Uncertainty in Wood Export
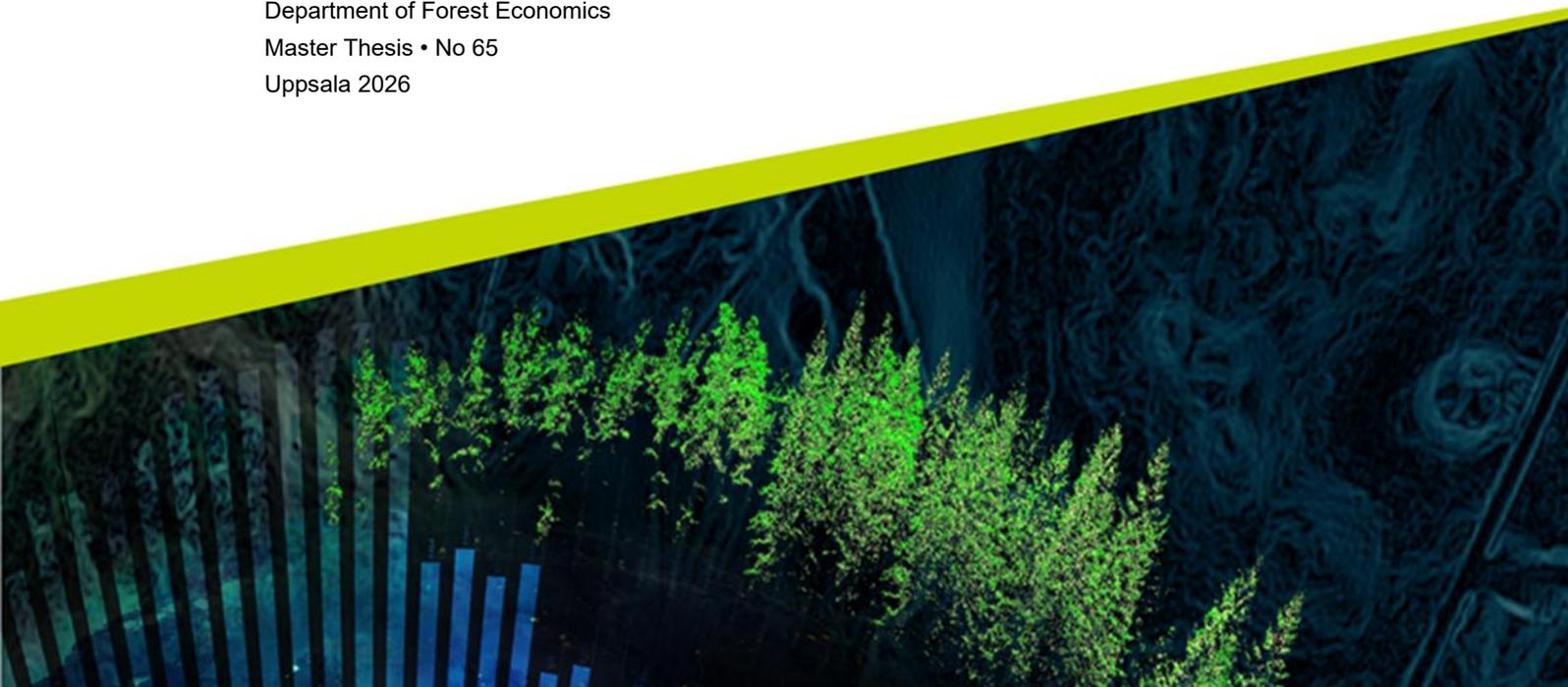## - Strategic Choices in Sawnwood and Pulp Export

Osäkerhet i trävaruexport - Exportstrategier för träråvara

Jessica Egonson & Viggo Granlund

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Summary

Global uncertainty causes unpredictability in the global trade environment. This affects Swedish exports of pulp and sawnwood. This thesis examines export planning and the managerial dilemma many decisions makers face; how early commitment to demand projection affects the risk of shift in trade environment resulting in poor performance and if export-allocation flexibility can create value.

This thesis follows a quantitative, scenario-based research design using real options theory and supply management theory. Using historical export data to create a baseline demand, volatility and stochastic shocks that varied across three trade environment scenarios (Liberalised, Status quo, Protectionist). Through a breakeven value the benefit of flexibility is captured, using a comparison between a rigid non-flexible export-allocation strategy and an export-allocation strategy that allows flexibility. Using Monte Carlo simulation, a service-band and flexibility cost the two export-allocations strategies had their breakeven value simulated in the three different trade environment scenarios.

The results showed that flexibility was scenario dependant. The breakeven value was positive in the Liberalised trade environment scenario, slightly negative in Status quo trade environment scenario and negative in the Protectionist trade environment scenario. The thesis showed that flexibility is justified in a favourable trade environment and not favourable in adverse and volatile trade environments.

Keywords: breakeven cost, export-allocation, flexibility, Monte Carlo simulation, real options, scenario simulation, supply chain management, trade environment, uncertainty

Sammanfattning

Global politisk osäkerhet skapar instabilitet i handelsklimatet och påverkar svensk export av sågade trävaror och massa. Denna studie undersöker hur tidiga prognosbaserade åtaganden kan bli kostsamma när handelsklimatet förändras och hur flexibilitet i exportallokering kan skapa värde för företag.

Studien följer en kvantitativ, scenariobaserad forskningsdesign med utgångspunkt i Real options teori och försörjningskedjeteori. Med hjälp av historisk exportdata skattas en referenslinje för efterfrågan och volatilitet samt stokastiska chocker som varierar mellan tre handelsklimatscenarion (Frihandel, Oförändrad handel, Protektionism). Flexibilitetens värde beräknas genom att jämföra fast exportallokering och flexibel exportallokering. Utifrån en Monte Carlosimulering, ett toleransintervall och en flexibilitetkostnad, beräknas sedan brytpunktsvärdet.

Resultatet visar att värdet av flexibilitet är scenarioberoende. Brytpunktsvärdet är positivt i frihandelsscenariot, svagt negativt i det oförändrade handelsscenariot och negativt i protektionismscenariot. Studien visar att flexibilitet är fördelaktig i ett gynnsamt handelsklimat, men ger sämre förutsättningar i volatila handelsklimat.

Nyckelord: brytpunktsvärde, exportallokering, flexibilitet, försörjningskedja, handelsklimat, Monte Carlosimulering, osäkerhet, scenariosimulering, Real Options

Table of contents

List of figures

1   Introduction

Chapter 1 introduces the background and problem statement of the study and defines the purpose and scope of the research.

Global trade in forest products such as sawnwood and pulp is strongly influenced by international trade policy, regulatory frameworks, and shifting market demand. The world is uncertain with increasingly unpredictable trade policies. However, in a world characterized by global interdependence, the dynamics of international trade have become a defining feature of modern economic activity. Yet, these same dynamics have also made global industries increasingly vulnerable to uncertainty. Trade policies, supply-chain disruptions, and shifting patterns of demand can rapidly alter the competitive landscape for firms that depend on exports (OECD, 2023). This is particularly true for resource-based sectors such as forestry, where long investment cycles and high capital intensity make flexibility both difficult and essential (FAO, 2022). Over the past decade, the global trade environment has undergone substantial transformation. Periods of trade liberalisation have been followed by waves of protectionism, while geopolitical tensions and environmental concerns have reshaped the rules governing cross-border exchange (Hetemäki et al., 2017; OECD, 2023).

