewed journal. Assessing the impacts of policies and regulations on softwood log supply in British Columbia. Authors: Mahsa Mojahednia, Kurt Niquidet, Harry Nelson, and Chris Gaston,
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Dedication

To Omid

Whose love and confidence is a constant source of inspiration and encouragement

And

To my parents, my brother and my sister

For their endless love, support and encouragement
Chapter 1: Introduction

“Log supply modeling is an essential interface between forest production economics and policy and decision making”


1.1 Background

Forests are used for various goods and services that have shaped societies throughout time and will continue to influence our future. These goods and services include shelter, food, recreation, fuel, and carbon storage. One of the main products derived from forests are logs which are turned into lumber, veneer sheets or wood chips and used in houses, buildings, furniture, heating, and making paper. Due to the significant role of wood products in people’s lives, it puts a high demand on logs which makes the security of log supply an important issue, especially for the forest industry. In other words, the availability of logs influences the production of wood products which in turn impact us all.

Log supply is an important topic in forest economics and is influenced by environmental issues, market signals, forest products demand, global trade, cost, and policy making (Bao-dong et al. 2014; Polyakov et al. 2010). For example, log supply will decrease, if environmental concerns cause government to introduce new policies that increases the number of protected areas and limits the harvesting activities. This decrease in supply results in higher prices in the market for the same demand as before. Another example is global trade and log exports in which international competition requires additional consideration. If for any reason the demand for logs and wood products in the international market increases, it is important to consider domestic log supply and demand for wood products in order to determine an acceptable increase in log and wood product export.

Furthermore, it is not only the quantity of logs that matters but also the size and quality which will influence the feasibility of products derived from those logs. As such, logs are graded based on their quality and size and are grouped into high grade (saw) and low grade (pulp) logs. The grade of a log affects forest production chains which results in efficient utilization where there is no need
to use the high quality logs for making pulp or paper when there is a lower quality log available (e.g. a pulplog).

In order to ensure efficient production and utilization of logs, the government and industry require sufficient information regarding log supply (the quality and quantity of logs and the variables impacting log supply). Given that there are a myriad of variables that can impact log supply, it is important to understand if and how these variables impact log supply. Modeling provides an effective tool to analyze and assess the impacts of each variable on log supply. In particular, Wear and Pattanayak, (2003) believe log supply modeling has three major roles:

(1) It helps identify the trade-offs between log supply and environmental attributes. For instance, the impact of environmental issues such as forest diseases, fire and climate change are mentioned in log supply analysis. As an example, Abbott et al. (2009) investigated the impact of Mountain Pine Beetle (MPB) on supply and global markets. They projected MPB affect will decrease log supply in BC, while increasing log prices. Davidson et al. (2003); Johnston and Williamson (2005); Williamson et al. (2009); and Savage et al. (2010), focused on the impacts of wild fire or climate change on log supply. These studies concluded the impacts of climate change and fire on log supply vary from region to region but fire mostly decreased the harvest levels1.

(2) It is important for the projection of log market activity and log prices. Based on economic theory, market factors such as prices or costs are always the main variables when modeling log supply. Studies conducted by Brännlund et al. (1985); Wear and Parks (1994); Jennings and Matysek (2000); Wear and Pattanayak (2003); Mutanen and Toppinen (2005); Turner et al. (2006); Zhang and Buongiorno, (2012); Fooks et al. (2013); and Sun et al. (2015) all included price in their models and identified the existence of a positive relationship between the price and log supply.

(3) It helps evaluate the level and distribution of benefits and costs of forest policies. Knowledge of log supply plays a key role for policy making. Recognition of the determinants (quantitative or qualitative) affecting log supply is essential for adequate policies and decisions about harvest

1 These studies are not the aim of this research.
levels (Bolkesjø et al. 2010). Moreover, the changes in the policies can impact log supply. For instance, in Canada, the provincial government influences the supply by introducing policies and regulations such as taxes and Annual Allowable Cut (AAC). Mutanen and Toppinen (2005) for Finland, and Zhang and Buongiorno (2012) for China are the examples of studies that have included policies and regulations.

One approach to model the log supply is to use an econometric approach that identifies the linkage between log supply components (e.g. harvest levels, forest stock, prices, costs, and forest product demand) (Turner et al. 2006). Historic data can be analyzed to identify relationships and trade-offs between variables that affect log supply in order to better predict the effects of policies on desired results (Bolkesjø et al. 2010). The other important output of econometric models is the price elasticity of the supply models. The estimates of econometric studies particularly price elasticities, can be used in developing trade models. Examples include the CINTRAFORE Global Trade Model (CGTM)\(^2\) (Cardellichio, 1989), the Timber Assessment Market Model (TAMM)\(^3\) (Adams and Haynes, 1980) and the EFI-GTM\(^4\) global forest sector model (Solberg et al. 2003) in Pacific Rim, North America and Europe, and the Forintek / FPInnovations Global Trade Model (Gaston and Marinescu, 2006; Chang and Gaston, 2014 Chang and Gaston, 2015 (forthcoming).

Geographically, most of the studies on log supply have been in Europe and the U.S. and were applied to private forest owners (Majumdar et al. 2009; Brännlund et al. 1985; Størdal et al. 2008; Bolkesjø and Solberg, 2003; and Koch et al. 2013). There is lack of studies in Canada (a country that has 400 million hectares of forest or other wooded land) (World Bank, 2014), and despite the important position of log supply in the economics of forest products in Canada, surprisingly little work has been done to analyze it.

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\(^2\) This model was developed by an international team of forest economics at the International Institute for Applied Systems Analysis (IIASA).

\(^3\) It was used widely for forest policy analysis in the United States.

\(^4\) It is a partial equilibrium model which is also multi-periodic.
Of the few studies on Canadian log supply, most used an optimization analysis approach (e.g. Niquidet et al. 2012 and Stennes et al. 2010) and only four used an econometrics approach. In these optimization studies, the models focused on the amount of logs that can be sustainably harvested, given assumptions about the availability of the forest resource, growth rate and factors influencing access to the resource.

As mentioned earlier, there are four studies in Canada that used an econometric approach and estimated log supply models. These studies were based on data from British Columbia (BC) and three of them focused on log export restriction policies. Margolick and Uhler (1992), used partial equilibrium approach to investigate the economic impact of log export restriction and log export tax\(^5\) in BC. They used price elasticity of 0.3 to estimate the log supply model. Zhang (1996), investigated trade-offs between employment related to log export restrictions. He estimated log supply and demand equations by using quarterly time-series\(^6\) data and calculated a price elasticity of 0.11. Fooks et al. (2013), evaluated the price elasticity of log supply in BC. The main objective of their study was to investigate advantages of log export bans. Their model was based on time-series data and they reported a long-run elasticity of 1.03.

There is only one study conducted by Sun et al. (2015) that focused on estimating a coastal log supply model for BC using log price, stumpage, transportation and labour cost variables. They reported a short-run supply elasticity of 0.43 and calculated a long-run elasticity of 0.66.

Unfortunately, none of the models mentioned above distinguished between types of logs, and since the trees are heterogeneous in BC, it is an important matter that needs to be considered. There are also significant regional divergences across BC, reflecting variations in the type of forest resource, type of forest manufactured products and different export markets. For example, tidewater greatly expands the ability for firms to access logs on the coast while transportation costs are more significant in the interior where logs have to travel by truck or rail. In fact, no models to date have independently estimated log supply for BC interior forests where the majority of harvest takes

\(^5\) Known as log export levy.

\(^6\) The kind of data measured over time for one subject (Wooldridge, 2013).
place. Equally important, 95% of BC forested lands are publicly owned and governed by the province. This means BC’s log supply is not only influenced by end product markets, but also government policy, particularly at the provincial level. Despite the vast public ownership of forests in BC, there is a lack of quantitative research and studies that are aimed for forest policy analysis.

1.2 Research objectives

The current research has three main objectives:

1. Develop log supply models for BC regions;
2. Identify relationships between government policies, market factors and log supply; and
3. Calculate supply elasticities for two categories of logs (high grade logs and low grade logs).

These objectives are achievable through:

1. Introducing the log supply as a function of prices, costs and government policies;
2. Identify the appropriate econometric methods; and
3. Estimating the models.

The model presented in this study differs from previous ones as it takes into account log quality and considers the impact of policy interventions. The model utilizes actual harvest levels, rather than inventory data or the AAC, and monthly data that allows for more observations and accurate estimation.

1.3 Case study

BC is located on the Pacific coast of Canada and is chosen as the case study for this research because of various reasons: first, approximately, two-thirds of BC is covered with forests (roughly 60 million hectares) and forestry is one of the main drivers of the BC economy, especially in rural areas (Niquidet, 2007). Second, BC has approximately 7% of world’s total log supply (including Western Red Cedar, Douglas Fir, Spruce, and Western Hemlock) (Fooks et al. 2013). Third, this province is one of the major log producers in Canada and is somewhat unique compared to the rest of the world since the majority of its forests are publicly owned. The majority of BC’s forests are
regulated by the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO). Ninety-five percent of the area is owned by provincial government, 1% federally and 4% privately.

BC first introduced cut controls on Crown land starting in 1949 when the Province became concerned about the rate of harvesting. Since then, an AAC determines the log volume that can be harvested on an annual basis. Over the last 10 years, the average harvest—on areas regulated by AAC—was 69 million cubic metres annually while the average AAC was 78 million cubic metres. The volume of logs harvested every year has been below the AAC on Crown lands for much of the past twenty years. There have also been significant increases in the provincial AAC, starting in 2000s in response to the Mountain Pine Beetle epidemic so that beetle-killed wood could be utilized before it degrades (British Columbia and Ministry of Forests, 2011). However, forecasts estimate that by 2025 the log supply will decrease to 50-60 million cubic metres per year after the beetle epidemic has run its course (Ministry of Forests, Mines and Lands, 2010).

There are also flexibilities in the AAC system. For instance, one can harvest less during one year and then harvest more the next year as long as it does not exceed the accumulative 5 year AAC. Figures 1-1 and 1-2 compare the AAC and harvest levels for the coast and interior regions in BC. The actual harvest levels have almost never been the same as the AAC during these years. There are quite diverse patterns which indicate that other factors impact harvest levels and the AAC has not been limiting.

Figure 1-1 shows that on the coast the harvest levels were close to the AAC in 2000 and then dropped, until 2004 where a peak occurred and it went back to be close to the AAC. The gap grew wider during 2005 and 2009, but since then there was an increase in harvest levels which reduced the gap.

Figure 1-2, shows the harvest levels and the AAC for the interior. This graph demonstrates that the AAC was close to the harvest levels from 2000 until 2006, after which the gap grew wider and the harvest levels did not recover. The minimum harvest level occurred in 2011 and the maximum was in 2004.
**Figure 1-1** Comparison of harvest levels and AAC in British Columbia-coast

**Figure 1-2** Comparison of harvest levels and AAC in British Columbia-interior

Source: Harvest Billing System (2013), and Nelson and Hotte, (2013)
Overall, harvest levels, dropped by 24% between 2000 and 2013 on the coast. In the interior, this difference is 46%. Comparing the AAC and harvest levels raises some questions, such as: what causes these fluctuations in harvest levels in BC? How do provincial policies and regulations impact harvest levels? And how do market variables affect harvest levels?

As mentioned earlier, BC has been selected for this study due to its size and the importance of forestry to the provincial economy, as well as its contribution to world forest products trade. Furthermore, BC is somewhat unique compared to the rest of the world due to the vast public ownership of its forests and diversity of its trees and grades. BC as a case study is further discussed in details in Chapter 3.

1.4 Thesis structure

Chapter 2 reviews the literature on log supply modeling and the studies that used econometrics methods.

Chapter 3 discusses policy changes in BC. Moreover, the data that introduces the dependent and independent variables are presented.

Chapter 4 describes the theoretical and empirical models that were used for this research, followed by the results of the modeling.

Chapter 5 summarizes the research, including implications, limitations and suggestions for future research.
Chapter 2: Literature review

2.1 Synopsis

This chapter begins with an introduction to the log supply models and their modeling approaches (Sections 2.2 and 2.3). Section 2.4 reviews previous studies on modeling the log supply that used econometric approach including models outside and inside BC. In section 2.5, a conclusion on main variables included in different models is presented.

2.2 Log supply models

In economics the term “supply” has a specific meaning; the amount of any goods or services that sellers are willing to provide at a given price, with technology, costs, and expectations being the main determinants of supply (Mankiw, 2014). In forestry, log supply is defined as the quantity of the standing logs that are available for harvest at a range of prices (Jennings and Matysek, 2000). However, some studies considered the actual harvested logs as a better estimation of the log supply rather than the AAC levels or forest stock (e.g. Fooks et al. 2013 and Sun et al. 2015).

Based on economic theory, prices and costs are included in the majority of supply models (Mankiw, 2014). After determining the elements of log supply, these models analyze changes brought by forest industry, government policies, environmental issues, global trade, and other market factors (Bao-dong et al. 2014). Some studies also included forest stock in their log supply models (Turner et al. 2006).

2.3 Modeling approach

Based on theory of rational behaviour, historical data of consumption and production decisions are used to estimate the log supply model using regression techniques that incorporate variables such as log prices, stumpage and forest stock on log supply (Turner et al. 2006 and Bao-dong et al.

7 Stumpage is paid by the forest owners or licensees and loggers to the government for the right to harvest logs in the forests.
In the literature, the models with this approach are mostly referred as econometric models or studies (e.g. Wear and Pattanayak 2003; Mutanen and Toppinen 2005; and Sun et al. 2015). In this thesis, we use the same terms.

Econometric studies of log supply are important in several ways. First, they can help in understanding how the log markets work along with evaluating success of different policies (Bolkesjø and Solberg, 2003). Second, they provide fundamental quantitative information which can be used for forecasting market and policy analysis (Buongiorno, 1996; Wear and Pattanayak, 2003; Fooks et al. 2013; and Toppinen and Kuuluvainen, 2010). And third, their ability to estimate elasticities. For instance, price elasticity is able to show the responsiveness of the supply with changes in price. Elasticities can also be used to evaluate producers’ responses to taxes, regulations, market shifts, and changes in forest policy (Zhang and Buongiorno, 2012).

As mentioned earlier, econometric models can be used to show the relationships between different variables and there are statistical tests to examine the validity of the parameters and the theory (Buongiorno, 1996). However, there are still some limitations to econometric models that are important to note. For example, data availability and the quality of data can alter parameter estimation (creating statistical issues like not being stationary or collinearity). Additionally, choosing the right methodology and modeling approach is challenging because of determining the true structure of demand and supply equations (Toppinen and Kuuluvainen, 2010). Despite these limitations, Buongiorno (1996) encouraged the econometric modeling approach based on the basic modeling assumptions and the capacities of each method.

