MS-E2177 - Seminar on Case Studies in Operations Research

Effects of Import Tariffs to International Plywood Trade in the UK

Final Report

Aukusti Kiuru
Elias Koivulehto (Project Manager)
Janne Lahti
Tuukka Stewen

May 28, 2020

Contents

1 Introduction

The export of wood products is very important to Finland, as it constitutes for 20% of the total export of goods [1]. Our client for this project is Metsä Wood, one of the main Finnish wood product producers and a part of the forest industry group Metsä Group. Since the export of wood products is part of the core business of Metsä Wood, they are interested in the effects of international trade restrictions to the export of their plywood products.

1.1 Background

The main products of Metsä Wood include laminated veneer lumber, birch and spruce plywood, and other construction and timber products [2]. In this project, we will focus on the two variants of plywood they produce – birch and spruce plywood – and study the effects import tariffs have on their trade.

Plywood is a material made of multiple thin sheets of wood that are glued together, and it is used in various applications in construction and manufacturing. The different varieties of plywood include hardwood plywood (birch plywood is of this variant), softwood plywood (spruce plywood is of this variant), and other types such as tropical plywood. This differentiation is important, as the applications are different for each type of plywood, and different trade agreements, such as tariffs, are put in place for the different varieties [3].

Import tariffs are taxes on the import of goods from foreign countries, and together with import quotas form the basic structures of trade protection [4]. Tariffs are used to support domestic production of goods, by ensuring that domestic prices stay competitive by raising the price of imports. For example, the EU has import tariffs for the import of both hardwood and softwood plywood [5] from certain countries. Countries (or a coalitions of countries, such as the EU) can differentiate between different partner countries, by giving some countries reductions on tariffs based on the agreements between said countries. For certain products, the tariff mechanism also includes a quota that is shared with all importer countries: before the quota is fulfilled, the import is tariff-free, and the tariff is added after the quota is fulfilled. [6]

Tariffs are important as an instrument of political and economic power, as they can be used to balance the import and domestic production of goods. A quite recent example of this is the tariff introduced by the United States to the import of hardwood plywood from China. In 2017, the US International Trade Commission reported that China was importing hardwood plywood to the US at lower than fair price, made possible by subsidies by the Chinese government. It was speculated that this was done intentionally to hinder the domestic production of plywood in the US, and to counteract this, the US International Trade Commission introduced a tariff to the import of hardwood plywood from China. [7]

Another example of a shifting political landscape is the situation with the UK and Brexit. It is speculated by the project team and the client that the UK might remove some of its import trade restrictions of plywood products after leaving the EU to lower prices and boost trade, since there are little domestic production of plywood and similar wood products in the UK.

1.2 Objectives

It is hypothesised by the client that tariffs have a significant effect on international plywood trade. Our objective is to use statistical methods to test this hypothesis and analyse the dynamics of international plywood trade. We focus on the import trade to the UK, since there is little domestic production of plywood and thus the import quantities can be used to model the overall demand of plywood in the UK. Furthermore, we focus on the trade of softwood and hardwood plywood. We use price-response functions and price elasticities to model price-demand relationships between the most important importer countries, and use this information to predict the trade impacts of potential changes in tariffs.

This objective can be divided into four tasks. First, we familiarize ourselves with the subject matter and methodological approaches, and scope the project appropriately. Second, we gather the data we need and preprocess it to be used in the statistical analysis. The third task consists of the actual model building and calculating the price elasticity measures. Finally, we analyze these results in order to give data-driven recommendations to our client. It is important to note, that although presented in a linear fashion, these tasks did overlap during the project, as some of the processes were iterative. Based on findings in the model building phase, for example, new methodology needed to be studied and additional data was required.

2 Literature review

In this section we will introduce the concepts of price elasticity and price-response function. It is important to understand them, since the data analysis and modelling presented in later sections is largely based on these methods.

2.1 Price elasticity

Price elasticity of demand is a measure for analysing the effect of price changes to demand. It is defined as the ratio between the percent change in the demand of a good and the percent change in the price of the same good. For example, the price elasticity of product A is defined as

$$\mathrm{PE}_A = \frac{\Delta q_A / q_A}{\Delta p_A / p_A} \tag{1}$$

where q_A is the initial demand of A, Δq_A is the change in the demand of A, p_A is the initial price of A, and Δp_A is the change in the price of A. [4]

For infinitesimal changes, price elasticity is defined as

$$\mathrm{PE}_A = \frac{\partial q_A}{\partial p_A} \cdot \frac{p_A}{q_A}, \tag{2}$$

where $\frac{\partial q}{\partial p}$ is the first derivative of the price-response function (also known as the demand curve), p is the sales price and q is the demand. [8]

It is assumed that in almost all situations the price elasticity is negative, meaning that an increase in price will lower the demand, and a decrease in price will increase the demand. Demand is said to be inelastic if the price elasticity is between -1 and 0. In this situation, revenue can in theory be increased by raising prices, since an increase in price would decrease the demand less than the relative price increase. Demand is said to be elastic if the price elasticity is less than -1. In this case, revenue can in theory be increased by decreasing prices, since a decrease in price would increase the demand more than the relative price decrease. If the price elasticity is exactly -1, demand is said to be unit elastic. For goods with unit elastic demand, an increase or decrease in price will not affect the total revenue. [4]

The price elasticity measure defined above is also sometimes referred to as own-price elasticity, to avoid confusion with cross-price elasticity measures. Cross-price elasticity measures the effect of price changes to demand across multiple different goods on the same market. It is defined as the ratio between the percent change in the demand of a good and the percent change in the price of another good. For example, the cross-price elasticity between the demand of product A and the price of product B is defined as

$$\text{CPE}_{AB} = \frac{\Delta q_A / q_A}{\Delta p_B / p_B} \tag{3}$$

where q_A is the initial demand of A, Δq_A is the change in the demand of A, p_B is the initial price of B, and Δp_B is the change in the price of B. [4]

For infinitesimal changes, cross-price elasticity is defined as

$$\text{CPE}_A = \frac{\partial q_A}{\partial p_B} \cdot \frac{p_B}{q_A}, \tag{4}$$

where $\frac{\partial q_A}{\partial p_B}$ is the first derivative of the price-response function of products A and B, p is the sales price of B and q is the demand of A. [8]

If the resulting cross-price elasticity between the products is negative, the products are said to be complements; a decrease in the price of good A will increase the demand of B, and an increase in the price of good A will decrease the demand of good B. If the resulting cross-price elasticity between the products is positive, the products are said to be substitutes; an increase in the price of good A will increase the demand of B, and a decrease in the price of good A will decrease the demand of good B. [4]

2.2 Price-response function

Price-response function describes the relationship between the demand and sales price of a certain good. It is defined as

$$q = q(p), \tag{5}$$

where q is the demand of the good and p is the sales price. [8]