The COVID-19 pandemic, Russia's invasion of Ukraine, and the growing influence of sustainability-driven trade mechanisms such as the EU's Carbon Border Adjustment Mechanism, have demonstrated how vulnerable even established export industries are to rapid shifts in the international policy (FAO, 2020; OECD, 2023).

This balance between commitment and flexibility is particularly relevant to export-oriented industries with global supply chains. As Christopher and Peck (2004) and Jüttner (2005) emphasize, global supply chains must increasingly be designed for resilience—the capability to anticipate, respond to, and recover from disruptions. Such resilience is achieved not only through redundancy but also through strategic flexibility; the ability to reallocate production, switch suppliers, or enter and exit markets as conditions change (Nembhard et al., 2005; Huchzermeier & Cohen, 1996). Understanding and valuing this flexibility requires analytical tools that can capture uncertainty and its impact on decision-making.

This thesis therefore combines insights from real options theory and supply chain management to evaluate how export-oriented forest companies can manage uncertainty in the global trade environment. Using EUROSTAT data as a baseline and Monte Carlo simulation as the analytical tool, the study explores how different future trade policy scenarios could influence Swedish exports of pulp and sawnwood between 2025 and 2040.
By modelling export flexibility as a portfolio of real options, this research provides a structured and quantitative way of assessing how uncertainty affects firm strategy. The results are expected to offer both theoretical and practical insights advancing our understanding of flexibility in supply chain decision making and providing a decision support framework for managers in the forest industry operating under global uncertainty. Given the inherent uncertainty surrounding future trade conditions, a simulation-based approach grounded in real options theory is employed to evaluate the economic value of export-allocation flexibility.

1.1 Problem Background

Global trade in forest-based products, such as sawnwood, pulp, and paper, is shaped by a complex interplay of international policies, market dynamics, and regulations. Over the last two decades, globalisation and technological advancement have fostered greater integration of forest-product markets, enabling efficient international supply chains and diversified export portfolios. However, this interdependence has also made the sector more vulnerable to external shocks, including geopolitical tensions, trade barriers, and logistics disruptions. As a result, firms operating across borders face a pressing need to develop strategies that are not only efficient under stable conditions but also resilient and adaptive when the external environment changes (Christopher & Peck, 2004; Jüttner, 2005).

In recent years, the global trade environment has entered a period of heightened uncertainty. Trade conflicts between major economies, such as the United States, China, and the European Union, have contributed to unpredictable tariff structures and regulatory conditions. In parallel, new sustainability regulations, such as carbon border adjustment mechanisms and stricter forest-origin reporting requirements, are increasingly affecting global trade flows. Combined with fluctuating transport costs and supply chain bottlenecks, these developments have created a business environment characterized by volatility and risk (OECD, 2023; FAO, 2022).

Forest-based industries play a critical role in the transition toward a bio-based and low-carbon economy, supplying renewable materials that can replace fossil-based products (Hetemäki et al., 2017; FAO, 2020). At the same time, the sector remains heavily dependent on global trade flows, as demand for pulp, paper, and sawnwood increasingly originates outside traditional markets (Swedish Forest Industries Federation, 2023). This dual reality, between environmental sustainability and market volatility, creates a complex managerial challenge. Companies must simultaneously pursue sustainable growth and maintain the flexibility required to adapt to fluctuating trade conditions (IVA, 2023).

Sweden, as one of the world's largest exporters of forest-based products, is particularly exposed to these global dynamics. The forest industry is a cornerstone of Sweden's bioeconomy, contributing roughly 10 percent of national export revenues and employing more than 100 000 people (Swedish Forest Industries Federation, 2024). The European Union remains the primary export market, but growing demand in Asia, North America, and MENA is gradually reshaping trade patterns. These structural shifts have increased both opportunities and risks, especially as competition for raw materials intensifies globally (IVA, 2023). Furthermore, the Swedish forest industry faces mounting expectations to operate sustainably and to integrate environmental and social considerations into strategic decision-making. The discussion about corporate responsibility, emphasizes that firms today must balance profitability with environmental stewardship and long-term societal value creation. In an increasingly uncertain global context, this balancing act becomes more complex, companies must not only achieve financial resilience but also ensure that their operations align with sustainability goals and stakeholder expectations.

From a business administration perspective this uncertainty creates a management dilemma, namely, how to balance commitment and flexibility. Large-scale industrial investments, such as establishing export routes, negotiating supplier contracts, or adopting certification systems, are often irreversible and require long-term commitments. Yet, the value of these commitments depends on future trade conditions that cannot be predicted with confidence

(Trigeorgis & Tsekrekos, 2018). Firms must therefore seek strategies that preserve their ability to adapt without undermining operational efficiency.

In sum, the international forest trade landscape has become more uncertain, complex, and strategically demanding. Swedish forest companies must navigate a shifting environment where policy changes, market volatility, and sustainability pressures converge. Understanding how to manage these uncertainties and strategically prepare for different trade scenarios is therefore essential for maintaining competitiveness and long-term viability in the forest-based bioeconomy.

1.2   Problem

Despite the strategic importance of export allocation for Swedish forest firms, there remains limited understanding of how such decisions should be evaluated under uncertain trade conditions. Export volumes of pulp and sawnwood, two of Sweden's most important export commodities, are directly influenced by the global trade environment, where geopolitical conflicts, environmental regulations, and protectionist measures play a central role (FAO, 2022; Swedish Forest Industries Federation, 2023).

For companies engaged in international trade, this creates a complex decision environment. Managers must decide where to allocate production capacity, which markets to prioritise and how to structure supply chains to remain resilient under shifting trade conditions. Such decisions involve substantial capital commitments and long planning horizons, making them vulnerable to uncertainty and irreversibility. Once investments in logistics routes, production configurations, or certifications are made, they are costly to reverse, thus increasing the risk of sunk costs and reduced flexibility.

A key strategic challenge, therefore, is how to maintain flexibility while pursuing efficiency. Committing fully to specific trade routes or markets may improve short-term performance but leaves the firm exposed if external conditions change. Conversely, maintaining too much flexibility can result in higher costs or underutilized capacity. Finding the optimal balance between flexibility and commitment under uncertainty is thus a critical management problem.

Previous research on global forest-product trade has primarily taken a macroeconomic perspective, focusing on trade flows, price elasticity, and policy effects (Hetemäki et al., 2017; FAO, 2020). While these studies are valuable, they often overlook the firm-level strategic implications of uncertainty. From a business administration perspective, there remains limited empirical understanding of how forest-sector firms can quantitatively evaluate flexibility in export decision-making. Although real options theory provides a conceptual foundation for valuing flexibility under uncertainty (Trigeorgis & Tsekrekos, 2018), it has been applied only sparingly in the context of forest-sector exports. Similarly, while supply chain management literature emphasizes the importance of agility and resilience (Christopher & Peck, 2004; Jüttner, 2005), few studies integrate these ideas into a coherent, quantitative framework for strategic export planning. Existing research often focuses either on macroeconomic trade models or on operational logistics optimization, leaving a gap in understanding how firms can quantitatively evaluate strategic flexibility at the firm level (Cucchiella & Gastaldi, 2006). Bridging this gap is essential for industries facing long investment horizons and complex international dependencies like Sweden's forest sector.

This thesis therefore addresses a critical knowledge gap at the intersection of trade policy uncertainty, forest-sector strategy, and supply-chain flexibility, where existing research

provides limited quantitative guidance at the firm-decision level. It focuses on how firms can use quantitative modelling to evaluate and manage strategic options in response to uncertain trade conditions, an area of growing relevance given the volatility of the global economy and the forest sector's reliance on international markets.