Before introducing more details on econometric modeling approach, two important factors must be addressed prior to modeling log supply. The next section reviews the important issues being time period and forest ownership:

**Time period**

Supply models differ in their defined time scales. Pattanayak et al. (2002) mentioned the differences between the short-run and long-run models by explaining that short-run models observe fluctuations in log harvest and log prices, while assuming a fixed forest inventory at a
certain time. By contrast, in the long-run, the prices and costs are known and there is enough time for the inventory to adjust. Generally, annual data for more than 15 years can be considered long-run supply.

The availability of data may influence the choice between estimating short-run or long-run supply, however, the objective of the study is also important. For instance, models interested in forecasting choose long-run period which influences modeling approach and estimation methods.

**Forest Ownership**

Generally speaking forests are owned publicly or privately, although there is a diverse ownership between countries. Based on reports from White and Martin (2002) and Sunderlin et al. (2008), roughly 75% of the forests in the world are under public ownership and 14% under private ownership. The remaining (such as in China) are collectively owned either by Indigenous people or communities. Publicly owned forests are used for environmental services and other purposes such as recreation or logging activities (Wear and Flamm, 1993), while the private owners seek to gain utility or profit benefits (Marcouiller et al. 1996). On the other hand, proportions of ownership are different in each country. For instance, in Canada, 7% of the lands are owned privately (approximately 30 million hectares), while in Sweden 50% of the forests are owned by private owners (Shashi, 2009).

The knowledge of forest ownership helps in picking the correct modeling approach and methodology (Prestemon and Wear, 2000). Prestemon and Wear (2000), suggested that log supply models vary with ownership and for each type of ownership separate models must be used. Furthermore, log supply models strive to summarize the production behaviour of forest owners in a market setting (Polyakov et al. 2010). So, when the ownership type is determined one other important factor that needs to be defined is the goal of the owner. Assuming private or public ownership, either profit or utility maximization is used to model the behaviour of the owners. In profit maximization, the owners make decisions based on maximizing profit without considering the benefits of non-market products. On the other hand, in utility maximization, the forest owner considers non-monetary benefits (Beach et al. 2005). For example, Hyberg and Holthausen (1989) mentioned that utility maximizers harvest less than profit maximizers. The utility maximizers
invest more in reforestation because the forests on their lands create non-market goods like recreation and wildlife, thereby gaining utility.

When it comes to modeling log supply, there are two ways of estimating an aggregate supply model: (1) aggregating individual harvest choices; and (2) defining an aggregate production function (Wear and Pattanayak, 2003). The former is mostly used in defining harvest decisions in private ownership with a focus at the stand level, while the latter emphasizes on the forest as a whole. Both methods lead to the same results, but depending on the nature and objective of the research one can be more suitable than the other.

Modeling individual choices are most often used in studying private forest land owners, most commonly referred to as non-industrial private forest owners (NIPF) in the literature. The majority of the studies regarding modeling supply is focused in the US and Europe where there is more private ownership (Hyberg and Holthausen, 1989; Kuuluvainen and Salo, 1991; Bolkesjø and Baardsen, 2002; Amacher et al. 2003; Linden and Leppänen, 2003; Bolkesjø and Solberg, 2003; Beach et al. 2005; Favada et al. 2009; and Majumdar et al. 2009). In these studies, log supply is typically derived from the models that are obtained from individual harvesting decisions where the forest owner has a choice between harvesting and delaying harvesting. For individual choice models, different variables such as owner’s income, wealth, age, education, or amenity choices play a key role in the forest owner’s decisions (Wear and Pattanayak, 2003).

Based on the objective and characteristics of this research, the aggregate supply model approach is chosen. The majority of the models that include aggregate log markets use the same log supply model in which supply is a function of price, forest inventory, and other supply shifters (Wear and Pattanayak, 2003). In other words, aggregate short-run supply can be estimated by finding econometric relationships between short-run supply, price, and forest conditions (Wear and Park, 1994).

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8 The focus is on a particular stand.
2.4 Literature review on log supply studies

This section provides a review of literature on models that used an econometric approach to estimate log supply in large regions where the owner tends to maximize its profit. These studies were chosen because: first, they developed log supply models; second, they used econometric approach to identify relationships between market and policy changes and log supply; and third, they reported price elasticities. This review helps us identify various models and methods that are used to model log supply. The review also reveals the gaps and limitations of this research area.

Since the main objective of this research is to develop a log supply model for BC, for this thesis, these studies are divided into two main categories based on the region they were conducted: (1) Studies outside BC, (2) Studies inside BC. This categorization helps in learning from the experiences of other regions to investigate what variables they have included in their models and to compare their models with the ones used for BC, in order to explore the gaps and limitations in the literature.

For a better comparison, before introducing the studies we present different methods that were used in them to model log supply.

Methods used in literature

The methods used by the following studies vary depending on the type of data and the objective of the research. These methods include: Ordinary Least Square (OLS); Fixed Effects (FE); Random Effects (RE); Least Square Dummy Variables (LSDV); Two Stage Least Square (2SLS); Three Stage Least Square (3SLS); and Instrumental Variables (2SLS).

OLS is the basic and the most common method of estimating parameters in a regression analysis. This method is not appropriate when autocorrelation or heteroscedasticity are present in the model. OLS is called Pooled OLS when used for panel-data. LSDV is similar to the Pooled OLS but it includes dummy variables (Gujarati, 2003; Wooldridge, 2012). Assuming the price endogeneity,

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9 When different subjects are observed over different time point, they are called panel data (Wooldridge, 2013).
the Instrumental variables (2SLS) method or 2SLS method for simultaneous equations models are used. In simultaneous equations models, the assumption is that price and quantity are endogenous, which are determined in a system of equations. In addition, the instrumental variables are the exogenous variables that appear in the demand or supply equations. 2SLS methods (in simultaneous equations models and Instrumental Variables) are further discussed in details in Chapter 4.

3SLS is the method of estimating system of equations models where one or more equations have endogenous variables. This method results in more efficient estimates compared to 2SLS. When using 3SLS, one must be sure there is no misspecification in any parts of the model, or the estimates would be biased through the whole system of equations. 3SLS is best applied when errors are independent and identically distributed (i.i.d). In case of suspected misspecification, such as autocorrelation and heteroskedasticity (violation of i.i.d assumption), 2SLS is preferred because this method is capable of having heteroskedasticity and autocorrelation robust errors.

2.4.1 Studies outside BC

We reviewed these studies because they cover a large region, consider the forest as a whole and estimate aggregate supply by assuming perfect competition in the log market and profit maximization as the goal of the owner (the same assumptions we have for our modeling approach in this research). These models do not include individual harvest choice models because they focus on harvesting decisions of the owner while the owner’s goal is utility maximization. The revision of these models showed that they included two main groups of variables: market variables and policy variables. In this research, we separate the studies that include policy variable in their models from the ones not including it. This distinction helps us figure out how to include policy variable in the model.

The first group includes studies that considered market factors, as follows:
Brännlund et al. (1985) estimated aggregate supply and demand models for sawlog and pulpwood in Sweden using simultaneous equations models,\(^\text{10}\) with the assumption of profit maximization. They used annual time-series data from 1953 to 1981. Brännlund et al. assumed the sawlog price is found at the intersection of the supply and demand curves. The pulpwood price is “determined” and is assumed to be exogenous since in Sweden the industry does the price negotiations of pulpwood. For sawlog demand and supply models, they used the 2SLS method of estimation. 3SLS could not be used in this case since autocorrelation was present. For pulpwood supply, they chose the OLS method because there was no difference between the OLS and 3SLS results. The sawlog demand equation consisted of sawlog and lumber prices, and the ability to pay for lumber (the difference between the price of log and wage). The sawlog supply side included price of sawlog and pulpwood, and cutting costs. For the pulpwood supply model, the variables were sawlog and pulpwood prices, cutting costs, lagged pulpwood prices, and quantity. The results of estimation for sawlog show that all the variables were significant and pulpwood prices and cutting costs had a negative impact on supply. In the pulpwood supply model, the results indicate that all the variables were significant except the sawlog price and cutting cost. Sawlog prices had a positive impact on sawlog supply. Moreover, pulpwood prices also have a positive impact on pulpwood supply. Finally, Brännlund et al. reported a supply price elasticity of 0.61 for sawlogs and a price elasticity of 0.74 for pulpwood.

Wear and Pattanayak (2003) first described the differences between modeling approaches for log supply and completed an empirical analysis by developing log supply and demand equations based on profit maximization for pulpwood and sawlogs. They used annual time-series data from 1965 to 1994 in Southeastern US and estimated simultaneous equations models using 3SLS method. The supply models for sawlog and pulpwood consisted of pulpwood and sawlog prices, planted forest capital and natural forest capital. The sawlog demand model included lumber prices, lagged sawlog quantity, and wages, while the pulpwood demand model consisted of paper prices, lagged pulpwood quantity and wage. Wear and Pattanayak conclude that natural and planted forest capital had positive effects on sawlog supply. For the pulpwood supply the only significant variable was

\(^{10}\) This model is discussed in section 4.2.1.
planted forest capital. The results also show that in sawlog supply, the price of sawlog was significant and had a positive impact on supply. Moreover, pulpwood prices did not impact the sawlog supply and also sawlog prices did not have any effect on pulpwood supply. Wear and Pattanayak, reported a price elasticity of 1.37 for sawlog and a price elasticity of -1.25 for pulpwood.

The main objective of Turner et al. (2006) was to apply Global Forest Products Model (GFPM) from the study conducted by Buongiorno et al. (2003) for multiple countries to predict the amount of forest area and forest stock in future for those countries. One part of their study was to develop an international short-run log supply model for 180 countries. They used annual panel data from 1990 to 2000 and their methods of estimation included FE, RE, Pooled OLS and 2SLS. They suggested that the 2SLS method enables more consistent estimates since the price was endogenous. The variables in their log supply equation were log price, forest area and density, proportion of forest in public ownership, interest rate, and income per capita. Forest area, forest density and income per capita all showed to have positive impacts on log supply. Interest rate was not significant and did not impact the log supply. The results also show that price had a positive impact on log supply with a price elasticity is 1.58.

In 2010, Bolkesjø et al. estimated log supply for sawlog and pulpwood for 102 Norwegian municipalities. They included annual cross-section, panel, and time-series data from 1980 to 2000 to develop their models. Bolkesjø et al. used several methods of estimation such as OLS for time-series data, and FE, RE and Pooled OLS for panel data. They also included a first difference model for their panel data. Variables in sawlog model were sawlog and pulpwood prices, growing stock and interest. They used the same variables for the pulpwood model. For both sawlog and pulpwood, their preferred model of estimation was the first difference model. They concluded that using cross-section and time-series data were not suitable for their research because the results had large square errors. They discarded the other methods because of significant serial correlation.

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11 One type of data that observes different or many subjects over one point of time (Wooldridge, 2013).

12 In the first difference model, the lagged variables are calculated then the difference between the variable and the lagged variable is used for modeling. This helps in addressing the problem of omitted variables in panel data.
The results indicate that standing stock was significant for both sawlog and pulpwood supply and had a positive impact on both supply models. The interest rate was not significant for sawlog supply but it did impact the pulpwood supply. Sawlog price had a positive impact on sawlog and pulpwood supply. Pulpwood price did impact the pulpwood in a positive way but did have a negative impact on sawlog supply. Sawlog price elasticity is 0.89 and pulpwood price elasticity is 0.53.

The models mentioned above estimated log supply and calculated price elasticities using econometric approach with the assumption of profit maximization. The results are consistent with economic theory. For instance, if the price of logs increases, the supply also will increase. The review showed that the studies with time-series data used simultaneous equations models using OLS, 2SLS or 3SLS methods, while studies with panel data mostly focused on choosing between FE, RE or Pooled OLS. The range of the elasticities for sawlog is from 0.61 to 1.37 and the range of elasticity for pulpwood is from 0.53 to 1.25.

The majority of the previous studies on log supply assumed that all logs are homogenous, with price not being different between logs species, sizes or grade. Three of the studies mentioned above (Brännlund et al. 1985; Wear and Pattanayak 2003; and Bolkesjø et al. 2010) estimated two separate models, one for sawlog and one for pulpwood. In their studies, pulpwood refers to the logs with smaller diameter or byproducts of sawlogs (residues, branches, small parts of main stem and etc.).

Besides not presenting the specific way of distinguishing different log grades, these studies had some limitations. For example, Brännlund et al. (1985) used 3SLS method that raises the concern of misspecification which can lead into unbiased results. Although Wear and Pattanayak (2003) provided a comprehensive introduction and background on modeling approaches, they did not provide in-depth discussion or conclusion on the result of their model. They also did not include other market factors such as costs in the log supply models. And finally, Turner et al. (2006) assumed log are homogenous and did not distinguish different log types in their model.

Table 2-1 shows the summary of the studies mentioned above.
Table 2.1 Summary of log supply studies outside BC including market variables

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Region</th>
<th>Method</th>
<th>Data/Period</th>
<th>Main objective</th>
<th>Right-hand side variables</th>
<th>Supply price elasticities</th>
</tr>
</thead>
</table>
| Brännlund et al.  | Sweden       | Simultaneous equations      | Annual time-series 1953-1981 | Estimate aggregate sawlog and pulpwood supply | • Sawlog supply: sawlog price, pulpwood price and cutting costs  
• Pulpwood supply: sawlog price, pulpwood price, lagged pulpwood price, lagged pulpwood supply, and cutting cost  
• Sawlog demand: lumber price, sawlog price and the ability to pay for lumber and lagged quantity of lumber | Sawlog = 0.61  
Pulpwood = 0.74 |
| (1985)            |              | OLS, 2SLS, 3SLS             |             |                                 |                                                                                           |                           |

**Key findings:** In sawlog supply model the preferred method is 2SLS. Sawlog price, pulpwood price and cutting costs are all significant with sawlog price having positive impact on sawlog supply while the other two have negative impacts on sawlog supply. For pulpwood supply, the preferred method is 3SLS and the pulpwood price and lagged price and quantity are significant. Pulpwood price has a positive impact on pulpwood supply.