In this definition the demand is a function of the price. In other words, through this function, the market is assumed to react with demand to changes in sales price. When monopoly conditions are assumed (i.e. when there is no competition in the market), the most simple hypothesis is a linear relationship between demand and price

$$q = a - bp, \quad a > 0, \quad b > 0, \tag{6}$$

where a is the intercept on the demand axis and b is the slope of the price-response function. In this linear form, parameter a gives the maximum demand at a price of zero, and b shows the responsiveness of demand to price changes. The price elasticity for this linear function is $\mathrm{PE} = -bp/(a - bp)$. Note that when the relationship between price and demand is linear and the change in demand in response to a change in price is the same everywhere, the price elasticity function has larger negative values when prices are higher. [8]

The situation becomes a little more complex when the market is competitive and monopoly conditions cannot be assumed. Regarding the independent variables, both one's own price and the price of competitors' goods must be addressed in a competitive market. One way to do this is to add all the competitor prices to the model as additional independent variables. However, this method has proven to be often unreliable, since the effect of each individual price is hard to isolate. Other methods include calculating the average of the competitor prices $\overline{p}$ and using it as a single additional variable with its own coefficient, or using relative price $p_i/\overline{p}$ (where p_i is one's own price) as the independent variable. Using average competitor price as an additional regressor, we get the linear model

$$q = a - bp_i + c\overline{p}, \quad a > 0, \quad b > 0, \quad c > 0, \tag{7}$$

where c is the coefficient of the competitor price element of the model. [8]

Another thing to consider in a competitive market is the choice of dependent variable, as the demand can be interpreted either as a quantity or a market share. This decision depends on the total market dynamics. If the total demand of a market is constant, we can use quantity as the dependent variable. However, if the total demand is changing, using market share as the dependent variable is preferred. [8]

There are also alternatives to the linear model of price-response that apply in a competitive market situation, one of which is the multiplicative model. In the multiplicative model, the relative price $p_i/\overline{p}$ is used as the independent variable. It is defined as

$$m_i = a(p_i/\overline{p})^b, \tag{8}$$

where m_i is the market share, a is a multiplier parameter and b is the price elasticity. Cross-price elasticity is calculated similarly, by substituting the relative own-price $p_i/\overline{p}$ with a competitor's price $p_j/\overline{p}$. Since in the multiplicative model the elasticity measure b is in the exponent, it can be interpreted as a constant price or cross-price elasticity. [8]

Choosing between the linear and multiplicative models is not straightforward and a general recommendation is impossible to give. On the other hand, the linear model is more robust and has realistic characteristic to it as it defines a maximum demand and price for the extreme situations. However, the price elasticity measures cannot be interpreted as easily, as they grow rapidly around larger price values. It is also sometimes oversimplified to model the relationship of price and demand as linear. The multiplicative model on the other hand simplifies the price elasticity measures and can therefore be unrealistic, because it does not provide an estimate of a maximum price and can give false suggestions in favor of price increases. Still, with some data the relationship between price and demand is best modelled with a multiplicative model. [8]

For the above reasons, price and cross-price elasticity measures are most reliable around the current price with both models, and any extreme extrapolation should be considered carefully.

3 Data

In order to study the effect of price and further the effect of tariffs on the import quantity, we first need to form appropriate datasets. In total we need to get three different datasets: 1. a dataset that has information on the import quantity and value per product from different importing countries, 2. a dataset that has the tariffs associated with each country and each product, 3. a dataset that has the information on when the quota has been fulfilled for the softwood plywood, since for softwood plywood import to EU there is a shared quota with all the importing countries. Imports made before the quota is fulfilled are tariff-free even though a specific tariff should otherwise be added. In the next sections we first explain from which sources we get our data and after that we explain the necessary preprocessing steps done for the data.

3.1 Dataset

We start by getting a dataset that has the information on the import quantity and value. This dataset we get form Eurostat [9]. The dataset we get from there consists of the import quantity and import value to UK for each different product and importing country. In this dataset the imports are aggregated on a monthly level starting from 2010 and ending to 2019. In this report we mainly study the effect of tariffs to softwood and hardwood plywood. However, we also test if the price of oriented strand board

(OSB) affects the import quantities of softwood plywood, since analysts at Metsä wood say that OSB could be considered to be a substitute for softwood plywood. Therefore, the products which are included in our dataset are softwood and hardwood plywoods and the OSB. The information on these products we get by filtering the product based on the right HS-6 code (Harmonized Commodity Description and Coding Systems using 6 digits). The softwood plywood is filtered using code 441239, the hardwood plywood using codes 441232 and 441233, and the OSB using code 441012.

The second dataset, having the appropriate tariffs for each country, we get from World Integrated Trade Solutions (WITS) [10]. This dataset has the tariffs that will be applied to each product (based on HS-6 code) imported from the different countries each year. The third dataset, having the information on when the yearly import quota of softwood plywood to EU has been fulfilled, we produce based on the information found from CIRCABC [11]. The information that the first two datasets hold is shown below in Table 1, and in Table 2, we show the date when the quota of softwood plywood import to EU has been fulfilled. The yearly import quota of softwood plywood to EU has been 650 000 m^3 during the last 10 years. After the quota has been fulfilled in each year a specific tariff is added to the imports based on made agreements.

Table 1: Information that is obtained from the different sources.

Source	Variable	Meaning
Eurostat	Reporter	Reporting country, in this case UK
	Partner	Importing country
	Product	Product type (Hardwood plywood / Sofwood plywood / OSB)
	Period	Import period (monthly level)
	Indicator	The method in which the import is expressed (Value / Quantity)
	Indicator value	The value corresponding to the indicator
WITS	Reporter	Country that has made a tariff for imports, in this case EU
	Product	Product the tariff is associated with
	Partner	Country the tariff is associated with
	Tariff year	Year the tariff is associated with
	Tariff value	Value of the tariff

Table 2: The date in each year when the quota of softwood plywood imports to EU have been fulfilled.

Year	Date
2010	4.8.2010
2011	30.6.2011
2012	24.7.2012
2013	12.7.2013
2014	16.6.2014
2015	26.5.2015
2016	17.5.2016
2017	26.5.2017
2018	23.4.2018
2019	1.4.2019

3.2 Preprocessing

After obtaining the appropriate information needed for our analysis, we compose a dataset where all the information is stored. Then we choose to remove some countries from our analysis, if the import quantity to UK is less than some threshold. We do this since including countries which have very small market shares compared to other countries will complicate the analysis, without providing relevant additional information. We choose to remove from our analysis those importing countries in each product group that are not among the highest importing countries corresponding to at least 90 % of the whole market during time span from 2010 to 2019. In other words we end up in a situation, where the highest importing countries corresponding to 90 % of the whole market are considered. These countries are shown in Table 3 for each product category.