1.3 Aim

The aim of this thesis is to evaluate whether export-allocation flexibility creates economic value for Swedish pulp and sawnwood exports under alternative future trade-policy environments, and to estimate the breakeven cost of such flexibility under trade uncertainty. This is achieved by modelling export-allocation decisions as real options and comparing flexible and non-flexible export strategies across alternative trade environment scenarios from a business-economics perspective.

Three research questions were created in order to achieve the aim of this study, focusing on the conceptualisation of export-allocation flexibility, the effect of export-allocation flexibility under different trade conditions and how uncertainty, irreversibility and flexibility costs affect export strategies. The study addressed following research questions:

- **RQ1**: *How can export-allocation flexibility be conceptualised as real options under trade uncertainty?*
- **RQ2**: *What is the effect of export-allocation flexibility under different trade conditions?*
- **RQ3**: *How do uncertainty, flexibility costs, and irreversibility affect flexible export strategies?*

1.4 Scope and Delimitations

This study was limited to Swedish exports of pulp and sawnwood over the period 2025–2040. Export flows were represented by aggregated destination regions as defined in the dataset and simulation model, rather than by individual countries.

The analysis was sector-specific and did not include macroeconomic feedback effects, exchange-rate dynamics, or economy-wide substitution effects. Prices and full profit maximisation were not modelled; instead, performance was evaluated using a volume-based approach translated into economic outcomes through a service-band logic and penalty costs for under- and over-delivery.

Uncertainty and flexibility were represented in reduced form. Demand uncertainty was modelled through stochastic shocks estimated from historical export data, while flexibility was represented as the ability to reallocate export volumes across region–product combinations at an explicit cost. The model did not incorporate detailed operational constraints such as capacity limits, facility locations, or lead-time structures.

2 Theory

Chapter 2 presents the relevant theories that serve as a basis of this study. It describes the relationship between the theories and the link to the analysis.

2.1 Real Options Theory

Real options theory is a strategic framework approach that allows business decisions regarding financial options under uncertainty. Compared to traditional investment theories, which often posit that an investment should be undertaken when the net present value is positive, real options theory instead suggest that businesses should maintain flexibility in timing and scale when the decision regarding the investment involves an uncertain future outcome and can be directly irreversible (Dixit & Pindyck, 1994). This context shows that making commitments prematurely might cause inefficiencies and that businesses can use valuable flexibility as an asset when there is an opportunity to adapt or adjust the investment.

Within the literature, Trigeorgis (1996) summarizes the principal categories of real options applicable to managers. A deferral option enables businesses to delay commitment until more information regarding the investment is known, an expansion option allows for growth when aspects surrounding the investment is improved, a switching option provides the means to reallocate resources to alternative markets or operational approaches, and a scale down option functions as a buffer by temporarily reducing activity when conditions regarding the investment are unfavourable. Together, these options show how resilience can still be met by averting risk while being prepared to secure potential opportunities.

In strategic management research, these options are considered as valuable due to the capacity of transforming uncertainty from a forced commitment into an opportunity that allows flexibility. Tong and Reur (2007) highlights how a real options framework reframes uncertainty into sequencing decisions, allowing businesses to take on commitments in smaller steps rather than all at once. This emphasises how real options is not only a method for valuation but also provides guidance in structuring strategic choices under uncertainty. For this thesis, real options theory will provide an understanding of how businesses might manage strategies to manoeuvre external uncertainties. By approaching these strategic choices as options instead of forced commitments, it allows for the possibility of using it as a framework to analyse how flexibility regarding decision-making can be implemented into alternative future scenarios. This is especially significant for businesses that operate within international markets and are highly affected by shifts within the global trade environment. For businesses that are export-dependent such as the Swedish forest industry, this approach is essential as it establishes how it can remain resilient by deferring, expanding, switching and scaling-down strategically in response to uncertainty. Although the options literature distinguishes multiple option categories, the flexibility analysed in this thesis aligns most directly with a switching option, by which export volumes can be reallocated across destination markets as conditions change.

2.2   Supply Chain Management

The supply chain, according to Chopra (2019), includes every party and activity required to meet a customer request. This includes suppliers that provide inputs, manufacturers that convert them, warehouses that store them, transportation that moves them, retailers that sell them and customers who create demand. The overarching objective is to maximize the surplus of the supply chain, which is the value placed on the product by the consumer minus the total cost of the supply chain to deliver it. The surplus is created jointly across firms and good decisions need to focus overall rather than a single stage.

To make management easier, decisions can be viewed across three-time horizons: strategy, planning, and operations. Strategy concerns long-term choices such as market positioning and capacity, planning translates strategy into coordinated demand and supply plans, and operations executes these plans in the short run. A key implication of this view is that performance depends on alignment between plans and day-to-day decisions and on coordination across functions such as marketing, operations, and finance.

Chopra (2019) also distinguish between push and pull processes, where activities are performed either in anticipation of demand (push) or in response to customer orders (pull). In this thesis, export allocation is primarily a planning (push) decision, while the flex strategy represents an ability to adjust allocations after demand and trade conditions are realised, closer to a pull response.

When creating and designing a supply chain in line with business strategy, it is important to balance responsiveness and efficiency. In this context, responsiveness relates to the ability to reallocate volumes across markets when demand shifts, while efficiency relates to keeping plans stable and minimising coordination and switching frictions. This trade-off is central to the flex versus no-flex comparison: maintaining fixed allocations can be efficient, while allowing reallocation can improve responsiveness but requires coordination, replanning, and logistical adjustments. The analysis therefore evaluates export performance by how closely realised export volumes align with realised demand, given these trade-offs.

2.3   Integrated Conceptual Framework

The theoretical framework incorporates elements from both real options theory and supply chain management theory. Together, the theories provide the foundation for this thesis by explaining how uncertainty, managerial decision-making, and supply chain performance interact. Real options theory contributes the valuation logic for flexibility under uncertainty, while supply chain management defines the decision domains and operational context in which flexibility is created and exercised, for example through allocation, capacity, routing, sourcing, and market reallocation. These links are supported by prior literature that combines real options and supply chain flexibility perspectives (Nembhard et al., 2005; Huchzermeier & Cohen, 1996; Cucchiella & Gastaldi, 2006).

Real options theory creates options to incorporate flexibility into the supply chain. Conceptualizing flexibility as a set of options to take specific actions when uncertainty occurs is the key concept of real options theory. Supply chain decisions can therefore be interpreted as real options embedded within the supply chain itself and the decision to exercise these options is shaped by uncertainty, irreversibility and exercise cost (Huchzermeier & Cohen, 1996).

Expressing the interaction between real options theory and supply chain management as a causal chain, environmental uncertainty creates volatility in performance, while managerial flexibility determines how the firm can respond to changing conditions (Huchzermeier & Cohen, 1996). Following the literature on real options theory, the timing and value of exercise depend on uncertainty, irreversibility, and contracting costs (Trigeorgis, 2017). In the context of this thesis, these mechanisms are reflected in the trade-off between maintaining committed export allocations and allowing adjustments when conditions change.