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Region</th>
<th>Method</th>
<th>Data/Period</th>
<th>Main objective</th>
<th>Right-hand side variables</th>
<th>Supply price elasticities</th>
</tr>
</thead>
</table>
• Sawlog demand: lumber price, lagged sawlog supply and wage  
• Pulpwood demand: paper price, lagged pulpwood supply and wage | Sawlog = 1.37  
Pulpwood = -1.25 |
|                   |              | OLS, 3SLS                   |             |                                 |                                                                                           |                           |

**Key findings:** In the sawlog supply model, sawlog price, natural forest capital and planted forest capital are significant and they all have positive impacts on sawlog supply. For the pulpwood supply, all the variables are insignificant except planted forest capital.
<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Region</th>
<th>Method</th>
<th>Data/Period</th>
<th>Main objective</th>
<th>Right-hand side variables</th>
<th>Supply price elasticities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turner et al. (2006)</td>
<td>180 countries</td>
<td>Partial spatial equilibrium</td>
<td>Annual panel data</td>
<td>Modeling international wood supply through spatial equilibrium Global Forest Products Model</td>
<td>log price, forest area and density, proportion of forest in public ownership, interest rate, and income per capita</td>
<td>1.58</td>
</tr>
<tr>
<td>Bolkesjø et al. (2010)</td>
<td>Norway</td>
<td>Single equation model and first difference • OLS • Pooled OLS • Fixed effects • Random effects</td>
<td>Annual panel data, cross section, and time-series 1980-2000</td>
<td>Modeling sawlog and pulpwood supply for 102 Norwegian municipalities</td>
<td>• Sawlog supply: sawlog price, pulpwood price, standing stock, lagged sawlog harvest levels and interest • Pulpwood supply: pulpwood price, pulpwood price, standing stock, lagged pulpwood harvest levels and interest</td>
<td>Sawlog = 0.89 Pulpwood = 0.53</td>
</tr>
</tbody>
</table>

**Key findings:** Price, forest area, forest density, and income per capita all have positive impacts on log supply. Interest rate is not significant and do not impact the log supply.

**Key findings:** The preferred model is the first difference model. All the variables are significant and have positive impact on sawlog supply except the pulpwood price. All the variables are significant for the pulpwood supply. The all have a positive impact on pulpwood supply.
The second group of studies not only included market variables, but also considered policy changes in their models.

Mutane and Toppinen (2005) evaluated how the major change of the forest taxation system in Finland affected industrial private forest owners. They used quarterly time-series data from 1986 to 2003. Their model included two species of coniferous sawlog: Spruce and Pine. Mutanen and Toppinen used simultaneous equations models and 2SLS method to estimate two models for Spruce and Pine species. The variables in their supply models were the price of logs, lagged log prices, lagged quantity, and interest rate for both species. They also added a dummy variable to represent the forest taxation reform that happened in the 1990s. The demand equation included sawlog price, export price of final products, production capacity of sawmill industry, and lagged quantity. To control for seasonality, seasonal dummy variables were used for both demand and supply models. The results show that lagged prices have a negative impact on sawlog supply while the first difference of interest had a positive impact on log supply. Mutanen and Topinnen, conclude that there was seasonal variation in sawlog quantities. The results also indicate that the supply was highly elastic with the price elasticity of Pine sawlog 7.11 and Spruce 7.72. The results also showed that the changes in policy increased log supply.

In 2012, Zhang and Buongiorno, estimated a supply model to assess the impacts of market and government policies on log supply in China. They investigated how production quotas and land tenure reforms impact log supply. Zhang and Buongiorno used panel and time-series data from 1999 to 2009 with different estimation methods assuming (a) price is exogenous and (b) price is endogenous. For (a), they used two methods: Least Square with dummy variables (LSDV); and RE. Based on Hausman test and goodness of fit, they chose LSDV. For (b), they used Instrumental Variables (2SLS) method. Their preferred method was LSDV because the results of LSDV and 2SLS method were slightly different. The variables in their models were price, wage, interest rate, stock level, production quota, and a dummy variable for the policy change. The results

---

13 Since interest rate was not stationary, the first difference of interest was used.
14 Generally speaking, it is a test to help for choosing between two LSDV and RE methods.
show that all the variables were significant, except the interest and wage. The significant variables did have a positive impact on log supply. Zhang and Buongiorno concluded government policies were significant but with a limited positive impact on log supply. They calculated price elasticity of 0.31.

Both studies mentioned above showed the changes in the policy had a positive impact on log supply. In order to show the impact of policies, these models used dummy variables with the value of 0 before the policy change and a value of 1 after the policy change (only one dummy variable is used). The method they used differed based on the type of the data; 2SLS for time-series data and LSDV for the panel data. The elasticities range from 0.31 to 7.72. The research conducted by Mutanen and Toppinen (2005) and Zhang and Buongiorno (2012) had limitations since they did not distinguish between different log grades and assumed the logs are homogenous in their model.

Table 2-2, summarizes the studies mentioned above.
**Table 2-2** Summary of log supply studies outside BC including market and policy variables in their models

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Region</th>
<th>Method</th>
<th>Data/Period</th>
<th>Main objective</th>
<th>Right-hand side variables</th>
<th>Supply price elasticities</th>
</tr>
</thead>
</table>
| Mutanen and Toppinen (2005) | Finland    | Simultaneous equations models • 2SLS | Quarterly time-series 1986-2003 | Determining the supply effect of taxation reforms on Finnish sawlog market | • Sawlog supply: sawlog price, lagged price of sawlog, interest rate, taxation reform, seasonal dummy variables, lagged, and initial growing stock  
• Sawlog demand: sawlog price, production capacity of sawmill industry, export price of lumber, lagged quantity and seasonal dummy variables | Pine sawlog = 7.11  
Spruce sawlog = 7.72 |
| Zhang and Buongiorno (2012) | China      | • LSDV  
• RE  
• Instrumental variables (2SLS) | Annual panel data and time-series 1999-2009 | Investigate impact of markets (prices and costs), and policy (production quotas and land tenure reforms) on China’s log supply | Log price, log harvesting costs, interest rate, policy variable, wage, and stock level | 0.31 |

**Key findings:** Taxation reforms increase sawlog supply. Price, first difference of interest and lagged price are significant. Lagged prices has a negative impact on log supply but the other two have a positive impact on log supply.

**Key findings:** The preferred method is LSDV. All the variables are significant except the interest and wage. The significant variables have a positive impact on log supply. Policy change increases the log supply.
2.4.2 Studies in BC

The studies mentioned in this section were chosen because they used econometric method to estimate log supply in BC. The review of these studies helps us compare our models and results with previous studies. In addition, it enables us to find the gaps and limitations.

There are only a few studies examining log supply in BC. In this thesis, these studies are divided into two groups as follows:

The first group of studies includes those that estimated log supply by focusing on log export restriction policies. This is specific to BC, where there is a market for log export and there are policies regarding log export. For the most part, this speaks to BC coastal because of geography (access to tidewaters and ports). The results regarding supply modeling is presented here, since in this research we only focus on log supply estimation:

Margolick and Uhler (1992) used a partial equilibrium approach to investigate economic impact of log export restriction and log export tax on BC coast. However, they did not estimate supply and demand elasticities but used the elasticities from another study conducted by Constantino (1986) to build their supply and demand curve. Constantino estimated log supply elasticities using large computational models and calculated price elasticity of 0.3 for sawlogs from 1925 to 1981. Margolick and Uhler built demand and supply models using high grade logs from different coastal species.

Zhang (1996) estimated log supply and demand equations for the BC coast by using quarterly time-series data from 1990 to 1994. The main purpose of his study was to investigate how changes in log export restrictions impacts employment. He used simultaneous equations models using OLS method of estimation. The supply models included variables such as log prices, lumber prices, and seasonal dummy variables while the demand model included log price and lumber production. The results indicate that the variables were not significant, but Zhang mentioned that he uses the coefficients of his models for his research because the elasticities of demand and supply are within the range of previous studies in the literature. Zhang reported supply elasticity of 0.11.
Fooks et al. (2013) investigated the impact of log export bans on log supply in BC based on monthly time-series data from 1995 to 2008. They used Vector Error Correction Model (VECM)\textsuperscript{15} to estimate the potential efficiency of log export ban removal. The variables in the supply model included log price, stumpage and fuel price. The demand model consisted of variables such as log price, lumber price and interest rate. The results of estimation for the supply model show that fuel was insignificant and the stumpage was significant and had positive impact on log supply. They reported that price was significant and the price elasticity was 1.03.

The second group includes one study that estimated log supply and its focus was on log supply itself. Sun et al. (2015) estimated a log supply model for BC coast. They also estimated log supply models for eight forest districts\textsuperscript{16} and used monthly panel data from 2003 to 2013 using FE method. Their log supply was a function of log price, stumpage price, cost of labour and energy, and interest rate. They also included seasonal dummy variables and a US recession dummy variable. The results of their model for the BC coast show that the wage, recession and several of the seasonal dummy variables were significant, with wage and recession having a negative impact on log supply. They concluded seasonality existed in the model and the harvest levels decreased in cold months. Their study reported a short-run supply price elasticity of 0.43 and a long-run price elasticity of 0.66.

Various models and methods such as simultaneous equations models, VECM and FE were used in the studies mentioned above. Overall, the only study that focused on log supply was conducted by Sun et al. (2015), however, they did not distinguish different log types. The studies mentioned in the first group focused on log export restriction. Their models have limitations such as not presenting explicit log supply and demand models, using outdated data, and not distinguishing between types of logs. Moreover, Fooks et al. (2013) did not distinguish BC regions into coast and

\textsuperscript{15} VECM is a system of multiple time-series that estimates joint dynamic behaviour of variables and considers long-run relationships. It differs from other methods since it is suitable for forecasting

\textsuperscript{16} Based on the objective of our research, we only focus on the model that estimated log supply for BC Coast which encompasses the eight districts and all other resources.
interior and considered BC as one homogenous region. The elasticities in the models mentioned above range from 0.11 to 1.03.

The review of log supply studies in BC showed that there is lack of up to date research on log supply models using econometric approach while focusing on log supply. The studies mentioned above focused on BC coast only (except Fooks et al. (2013) that considered BC as one region) and there is no other study that estimated log supply for BC interior. Despite the vast public forest ownership in BC and major policy changes in the past decade none of the studies included policy changes in their models.

Table 2-3 shows the summary of studies that estimated log supply in BC.
### Table 2-3: Summary of log supply studies inside BC

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Region</th>
<th>Method</th>
<th>Data/Period</th>
<th>Main objective</th>
<th>Right-hand side variables</th>
<th>Supply price elasticities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Margolick and Uhler (1992)</td>
<td>British Columbia coast</td>
<td>Partial equilibrium model (demand and supply model)</td>
<td>Used elasticity based on data from 1925 to 1981</td>
<td>Investigating the economic impact of removing log export restrictions on British Columbia</td>
<td>Log price, US export prices, and logging cost</td>
<td>0.3</td>
</tr>
</tbody>
</table>
- Log demand: log price and lumber production | 0.11                      |
| Fooks et al. (2013)  | British Columbia coast | Vector error correction model           | Monthly time-series 1995-2008 | Examining the benefits of log export bans removal  
- Log supply: log price, stumpage and fuel  
- Log demand: log price, interest rate and lumber price | | 1.03                      |

**Key findings:** Removal of log export restrictions would result in an increase in price of log in BC. They conclude it will benefit the economy of the province.

**Key findings:** The variables in the supply model are not significant. Removal of log export restrictions benefits the economy of the province.
### Key findings
Price and stumpage are significant and they have positive impact on supply. Fuel is insignificant. Overall, elimination of log export restrictions increases the economics efficiency.

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Region</th>
<th>Method</th>
<th>Data/Period</th>
<th>Main objective</th>
<th>Right-hand side variables</th>
<th>Supply price elasticities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun et al. (2015)</td>
<td>British Columbia coast</td>
<td>Fixed effects method</td>
<td>Monthly panel data 2003-2013</td>
<td>Estimate short-run supply</td>
<td>Log price, cost of stumpage, cost of labour, cost of energy, interest rate, US recession, and monthly dummy variables</td>
<td>0.43</td>
</tr>
</tbody>
</table>

### Key findings:
Log price and wages are significant while interest, stumpage and cost of fuel are not significant. Wages have a negative impact on log supply. Price has a positive impact on log supply.
2.5 Conclusion and discussion

This chapter first introduced log supply models and the approach used in previous studies to model log supply. A review of the literature showed that ownership and owner’s goal are important and must be defined before any analysis. Based on the type of ownership, public or private, variables included in the models will vary. For instance, for log supply models with private ownership and utility maximization as the owner’s goal, variables such as age, education and preferences of the owner are important. However, for large regions where the owner’s goal is profit maximization, the log supply model includes variables such as price, stumpage, interest rate, and forest inventory.

Another important factor that needs to be addressed is the time period at which the log supply is modeled. Log supply models can be defined in short-run or long-run and the estimating methods and interpretation of the results can differ based on the chosen temporal time scale.

Based on the objective and characteristics of this research, the aggregate supply model approach was chosen. The majority of the models that include aggregate log markets use the same log supply model in which supply is a function of price, forest inventory and other supply shifters (Wear and Pattanayak, 2003). In other words, aggregate supply can be estimated by finding econometric relationships between short-run supply, price, and other market factors (Wear and Park, 1994).

According to the objective of the current research, the studies that used econometric approach in large region where the owner’s goal is profit maximization were reviewed. The studies were divided into two categories: studies in BC and those outside of BC. This categorization helps in identifying the gaps, limitations, and some of the important variables that were included in log supply models. These variables are summarized below:

**Price and other market forces** are essential in determining log supply (Brännlund et al. 1985; Wear and Pattanayak 2003; Turner et al. 2006; Bolkesjø et al. 2010; Mutanen and Toppinen 2005; Fooks et al. 2013; and Sun et al. 2015). These studies found a significant and positive relationship between the log price and supply and reported log price elasticities. The cost variables that were significant in the models mostly had a negative impact on supply.
The other group of log supply studies that were examined not only included the variables mentioned above but also included policy as a variable in their models.

**Policy** can impact log supply in different ways, including changes in taxes or land tenure reforms. Few studies have investigated the impact of policy changes in a broad region (e.g. Mutanen and Toppinen 2005 and Zhang and Buongiorno 2012). Government policies have a strong role in influencing harvesting decisions. Harvesting regulations such as minimum harvest levels set by provincial governments in Canada are one way of controlling harvest levels. Provincial governments can limit harvest in certain areas by designating areas for conservation purposes or as parks. Market-based regulations, such as setting log charges (stumpage), tax incentives and credit subsidies also impact harvest levels. Exports bans, export tax and quotas are trade related policies that can further affect harvest levels. For instance, if the federal or provincial government is interested in developing the domestic forest industry, high export tax or export bans can be implemented. The government also monitors forest industry activities and decisions of tenure holders to ensure the harvesting, planting and management of forests adheres to forest policies and regulations. Mutanen and Toppinen (2005) as well as Zhang and Buongiorno (2012) both noted policy as an influencing factor for log supply. They used a dummy variable to show how the policy change impacts log supply.