Table 3: Countries in our analysis. In the table also the corresponding market share in the product category is shown.

Product (HS-6 code)	Country (Market share during last 10 years)
Hardwood plywood (441232 / 441233)	China (57 %) Russia (14 %) Malaysia (10 %) Finland (5 %) Uruguay (4 %)
Softwood plywood (441239)	Brazil (52 %) Finland (15 %) China (14 %) Chile (9 %)
OSB (441012)	Ireland (41 %) Latvia (36 %) Germany (13 %)

After choosing which importers to include in our analysis, we start the actual preprocessing. First, we modify the import data, such that we are able to calculate import value (in euros) per import quantity (in 100 kg), taking into account the right tariff based on the information we have obtained from WITS and CIRCABC. This way we are able to calculate the import price in euros per 100 kg.

After determining the price with the tariff, we study the data in case of possible outliers. We use the prices we have previously calculated to determine appropriate limits outside of which a price can be considered to be an outlier. We determine the lower, b_{lower}, and upper, b_{upper}, limits using interquartile range as follows

$$b_{\text{lower}} = q_1 - 1.5 \cdot \text{IQR} \tag{9}$$

$$b_{\text{upper}} = q_2 + 1.5 \cdot \text{IQR}, \tag{10}$$

where q_1 and q_2 are the 25% and 75% quantiles of the average monthly prices for each product and importing country and IQR is the interquartile range of the average monthly prices for each product and importing country [12].

Now, based on Equations (9) and (10), we are able to determine the monthly prices that are outliers compared to the prices from the same importing country. There might be many reasons why a certain data point is an outlier. When we analyse the outliers it is clear that for some of the data points the reason is that there might be some errors in either the reported quantity or the value that has been imported to UK. Figure 1 shows the outliers for each importing country and product category. When analysing the outliers, we choose that outliers that are clearly errors in the data will be removed from the analysis and those data points that are just barely outside the bounds will be moved to either lower or upper limit, depending on the outlier type.

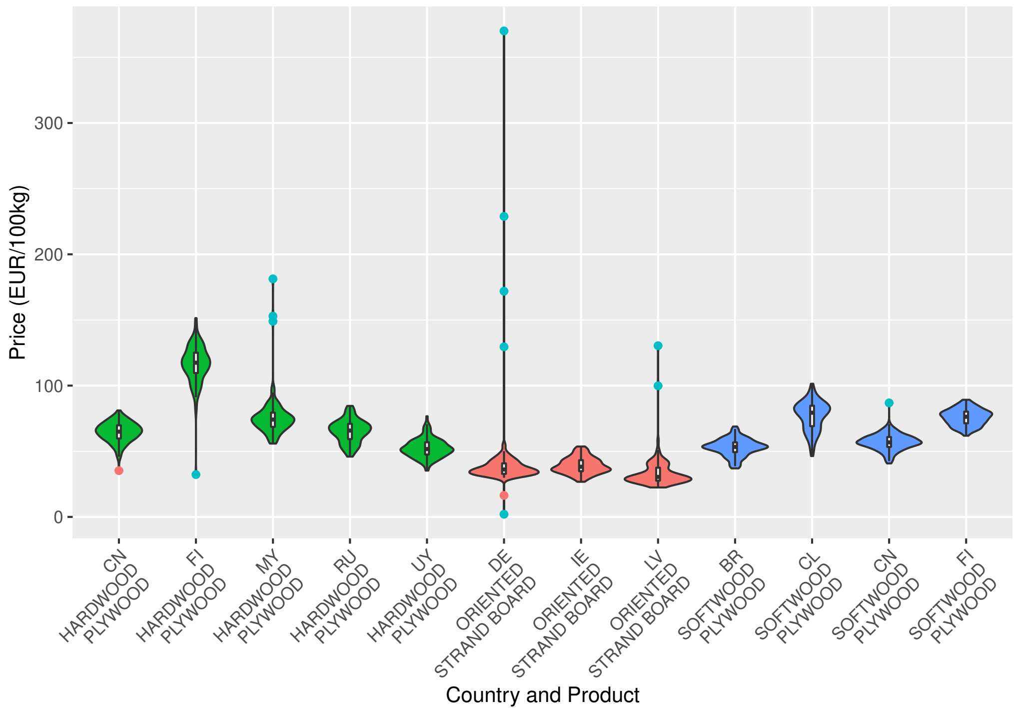

Figure 1: The distribution of the prices for each importing country and product, together with the outliers in the data. The outliers close to the upper or lower bound are marked with red color, whereas the outliers far from the bounds are marked with blue color.

Finally, to get a better idea of the built dataset, we make visualizations of the import quantity and the import price for the different product types. These visualizations are shown below in Figures 2, 3 and 4. From the figures it can be seen that especially in the softwood plywood the quantity of imported plywood from Brazil has a very clear seasonal effect in it. This can be partly explained by the import quota, which determines the tariff for the imports of softwood plywood. For instance, for Brazilian softwood plywood the tariff is 0% before the fulfillment of import quota and after that it increases to 7%. Furthermore, these figures show that in the import of Chinese hardwood plywood to UK there has been a clear drop in the beginning of circa 2017, without clear changes in the prices during that time.

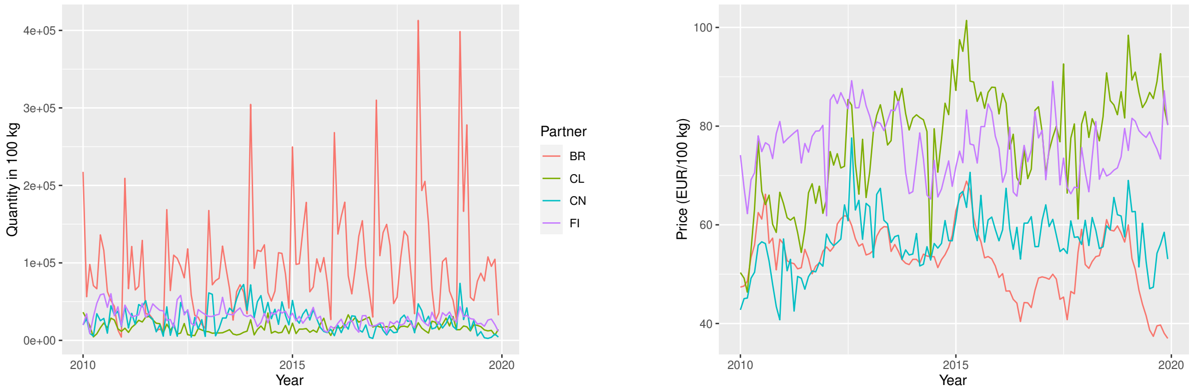

Figure 2: Import quantity and average price per importing country, for softwood plywood import.