In this thesis, the integrated real options theory and supply chain management perspective provides a lens for analysing how Swedish forestry exporters can manage trade uncertainty through export-allocation flexibility. Real options theory explains why export-allocation flexibility can create value under uncertainty when commitments are partly irreversible and flexibility involves exercise costs. Supply chain management clarifies where this flexibility is exercised operationally, through planning decisions that allocate and reallocate export volumes across destination markets and highlights the trade-off between efficiency and responsiveness. Figure 1 summarises the integrated logic of the framework and illustrates how trade-policy conditions relate to export-allocation flexibility and, ultimately, export performance and the value of flexibility.
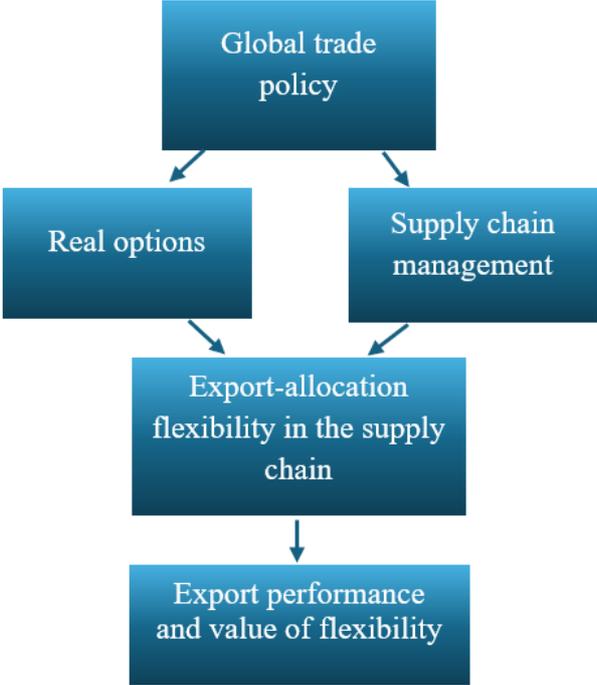
Figure 1. Theoretical framework showing how global trade policy, through real options and supply chain management can affect decisions in export-allocation flexibility in the supply chain.

Figure 1 illustrates how global trade policy affects export performance. Global trade policy is at the top of the figure and represents external market-access conditions such as tariffs, non-tariff measures, administrative requirements, and trade agreements. Changes in these conditions shape the uncertainty and attractiveness of destination markets, which in turn affects the relevance and value of export-allocation flexibility.

The framework combines two theoretical lenses. supply chain management theory establishes where flexibility exists within the operational practise and how it can be applied, by for example reallocation of volumes across regions, logistics adjustment and decisions regarding

capacity. Real options theory shows that flexibility creates economic value under uncertainty because, when export commitments are partly irreversible, firms can treat flexibility as an option, used only when conditions warrant it. The value of flexibility changes with uncertainty, irreversibility and exercise costs.

The perspectives gather into the central construct of the framework which is export allocation flexibility in the supply chain. In this thesis, flexibility refers to the ability to adjust export allocations across destination markets when conditions change, whereas the no-flex case represents committed allocations that remain fixed. Exercising flexibility is associated with adjustment costs, reflecting the managerial and operational hurdles of reallocating exports, such as coordination, renegotiation, re-planning, and switching costs. The box in the bottom of Figure 1, export performance and value of flexibility, represents how export performance is evaluated by how well exports match market conditions under uncertainty. Flexibility is preferred when the expected improvement in performance under uncertainty outweighs the costs of maintaining and exercising that flexibility.

3   Method

Chapter 3 outlines the methodology process of the research design and the model. Defining the equations and the variables involved in the workflow.

3.1   Research Design

This thesis adopted a quantitative, scenario-based research design to assess how alternative trade environment scenarios may affect the Swedish export volumes of pulp and sawnwood.

In order to assess how changes in trade environment affected the value of flexibility in export-allocation a demand baseline was created from historical export data using EUROSTAT data from the years 2002-2024. That baseline was then used to simulate how demand, under three hypothetical trade environment scenarios, changed during 2025 until 2040.The scenarios mirrored trade-policy changes such as quotas, regulations, tariffs and non-tariff measures, but were captured in a reduced form through demand and demand volatility instead of direct tariff equations.

The quantitative model was specified as a sector specific, volume based stochastic allocation model that isolated the exports of wood products from the Swedish forestry sector. This perspective allowed the analysis to focus on trade policy shocks without having to consider the macroeconomic effects.

The core of the research design was the comparison between two export-allocation strategies:

- *No-flex strategy*: the export volumes were fixed in advance per region, product and year combination based on the demand forecast in the baseline. Once these export volumes were committed, the allocations were not allowed to change when trade-environment shocks and demand uncertainty materialised.
- *Flex strategy*: the export volumes could be reallocated or adjusted after trade environment and demand uncertainty had been realised, with a fixed and variable cost of flexibility.

3.2   Trade Environment Scenarios

To reflect uncertainty regarding future trade environment conditions, the projections of future baseline exports were fixed into three alternative scenarios: *Liberalised*, S*tatus quo* *Protectionist* trade environment. In this thesis, "trade environment" refers to the overall difficulty or ease of market access for Swedish wood exports, depending on the effects from tariffs, non-tariffs and regulatory requirements in major import regions. The scenarios weren't intended as future forecasts, but rather as hypothetical "what if's", where the efficiency of flexibility could be assessed:

- *Liberalised scenario*: more predictable and liberal trade environment with fewer trade barriers, lower tariffs and simpler regulatory processes. Higher overall demand but lower demand volatility.
- *Status quo scenario*: trade environment without any changes from the baseline demand extrapolated from EUROSTAT data. No change in demand or demand volatility.
- *Protectionist scenario*: more unpredictable trade environment with stricter regulation processes, higher tariffs and more frequent trade barriers. Lower overall demand but higher demand volatility.

In the model these scenarios were created by changing two parameters: a mean shift in demand μ_s and a demand volatility multiplier v_s. In the Status quo scenario, the parameters were set to $\mu = 0$ and $v = 1$, the scenario used the baseline demand and demand volatility and therefore represented a continuation of current trade conditions. The Liberalised scenario was set to $\mu = +0.1$ and $v = 0.8$, corresponding to a slightly higher demand and 20% lower demand volatility. The Protectionist scenario was set to $\mu = -0.1$ and $v = 1.2$, corresponding to slightly lower demand and a 20% higher demand volatility. This representation translated easier or harder market conditions into quantitative differences, while keeping all other variables within the model unchanged.

3.3   Motivations and Assumptions

The thesis had two main motivations. The first, to shape the model as closely as possible to conditions experienced by Swedish forest businesses, to create a reasonable decision basis for managers of those businesses. The second, for the model to be tractable and transparent enough for the results to be easily interpreted without relying on complex econometric models, i.e. to have a model not dependent on macroeconomics, like currency effects and interest rates. The assumptions stated below were therefore deliberately chosen for the purpose to balance clarity and realism. The model therefore used volume as its only metric to avoid using monetary value. The value is therefore represented by volume; where an increase in volume leads to a higher value and a decrease in volume leads to a lower value.

The first area of assumptions was related to demand. Based on historical exports, the regional demand for each product was estimated through a linear time trend. Every combination of region, Asia, Europe, MENA and North America and product, pulp and sawnwood, had its demand and volatility extrapolated. Random shocks were added to the volatility, and the shocks were dependent on the trade environment scenario. All the trade environment scenarios used the same shock effect, were a randomly generated and normally distributed number was created and then applied into the different trade environment scenario product, region and year combination. Normal distribution is widely used in risk and scenario analysis, due to being characterized by mean and variance and allows for both positive and negative

deviations around the trend. These shocks were assumed independent across regions, products and years. This simplified the model and avoided estimating a large correlation structure on limited data. However, the shock was created to work in tandem with the volatility of a specific region and product combination to try and mimic the patterns from EUROSTAT as closely as possible without losing randomness. As a result, the simulated value of flexibility should be interpreted as a cautious lower-bound estimate: by assuming independent shocks across products, regions and years, the model likely understates situations where several markets are hit simultaneously, and the value of flexibility would change.