Several studies investigated variables influencing log supply in different regions with various ownerships and characteristics. A lot of the reported work has been conducted in the US and Europe, where most of the forest industry ownership is based on NIPF. The majority of these studies include individual choice models (Amacher et al. 2003; Favada et al. 2009; Majumdar et al. 2009; Størdal et al. 2008; Bolkesjø et al. 2007; Bolkesjø and Solberg, 2003; Beach et al. 2005; and Koch et al. 2013) but there is still a gap in studies that used econometric methods on vast regions where the owner’s goal is profit maximization, especially for countries with public ownership (such as Canada).
Chapter 3: Case study and data

3.1 Synopsis

In this chapter, section 3.2 provides background information about British Columbia’s forests. Section 3.3 briefly discusses major changes in forest policy that are related to the current research. Log grades in BC are presented in section 3.4. In section 3.5, more detailed information about the variables and data that are used in this research are introduced. Section 3.6, provides a conclusion of the policy changes and data used in this research.

3.2 Background

BC has 60 million hectares of forestland, of which 24 million hectares is considered productive forest land and available for log harvest. The majority of the trees are coniferous which makes BC the largest softwood log producer in Canada. The rest of the forestlands in BC are used for recreation, visual quality and tourism (Ministry of Forests, Mines and Lands, 2010). The Ministry of Forests, Lands and Natural Resource Operations (MFLNRO), has jurisdiction over the forests in BC. Ninety-four percent of the BC forest area is publicly owned, 4 % privately, 1 % federally, and less that 0.1% by First Nation. Predominant public ownership in BC makes the provincial government an important agent in forest related subjects. For example, the province regulates forest practices, through acts or regulation\(^{17}\), offers different harvesting licenses agreements and sets maximum harvest levels.

The government first introduced cut controls starting in 1949 when the provincial government became concerned about the rate of harvesting. Since then, the AAC, the amount of logs allowed to be harvested over a certain time period, has been set for management units on periodic basis by the chief forester MFLNRO (Ministry of Forests, Mines and Lands, 2010).

\(^{17}\) For instance they introduce requirement for logging, reforestation, planning, road building, etc.
3.3 Provincial governments and policy change

3.3.1 Before changes in policy

During 1990s the Provincial government (controlled by the New Democratic Party (NDP)) was mostly responsive to the environmental plans. In response to the environmental protests, the provincial government doubled the protected forest areas and increased stumpage fees\(^{18}\) (Cashore et al. 2011). As a result of environmental restrictions, AAC declined significantly. Not only did the changes in policy increase environmental protection for the forests, but also at the same time increased the cost of log production for the forest industry (Haley, 1996).

BC coast was losing its competitive advantage of exporting logs to Japan, Europe and Russia due to increased costs. In addition, the US\(^{19}\) decreased purchase of logs and other forest products from the BC coast. Meanwhile, on the coast, the costs were increasing faster than the prices and many mills were shut down. Twenty-seven mills closed between 1997 to 2002, 13,000 people lost their jobs, and government’s revenue decreased by more than $600 million (British Columbia Ministry of Forests, 2003). In 2001, Peter Pearse prepared a report on the coastal forest industry. He mentioned that the costal forest industry has a critical condition and recommended adding more flexibility to the regulations regarding the industry and relaxing some of the restrictions (Pearse, 2001). Compared to the coast, the interior was facing less problems due to its lower logging costs and more advanced milling technology (Nelson et al. 2006).

3.3.2 Policy change

In 2001, the British Columbia Liberal Party won the majority of the seats in the provincial election. The lumber dispute with the US\(^{20}\), the poor condition of the coastal forest industry (high costs and losing their competitiveness), and a new government that was in favour of market based policies

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\(^{18}\) For more details about the advantages and disadvantages of the previous system please see Niquidet (2008).

\(^{19}\) The US has the biggest market for forest products in the world and is the biggest market for BC logs and lumber products.

\(^{20}\) This subject is a broad and controversial matter. The agreement has been largely analyzed and discussed in several papers (e.g. van Kooten, (2002) and Gagné, 2003). The agreement is not the concern of the current research.
motivated policy changes for BC. The provincial government introduced the New Era Forest Policy Agenda and undertook significant market and price reforms.

One important aspect of the policy changes was the Forestry Revitalization Plan (FRP) which was announced in March 2003. The plan was a set of market-based policies and regulations to respond to the Canada–US softwood lumber trade dispute and also to the increased competition with other producers around the world. The government expected some projected benefits out of this change such as an increased competitiveness and a better response by licensees to the market conditions, better business opportunities, more jobs, and an efficient industry (British Columbia Ministry of Forests and Range, 2011). The overall goal of the FRP was to add more flexibility for the forest industry by decreasing the government role in the market (Niquidet, 2008 and Zhang, 2007).

One part of the FRP included tenure reallocation and tenure transfer. Previous studies such as Nelson et al. (2006); Niquidet et al. (2007) and Niquidet (2008) investigated the changes in the tenure system in BC in detail. The other part of the FRP included an increase in the amount of auctioned logs in British Columbia’s log sales program (through BC Timber Sales, BCTS). The amount of logs auctioned in BCTS was supposed to be used in the new stumpage system to set a market-based stumpage rate (MPS)21 (Niquidet et al. 2007).

Another change included in FRP was the introduction of new processing and cut control regulation. In the old system the licensees had to harvest certain tree species and log grades (cut and remove requirements), harvest within a certain percentage of their AAC (disregarding market conditions) and process the logs in local manufacturing facilities (appurtenancy requirements). The new system eliminated minimum harvest levels, appurtenancy requirements and there was no penalty for mill closures. Moreover, the licensees could harvest any tree species or log grades, and they had to pay stumpage on any log which was left standing or felled but did not have to take certain logs to the market (take or pay policy). In addition, there were no penalties for leaving a standing log (Niquidet, 2007 and British Columbia Ministry of Forests and Range, 2011). The new system

21 For more information on BCTS please see (Niquidet et al., 2007).
was adding more flexibility for the loggers by relaxing some of the regulations, which resulted in decreasing the role of government regulation and relying more on market forces.

In this research, we aim to investigate if new processing and cut control regulations impacted log supply in the BC coast and interior. In order to do that, we introduce a dummy variable that holds a value of 0 before the change in the policy and a value of 1 after the change in the policy. Further details on modeling and methodology will be discussed in section 4.3. With the changes in policy we expect to see the loggers adjust their harvest levels based on market forces more and react to the changes in the log prices or harvesting costs.

3.4 Log grade

The end use product and the quality of the log are important in determining its value. Logs are scaled under the Forest Act\(^\text{22}\), meaning that their quality and volume are determined. Grading provides information about log quality giving relevant information for forest management purposes. One main reason for grading is its ability to provide information about the value of the logs. Based on the end use of the log, certain log grades are required (e.g., different log types are required for the production of lumber compared to pulp). Based on legal requirements, all the harvested logs in Crown land or private land must be scaled. Grading happens under the Scaling Regulation, which includes two grading schemes: coast and interior. Grades show the size, quantity and quality that are available for making certain end products. These products are lumber, veneer, shingles and chips on the coast and lumber and chips in the interior (Timber Pricing Branch, 2011).

The species and grades of trees are not the same in these areas. The coast has species such as Balsam, Hemlock, Cedar, Cypress, Douglas Fir, and Sitka Spruce, while in the interior there are species such as Larch, Birch, Willow, Lodge pole pine, interior Douglas Fir, Sub-alpine Fir, and Engelmann Spruce. All these species have different grades including B, C, etc. through Z on the

\(\text{---------------------------}\)

\(^{22}\) For detailed information about the Forest Act and the brief history of forest policy in BC please see Haley and Luckert (1990).
coast and sawlog code 1, sawlog code 2, lumber reject code 4, undersized code 6 and firmwood reject code Z in the interior. In this categorization B and sawlog code 1 are considered as the highest log quality while Z and undersized code 6 the lowest (Timber Pricing Branch, 2011). The assumption in this research is that high grade logs are used to make products like lumber and low grade logs are used in the manufacture of pulp. X and lower grades for all coastal species are considered low grade. In addition, grade U for Hemlock and Balsam is also considered low grade. For the interior, sawlog code 1 and sawlog code 2 are considered as high grade logs.

There are many physical characteristics that impact log grades. For instance, it must be determined what portions of the log are suitable for wood products, because it can indicate the log’s commercial value. There are also some requirements regarding the quality factors of logs such as size of knots, presence of pitch pockets23, ring count 24 and stain25. More detailed and technical information about the grading process can be found in the coast and interior log grading manual MFLNRO (Ministry of Forests, Lands and Natural Resources, 2011).

3.5 Data

For the current research, the province of BC is divided into coast and interior. Monthly time-series data are used and the data range is from January 2000 to December 2013 for the coast and January 2004 to December 2013 for the interior, the later as log price data were not available for years 2000 to 2003. The data covers the information on Crown land. Based on the description in coast and interior appraisal manual (mentioned in section 3.4) the grades of log were divided into high grade and low grade. We only include softwood logs data since BC harvests mostly softwood species. As discussed in Chapter 2, the other studies in BC did not distinguish different log grades

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23 They can lower the value of lumber and veneer.
24 When the separations between the rings are narrower, the woody tissue is denser, meaning it can produce stronger lumber and higher quality veneer.
25 It does not weaken the wood fibre but will affect the appearance of the wood. It will be important when the end product is used for finishing or decorative purposes
and assumed logs are homogenous. In this research, we assume the logs are not homogenous and distinguish them into two different categories based on coast and interior appraisal manual.
3.5.1 Log harvest levels

The MFLNRO provides monthly data on the volume of logs that has been harvested, based on billing history (MFLNRO, 2014). The data includes all BC by region/district, all species, all products and grades. The harvest levels are in cubic metres.

Figure 3-1 shows the trend in high grade harvest levels in BC coast. The maximum harvest levels is approximately 2 million m$^3$ in 2004, and the lowest point is around 50,000 m$^3$ in 2003. The graph shows there were huge fluctuation in certain months of the years from 2000 to 2005 while the fluctuations decreased after 2008. Seasonality also exists in months such as January and July.

Figure 3-2 illustrates harvest levels for low grade logs in BC coast. The graph shows larger fluctuations before 2005, while after 2005 harvest levels decreased significantly with less variation. The minimum harvest levels was around 4,000 m$^3$ in year 2003 and the maximum level was around 200,000 m$^3$ in year 2000.

![Figure 3-1 Monthly harvest levels-High grade-coast](image)

---

Figure 3-1 Monthly harvest levels-High grade-coast
Harvest levels for the interior are shown in Figure 3-3 and 3-4. High grade log harvest levels decreased after its peak in 2004. Moreover, seasonality is present through the whole graph. High grade logs harvest levels show almost a repetitive pattern especially after 2008, with sudden increase in February and decrease in May. Minimum harvest level was approximately 100,000 m$^3$ and the maximum level was around 10 million m$^3$.

The low grade logs, experienced bigger variations during 2008 to 2010. Minimum harvest level was approximately 40,000 m$^3$ and the maximum level was around 2 million m$^3$ (Figure 3-4).
Figure 3-3 Monthly harvest levels-High grade-interior

Figure 3-4 Monthly harvest levels-Low grade-interior
3.5.2 Log price market

Log prices are determined in the market, where the loggers sell logs to the mills. The mills are asked to report the trading prices every month and based on those reports, Log Pricing Branch of the MFLNRO reports the log prices separately for the coast and interior, in Canadian dollars (Log Pricing Branch, 2014). To calculate the real price, the monthly Consumer Price Index was used to deflate the prices. CPI is provided in Table 326-0020 (Government of Canada, 2014a) of Statistics Canada.

For the analysis year 2002 was chosen as the base year. An example of how to make the new CPI* is provided. Suppose calculation of the \( CPI_{\text{Jul 2012}}^* \) is required:

\[
CPI_{\text{Jul 2012}}^* = \frac{CPI_{\text{Jul 2012}}}{CPI_{\text{Jul 2002}}} \times 100
\]

In which \( CPI_{\text{Jul 2002}} \) is the CPI of the base year. The same practice is done for all CPI data points to get CPI* (2002=100).

Using this formula the prices are deflated:

\[
Real P_t = \frac{P_t}{CPI_t^*/100}
\]

Where \( P_t \) is the log price at time \( t \).

All the prices were deflated prior to the estimation in this research.

Figure 3-5 shows the trend in real log prices for period of 2000 to 2013 in 2002 dollars (2002=100). The price fluctuates around 120 dollars per cubic metres. The lowest log price was around 72 $/m³ in March 2009 and the highest price was 226 $/m³ in December 2002.
Figure 3-5 Monthly log prices-High grade-coast

Figure 3-6, shows monthly low grade prices for the BC coasts. Based on Figure 3-6, the average price for low grade log is around 35 dollars per cubic metres. The minimum price level was 21 $/m³ and the maximum price was 49 $/m³.

Figure 3-7, indicates high grade log prices for the BC interior. Referring to Figure 3-7, the prices experience larger fluctuations during 2011 to 2013. The minimum price was 30 $/m³ and the maximum price was 100 $/m³.
**Figure 3-6** Monthly log prices-Low grade-coast

**Figure 3-7** Monthly log prices-High grade-interior
Figure 3-8, demonstrates the trend in monthly log prices for low grade logs in the interior. Low grade log prices experienced a sudden decrease in 2009. This may be associated with the recession that happened in 2008. The variations are larger during 2010 to 2013.

![Figure 3-8 Monthly log prices-Low grade-interior](image)

### 3.5.3 Log export market

BC exports a range of forest products to overseas markets (Niquidet and van Kooten, 2006). For instance, Canada exported around 7 million cubic metres of logs in 2013 and 6 million cubic metres of that was exported from BC (Global Trade Atlas, 2014 and BCStats, 2014). BC’s location benefited its industries for log exporting and based on different situations, there has been some different log export policies to help BC’s wood-processing industries to develop and grow.

Canada and the Province of BC both have a long history of log export restriction policies. There are studies that specifically evaluated the impacts of these policies on log supply, including Margolick and Uhler (1992), Zhang (1996) and Fooks et al. (2013). The objective of the current research is incorporating the impact of log export prices on log supply in coastal BC, and not
assessing the log export policies. According to Fooks et al. (2013), if the log export prices increase it will encourage more export. Based on the AAC and export restriction policies, it can also increase the harvest levels. For instance, if the log export prices increase it will encourage the licensees to harvest more logs and export them.