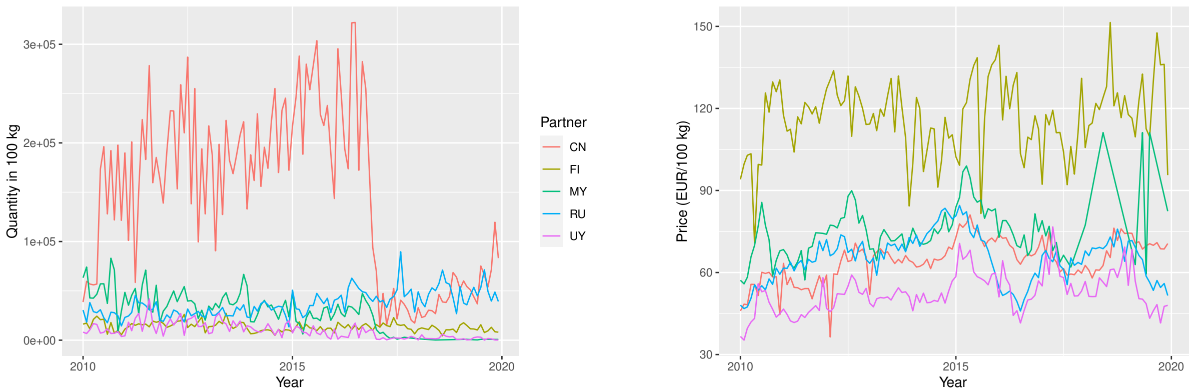

Figure 3: Import quantity and average price per importing country, for hardwood plywood import.

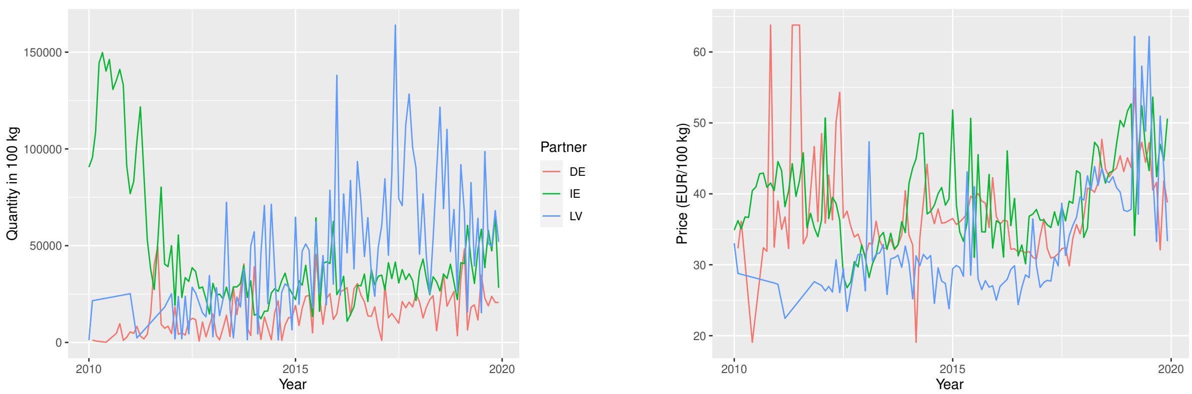

Figure 4: Import quantity and average price per importing country, for oriented strand board import.

4 Model

A model to describe the relationship between demand and price is constructed to study the effects of price on the import volumes of different importer countries. The model utilizes acquired data on import volumes and import prices discussed in Section 3. The model helps study the relationship between prices and import volumes of different importer countries and provides price elasticities. The model is employed to study the relationships between price and import volumes for two different plywood types, hardwood plywood and softwood plywood, independently.

The model is based on a relationship between price p and demand q as the price-response function in Section 2.2. Since UK does not have any domestic production of plywood, it is assumed that the demand of both plywood types are fulfilled entirely by imports. Furthermore, it is assumed that the total demand of plywood in UK does not depend on the price of plywood, i.e., solely on for example the need of plywood in construction projects, and the price is determined by the market regarding the total demand. Consequently, prices only determine from which countries the plywood is imported, i.e., the import shares from different countries are determined by the (relative) prices between the importer countries. As the model utilizes only import volumes and prices to UK, import demands of other countries are not taken into account in the model.

On the base of the model, the relationship between price and quantity is described as a multiplicative price-response function (see Equation (8)). The multiplicative function has its limitations as discussed in Section 2.2, but is commonly used in different fields when the relationship between demand and price is modelled and elasticities are estimated (see, e.g., [13, 14, 15, 16]). The multiplicative price-response function is assumed to hold between all the quantities and all the prices between each importer, i.e., the relationship of import volume of any importer and price of any importer will fulfill the multiplicative price-response function. Thus, the effect of prices of different countries on import volumes of different countries can be studied using the demand as dependent variable and price as independent variable, i.e., explaining the changes in demand by the changes in prices.

4.1 Variables of the model

The data has monthly values for import quantities and prices for each importer as discussed in Section 3. The monthly data has rapid changes in both values, but based on knowledge of the client about the nature and length of the delivery contracts, the effect of the price on the import quantities is not necessarily as rapid. In order to make the relationship between the import quantity and prices more realistic by taking into account the common contract practices of the business, moving averages of the import quantities and prices are computed for each month for each importer. A moving average of three months is applied for the both variables. Later in the report when quantities q_i and p_i are referred to, the values after applying the moving average are considered. Furthermore, q_i and p_i are considered as vectors containing all the monthly values for country i.

The dependent variable in the model to describe the demand is selected to be the *market share* m_i of a country i. This is due to the assumption that the total demand of the plywood in UK is not constant and it is determined by factors other than price, as stated earlier. If the pure import volumes as kilograms were used as the dependent variables, changes in the total demands of the plywoods could have a major effect also on the relative country-wise imports, and by using market shares, the absolute changes in the overall demand affecting also the relative demands are excluded from the analysis. A market share m_i of a country i is computed as

$$m_i = \frac{q_i}{Q}, \tag{11}$$

where q_i is the import volume of country i and Q is the total import volume of all countries, i.e., the total demand of the market.