The second area of assumption relates to how the trade policy was expressed as an uncertainty. The thesis used a shift in demand and the dispersion of demand shocks as a reduced form of trade policy parameters, rather than modelling quotas, tariffs and regulatory measure in a full structural framework. The parameters for the Status quo trade environment scenario were unchanged, $\mu=0$ and $v=1$, meaning no deviation from baseline demand or demand volatility. As described in 3.2, the Liberalised scenario assumes $\mu=+0.1$ and $v=0.8$, while the Protectionist scenario $\mu=-0.1$ and $v=1.2$. These parameters were chosen to meet three criteria. First, they had to be consistent with historical variability: a $\pm10\%$ systematic deviation in demand and a $\pm20\%$ change in volatility were smaller than the largest historical year to year fluctuations, but large enough to be managerially relevant. Second, they had to be interpretable to managers, where the scenarios were framed as Liberalised, Status quo and Protectionist trade environments, consistent with scenario planning guidance to construct contrasting positive and negative scenario worlds (Shoemaker, 1995). Third, they had to be compatible with the service-band design: the $\pm20\%$ volatility scaling directly affects how often demand falls outside of the $\pm20\%$ service-band around planned volumes. Pilot simulations validated that these settings generated material penalty costs and flexibility values without pushing the system into implausible or extreme outcomes.

The third area of assumption concerned the design of the service-band and the penalty structure. To translate operational performance into the value measure used in the model, a symmetric service-band of $\pm20\%$ around planned demand was introduced. This width was calibrated using historical export deviations. When observed exports for 2002-2024 were compared with the estimated trend, most annual deviations fell within $\pm20\%$, while the relatively few outlier years recorded average absolute deviations close to 20%. Deviations inside the service-band were therefore interpreted as normal forecast noise that firms can typically absorb operationally and were not penalised in the value function. Only deviations outside the $\pm20\%$ band were treated as service-band failures, either as an overshoot which represented an excess in inventory and tied-up capital or as a shortfall which represented a stock-out of inventory and lost sales. The penalty weights were set at $\lambda_{under} = 1$ for shortfall and $\lambda_{over} = 0.5$ for overshoot, reflecting that shortages typically carry higher economic impact than overages in service-oriented supply chains (Chopra, 2019). The weights were not statistically estimated but rather chosen to be consistent with supply chain management and adding economic logic to the model.

Pulp and sawnwood use different measurements, tonnes and cubic meters (m^3) respectively, so to convert pulp into volume, a conversion factor was used. That number is 2 cubic meters per tonne pulp for softwood, which is the main type of wood used in Sweden (Environmental Product Declaration, 2021). This is an assumption made for the purpose of this study and other types of wood may have different conversion factors.

3.4   Data Collection

The empirical core of this thesis was based on historical export data collection from Eurostat for the period 2002-2024. The datasets cover the annual export volumes of sawnwood (HS4407) and pulp (HS 4701-4705), two key exports products for the Swedish forestry industry. The products were extracted from EUROSTAT in cubic meters for sawnwood and tonnes for pulp, later converted into volume, and aggregated into four export regions: Asia, Europe, Mena and North America. In Appendix 1, there is a list of which countries are included in each region.

3.5   Demand Modelling

Market demand was modelled at an annual frequency for each product-region combination. The objective was to create a realistic time series of realised demand around a deterministic trend, so that flex and no-flex strategies could be compared under different trade environment scenarios. The starting point was a deterministic baseline trajectory for each region and product combination. The level in the base year, 2025, is anchored to the latest observed exports, and future years follow a linear trend estimated from historical data. For each region-product pair (r, p), baseline demand in year y with a 2025-2040 horizon ($y = 1, \dots ,16$) was specified as;

$$Baseline_{r,p,y} = \alpha_{r,p} + \beta_{r,p}y \tag{1}$$

where $\alpha_{r,p}$ is the intercept and $\beta_{r,p}$ the annual slope. The intercept $\alpha_{r,p}$ was calibrated so that $Baseline_{r,p,1}$ was equal to the observed export level in 2025. The baseline represented demand without volatility shocks and was also the quantity used as the base demand in the no-flex strategy option.

A stochastic shock term was added. That shock term was assumed to be normally distributed and independent across region, product and year, with a region-product specific volatility $\sigma_{r,p}$ estimated from historical deviations from baseline demand. The trade environment scenarios introduced in section 3.2 were affected differently by this shock process, through a demand volatility multiplier v_s for each scenario s (Liberalised, Status quo, Protectionist). Formally, the demand shock for region r, product p and year y was modelled as:

$$Shock_{r,p,y} \sim N\left(\mu_s, \left(\sigma_{r,p}v_s\right)\right) \tag{2}$$

the Liberalised scenario applied $\mu = +0.1$ and $v = 0.8$, the Status quo scenario $\mu = 0$ and $v = 1$, and the Protectionist $\mu = -0.1$ and $v = 1.2$, as mentioned in 3.2. Realised demand was then captured by adding the effect of the shock to the demand:

$$Demand_{r,p,y} = \left(Baseline_{r,p,y}\left(1 + Shock_{r,p,y}\right)\right) \tag{3}$$

The model setup ensures that the baseline is equivalent to the expected demand under the Status quo scenario, while the Liberalised and the Protectionist scenario experienced shift both in demand and demand volatility. If demand ended up negative it was counted as 0, to avoid negative demand. In the following steps of the model, demand was compared to a service-band.

3.6   Supply Chain Configuration

For each $(Region, Product, Year)$ combination, the baseline demand from the model defined the planned export volume, denoted $Plan_{r,p,y}$. In the no-flex strategy this was executed without any adjustments. The simulated demand was then compared against the service-band, where a simulated demand that deviated more than $\pm 20\%$ from the baseline demand was penalised. The service-band was denoted as $[a-, a+] = [0.8, 1.2]$. After demand was realised, shortfall and overshoot were calculated as follows:

$$Shortfall_{r,p,y} = \max\left(0, Demand_{r,p,y} - a^- Plan_{r,p,y}\right) \qquad (4)$$
$$Overshoot_{r,p,y} = \max\left(0, a^+ Plan_{r,p,y} - Demand_{r,p,y}\right)$$

These quantities were then used as inputs to the penalty and value functions as described in 3.7. For the no-flex strategy, "value" per year was the planned export volume subtracted with the penalty cost, in volume, from shortfalls and overshoots. In the flex strategy, an adjustment decision $\Delta_{r,p,y}$ was introduced, where positive values represent adding volume to that combination and negative values to removing volume in order to stay inside the service-band. The no-flex and flex strategies were therefore:

$$Plan_{r,p,y}^{no-flex} = Plan_{r,p,y} - Penalty_{r,p,y}$$
$$Plan_{r,p,y}^{flex} = Plan_{r,p,y} + \Delta_{r,p,y} \qquad (5)$$

Shortfall and overshoot were then recomputed relative to $Plan_{r,p,y}^{flex}$. As stated earlier, reallocation was treated as a reduced form of flexibility, without modelling upstream capacity constraints. The economic trade-off from exercising flexibility was captured through explicit flexibility costs. Two components were applied: a variable cost c_{flex} per unit reallocated and a fixed cost K_{flex} per year. Total flexibility used in a year y was measured as the total absolute reallocation:

$$Sum_{\Delta_y} = \sum_{r,p} \left|\Delta_{r,p,y}\right| \qquad (6)$$

The flex value in a year y was defined as penalty cost avoided by reallocation subtracted by the variable and fixe flexibility costs. Hence, the breakeven unit flexibility cost for year y was computed as:

$$c_{r,p,y}^* = \frac{\left(V_{r,p,y}^{flex} - K_{flex} - V_{r,p,y}^{no-flex}\right)}{B_{r,p,y}}, \qquad if \ B_{r,p,y} > 0 \qquad (7)$$
$$c_{r,p,y}^* = undefined, \ if \ B_{r,p,y} = 0$$

which is defined only when $B_{r,p,y} > 0$. Intuitively, $c_{r,p,y}^*$, is a breakeven comparison between no-flex and flex where a positive $c_{r,p,y}^*$ points to flex as the better choice whilst a negative $c_{r,p,y}^*$ means that no-flex is the better strategy for that combination of region, product, year and trade environment scenario.