Export prices are reported in BC Stats which is a central statistics agency for the province (BC Stats, 2014). The log export prices were categorized based on commodity and country of destination. The data used for this research distinguishes between logs for pulping as low grade and logs for lumber and veneer for high grade.

Figure 3-9 shows the log export prices for high grade logs. Overall, the export price decreased during 2000 to 2013.

![Figure 3-9 Monthly log export prices-High grade](image-url)
Figure 3-10 demonstrates the low grade log export prices. There are more fluctuations in low grade export prices compared to the high grade log, but since low grade log export volume is very low the prices might be less reliable. The other issue with low grade log prices is that in some months the export data for low grade logs was not available and the quantity and price were both zero. These point are not shown in the graph but these certain months are not included in the analysis.

![Figure 3-10 Monthly log export log prices - Low grade](image)

**Figure 3-10 Monthly log export log prices - Low grade**

### 3.5.4 Stumpage price

BC has historically used Comparative Value Pricing (CVP) for setting stumpage fees. Introduced in 1987, CVP utilizes a revenue target set by the government and then using the stand’s value index and the mean value index of the stands the stumpage was calculated\(^{26}\). In 1991, BC Ministry of Forests started using a more market based pricing system (known as MPS). With the new

\(^{26}\) This method is not the concern of this research, for more detailed information please see Niquidet and van Kooten, (2006).
system, a small percentage of annual harvests were auctioned. In 2003, this small percentage was increased when the provincial government introduced the new policy changes (Niquidet and van Kooten, 2006 and MFLNRO, 2004).

Stumpage is reported by the BC Ministry of Forests, along with harvest levels in the harvest billing system (MFLNRO, 2014). In this research, stumpage price is calculated by dividing the sum of stumpage revenue based on grades over the sum of the volumes for each month. The stumpage prices are deflated by CPI and they are in Canadian dollars.

Figure 3-11 shows the stumpage prices for high grade logs on the coast. The graph also shows small fluctuations in stumpage price after January 2010, while before this time it was much larger.

![Figure 3-11 Monthly stumpage prices-High grade-coast](image-url)
Figure 3-12, illustrates the low grade log stumpage price. After 2005, the stumpage price decreased significantly and fluctuated around 25 cents. This may be associated with the change in the stumpage pricing system.

![Graph showing monthly stumpage prices for low grade logs from January 2000 to January 2013.](image)

**Figure 3-12** Monthly stumpage prices-Low grade-coast

Figures 3-13 and 3-14 show the stumpage price for BC interior for high grade and low grade logs. The high grade stumpage prices decreased in 2007 and started to increase from 2013. Low grade stumpage price seems to have a consistent trend except a sudden increase in 2009.
Figure 3-13 Monthly stumpage prices-High grade-interior

Figure 3-14 Monthly stumpage prices-Low grade-interior
3.5.5 Wage

As mentioned in the literature review, costs are one of the factors affecting log supply. For this research and according to the modeling approach and estimation method, labour cost (wage) was chosen as an indicator of the cost. Wage prices were obtained from Table 282-0071 of Statistics Canada. The average hourly rate of forestry, fishing, mining, quarrying, oil and gas is used as wage rate (Government of Canada, 2014b). Wage is deflated by CPI and is in Canadian dollars per hour. Figure 3-15 shows the monthly trend in wages. There is no sudden change in the wage rates during these fourteen years.

![Figure 3-15 Monthly average hourly wage rate of forestry, fishing, mining, quarrying, oil and gas](image)

3.5.6 Final product price

For this research, supply is jointly determined with demand (the modeling details are presented in section 4.2.1). One of the factors impacting demand of log is the price of the final product (Wear and Pattanayak, 2003). For high grade logs the assumed final product is random lengths North America framing lumber composite (Fooks et al, 2013) used the same approach). Monthly prices
were obtained from the Random Lengths website (Random Lengths, 2014). The prices are in US dollar per thousand board feet.

The monthly exchange rates for the US and Canadian dollars were sourced from Bank of Canada (Bank of Canada, 2014) and volumes in thousand board feet were converted to cubic metres by dividing the numbers by 2.35. Figure 3-16 shows monthly lumber prices in Canadian dollars. The maximum price was 273 $/m$^3$ and the minimum price was 77 $/m^3$. This number is different for the model in the interior since the data range is from 2004 to 2013. The minimum price for the interior was 72 $/m^3$ and the maximum was 239 $/m^3$.

![Figure 3-16 Monthly price of random lengths framing lumber composite](image_url)
Final product for low grade log is Northern Bleached Softwood Kraft pulp prices from Intelligence Industry Inc. where the prices are in US dollars per tonnes (Intelligence Industry Inc, 2015). Similar to the lumber prices, pulp prices were converted into Canadian dollars. Figure 3-17 demonstrates pulp prices from 2000 to 2013 in tonnes per cubic metres.

![Figure 3-17 Monthly prices of pulp Northern Bleached Softwood Kraft pulp (NBSK)](image)

3.5.7 Policy

To assess the impact of policy changes on log supply, we will introduce a dummy variable in our models in section 4.3 for both regions, coast and interior. To show the impact of the policy, we need to include the time period before the change in policy and after the change in policy.

The FRP was announced in March 2003 and generally it takes some times for the policy to be fully implemented. For example, for the coast the regulations regarding MPS (which was one part of the FRP) took place in February 2004. We therefore assume that the policies regarding processing and cut control regulations to become effective from that date.
For the interior, it took longer to introduce the changes. First, there was a major log grade change in the interior in April 2006. Before this date, log grades were reported as one group of higher grade logs and grades 3, 4, 5, 6 and Z. After the changes two sawlog grades were introduced, grades 1 and 2, while grades 3 and 5 were merged to lumber reject 4 grade (Ministry of Forests, Lands and Natural Resources, 2011). For this research, grades 3, 4, 5 and 6 were considered as low grade before 2006, and after 2006 grades 4 and 6 were included in the low grade data. After the grade change in June 2006, provincial government announced the change in the stumpage pricing system (MPS). We assume that the change in the policy happened in the interior in 2006.
Table 3-1 and 3-2 show the summary statistics of the data for each region on different grades

**Table 3-1** Summary statistics for BC coast logs, 2000-2013

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>High grade harvest levels (m$^3$)</td>
<td>1,075,016</td>
<td>438,447</td>
<td>53,340</td>
<td>2,342,871</td>
</tr>
<tr>
<td>Low grade harvest levels (m$^3$)</td>
<td>68,530</td>
<td>71,396</td>
<td>4,579</td>
<td>284,091</td>
</tr>
<tr>
<td>High grade log price ($/m$^3$)</td>
<td>148</td>
<td>31</td>
<td>72</td>
<td>226</td>
</tr>
<tr>
<td>Low grade log price ($/m$^3)</td>
<td>36</td>
<td>5</td>
<td>21</td>
<td>49</td>
</tr>
<tr>
<td>High grade log stumpage ($/m$^3)</td>
<td>12</td>
<td>7</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td>Low grade log stumpage ($/m$^3)</td>
<td>4</td>
<td>5</td>
<td>0.18</td>
<td>18</td>
</tr>
<tr>
<td>High grade log export price ($/m$^3)</td>
<td>107</td>
<td>20</td>
<td>70</td>
<td>170</td>
</tr>
<tr>
<td>Low grade log export price ($/m$^3)</td>
<td>64</td>
<td>29</td>
<td>14</td>
<td>149</td>
</tr>
<tr>
<td>Framing lumber composite ($/m^3$)</td>
<td>137</td>
<td>43</td>
<td>72</td>
<td>273</td>
</tr>
<tr>
<td>Pulp price ($/tonne)</td>
<td>810</td>
<td>77</td>
<td>650</td>
<td>1,106</td>
</tr>
<tr>
<td>Wage ($/h)</td>
<td>24</td>
<td>1.45</td>
<td>21</td>
<td>27</td>
</tr>
</tbody>
</table>
Table 3-2 Summary statistics for BC interior logs, 2004-2013

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>High grade harvest levels (m³)</td>
<td>2,593,750</td>
<td>1,827,343</td>
<td>142,421</td>
<td>10,857,406</td>
</tr>
<tr>
<td>Low grade harvest levels (m³)</td>
<td>752,019</td>
<td>539,686</td>
<td>49,032</td>
<td>2,202,566</td>
</tr>
<tr>
<td>High grade log price ($/m³)</td>
<td>68</td>
<td>18</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Low grade log price ($/m³)</td>
<td>27</td>
<td>7</td>
<td>12</td>
<td>49</td>
</tr>
<tr>
<td>High grade log stumpage ($/m³)</td>
<td>11</td>
<td>5</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Low grade log stumpage ($/m³)</td>
<td>0.24</td>
<td>0.04</td>
<td>0.2</td>
<td>0.45</td>
</tr>
<tr>
<td>Framing lumber composite ($/m³)</td>
<td>130</td>
<td>37</td>
<td>77</td>
<td>239</td>
</tr>
<tr>
<td>Pulp price ($/tonne)</td>
<td>810</td>
<td>74</td>
<td>651</td>
<td>977</td>
</tr>
<tr>
<td>Wage ($/h)</td>
<td>24</td>
<td>1.45</td>
<td>21</td>
<td>27</td>
</tr>
</tbody>
</table>

3.6 Conclusion and discussion

In this chapter the major policy changes that occurred in BC were presented followed by the data used in the models of this research.

Policy is one of the major responsibilities of the government. Any changes in provincial policy impact industry, communities, First Nations, and the overall economic health of the province, due to vast public forest ownership in BC. Significant policy changes were presented during the 2000s by the Liberal government in BC and major changes were included in the FRP. Generally speaking,
these changes decentralized the role of the provincial government in the forest sector. In this plan, the government’s role became less significant in determining how and where the log must be used (Niquidet, 2008). The government believed this change would lead into a higher flow of logs in the open markets and would support a market based pricing system (British Columbia Ministry of Forests, 2003 and Niquidet, 2007).

The log grading process has its own procedures and is different between the coast and interior. The differences between the log grading schemes were explained based on the coast and interior Appraisal Manual. To address log grade diversity in our research, each region had two separate models, one for high grade logs and one for low grade logs (presented in section 4.3). The data for harvest levels, log prices, stumpage and log export prices were divided into high grade and low grade which helps analyzing the models regarding the grade differences.

The data on economic and forestry variables is available through the provincial and federal government for the forest sector in Canada. Graphs were offered to help in visualizing the fluctuations. The period 2000 to 2013 was chosen in this study to include the period in which major policy changes occurred. Including the period before the policy was changed enables us to investigate how the policy impacts log supply.
Chapter 4: Methodology and results

4.1 Synopsis

This chapter discusses the models used for log supply for the BC coast and interior. The first section introduces the theoretical background and the demand and supply models used for the estimations. Section 4.3 discusses the estimation method. In section 4.4 the results and further tests are presented and discussion on the results are presented. A conclusion regarding the results is presented in section 4.5.

4.2 Theoretical model

4.2.1 Simultaneous equations models

Economic variables can be divided in two broad groups, exogenous and endogenous. Exogenous variables impact the model but are not correlated with the error terms (other factors that might influence the model but are not included in the model), and they are determined by elements outside of the model. Endogenous variables might be correlated with the error term and are often determined within the model. This means that the model is used to find their value (Gujarati, 2003 and Wooldridge, 2013).

Some studies on log supply assume independent variables are all exogenous (e.g. Bolkesjø et al. 2010 and Sun et al. 2015), while others such as Zhang and Buongiorno (2012) considered one or two endogenous variables in their models and used instrumental variable methods to estimate log supply. This method is used to solve the endogeneity problem of the explanatory variables. The instrumental variable has to be (a) correlated with the endogenous variable but (b) uncorrelated with the error term in the equation, so it is challenging to find the right instrumental variable27 (Wooldridge, 2013).

27The full description of usage of instrumental variables are explained in Wooldridge, (2013) chapter 15.
Another approach is when there is an equilibrium mechanism where the economic variables influence each other in a two way flow (Brännlund et al. 1985; Toppinen and Kuuluvainen, 1997; and Mutanen and Toppinen, 2005). This is called simultaneity which is one form of endogeneity for the independent variables. In these models the independent variable(s) is determined jointly with the dependent variable. One usage of simultaneous equations models is in aggregate time-series models. Common example of simultaneous systems is when supply is sometimes jointly estimated with demand because of price endogeneity (supply and demand equilibrium) (Gujarati 2003; Wear and Pattanayak 2003 and Wooldridge 2013).

In the current research, we introduce a similar approach to the latter and assume the quantity and price are determined by the intersection of supply and demand simultaneously. For this reason, supply and demand models are introduced separately and then they are estimated simultaneously.

4.2.1.1 Log supply

One objective of the forest land owners such as government, industry or private owners is to have efficient production of logs. Perfect competition is assumed for production factors and final products while there is no imperfection in capital market and uncertainty for decision making. The log supply model that is used in this research is in a competitive environment based on the theory of the firm (Brännlund et al. 1985; Toppinen and Kuuluvainen, 1997; Mutanen and Toppinen, 2005; and Bolkesjø et al. 2010).

Our approach to define the supply model is similar to Brännlund et al. (1985), Bolkesjø et al. (2010), Zhang and Buongiorno (2012), and Sun et al. (2015). Assuming the coast and interior logging companies have the same production function while trying to maximize their profit, the logging company profit function is:

\[ \pi(R, C) = \max_Q (R(P, Q) - C(S, W)) \] (4-1)

Where \( R \) is the harvest revenue which includes log price \( P \) and log quantity \( Q \) and \( C \) is the production cost that consists of stumpage \( S \) and labour price \( W \). Using Hotelling’s lemma,
partial derivative of the profit function regarding log price, the short-run log supply function is obtained from the logging company’s profit function:

$$\frac{\partial \pi}{\partial P} = Y(P, S, W, Z) \quad (4-2)$$

$$Q_t = f(P_t, C_t, Z_t) \quad (4-3)$$

Here f represents a functional form that relates time period and log production, $Q_b$ to the stumpage, $S_t$, log price, $P_t$, the cost of input in log harvesting, $C_t$, and other factors that may influence log supply, $Z_t$.