Furthermore, as we are analyzing a competitive market, also the prices of the competitors are taken into account in the price-response function when studying both own-price and cross-price elasticities. Possible approaches are, e.g., to use both own price p_i and all the competitors' prices p_j as independent variables for market share m_i for country i, own price p_i and the average of the competitors' prices, or relative price $p_i/\overline{p}$, where $\overline{p}$ is the average of all the prices [8]. As discussed by Simon and Fassnacht [8], using all the prices as independent variables for explaining one market share is not straightforward and will lead to problems with multicollinearity, and thus, is not used here. Instead, prices are scaled to relative prices, as this also removes the effect of possible trends in prices, i.e., only relative changes in prices between the countries affect the demand (here, market share). The relative prices are computed by scaling the prices with weighted average of all the prices using market shares as weights. However, when computing the relative price for each country, the own price of the country is not included in the weighted average of the prices. Based on Kucher [17], this offers "better explanatory quality, statistical significance, and economic plausability" [8]. Consequently, the relative prices used in the price-response function are computed as

$$p_i^* = \frac{p_i}{\overline{p}} \ , \tag{12}$$

and where p_i is the original absolute price for country i and

$$\overline{p} = \sum_{j \neq i}^{n} m_j p_j \ , \tag{13}$$

where n is the total number of countries used in the model.

The final price-response function for a country i which is assumed to hold between the market shares and relative prices is

$$m_i = a \left(p_j^*\right)^b \ , \tag{14}$$

where m_i are the market shares of the country i, p_j are is the original absolute prices of the country j, and a and b are constants.

The basic model for the market share, i.e., Equation (14) with variables from Equations (11) and (12), is utilized for estimating the price elasticities of both hardwood and softwood plywood using the quantity and price data for them. However, when concerning softwood plywood, a slightly modified model is also constructed. Now, also a competing product, OSB, is taken into account. As it is assumed that the OSB competes on the same market as softwood plywood and they are sometimes substitute products for each other, the market shares are computed such that the import quantities of softwood plywood and OSB are assumed to form the total demand of the market. Consequently, the market shares for the softwood plywood while taking OSB into account are computed as

$$\hat{m}_i = \frac{q_i}{Q_{SP} + Q_{OSB}} \ , \tag{15}$$

where q_i are the import quantities of either softwood plywood or OSB from country i, $\hat{m}_i$ are the market shares for the corresponding product, and Q_{SP} and Q_{OSB} are the total import quantities of softwood plywood and OSB, respectively. However, as the pricing of these two products is relatively different while OSB being clearly cheaper product, the relative prices are not computed by scaling the prices with (weighted) averages of the all prices of both products together. The prices are assumed to have different markets, and consequently, the prices are scaled within each product independently, i.e., applying the Equation (12) for the prices of both softwood plywood and OSB separately. Otherwise, the same price-response as in the basic case, i.e., Equation (14), is assumed to hold, and the extended model for the softwood plywood (with OSB) consists of Equation (14) with variables (15) and (12).

4.2 Estimation of the price elasticities with linear regression

A property of the multiplicative price response function, as Equation (14), is that it assumes a constant price elasticity PE, and is thus also referred to as a constant elasticity demand function. The price elasticity is the constant term b in Equation (14). The price elasticity $\mathrm{PE} = b$ can be statistically estimated using linear regression when the Equation (14) is linearized by applying logarithms on both sides of the equation, which leads to

$$\log m_i = \log a + b \log p_i^* \; . \tag{16}$$

As $m_i \geq 0$ and $p_i^* \geq 0$, the logarithms of these values are defined and the equation above can be used. Now, the relationship between the logarithms of the market shares m_i and logarithms of the relative prices p_i^* is clearly linear with constant parameter $c = \log a$ and the price elasticity $b = \mathrm{PE}_i$ as the coefficient of the logarithms of the relative prices. Thus, when applying a standard linear regression for a country i using the monthly market shares m_i as dependent variable and its monthly relative prices p_i^* as explanatory variables, its own-price elasticity PE_i can be obtained straightly as the regression coefficient b for the (logarithmic) price. Similarly, when applying linear regression for country i using its market shares m_i as the dependant variable and a relative prices p_j^* of a competitor j as the explanatory variable, the cross-price elasticity between the market share of country i and the relative price of country j, i.e., CPE_{ij}, can be estimated by obtaining it as the regression coefficient b.

As stated earlier, standard linear regression analysis is applied to estimate the constant parameters, and one of them can be represented as own-price elasticity or cross-price elasticity depending on the choices of countries for the market share and the (relative) price. The regression model for estimating the parameters is now, when denoting the logarithms of the market shares of a certain country as $\log m_i = y$ and relative prices as

$\log p_i^* = x$, and different data points with index k,

$$\log m_k = c + b \log p_k^* + \epsilon_k \tag{17}$$

$$\Leftrightarrow \qquad y_k = c + b x_k + \epsilon_k \ , \tag{18}$$

where ϵ_k are the error terms of the regression model and c and b are unknown constants to be estimated. More accurately, c is the intercept term of the model, and b is the coefficient of the relative price, i.e., price elasticity PE.

Due to the seasonal nature of the demand, the basic regression model (17)–(18) is extended to mitigate the effect of the seasonality, as the objective is to distinguish and explain only the effect of the price. Due to the import quota, the import quantities and consequently market shares have a heavy seasonal behavior with the softwood plywood, which can be also seen in Figure 2. In addition, as the plywoods are mainly used in construction business which is relatively seasonal due to times of the year which contain different weather conditions, the seasonal effect is reasonable to take into account also when investigating the hardwood plywood.

In order to mitigate the effect of the seasonality in the estimation of the price elasticities, dummy explanatory variables are introduced to capture and explain the effect of the seasonality in the market shares (see, e.g., [18]). As the seasonal component repeats with an interval of a year, 11 dummy explanatory variables are included in the model, denoted as d_k^h, where $h = 1, \dots, 11$, to make a distinction in the data between the different months. For each dummy variable, a coefficient γ^h is estimated. The regression model has a form

$$\log m_k = c + b \log p_k^* + \sum_{h=1}^{11} \gamma^h d_k^h + \epsilon_k \tag{19}$$

$$\Leftrightarrow \qquad y_k = c + b x_k + \sum_{h=1}^{11} \gamma^h d_k^h + \epsilon_k . \tag{20}$$

The values of the dummy variables are determined so that the value of the dummy variable is 1 for all the data points corresponding to the month the dummy variable is assigned to, and otherwise 0. For instance„ for all the data points of Februaries, the dummy variable corresponding to February has a value 1 and the other dummy variables have value 0. However, it should be noted that only 11 dummy variables are needed, since when using 12 dummy variables together with the intersect c the explanatory variables would be perfectly multicollinear in the model, and thus, by dropping one dummy variable the acquired effect is achieved while keeping the model usable.

The constants c and b of the model (19)–(20) are obtained applying ordinary least squares (OLS) method, i.e., minimizing the sum of the squares of the error terms ϵ_k. Using OLS requires several assumptions about the variables and the error terms in the regression; it is assumed that the expected value of error terms ϵ_k is zero, their variance is constant (i.e., variances should be homoscedastic), and correlation between the errors is zero. The assumptions were tested using the constructed regression model and the data, and there were slight differences on the behavior of the error terms depending on the countries used in estimation. However, based on these experiments, the assumptions were fulfilled adequately with most of the data, and OLS estimation was decided to be applicable in this analysis.