3.7 Service-band and Cost Penalty

To keep the model relevant to the thesis, a service-band around expected demand was added, a penalty cost function for over-and under-supply. For each product, region and year combination a stochastic demand realisation was simulated. Deviations from the planned level were allowed within the service-band to reflect normal forecast error.

This service-band applied $\pm 20\%$ to planned demand, using a lower bound $a^- = 0.8$ and an upper bound $a^+ = 1.2$ (see section 3.3 for the calibration and motivation). When the realised demand fell within the band, no penalty was incurred. However, when the demand fell below the lower bound, the deviation was marked as a shortfall and when it exceeded the upper bound, the deviation was marked as an overshoot. Shortfall and overshoot were computed as in equation 4 in section 3.6 and were expressed in volume units.

To link these deviations into the value measurement model, linear penalty weights were added. The weights were set to $\lambda_{under} = 1$ for shortfalls and $\lambda_{over} = 0.5$ for overshoots. The penalty cost for each (r, p, y) combination was defined as:

$$Penalty_{r,p,y} = \lambda_{under} Shortfall_{r,p,y} + \lambda_{over} Overshoot_{r,p,y}. \tag{8}$$

The total service-related penalty for a given scenario was yielded by aggregating $Penalty_{r,p,y}$ for every combination of region, product and year. The penalty function was only applied to the no-flex strategy since the flex option never deviated outside the service-band according to the model.

3.8 Workflow Summary

To improve transparency of the process, Table 1 below summarizes the workflow used in the model. Table 1 maps each step to the equivalent equations and variables defined in sections 3.5−3.8. Steps 1−3 compute the realised demand outcome for a single run for a given (r, p, y) (Eqs.1−3). Steps 4−6 asses the no-flex and flex outcomes through service-band deviations and penalties (Eqs.4,5,8). Steps 7-8 measure flexibility and compute the breakeven value (Eqs.6−7).

Table 1. Step-by-step workflow summarised in table-form.

Step	What is done	Key Inputs	Outputs
1	Baseline demand (Eq.1)	Historical exports−$\alpha_{r,p}, \beta_{r,p}y$	$Baseline_{r,p,y}$
2	Scenario parameters	Scenario (μ_s, v_s)	μ_s, v_s
3	Realised demand (Eqs.2−3)	$Baseline_{r,p,y}, \sigma_{r,p}, (\mu_s, v_s)$	$Shock_{r,p,y}, Demand_{r,p,y}$
4	No-flex deviations (Eq.4)	$Plan_{r,p,y}, [a^-, a^+], Demand_{r,p,y}$	$Shortfall_{r,p,y}, Overshoot_{r,p,y}$,
5	No-flex penalties (Eq.8)	$Shortfall_{r,p,y}, Overshoot_{r,p,y}, \lambda_{under}, \lambda_{over}$	$Penalty_{r,p,y}$
6	Define no-flex and flex (Eq.5)	$Plan_{r,p,y}, Penalty_{r,p,y}, \Delta_{r,p,y}$	$Plan_{r,p,y}^{no-flex}, Plan_{r,p,y}^{flex}$
7	Measure flexibility costs (Eq.6)	$\Delta_{r,p,y}, K_{flex}, c_{flex}$	$Sum_{\Delta_y} = \sum_{r,p} \left| \Delta_{r,p,y} \right|$
8	Compute breakeven (Eq.7)	$V_{r,p,y}^{flex}, V_{r,p,y}^{no-flex}, K_{flex}$	$c_{r,p,y}^*$

3.9 Monte Carlo Simulation

A Monte Carlo simulation was used to quantify demand uncertainty according to the no-flex and flex strategies and to quantify the distribution of outcomes under each trade environment scenario. The model was repeated N=1000 for all three of trade environment scenarios and for every $(Region, Product, Year)$ combination, where every run represented one single realised demand for that combination.

In each run, the no-flex and the flex strategy was compared against the same realised demand draw. The simulation captured the total reallocated volume in the flex strategy Sum_{Δ_y} and the breakeven unit flexibility cost $c^*_{r,p,y}$. The breakeven value was undefined when $Sum_{\Delta_y} = 0$. The distribution of $c^*_{r,p,y}$ across runs of the simulation for each scenario and year was synthesised using mean, median and the percentile bands (P05-P95). The variables were then provided as a basis for the results in presented in Chapter 5.

4   Empirical Background

Chapter 4 provides empirical context for the study. Introducing an overview of the data source used in the research.

4.1   Eurostat

Eurostat is the European Union's official statistical agency. It produces comparable and reliable data that enables comparisons across regions and countries. The data is coordinated into joined methodologies, definitions and classifications in partnership with national statistical authorities (Eurostat, n.d.1).

The EU database for international trade provide the Comext database. Comext defines goods as "all movable property including electricity" (Eurostat, n.d.2). The database consists of historical and current data from member states and data from considerable amount of non-member states. Comext records trade in goods through exports and imports between reporting country and partner country over a specific time, such as a month or a year. Each trade product in Comext is classified by the Harmonized System (HS), a standardized system created and administrated by the World Customs Organisation. The harmonized system is based on fixed rules and is identified by a six-digit code that is both logically and legally relevant and is regularly revised to keep pace with market changes (World Customs Organization, n.d.).

In this thesis, Comext was used as a complementary source for trade statistics to ensure EU-consistent definitions and comparability when describing export and market structure. Trade values (EUR) and physical quantities (e.g., tonnes) can be reported depending on product category. When classification revisions occur, Eurostat provides mapping and metadata to support consistent time-series interpretation (Eurostat, n.d.3).

5 Results

Chapter 5 presents the findings of the study. The main outcomes are reported using figures and tables.

5.1 Breakeven Values

This section presents the results from the Monte Carlo simulations across the three trade-policy scenarios: liberalised, status quo and protectionist. For each scenario, the simulations produced a distribution of the breakeven unit cost of flexibility c_y^* for all region, product and year combinations.

The main performance indicator for the model is the breakeven unit cost of flexibility c_y^*. This variable is defined as cost per unit of reallocated volume at which no flex and flex express the same total value after accounting for fixed flexibility costs and service-band penalties. A higher c_y^* means flexibility is more valuable, whereas a negative c_y^* indicates that a flex strategy is never beneficial value-wise. In table 2, aggregated mean, median and percentiles breakeven value for each region, product and year combination is presented per trade environment scenario. The values provide a price ceiling for flexibility in each scenario. Remember that the median breakeven value is a more useful guidance in this thesis since it ignores the outliers that influence the mean breakeven value.

Table 2. Summary of the result of the thesis where mean, median 5th and 95% percentiles are presented for each trade environment scenario.