Using the model from Sun et al. (2015) and adjusting it to the objective of this research, harvest costs are stumpage price and wage, while other variables are government policy changes and seasonality where the data is observed over a number of months, t. The short-run aggregate supply model is:

$$Q_t^s = f(P_t, S_t, W_t, \text{ExP}_t, \text{Pol}_t, \text{Month}_t) \quad (4-4)$$

Where $Q_t^s$ is the log supply, $P_t$ is the log price, $W_t$ is the cost of labour, $\text{ExP}_t$ is log export price, and $\text{Pol}_t$ is the policy dummy variable. Using seasonal dummy variables helps in following the impact of seasonality in the monthly data (Wooldridge, 2013). Zhang (1996), Mutanen and Toppinen, (2005) and Sun et al. (2015) also used seasonal dummy variables in their models.

4.2.1.2 Log demand

Following a similar approach as Mutanen and Toppinen, (2005), we assume mills are looking to maximize their profit (like the supply model). The aggregate demand function is:

$$Q_t^d = f(P_t, FP_t, \text{Month}_t) \quad (4-5)$$
Where $Q_t^d$ is demand for logs, $P_t$ is the log price, $FP_t$ is the final product price which is framing lumber composite and pulp prices and the same as in the supply function, $Month_t$ includes eleven monthly dummy variables.

### 4.3 Empirical model

Following the approaches of Brännlund et al. (1985), Mutanen and Toppinen (2005), Bolkesjø et al. (2010), Zhang and Buongiorno (2012) and Sun et al. (2015), and assuming a Cobb-Douglas functional form and a logarithm transformation, the empirical form of the models 4-4 and 4-5 are as below:

**Coast-High grade**

**Demand:**

\[
\ln Q_t^{chd} = \gamma_0 + \gamma_1 \ln P_t^{ch} + \gamma_2 \ln Q_{t-1}^{ch} + \gamma_3 \ln P_{t-1}^{ch} + \gamma_4 \ln FP_t^h + \gamma_5 \text{Jan} + \gamma_6 \text{Feb} \\
+ \gamma_7 \text{Mar} + \gamma_8 \text{Apr} \\
+ \gamma_9 \text{May} + \gamma_{10} \text{Jun} + \gamma_{11} \text{Jul} + \gamma_{12} \text{Aug} + \gamma_{13} \text{Sep} + \gamma_{14} \text{Oct} + \gamma_{15} \text{Nov} + u_{1t}
\]  

\[ (4-6) \]

Where $Q_t^{chd}$ is log demand for high grade log, $P_t^{ch}$ is the high grade log price, $Q_{t-1}^{ch}$ is lagged demand for high grade log, $P_{t-1}^{ch}$ is lagged price for high grade log, $FP_t^h$ is the final product price for high grade log, $u_{1t}$ is the error term, and the rest of the variables show each month dummy variable from January to November.

In order to show January in monthly dummy variables, a value of 1 is given to January and 0 to the other months; thus there is no need to add a dummy variable for December. Ln shows the natural logarithm of a variables, so $\gamma_1$ to $\gamma_4$ indicate the elasticities (Wooldridge, 2013).

---

\[ 28 \] The standard Cobb-Douglas production function is $Y = AL^\alpha K^\beta$ where $Y$ is the total production, $L$ is the labour input, $K$ is the capital input and $A$ is total factor productivity. $\alpha$ and $\beta$ are elasticities of labour and capital output (Fraser 2002).
Supply:

\[
\ln Q_{t}^{\text{chs}} = \beta_0 + \beta_1 \ln P_t^{\text{ch}} + \beta_2 \ln P_t^{\text{cl}} + \beta_3 \ln S_t^{\text{ch}} + \beta_4 \ln W_t \\
+ \beta_5 \ln \text{ExP}_t^h + \beta_6 \ln Q_{t-1}^{\text{chs}} + \beta_7 \text{Pol}_t^c + \beta_8 \text{Jan} + \beta_9 \text{Feb} + \beta_{10} \text{Mar} + \beta_{11} \text{Apr} \\
+ \beta_{12} \text{May} + \beta_{13} \text{Jun} + \beta_{14} \text{Jul} + \beta_{15} \text{Aug} + \beta_{16} \text{Sep} + \beta_{17} \text{Oct} + \beta_{18} \text{Nov} + v_{1t}
\]  

(4-7)

In which \(Q_t^{\text{chs}}\) is log supply for high grade log, \(P_t^{\text{cl}}\) is the low grade log price, \(S_t^{\text{ch}}\) is the stumpage price for high grade log, \(W_t\) is the labour cost, \(\text{ExP}_t^h\) is high grade log export price, \(\text{Pol}_t^c\) is the policy dummy variable and its value is 1 after the change of policy and 0 before the change and finally \(v_{1t}\) is the error term. \(\beta_1\) to \(\beta_7\) show the elasticities.

Cost-Low grade

Demand:

\[
\ln Q_{t}^{\text{cl}} = \rho_0 + \rho_1 \ln P_t^{\text{cl}} + \rho_2 \ln Q_{t-1}^{\text{cl}} + \rho_3 \ln P_{t-1}^{\text{cl}} + \rho_4 \ln \text{FPl}_t + \rho_5 \text{Jan} + \rho_6 \text{Feb} \\
+ \rho_7 \text{Mar} + \rho_8 \text{Apr} \\
+ \rho_9 \text{May} + \rho_{10} \text{Jun} + \rho_{11} \text{Jul} + \rho_{12} \text{Aug} + \rho_{13} \text{Sep} + \rho_{14} \text{Oct} + \rho_{15} \text{Nov} + u_{2t}
\]  

(4-8)

Where \(Q_t^{\text{cl}}\) the log demand for low grade log, \(Q_{t-1}^{\text{cl}}\) is lagged demand for low grade log, \(P_{t-1}^{\text{cl}}\) is lagged price for low grade log, \(\text{FPl}_t\) is the final product price for low grade log, and \(u_{2t}\) is the error term. \(\rho_1\) to \(\rho_4\) are the elasticities.

Supply:

\[
\ln Q_{t}^{\text{cls}} = \tau_0 + \tau_1 \ln P_t^{\text{ch}} + \tau_2 \ln P_t^{\text{cl}} + \tau_3 \ln S_t^{\text{cl}} + \tau_4 \ln W_t \\
+ \tau_5 \ln \text{ExP}_t^l + \tau_6 \ln Q_{t-1}^{\text{cl}} + \tau_7 \text{Pol}_t^c + \tau_8 \text{Jan} + \tau_9 \text{Feb} + \tau_{10} \text{Mar} + \tau_{11} \text{Apr} \\
+ \tau_{12} \text{May} + \tau_{13} \text{Jun} + \tau_{14} \text{Jul} + \tau_{15} \text{Aug} + \tau_{16} \text{Sep} + \tau_{17} \text{Oct} + \tau_{18} \text{Nov} + v_{2t}
\]  

(4-9)

In which \(Q_t^{\text{cls}}\) is the log supply for low grade logs, \(S_t^{\text{cl}}\) is the stumpage price for low grade log, \(\text{ExP}_t^l\) is low grade log export price, and \(v_{2t}\) is the error term. \(\tau_1\) to \(\tau_7\) indicate the elasticities.

\[^{29}\]Log export price is treated as an exogenous variable in our model. This price is set in world market place and BC is the price taker.
Interior-High grade

Demand:

\[
\ln Q_t^{\text{ihd}} = \theta_0 + \theta_1 \ln P_t^{\text{ih}} + \theta_2 \ln Q_{t-1}^{\text{ih}} + \theta_3 \ln P_{t-1}^{\text{ih}} + \theta_4 \ln FP_t^{\text{ih}} + \theta_5 \text{Jan} + \theta_6 \text{Feb} \\
+ \theta_7 \text{Mar} + \theta_8 \text{Apr} \\
+ \theta_9 \text{May} + \theta_{10} \text{Jun} + \theta_{11} \text{Jul} + \theta_{12} \text{Aug} + \theta_{13} \text{Sep} + \theta_{14} \text{Oct} + \theta_{15} \text{Nov} + u_3t
\]  

(4-10)

Where \( Q_t^{\text{ihd}} \) is the log demand for high grade log, \( P_t^{\text{ih}} \) is the high grade log price, \( Q_{t-1}^{\text{ih}} \) is lagged demand for high grade log, \( P_{t-1}^{\text{ih}} \) is lagged price for high grade log, \( u_3t \) is the error term, and \( \theta_1 \) to \( \theta_4 \) indicate elasticities.

Supply:

\[
\ln Q_t^{\text{ihs}} = \varphi_0 + \varphi_1 \ln P_t^{\text{ih}} + \varphi_2 \ln P_t^{\text{il}} + \varphi_3 \ln S_t^{\text{ih}} + \varphi_4 \ln W_t + \varphi_5 \ln Q_{t-1}^{\text{ih}} + \varphi_6 Pol_t^{\text{ih}} \\
+ \varphi_7 \text{Jan} + \varphi_8 \text{Feb} + \varphi_9 \text{Mar} + \varphi_{10} \text{Apr} \\
+ \varphi_{11} \text{May} + \varphi_{12} \text{Jun} + \varphi_{13} \text{Jul} + \varphi_{14} \text{Aug} + \varphi_{15} \text{Sep} + \varphi_{16} \text{Oct} + \varphi_{17} \text{Nov} + v_3t
\]  

(4-11)

In which \( Q_t^{\text{ihs}} \) is log supply for high grade log, \( P_t^{\text{il}} \) is the low grade log price, \( S_t^{\text{ih}} \) is the stumpage price for high grade log, \( Pol_t^{\text{ih}} \) is the policy dummy variable, and \( v_3t \) is the error term. \( \varphi_1 \) to \( \varphi_6 \) are the elasticities.

Interior-Low grade

Demand:

\[
\ln Q_t^{\text{ild}} = \omega_0 + \omega_1 \ln P_t^{\text{il}} + \omega_2 \ln Q_{t-1}^{\text{il}} + \omega_3 \ln P_{t-1}^{\text{il}} + \omega_4 \ln FP_t^{\text{il}} + \omega_5 \text{Jan} + \omega_6 \text{Feb} \\
+ \omega_7 \text{Mar} + \omega_8 \text{Apr} \\
+ \omega_9 \text{May} + \omega_{10} \text{Jun} + \omega_{11} \text{Jul} + \omega_{12} \text{Aug} + \omega_{13} \text{Sep} + \omega_{14} \text{Oct} + \omega_{15} \text{Nov} \\
+ u_4t
\]  

(4-12)

Where \( Q_t^{\text{ild}} \) the log demand for low grade log, \( Q_{t-1}^{\text{il}} \) is lagged demand for low grade log, \( P_{t-1}^{\text{il}} \) is lagged price for low grade log, \( FP_t^{\text{il}} \) is the final product price for low grade log, and \( u_4t \) is the error term. \( \omega_1 \) to \( \omega_4 \) indicate the elasticities.
Supply:

\[
\ln Q_{t}^{\text{ls}} = \theta_{0} + \theta_{1} \ln P_{t}^{\text{th}} + \theta_{2} \ln P_{t}^{\text{il}} + \theta_{3} \ln S_{t}^{\text{hi}} + \theta_{4} \ln W_{t} + \theta_{5} \ln Q_{t-1}^{\text{il}} + \theta_{6} \text{Pol}_{t} + \theta_{7} \text{Jan} + \theta_{8} \text{Feb} + \theta_{9} \text{Mar} + \theta_{10} \text{Apr} + \theta_{11} \text{May} + \theta_{12} \text{Jun} + \theta_{13} \text{Jul} + \theta_{14} \text{Aug} + \theta_{15} \text{Sep} + \theta_{16} \text{Oct} + \theta_{17} \text{Nov} + \nu_{4t}
\]  

(4-13)

In which \(Q_{t}^{\text{ls}}\) is the low grade log supply, \(S_{t}^{\text{il}}\) is the stumpage price for low grade log, \(\nu_{4t}\) is the error term, and \(\theta_{1}\) to \(\theta_{6}\) are the elasticities.

Before applying the model to the case study some important issues must be addressed. First, the model is applied to two regions in BC, coast and interior separately. Second, the trees are not homogenous across these regions, and the harvest levels are divided into high grade and low grade. The distinction was explained in section 3.4. In some other similar studies log stock and inventory were included in the models, but we do not use them in our models. As mentioned by Sun et al. (2015), when monthly data is used, it is very unlikely that they impact the harvest levels since the inventory does not change largely.

Table 4-1 lists the variables used in the demand and supply models.

**Table 4-1** List of variables used in demand and supply models

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Q_{t}^{\text{chd}})</td>
<td>log demand-high grade log-coast</td>
<td>(S_{t}^{\text{th}})</td>
<td>stumpage price-high grade log-interior</td>
</tr>
<tr>
<td>(Q_{t}^{\text{ild}})</td>
<td>log demand-low grade log-coast</td>
<td>(S_{t}^{\text{il}})</td>
<td>stumpage price-low grade log-interior</td>
</tr>
<tr>
<td>(Q_{t}^{\text{hd}})</td>
<td>log demand-high grade log-interior</td>
<td>(\text{ExP}_{t}^{\text{h}})</td>
<td>log export price-high grade log</td>
</tr>
<tr>
<td>(Q_{t}^{\text{id}})</td>
<td>log demand-low grade log-interior</td>
<td>(\text{ExP}_{t}^{\text{l}})</td>
<td>log export price-low grade log</td>
</tr>
<tr>
<td>(Q_{t}^{\text{hs}})</td>
<td>log supply-high grade log-coast</td>
<td>(W_{t})</td>
<td>labour cost</td>
</tr>
</tbody>
</table>
### Variables and Description

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q^\text{ls}_t$</td>
<td>log supply-low grade log-coast</td>
<td>$F^\text{fh}_t$</td>
<td>final product-high grade log</td>
</tr>
<tr>
<td>$Q^\text{hs}_t$</td>
<td>log supply-high grade log-interior</td>
<td>$F^\text{fl}_t$</td>
<td>final product-low grade log</td>
</tr>
<tr>
<td>$Q^\text{ls}_t$</td>
<td>log supply-low grade log-interior</td>
<td>$P^\text{lc}_t$</td>
<td>policy dummy variable-coast</td>
</tr>
<tr>
<td>$P^\text{ch}_t$</td>
<td>log price-high grade log-coast</td>
<td>$P^\text{lc}_t$</td>
<td>policy dummy variable-interior</td>
</tr>
<tr>
<td>$P^\text{cl}_t$</td>
<td>log price-low grade log-coast</td>
<td>$Q^\text{ch}_{t-1}$</td>
<td>Lagged log quantity-high grade</td>
</tr>
<tr>
<td>$P^\text{lh}_t$</td>
<td>log price-high grade log-interior</td>
<td>$Q^\text{cl}_{t-1}$</td>
<td>Lagged log quantity-high grade</td>
</tr>
<tr>
<td>$P^\text{ll}_t$</td>
<td>log price-low grade log-interior</td>
<td>$P^\text{ch}_{t-1}$</td>
<td>Lagged log price-high grade</td>
</tr>
<tr>
<td>$S^\text{ch}_t$</td>
<td>stumpage price-high grade log-coast</td>
<td>$P^\text{cl}_{t-1}$</td>
<td>Lagged log price-low grade</td>
</tr>
<tr>
<td>$S^\text{cl}_t$</td>
<td>stumpage price-low grade log-coast</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 4.3.1 Two Stage Least Square (2SLS)