The regression model (19)–(20) is employed in the case of hardwood plywood and softwood plywood for each pair of market shares and relative prices between all the considered importers. In that way, cross-price elasticities between all the considered importers are obtained, as well as own-price elasticities. For hardwood plywood, the market shares m_i for country i as such are used as the dependent variable, and for softwood plywood, the regression is done using both market shares of the market consisting only of softwood plywood, i.e., m_i, and market shares of the market consisting of softwood plywood and OSB, i.e., $\hat{m}_i$. For example, the cross-price elasticity of the market share of Brazil with respect to the (relative) price of China, $\mathrm{CPE}_{BR,CN}$ is obtained by applying the model using the market share of Brazil m_{BR} as the dependant variable ($\log m_{\mathrm{BR}} = y$) and the relative price of China p^*_{CN} as the explanatory variable ($\log p^*_{\mathrm{CN}} = x$). Correspondingly, the own-price elasticity of Finland $\mathrm{PE}_{FI} = \mathrm{CPE}_{FI,FI}$, i.e., the price elasticity of the market share of Finland with respect to the relative price of Finland, would be estimated using $\log m_{\mathrm{FI}} = y$ and $\log p^*_{\mathrm{FI}} = x$. A concise summary of how the price elasticities are estimated is provided in Table 4.

In addition to previously considered variables in the model, the effects of trend and lag effect of the price were also considered by using appropriate explanatory variables in the model. However, we chose not to include the trend variable, since a clear trend in the import quantities could not be seen from the data and utilization of the trend variable had a negligible effect on the performance of the model. Furthermore, no clear lagging effect could be seen in the data and taking it into account in the model again did not improve the performance of the model. Furthermore, also the changes in exchange rates were considered. However, as the value of the import quantity is reported by UK itself in the data in euros, it is assumed that the reported value is the value which is paid for them in UK. Thus, the changes in exchange rates between, e.g., British pound and Chinese yuan, during the years are already taken into account in the data.

Table 4: Summary of how own-price elastity for a country A, or cross-price elastity between countries A and B, is estimated

Price elasticity	Price-response	Regression model	Estimate
Own-price elasticity of country A	$m_A = a(p^*_A)^b$ or $\hat{m}_A = a(p^*_A)^b$	$\log m_{A_k} = a + b \log p^*_{A_k} + \sum_{j \neq i}^{11} \gamma^j d^j_k$ or $\log \hat{m}_{A_k} = a + b \log p^*_{A_k} + \sum_{j \neq i}^{11} \gamma^j d^j_k$	$\text{PE}_A = b$
Cross-price elasticity between market share of country A and price of country B	$m_A = a(p^*_B)^b$ or $\hat{m}_A = a(p^*_B)^b$	$\log m_{A_k} = a + b \log p^*_{A_k} + \sum_{j \neq i}^{11} \gamma^j d^j_k$ or $\log \hat{m}_{A_k} = a + b \log p^*_{A_k} + \sum_{j \neq i}^{11} \gamma^j d^j_k$	$\text{CPE}_{AB} = b$

5 Results

This section presents the price elasticities for softwood plywood and hardwood plywood for a total of three different models. For softwood plywood, in addition to the cross-price elasticities between different importer countries, we considered OSB as a potential substitute to softwood plywood. As similar substitute products were not assumed to exist for hardwood plywood, for hardwood plywood we only considered the substitution effects within its own market.

5.1 Softwood plywood

For softwood plywood the resulting own-price and cross-price elasticities between market share m_i and relative price $p_i/\overline{p}$, that are statistically significant ($p < 0.05$) and explain a significant amount of variation (adjusted $R^2 > 0.15$), are presented in Table 5.

As can be seen, the import demand of this type of plywood is generally own-price and crosspiece elastic with some exceptions. Based on the model, the imports from Brazil are most heavily responding to price changes in the Chinese plywood prices, rendering them as substitutes. Brazil imports also exhibit own-price and substitutive cross-price elastic behaviour towards price changes in Brazil itself and Chile, respectively. From the Finnish perspective, Brazil seems to be the main substitute for Finnish plywood as the cross-price elasticity is negative. Import from Chile is, with statistical significance, only seen as slightly own-price elastic and no clear cross-elasticities were found. By far the greatest elasticity was with the softwood plywood imports from China, as the data suggests relatively large responses both to China's own plywood price, and to the price of Brazilian plywood.

However, some strange behaviour is found in the data between the import market shares and prices of China, Finland and Chile. The data suggests that there would be a statistically significant, complementary cross-price elasticity between Finland and China, as well as an increase in market share in both Finland and China, as a response to a price drop in Chile. As the countries are assumed to be substitutes to each other rather than complements, this contradicts our assumptions and common sense, and is discussed more in Section 6.

Table 5: Statistically significant price elasticities for softwood plywood imports, not including OSB as a potential substitute. Price elasticities on red background imply that the the market describing those demands is different than assumed in the model.

Country$_A$	Country$_B$	Type	p-value	Adj. R^2	CPE$_{AB}$	m_A	m_B
Brazil	Brazil	Softwood pl.	$6.19{\cdot}10^{-8}$	0.436	-0.967	52%	52%
Brazil	Chile	Softwood pl.	$1.10{\cdot}10^{-16}$	0.611	1.151	52%	9%
Brazil	China	Softwood pl.	$4.46{\cdot}10^{-27}$	0.750	1.973	52%	14%
Chile	Chile	Softwood pl.	$1.00{\cdot}10^{-2}$	0.260	-0.530	9%	9%
China	Brazil	Softwood pl.	$6.84{\cdot}10^{-22}$	0.600	2.701	14%	52%
China	Chile	Softwood pl.	$1.31{\cdot}10^{-7}$	0.266	-1.440	14%	9%
China	China	Softwood pl.	$1.04{\cdot}10^{-10}$	0.355	-2.480	14%	14%
China	Finland	Softwood pl.	$4.49{\cdot}10^{-5}$	0.184	-1.796	14%	15%
Finland	Brazil	Softwood pl.	$9.20{\cdot}10^{-6}$	0.374	0.928	15%	52%
Finland	Chile	Softwood pl.	$6.90{\cdot}10^{-17}$	0.608	-1.326	15%	9%
Finland	China	Softwood pl.	$3.55{\cdot}10^{-23}$	0.701	-2.154	15%	14%

In addition to the price elasticities in the market formed by only softwood plywood importers, we tested the assumption of OSB being a potential substitute for softwood plywood. The results of this are presented in Table 6 with the same significance filtering as in the previous Table. As can be seen, there is only one statistically significant relationship between the import of softwood plywood and the price of OSB; it seems that the price of Irish OSB has a slight substitution effect on the import of Brazilian softwood plywood. Besides this relationship, no significant connection between OSB and softwood plywood imports were found in terms of price-response. It is also worth to note that introducing OSB to the market does not significantly change the existing relationships between importer countries.