Scenarios	Mean	Median	P95	P05
Liberalised	0,87	1,60	1,97	-0,57
Status quo	0,28	-0,11	1,99	-0,56
Protectionist	-0,12	-0,44	1,34	-0,52

In the Liberalised trade environment scenario, the breakeven mean cost is 0,87 and median is 1,60, suggesting, that on average, a firm can pay more for flexibility and still be indifferent to a rigid export plan. For the Status quo trade environment scenario, the mean is 0,28, while median is –0,11, meaning that it is unclear whether flexibility creates value or not In the Protectionist trade environment scenario, both the mean and median is negative with the values -0,12 and -0,44, flexibility is therefore never a good option since it does not add value in that trade environment scenario.

The percentile bands clarify the interpretation of the results further. In the upper 5th percentile (P95) all three scenarios have positive values, proving that flexibility is very valuable in 5% of the most favourable simulated paths. In contrast, the lower 5th percentile (P05) all three scenarios instead have negative values, indicating that in the worst 5% of the outcome's flexibility never adds value since the values are negative. While the median breakeven value is positive only in the Liberalised trade environment scenario and negative in the other two trade environment scenarios, the distribution of c^* is wide in all cases.

The number of simulations per year and per trade environment scenario that have a positive or negative breakeven value can be seen in Figure 2. In Figure 2 a clear pattern can be seen, about 75% of the simulations in the Liberalised trade scenario generate a positive breakeven

value, slightly below 50% of the simulations in the Status quo trade environment scenario and approximately 25% of the simulations in the Protectionist trade environment scenario.
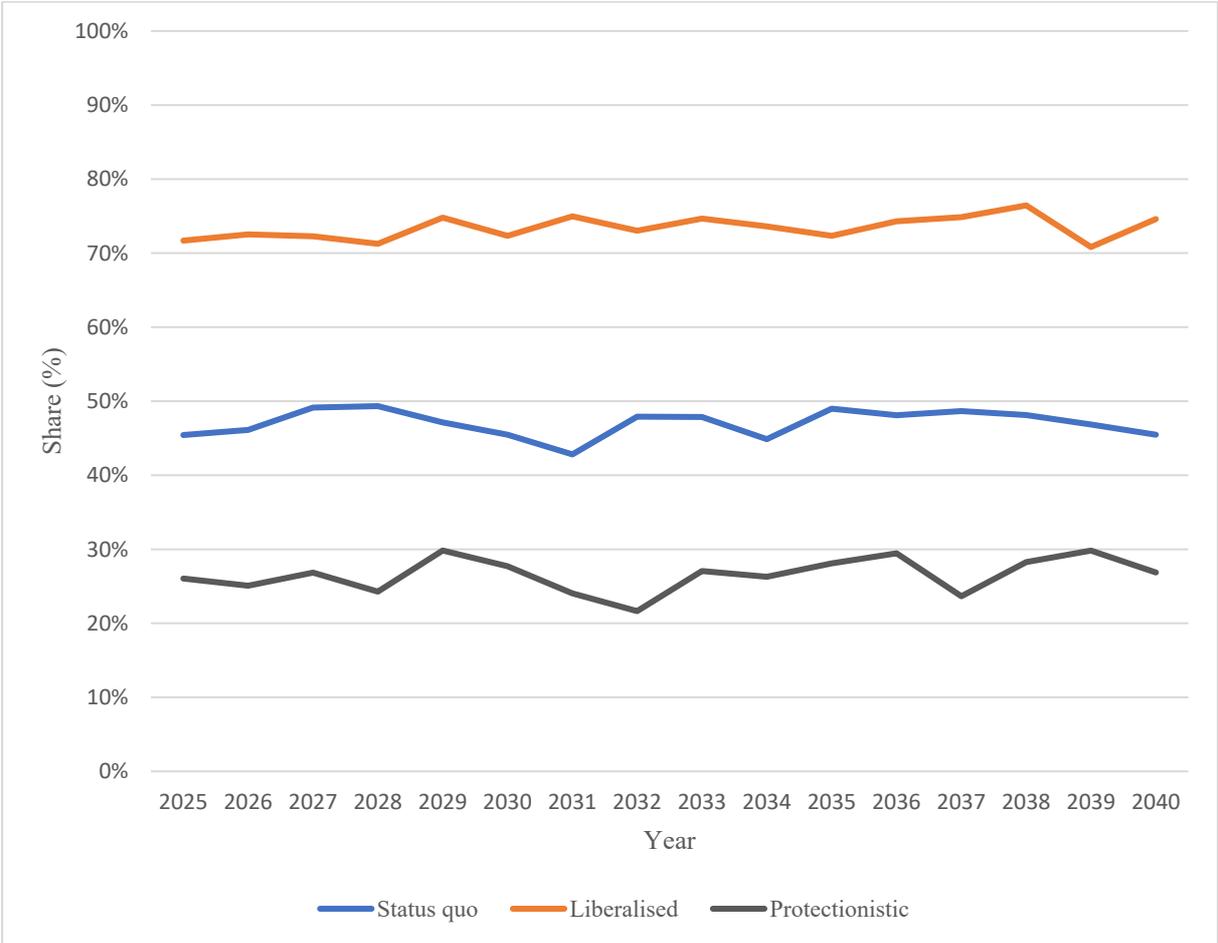

Figure 2. The share of positive breakeven values for the three trade climate scenarios for all simulations.

Another way of displaying the data can be done via a simple box plot, in this case presented in Figure 3, where the breakeven cost and the 5% and 95% percentiles for the three trade environment scenarios for the year 2040 can be seen. Each bar represents the breakeven flexibility costs for each trade environment scenario while the whiskers represent the 5%, lower whisker, and 95%, upper whisker, percentiles across the simulations for the year 2040. The differences in distribution are clearly visible, especially between the Liberalised trade environment scenario and Protectionist trade environment scenario. The Liberalised and Status quo trade environment scenario has a significantly higher number of extreme values than the Protectionist trade environment scenario. The other years have a similar distribution but for the purpose of showcasing the distribution only a single year was chosen.
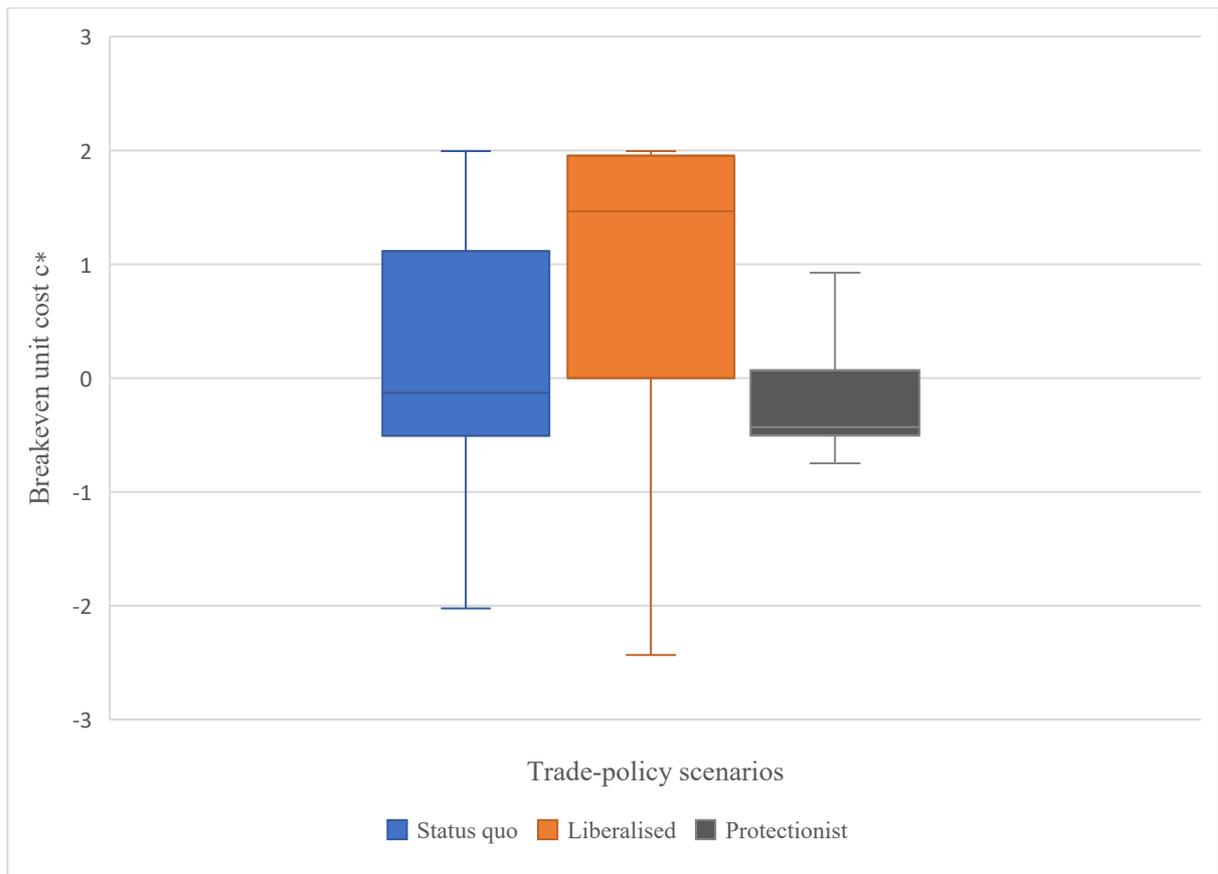
Figure 3. Breakeven value for the three trade climate scenarios for the year 2040.