One method for estimating the system equations models is by the Two Stage Least Square method (2SLS). We assume that price and quantity are endogenous and they are determined in a system of equations. In addition, the instrumental variables are the exogenous variables that appear in the demand or supply equations (Wooldridge, 2013).
Consider reduced forms of demand and supply models (either region or grade) without the constant and dummy variables:

\[ \ln Q_{t}^{chd} = \gamma_1 \ln P_{t}^{ch} + \gamma_2 \ln Q_{t-1}^{ch} + \gamma_3 \ln P_{t-1}^{ch} + \gamma_4 \ln FP_{t}^{h} \]  \hspace{1cm} (4-14)

\[ \ln Q_{t}^{chs} = \beta_1 \ln P_{t}^{ch} + \beta_2 \ln P_{t}^{cl} + \beta_3 \ln S_{t}^{ch} + \beta_4 \ln W_{t} + \beta_5 \ln ExP_{t}^{h} + \beta_6 \ln Q_{t-1}^{ch} \]  \hspace{1cm} (4-15)

For estimating the demand model with 2SLS method, we rewrite equation (4-15) and estimate this model by OLS method and we get the fitted value \( \ln \hat{P}_{t}^{ch} \):

\[ \ln \hat{P}_{t}^{ch} = \beta_1 \ln Q_{t}^{chs} + \beta_2 \ln P_{t}^{cl} + \beta_3 \ln S_{t}^{ch} + \beta_4 \ln W_{t} + \beta_5 \ln ExP_{t}^{h} + \beta_6 \ln Q_{t-1}^{ch} \]  \hspace{1cm} (4-16)

In the second stage we replace \( \ln P_{t}^{ch} \) by \( \ln \hat{P}_{t}^{ch} \) and use OLS method to estimate (4-14).

We have the same procedure for estimating the supply model. The only difference is that this time we rewrite (4-14):

\[ \ln P_{t}^{ch} = \gamma_1 \ln Q_{t}^{chd} + \gamma_2 \ln Q_{t-1}^{ch} + \gamma_3 \ln P_{t-1}^{ch} + \gamma_4 \ln FP_{t}^{h} \]  \hspace{1cm} (4-17)

And use \( \ln \hat{P}_{t}^{ch} \) in (4-15).

Each of these models were estimated separately for both coast and interior, high grade and low grade logs. Suspecting there might be autocorrelation and heteroskedasticity involved in the models, we ask for heteroskedasticity and autocorrelation consistent (HAC) standard errors while estimating the models. 2SLS gives us consistent and the best estimates for the coefficients that can be obtained in the model (Wooldridge, 2013).
4.4 Tests, results and coefficient interpretation

- Unit root test

In time-series data, the variables must be stationary, meaning the mean and the variance must be stable and remain constant over time. This enables us to study the changes and behaviour of a time-series over time (Wooldridge, 2013). In order to do this test for time-series, Augmented Dickey Fuller (ADF) (Dickey and Fuller, 1979) and Phillips-Perron (Phillips and Perron, 1988) unit root tests were applied.

The results showed that for all the variables, the tests reject the null hypothesis of the variable being non-stationary except for stumpage and framing lumber composite price. Since both tests showed the same interpretation, the results of one of them is presented in Appendix A and Appendix B.

In order to solve the problem, as suggested by Gujarati (2003) and Wooldridge (2013), the first difference of these variables $\ln \Delta FP_{ch}$ and $\ln \Delta S_{ch}$ are used. Assuming the variable is $S_{t}^{ch}$ and and $S_{t-1}^{ch}$ is the lagged variable, $S_{t}^{ch} - S_{t-1}^{ch}$ indicate the first difference of a variable. The tests show that the first difference of these variables are stationary.

- Variables significant test

To test the significance of the coefficients, two hypothesis are made in which the null hypothesis is if the coefficient is zero. The significance of the coefficients is tested in 1%, 5% and 10% of $\alpha$. If the p-value for a coefficient is smaller than $\alpha=0.01$, 0.05 or 0.1, we reject the null hypothesis and this means the coefficients are significant (Wooldridge, 2013).

- Goodness of fit

R-square shows how well the dependent variable is explained by the independent variables (Wooldridge, 2013). The R-squared results are presented in Tables 4-2 and 4-3.

The Wald-test is used for testing the significance of the whole regression. This test is similar to the F-test and the only difference is that it uses chi-square distribution. The null hypothesis is that
the regression is not significant while the alternative is that regression is significant. Similar to the variable significance test if the p-value for Wald statistic is smaller than α=0.01, 0.05 or 0.1, we reject the null hypothesis and this means the regression is significant (Wooldridge, 2013). The results are presented in Appendix C.

Table 4-2 shows the results of 2SLS estimation, for high grade and low grade logs in BC, coast.

Table 4-2 Results of 2SLS estimation for BC coast log supply, 2000-2013

<table>
<thead>
<tr>
<th>Variables</th>
<th>High Grade</th>
<th></th>
<th>Low Grade</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Demand 2SLS</td>
<td>Supply 2SLS</td>
<td>Demand 2SLS</td>
<td>Supply 2SLS</td>
</tr>
<tr>
<td>ln P^ch</td>
<td>-0.56 (-2.78)***</td>
<td>1.77 (2.44)**</td>
<td>-0.06 (-0.43)</td>
<td></td>
</tr>
<tr>
<td>ln P^cl</td>
<td>0.11 (0.69)</td>
<td>-2.46 (-2.44)**</td>
<td>1.01 (3.75)***</td>
<td></td>
</tr>
<tr>
<td>ln ΔS^c</td>
<td>0.01 (0.26)</td>
<td>0.03 (0.75)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln W</td>
<td>0.86 (1.12)</td>
<td>-2.34 (-5.58)***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln ExP</td>
<td>0.34 (2.75)***</td>
<td>-0.05 (-1.39)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln Q^c</td>
<td>0.51 (13.23)***</td>
<td>0.23 (2.38)**</td>
<td>0.70 (13.35)***</td>
<td>0.56 (9.88)***</td>
</tr>
<tr>
<td>ln ΔFP</td>
<td>-0.12 (-0.58)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln FP</td>
<td>-0.30 (-0.59)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln P^c</td>
<td>0.78 (4.98)***</td>
<td>-0.62 (-1.66)*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pol</td>
<td>0.65 (2.92)***</td>
<td>-0.53 (-4.12)***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan</td>
<td>-0.90 (-6.70)***</td>
<td>-0.72 (-7.65)***</td>
<td>-1.39 (-3.62)***</td>
<td>-1.33 (-5.20)***</td>
</tr>
<tr>
<td>Feb</td>
<td>-0.23 (-1.71)*</td>
<td>-0.33 (-1.73)*</td>
<td>-0.16 (-0.52)</td>
<td>-0.47 (-2.57)**</td>
</tr>
<tr>
<td>Mar</td>
<td>0.04 (0.71)</td>
<td>-0.06 (-0.92)</td>
<td>-0.22 (-0.61)</td>
<td>-0.42 (-1.83)*</td>
</tr>
<tr>
<td>Variables</td>
<td>High Grade</td>
<td>Low Grade</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>-----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Demand 2SLS</td>
<td>Supply 2SLS</td>
<td>Demand 2SLS</td>
<td>Supply 2SLS</td>
</tr>
<tr>
<td>Apr</td>
<td>-0.08 (-0.90)</td>
<td>-0.15 (-2.15)**</td>
<td>-0.16 (-0.54)</td>
<td>-0.27 (-1.48)</td>
</tr>
<tr>
<td>May</td>
<td>0.19 (3.63)***</td>
<td>0.30 (5.87)***</td>
<td>0.20 (0.63)</td>
<td>0.02 (0.10)</td>
</tr>
<tr>
<td>Jun</td>
<td>0.07 (0.96)</td>
<td>0.26 (6.73)***</td>
<td>0.16 (0.52)</td>
<td>-0.07 (-0.30)</td>
</tr>
<tr>
<td>Jul</td>
<td>0.01 (0.15)</td>
<td>0.19 (3.71)***</td>
<td>0.03 (0.09)</td>
<td>-0.07 (-0.23)</td>
</tr>
<tr>
<td>Aug</td>
<td>-0.20 (-2.23)**</td>
<td>-0.04 (-0.88)</td>
<td>-0.15 (-0.33)</td>
<td>-0.17 (-0.51)</td>
</tr>
<tr>
<td>Sep</td>
<td>-0.18 (-2.83)***</td>
<td>-0.17 (-4.86)***</td>
<td>-0.10 (-0.29)</td>
<td>-0.18 (-0.66)</td>
</tr>
<tr>
<td>Oct</td>
<td>0.00 (0.02)</td>
<td>0.05 (0.93)</td>
<td>0.24 (0.43)</td>
<td>0.05 (0.12)</td>
</tr>
<tr>
<td>Nov</td>
<td>-0.07 (-0.49)</td>
<td>-0.07 (-0.62)</td>
<td>0.01 (0.04)</td>
<td>0.05 (0.16)</td>
</tr>
<tr>
<td>R²</td>
<td>0.52</td>
<td>0.40</td>
<td>0.70</td>
<td>0.81</td>
</tr>
<tr>
<td>cons</td>
<td>5.73 (7.33)***</td>
<td>-3.32 (-0.63)</td>
<td>-1.32 (-0.31)</td>
<td>9.64 (5.22)***</td>
</tr>
</tbody>
</table>

Calculated long-run elasticities

<table>
<thead>
<tr>
<th></th>
<th>High Grade</th>
<th>Low Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.3</td>
<td>2.2</td>
</tr>
</tbody>
</table>

#observations

|                | 167        | 167        | 112        | 112        |

The significance of the variable: ***=significant at 1% level, **= significant at 5% level, *= significant at 10% level. Note numbers in the brackets are heteroskedasticity and autocorrelation consistent (HAC) standard errors.

As discussed in section 4.3, the coefficients in these models show the elasticities.

**Own price elasticity:** As expected, the log price coefficient is positive and statistically significant in the high grade log supply model. Own price elasticity of coastal high grade log is 1.77, meaning that if the price increases by 1%, the log harvest levels increases by 1.77%. Based on the results, high grade log supply is highly elastic in our model, indicating that supply is highly responsive to the changes in price, and therefore, a small change in price could cause a large increase in log supply. In the low grade log supply model, the coefficient of log price is positive and highly
significant. The elasticities indicate that 1% percent change in price increases the supply by 1.01%. This shows that the harvest levels of low grade logs are responsive to the changes of the low grade log prices. Overall, the loggers’ harvesting practices are sensitive to the changes of price in the market and they adjust their harvest levels based on that.

Cross-price elasticity: For the high grade log supply model, the low grade price coefficient is not statistically significant. This means that changes in low grade log prices do not impact harvest levels of high grade logs. Similarly, in the low grade log supply model, the results indicate that high grade log supply is not statistically significant. This means that if the high grade log prices change, low grade log supply remain the same. This is not surprising since each log grade is used for certain wood products. For instance, high grade logs that are ideal for making J grade lumber would not be used in making particleboards. Even if the price or demand for particle board increases, loggers would not be encouraged to harvest higher grade logs.

Wage: According to the results, the coefficient of the wage rate for high grade logs is not statistically significant. This variable thus do not seem to impact the high grade log supply. For the low grade log supply model, wage rate coefficient is negative and statistically significant. The negative relationship was expected for the wage rate coefficient since it is a cost. Based on the results, log supply is highly elastic with respect to the labour cost and a 1% increase in wage rates decreases low grade log supply by 2.34%.

First difference of stumpage: First difference of stumpage is not statistically significant in the high grade and low grade log supply models, which means that, this variable does not impact the log supply. In BC, stumpage is meant to capture the value of logs and not influence the harvest decisions. Our results are suggesting that this is the case. We cannot be sure how stumpage affects log supply because it was not stationary and we could not use the stumpage itself in our analysis. This is noted as a limitation.

Log export price: In the high grade log supply model, log export price coefficient is positive and statistically significant. The results indicate that a 1% increase in log export prices increases harvest levels by 0.34 %. This shows that loggers not only observe the domestic log prices, but also react to the changes in export market. The changes in log export price impacts harvest
decisions especially because of strategic location of the BC coast, the region where the majority of log export occurs. For the low grade log supply model, the coefficient of low grade log export price is not statistically significant meaning that changes in log export price do not impact low grade log supply.

*Seasonal dummy variables:* Several coefficients of seasonal dummy variables are statistically significant for both high grade and low grade log supply. This shows that seasonality is present in log supply (This was earlier obvious in Figure 3-1 and 3-2). The results showed consistency with the fact that harvest levels increase in the summer months for the coast and decreases in colder months such as January.

*Policy:* The coefficient of policy change is positive and highly significant for high grade logs. This means that policy changes impacted the harvest levels and increased the high grade log supply. On the other hand, the coefficient of policy change is negative and highly significant for low grade log supply, meaning that the change in policy decreases low grade log harvest levels. Due to the changes of the harvesting regulations (elimination of cut control or introducing take or pay policy) the licensees had the option to choose how much to harvest according to the market conditions (such as prices and costs). They did not have to harvest certain types and grades of logs (they did not have to harvest low grade logs if it was not efficient). In addition, low grade logs have lower prices compared to the high grade logs and log extraction cost are high, especially on the coast (Niquidet, 2008). It seems that the licensees decided to harvest higher grade logs and less low grade logs where they could sell the high grade logs with higher prices and cover their costs.

For both high grade and low grade logs, demand is inelastic, meaning that changes in the log price slightly changes the demand of logs. Similar to Bolkesjø et al. (2010) and Sun et al. (2015), lagged variables are used in the models for two reasons: first, the loggers need to do certain planning and need specific capital ahead of time before harvesting. Second, lagged variables improved the models statistically and they were statistically significant in both models.