Table 6: Statistically significant price elasticities for softwood plywood imports, including OSB as a potential substitute. In this table the market shares are calculated so that softwood plywood and OSB are considered as the same market. Price elasticities on red background imply that the the market describing those demands is different than assumed in the model.

Country$_A$	Type$_A$	Country$_B$	Type$_B$	p-value	Adj. R^2	CPE$_{AB}$	m_A	m_B
Brazil	Softwood pl.	Brazil	Softwood pl.	$1.97 \cdot 10^{-3}$	0.440	-0.603	33%	33%
Brazil	Softwood pl.	Chile	Softwood pl.	$6.12 \cdot 10^{-11}$	0.590	1.000	33%	6%
Brazil	Softwood pl.	China	Softwood pl.	$2.89 \cdot 10^{-18}$	0.700	1.802	33%	9%
Brazil	Softwood pl.	Ireland	OSB	$4.98 \cdot 10^{-2}$	0.417	0.377	33%	15%
Chile	Softwood pl.	Chile	Softwood pl.	$1.98 \cdot 10^{-4}$	0.234	-0.663	6%	6%
China	Softwood pl.	Brazil	Softwood pl.	$3.21 \cdot 10^{-19}$	0.538	3.011	6%	33%
China	Softwood pl.	Chile	Softwood pl.	$8.63 \cdot 10^{-7}$	0.218	-1.580	9%	6%
China	Softwood pl.	China	Softwood pl.	$1.95 \cdot 10^{-8}$	0.270	-2.573	9%	9%
China	Softwood pl.	Finland	Softwood pl.	$7.36 \cdot 10^{-5}$	0.153	-2.041	9%	10%
Finland	Softwood pl.	Brazil	Softwood pl.	$9.11 \cdot 10^{-8}$	0.307	1.278	10%	33%
Finland	Softwood pl.	Chile	Softwood pl.	$2.10 \cdot 10^{-14}$	0.477	-1.449	10%	6%
Finland	Softwood pl.	China	Softwood pl.	$1.46 \cdot 10^{-17}$	0.543	-2.276	10%	9%

5.2 Hardwood plywood

For hardwood plywood, the resulting cross price-elasticities are in Table 7. The model and filtering used is the same as with the softwood plywood. As can be seen, the results for hardwood do not look very promising, as there are only five detected statistically significant price-elasticities between the five largest importers. There is also a problem in the quality of these five results, as the majority of them seem contrary to common sense; the data suggests that the cross-price elastic behaviour between market share and relative price would be complementary with Finland and Russia, Malaysia and China, and Russia and Malaysia.

These low quality results for the hardwood plywood imports can be explained with the data. From Figure 3 it can be seen that between the end of 2016 and the beginning of 2017 the imports from China, the major importer with a market share of 57%, have decreased significantly. This distorts the total market and the market share percentages, and thus the market shares before and after this change are not comparable. We also found that analyzing these two periods separately was not sufficient to get any meaningful results, and studying the reasons behind the decrease in the imports from China are not in the scope of our model or this project.

Table 7: Statistically significant price elasticities for hardwood plywood imports. Price elasticities on red background imply that the the market describing those demands is different than assumed in the model.

Country$_A$	Country$_B$	Type	p-value	Adj. R^2	CPE$_{AB}$	m_A	m_B
China	Malaysia	Hardwood pl.	$1.93 \cdot 10^{-3}$	0.203	1.025	57%	10%
Finland	Russia	Hardwood pl.	$1.79 \cdot 10^{-5}$	0.212	-1.364	5%	14%
Malaysia	China	Hardwood pl.	$4.53 \cdot 10^{-4}$	0.203	-3.301	10%	57%
Russia	Malaysia	Hardwood pl.	$4.27 \cdot 10^{-3}$	0.157	-1.898	14%	10%
Russia	Russia	Hardwood pl.	$6.88 \cdot 10^{-8}$	0.242	-2.267	14%	14%

6 Discussion

As can be seen from the results, we detected several price-response relationships between relative price of plywood and market share in the import data of the UK. In this section, we analyze these results and their effects on real life trade, speculate about the reasons behind some peculiarities in the data, and give a recommendation to our client about the things to consider if trade protection measures would change in the UK.

6.1 Assessment of results

Based on the results of our analysis, we see that softwood plywood imports from Brazil act as a substitute to both Finnish and Chinese softwood plywood (meaning that a relative decrease in Brazilian softwood plywood price would negatively affect the import demand of both Finland and China). The price changes in softwood plywood from China also have a similar effect on the import quantities of Brazil, as have price changes in the prices of softwood plywood from Chile.

When oriented strand board (OSB) imports are taken into account as well, we also see a slight substitution effect of Irish OSB as a substitute to Brazilian softwood plywood. However, no other correlations between the price of OSB and market share of softwood plywood is found, and the cross-price elasticity between Brazil and Ireland is rather small in magnitude. We speculate that location plays a role here: Ireland – being close to the UK both geographically, politically and culturally – will generate a greater substitution effect with its OSB than OSB from other countries, as there are less amounts of frictions in other aspects of trade business between Ireland and the UK.

We see some peculiarities in the data when looking at Finland and China. Based on our results and contrary to common sense, Finland and China seem to be complements in the softwood plywood market. We speculate some reasons for this effect in the data. First of all, it is important to note that Finnish and Chinese plywood are priced differently and are also generally from different quality classes (Finnish softwood plywood being of higher quality). Also, the representatives of our client speculate that the material portfolios might also differ between the countries despite being under the same customs code, which would mean a less viable substitution effect.

It is possible that our assumptions of price-response do not work when comparing China and Finland, since the production capacity difference between them is so large. It is possible that as Finland's export capacity to the UK reaches its maximum, China can raise its prices as the competition from Finland is decreased. This would mean that the price-demand correlation needs to be interpreted the other way around in terms of causality: When the production capacity is reached, it is not price that is determining the demand of a good, but rather the market is determining the price for the good based on availability. An alternative theory to this are additional, hidden factors that would cause the rise in the demand of both countries' market shares, but this effect is hard to prove without a more comprehensive analysis of the plywood market as a whole.

6.2 Recommendations

From the point of view of our client Metsä Wood, the estimated cross-price elasticity of softwood plywood between Finland and Brazil would mean that if the British government decides to remove the tariff from the Brazilian import, it would have a diminishing effect on the import of Finnish softwood plywood to the UK. Also, since the current trade agreement between EU and Brazil includes a tariff-free quota, we speculate that removing the tariff would flatten the seasonality of Brazilian import compared to the current situation, and thus provide a more constant monthly competition against Finnish plywood from Brazil. As a topic of further research, one might want to take the point of view of Brazil and look at the plywood trade relationships it has with other countries to gain a better view of its export dynamics as a whole. One theory is that the export quantities to Europe are significantly influenced by the demand and prices in the US, but this effect is left out of the scope of this project.

Regarding other importer countries, we do not find clear substitution effects to Finnish softwood plywood imported to the UK in terms of cross-price elastic behaviour. For hardwood plywood, the situation remains inconclusive, as our model cannot reliably process the large drop in import quantities from China that began in the end of 2016. Based on the import prices alone, it can be speculated that Finnish hardwood plywood belongs to a different price category and is presumably also of different quality and/or part of different wood portfolio in comparison with the other importers of hardwood plywood. For this reason, we believe that UK's tariff reductions towards the most prominent competitors would not be a threat to the hardwood plywood trade between the UK and Finland.

7 References

[1] Finnish customs. "Finnish international trade 2018 Figures and diagrams"

[2] Metsä Wood products. https://www.metsawood.com/global/Products/Pages/Products.aspx (accessed 26.2.2020)

[3] European Customs portal. https://www.tariffnumber.com/2020/4412 (accessed 1.3.2020)

[4] Besanko, D., and Braeutigam, R. *Microeconomics*. Fourth edition. John Wiley Sons. 2020.

[5] Taxation and Customs Union. TARIC database. https://ec.europa.eu/taxation_customs/dds2/taric/taric_consultation.jsp?Lang=fi (accessed 27.2.2020)

[6] Finnish Customs. "Suomen käyttötariffi" (in Finnish). https://tulli.fi/tietoa-tullista/tullin-toiminta/kayttotariffi (accessed 26.2.2020)

[7] U.S. International Trade Commission. "Publication 4747: Hardwood Plywood from China"

[8] Simon H., and Fassnacht M. *Price Management*, 85-142. Springer, Cham, 2019

[9] European Commission. Eurostat. https://ec.europa.eu/eurostat/home. (accessed 20.2.2020)

[10] World Integrated Trade Solutions. https://wits.worldbank.org (accessed 24.2.2020)

[11] European Commission. CIRCABC. https://circabc.europa.eu (accessed 24.2.2020)

[12] Schwertman, N., Owens, M., Adnan, R. "A simple more general boxplot method for identifying outliers". *Computational Statistics & Data nalysis*, 47(1), pp. 165-174. 2004.

[13] Haas, R., Schipper, L. "Residential energy demand in OECD-countries and the role of irreversible efficiency improvements". *Energy Economics*, 20(4), 421-442. 1998.

[14] Corbo, V, and Chiara, O. "Trade Adjustment in the European Union - A Structural Estimation Approach". European Central Bank Working paper. 2013.

https://www.econstor.eu/bitstream/10419/153968/1/ecbwp1535.pdf
accessed (3.3.2020)

[15] Zieba, M. "Full-income and price elasticities of demand for German public theatre". *Journal of Cultural Economics*, 33(2), 85-108. 2009.

[16] Filippini, M. "Short-and long-run time-of-use price elasticities in Swiss residential electricity demand". *Energy Policy*, 39(10), 5811-5817. 2011.

[17] Kucher, E. *Scannerdaten und Preissensitivität bei Konsumgütern*. Vol. 58. Springer-Verlag, 2013.

[18] Lovell, M. "Seasonal adjustment of economic time series and multiple regression analysis". *Journal of the American Statistical Association* 58(304), 993-1010. 1963.

Self-assesment

During the 19 weeks of the course Seminar on Case Studies in Operations Research our team grew from four individual engineering students into a dynamic and ambitious group of makers. We managed to turn the different personalities of the team into its advantage while developing the project. Now, after all these weeks, we have a documented project that everybody of team members is proud of. Let us have a little closer look on what happened during the project.

Project plan and reality

Scope

One of the weaknesses of the original project plan was the lack of a clearly defined scope. The original scope was really broad, as the objective was just to explain the whole global plywood sales and the effect of import tariffs on it. In addition to a too large scope, a clear methodology was missing. Thus, the original project plan described a very loosely defined problem with with no clear answer how to solve the problem. Thanks to a constructive feedback, the team was able to narrow the scope down and find a clear methodology with the help of the client and a literature.

Risks

We are proud to say that none of the original estimated risks (analysis fails, data quality issues, too broad point of view, team member absence, communication issues with the client) were materialized during the project. Thus, it was highly important that we defined ways to avoid these risks at a very early state of the project. A proper planning ended up playing a very major role in the success of the project.

Schedule

The original planned schedule was managed to follow surprisingly well. The only major difference was in the timing of the modelling and analysis since it took longer for the team to have a right methodology to build the model and to base the analysis on. However, everything was managed to implement on time and there was enough time for writing of this final report.

Project execution

We were able to execute the project in a way it was planned in the original project plan. However, the theory and methodology had to be studied further after the initial plan, which made some differences to the original idea. The course report deadlines also helped us to develop the project in three main phases for each of the three seminars.

The amount of work

The original project plan did not have an approximation for the exact amount of work for the project. However, it was agreed by every member of the team that a successful execution of the project will easily take the work hours defined for 5 ETCS credits. Since the project was started and planned in the very beginning, there were no rush or panic with timing at any stage of the project.

Project challenges and successes

In the beginning our team found the topic rather unclear and there was some sort of confusion in getting started. First it seamed hard to find a comprehensive mathematical approach to the subject. Based on the first tests with the data it also seemed that it would be really hard to get any good results and enough material to write a report about.

Another challenge came in as the global pandemic hit the world in mid March. The team could no longer meet in person together and with the client. However, the new remote ways of working were called into play successfully and the project could be finished with honor.

We think that our biggest success was when we finally got a clear picture of implementing our project. Narrowing down the scope and finding a proper methodology was an iterative process in which the regular meeting with the client were highly important. As the scope and methodology became clear slightly after the first seminar, the implementation of the project proceeded very smoothly until the this point.

What could have been done better?

Team

The team could have had more meetings in the beginning of the course. While the subject seemed difficult and confusing, in the beginning more focus was put on the data rather than potential approaches that could be used.

Teaching staff

The seminar weeks could have been organized better. Writing a good feedback for opponent team in a day or two was a lot of work in addition to other school projects and work. Also information about the seminars and deadlines came very last minute, which the team found rather stressful.

Client organization

There is not much bad to say about the client organization since the co-operation worked out very well. The client was keen on meeting regularly and following the progress of the project, which was motivating also for the project team. However, having a bit better scoped project subject would have been easier for our team to get started. However, this iterative process was a very educational experience and is likely to be a good example of how projects are implemented in real life.