Before presenting and interpreting of the results in the interior, there is one issue that needs to be noted, being the Mountain Pine Beetle (MPB) epidemic that emerged in the BC interior in 2003. The MPB affected around 675 million cubic metres of Lodge pole pine stands. The provincial
government’s major response to this outbreak was an increase in AAC from 50 million cubic metres in 2001 to 70 million cubic metres in 2007 (Government of British Columbia, 2008). There are studies (e.g. Abbott et al. (2009)) that investigated how MPB impacts log supply in details, so we do not mention further details.

We did not include MPB as a variable in our models however, when interpreting the results we consider one outcome of this change being the substitution effect. In the interior, many trees that had higher log quality were treated as low grade because they were affected by beetle, but they could still be used for making good quality wood products because of their quality. Therefore, companies developed milling technologies to extract lumber from trees previously considered low grade.

The results of the estimation for the interior high grade and low grade models are shown in Table 4-3.
Table 4-3  Results of 2SLS estimation for BC interior log supply, 2004-2013

<p>| Variables | High Grade | | Low Grade | | |
|-----------|------------|---|------------|---|
|           | Demand 2SLS | Supply 2SLS | Demand 2SLS | Supply 2SLS |
| ln $P_{ih}^t$ | -0.77 (-2.17)** | 0.28 (3.58)*** | | -0.10 (-1.08) |
| ln $P_{il}^t$ | 0.21 (5.10)*** | 0.46 (2.27)** | 0.21 (3.45)*** |
| ln $\Delta S_{i}^t$ | -0.17 (-2.35)*** | | 0.21 (3.45)*** |
| ln $W_i$ | -0.54 (-1.88)* | | -0.69 (-2.64)*** |
| ln $Q_{i-1}^t$ | 0.92 (42.62)*** | 0.62 (11.46)*** | 0.86 (9.10)*** | 0.73 (8.86)*** |
| ln $\Delta FP_{i}^t$ | -0.57 (-1.85)* | | |
| ln$FP_{i}$ | | 0.19 (0.83) | |
| ln $P_{i-1}^t$ | 0.41 (1.37) | | -0.14 (-1.83)* |
| Pol$_t$ | -0.24 (-5.41)*** | | 0.12 (4.05)*** |
| Jan | 0.01 (0.23) | 0.05 (1.91)** | 0.18 (3.20)*** | 0.03 (0.87) |
| Feb | 0.11 (2.16)** | 0.20 (3.34)*** | 0.29 (3.00)*** | 0.17 (2.02)** |
| Mar | 0.07 (0.85) | 0.16 (1.67)* | 0.19 (2.06)** | 0.16 (2.37)*** |
| Apr | -0.29 (-3.26)*** | -0.25 (-7.46)*** | -0.09 (-2.34)** | -0.18 (-3.37)*** |
| May | -2.05 (-4.32)*** | -1.87 (-19.49)*** | -1.93 (-16.19)*** | -2.15 (-18.18)*** |
| Jun | 0.04 (0.62) | -0.51 (-4.22)*** | -0.16 (-0.89) | -0.50 (-2.92)*** |
| Jul | 0.65 (13.23)*** | 0.13 (2.36) | 0.90 (4.78)*** | 0.70 (3.81)*** |
| Aug | 0.31 (5.31)*** | 0.18 (2.25)** | 0.69 (3.79)*** | 0.46 (3.26)*** |</p>
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<tr>
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<td>Supply 2SLS</td>
<td>Demand 2SLS</td>
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<td>0.04 (0.96)</td>
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<td>0.91</td>
<td>0.88</td>
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The significance of the variable: ***=significant at 1% level, **= significant at 5% level, *= significant at 10% level. Note numbers in the brackets are heteroskedasticity and autocorrelation consistent (HAC) standard errors.

As discussed in section 4.3, the coefficients in these models show the elasticities.

**Own price elasticity:** As expected, log price coefficient is positive and statistically significant in high grade log supply. Own price elasticity of high grade log is 0.28, so if the high grade log prices increase by 1%, high grade log supply increases by 0.28%. Based on the results, log supply for high grade logs is inelastic. Therefore, changes in price would impact the log supply slightly. The results indicate that the log price coefficient is not statistically significant in low grade log supply. Thus low grade log supply is not affected by the low grade log price.

**Cross-price elasticity:** The results show that low grade log price is positive and statistically significant. This means that changes in low grade log price impact high grade log supply. The coefficient of high grade log prices is not statistically significant, so high grade log prices do not impact low grade log supply. This makes sense, since it is not reasonable to use high grade logs for the products that can be made with low grade logs. This is especially true for the interior, where after MPB there were plenty of low grade logs available.
Wage: In the high grade log supply, the results show that wage rate coefficient is negative and statistically significant. If the wage rate increase by 1%, the log supply decreases by 0.54%. For low grade log supply, wage rate coefficient is negative and is statistically significant. Therefore, this variable impacts low grade log supply. One percent increase in the labour cost decreases log supply by 0.69%. This is reasonable since wage is the cost of labour and higher costs means less harvest.

First difference of stumpage: The coefficient of the first difference of stumpage is negative and statistically significant for high grade log supply. Based on the results, 1% increase in the first difference of the stumpage causes supply to decrease by 0.17%. In low grade log supply, if the first difference of stumpage increases by 1% low grade log supply increases by 0.21%. Unfortunately, the interpretation includes the first difference of the stumpage and we cannot show how stumpage itself impacts the log supply. This is a limitation to our study.

Seasonal dummy variables: Several seasonal dummy variables’ coefficients are statistically significant. This indicates that seasonality is present in log supply, shown earlier in Figure 3-3 and Figure 3-4. Based on the results there is more log harvest during January through March and less in April, May and June, which is consistent with the fact that most of the harvesting in the interior takes place during the colder months.

Policy: The coefficient of policy change is negative and highly significant for high grade log supply. This means that changes in the policy impacted the high grade log supply in the interior. This change decreased high grade log harvest levels. For the low grade log supply, the coefficient of policy change is positive and is statistically significant. It means that changes in policy impacted low grade log harvest and after the policy change low grade harvest levels increased. This means that loggers harvested more low grade logs where they were paying less stumpage but also could sell the logs with higher prices above those of low grade logs.

In high grade and low grade logs, the demand is inelastic and the lagged variables were statistically significant in both models. According to Greene (2011), we divided the short-run elasticity by 1 minus the lagged dependent variable coefficient for calculating long-run elasticities. Long-run
elasticities are bigger than short-run elasticities which is reasonable since in the long-run all the inputs including capital can change (Sun et al. 2015).

4.5 Conclusion and discussion

In this chapter, the methodology and estimation process of the models were assessed. Simultaneous equations models were applied separately to two regions in BC, coast and interior. Since the trees are not homogenous, logs were placed into two categories of high grade and low grade. 2SLS method was used to estimate short-run log supply models for each region and log type.

The results of estimation were presented in the Tables 4-2 and 4-3, followed by interpretation and discussion on each variable. The results for the coast region showed changes in price and policy impact log supply for both grades of logs, while the first difference of stumpage does not impact log supply. Wage and log export price may or may not impact log supply based on different log grades. Seasonality was also present for both grades of log.

In the interior, policy, wage and first difference of stumpage impact log supply for both grades. However, the price only impacts high grade log supply.
Chapter 5: Conclusion

5.1 Conclusions

This thesis estimated separate log supply models for two regions in BC, coast and interior, based on different log grade categories and identified relationships between government, market factors and log supply. To address these goals: (1) modeling approaches were reviewed; (2) models inside and outside BC including market and policy variables were introduced; (3) policy change during 2000s in BC was discussed; (4) harvest levels, log prices, and other variables were introduced; (5) the methodology and models used in modeling log supply were presented; (6) significance of the variables and the impact of each variable were determined; and (7) supply elasticities were calculated.

The results of estimation in Chapter 4 showed that own price elasticity was significant in all regions with respect to different grades except for the low grade logs in the interior. Log supply is elastic in the coast region, therefore a small change in the log price, changes the harvest levels significantly. Overall, the elastic supply means that harvesting practices of the licensees are sensitive to the changes of price in the market. Therefore, the licensees adjust their harvest levels based on the changes of the log price. Log supply is inelastic in the interior meaning that a change in log price impacts the harvest levels slightly.

High responsiveness of supply to the price shows that the price plays an important role on the coast. This could be because the trees are more diverse on the coast and access to them is more challenging in some regions compared to the interior. Therefore, there will be no harvesting if the log price is not reasonable to cover the costs (such as harvesting costs, access cost, etc.). On the other hand in the interior, the trees are more homogenous, and although the price is important and significant, a small change in price would not make a big difference in harvest levels.

In previous studies in BC, Zhang (1996) estimated a log supply elasticity of 0.10 with using time-series data from 1989 to 1994 for BC coast. Fooks et al. (2013) also used time-series data from 1995 to 2008 and calculated supply elasticity of 1.03. In the most recent study, Sun et al. (2015) used panel data from 2003 to 2013 and estimated the log price elasticity of 0.43 for BC coast.
In our research, monthly time-series data from 2000 to 2013 were used to model log supply on the coast. Our results showed that the log supply elasticity for high grade logs was 1.77 while it was 1.01 for low grade logs. In the interior, the high grade log elasticity was 0.28 for monthly time-series data from 2004 to 2013.

The current study distinguished between high grade and low grade logs in BC and calculated separate price elasticities for them which was not done before. Moreover, to the knowledge of the author this thesis estimated a log supply model for BC interior for the first time.

Policy changes were included in the supply model for BC coast and interior in our research. These changes included introducing take or pay policy, elimination of minimum harvest levels, and removing the penalty for leaving a standing tree as presented in Chapter 3. A dummy variable was used to show the impact of policy with 2SLS method of estimation. The results showed that changes in policy impacted the log supply in BC.

After the change in policy high grade log harvest levels increased while low grade log harvest decreased for the coast region. It appears that giving the loggers the option to choose what to harvest based on the market, led into harvesting the logs that are sold with a higher price (high grade logs). This especially seems to be true on the coast, where log extraction costs are higher. For the interior, changes in the policy led to less high grade log harvest and more low grade log harvest. As mentioned in Chapter 4, the interior was affected by the MPB outbreak and the substitution effect existed there. It seems that the licensees harvest lower grade logs more while they could sell the logs with higher prices because the logs still had a better quality compared to low grade logs.

The impact of major policy changes that happened during the 2000s in BC was never assessed on log supply by econometric methods based on region and log quality. To the knowledge of the author, this research investigated this impact for the first time in BC.

The current research showed that costs and other market variables, such as wage and log export price, impacted log supply but the effect is different based on the region and log quality. The results of the current research is in line with Sun et al. (2015), who showed that wage impacts the log
supply and an increase in this cost would decrease harvest levels. The results of the research showed high grade log export price impacts the high grade log supply. This means that the loggers not only observe the domestic log prices, but also react to the changes in export market. The changes in log export price impacts harvest decisions especially because of strategic location of the BC coast, being the region where the majority of log export occurs.

Based on the results of the current research, seasonality impacted log supply in all regions and all log types. For the BC coast region, log harvest increased during warmer months and decreased during cold months. However, for the interior the harvest levels increased in cold months especially in January. The seasonality impact is in line with the results of Sun et al. (2015), who showed the impact of seasonality on harvest levels for the BC coast and found the same existing trend.

5.2 Implications

This thesis developed log supply models for BC coast and interior for two different log grades, using simultaneous equations models and 2SLS method of estimation. This research showed how changes in policy impact the harvest levels for two main log grades in the coast and interior. Furthermore, it demonstrates that not only policy, but also market factors (prices and costs) alter the harvest levels. The impacts were different based on the region and log grade and they were presented in Chapter 4 specifically. The provincial government and industry both have strongly vested interest in the BC log supply, and studying log availability is a key factor to their economic well-being. In this section we categorize some of the implications of the current research for government and industry.

Implications for provincial government:

- Through similar modeling and methodologies, provincial government can identify the impacts of its policies on the coast and the interior separately, based on different log grades. It is easier to forecast and measure the impacts of future policies by learning from the consequences of the current policies. This methodology can be beneficial for the assessment of the performance of such current policies.
• It is not only the changes in policy, but also other significant variables such as prices and costs that impacts log supply. When the government is aware of all direct and indirect variables, more effective policies can be made.
• The historical data showed that the AAC have been almost always higher than the actual harvest levels. By understanding what variables impact the log supply, the provincial government can set the new AAC levels based on the signals they receive from the loggers and the industry.
• The results of this thesis help in improving the general knowledge and understanding of the dynamics and obstacles, which can lead into innovation of new methods with which policies can be assessed.

Implications for industry:
• When industrial managers are aware of the results of the new policies, they can plan and decide ahead of time. They can identify the opportunities and competitiveness and plan better for production levels, sustainable production, costs and revenues. Furthermore, they can provide suggestions to the government for the future policy adjustments.
• Fibre cost is the main cost for the industry in BC, therefore the knowledge of the variables impacting the availability and supply of log is crucial for industry decision makers.

5.3 Limitation of the study and further research

5.3.1 Limitations

We had to implement the first difference of stumpage and final product variables in our models due to the fact that these variables were not stationary. However, when interpreting the results we were not able to see how stumpage or the final products impact log supply.

A dummy variable was chosen to show the impact of policy. There were number of changes in policy during 2000s but only one main group of changes were considered in the model (as explained in section 3.3.2). However, we cannot determine specifically which policy impacted the log supply in what way. In other words, it is not easy to see exactly what aspect of change in the policy specifically causes a certain reaction in the log supply.
The other limitation in investigating policy variable was not knowing the exact time when the new policy was fully implemented. We had to assume a certain time as 2004 for the coast and 2006 for the interior in our models.

Log prices for the interior were not available during 2000 to 2003, so the supply model could not be assessed during that time period.

Other models were also assessed using other variables, such as interest rate, fuel prices and the US housing start, however due to the high correlation between some of the variables that weakened the statistical properties of the models, they were not used in the model.

5.3.2 Future work

(1) The current research considered short-run supply while focusing on the historical relationship of the variables. By using another econometric approach such as VAR or VECM, estimations for long-run supply for BC coast and interior based on different log grades could be obtained. These models help in forecasting purposes or running what-if scenarios to investigate the impact of certain policies on log supply.

(2) The results of this model can be used in models for the industry. For example, it can be incorporated into a trade-flow model (i.e., partial equilibrium model) to examine the potential impacts of log export policy (e.g. export restriction or free trade) on regional economy.
References


Niquidet, K., 2007. ESSAYS ON THE ECONOMICS OF BRITISH COLUMBIAN TIMBER POLICY.


## Appendices

### Appendix A

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<th>Variables</th>
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The rejection of null hypothesis of non-stationary: ***=significant at 1% level, **= significant at %5 level, *= significant at 10% level.
## Appendix B

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Appendix C

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