6 Analysis

Chapter 6 explore the interpretation of the findings. Examining the results and correlation to the theories and the conceptual framework.

The differences observed across trade environment scenarios can be explained by the interaction between demand, demand volatility, and the structure of the flexibility mechanism. In stochastic environments, intermittent high-demand periods create opportunities for flexibility to stay within the service-band in order to avoid over- and undershoot penalties, even when such periods occur irregularly. Compared to the Status quo and Protectionist trade environments, the Liberalised trade environment scenario generates more opportunities for flexibility to create value. The option to exercise flexibility as a real option triggers when service-band violations occur, which can be seen in the conceptual framework.

For an easy comparison between the three trade environment scenarios, Figure 4, Figure 5 and Figure 6 showcases the median and 5% and 95% percentiles for the Status quo, Liberalised and Protectionist trade environment scenario respectively. In Figure 4, showing the Status quo trade environment scenario, the median can be seen as a line with breakeven values on or slightly below breakeven values of zero. The lighter blue area represents 90% of all breakeven values, all values within the 5th and 95th percentiles. This means that on average, for the Status quo trade environment scenario, a manager can expect the no-flex strategy to be slightly more valuable than a flex option, although the difference is small. A breakeven value of zero would mean there is no difference between no-flex and flex strategies.
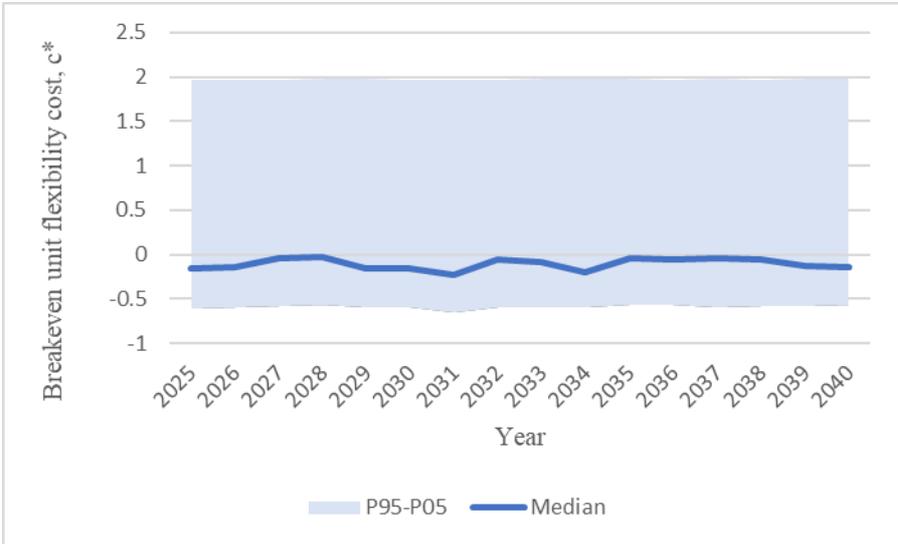
Figure 4. Percentile band and median of the breakeven values for the Status quo trade environment scenario.

The median and percentile band for the Liberalised trade environment scenario can be seen in Figure 5. The percentile band has a similar spread as the Status quo trade environment scenario, but the median breakeven value is much higher, hovering around 1.6 in breakeven cost per unit. This means that it is very beneficial to choose the flexible strategy in this trade environment scenario. The similarity in percentile spread between the Liberalised trade environment scenario and the Status quo trade environment scenario is because of the randomness of the shock and the variability of some region and product combinations.
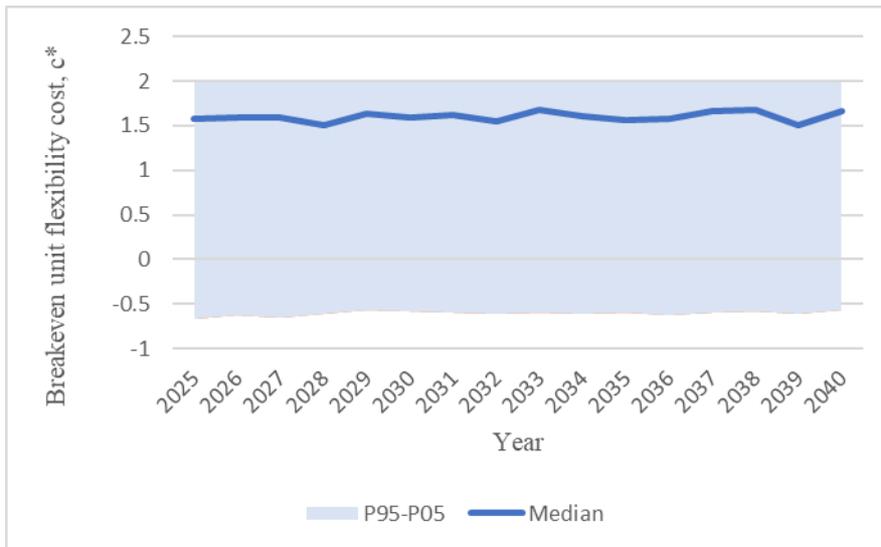
Figure 5. Percentile band and median of the breakeven values for the Liberalised trade environment scenario.

In Figure 6 the Protectionist trade environment scenario is presented. Here there are some differences compared to the other two trade environment scenarios, the size of the percentile band is smaller and the median is much lower. The negative breakeven median value in this trade environment scenario means that there is no benefit of using a flexible strategy, only costs, instead a manager should choose a strategy without flexibility. The lower value of the upper 95% percentile shows that there are fewer large positive breakeven simulations in this trade environment scenario then the Liberalised and Status quo trade environment scenario.
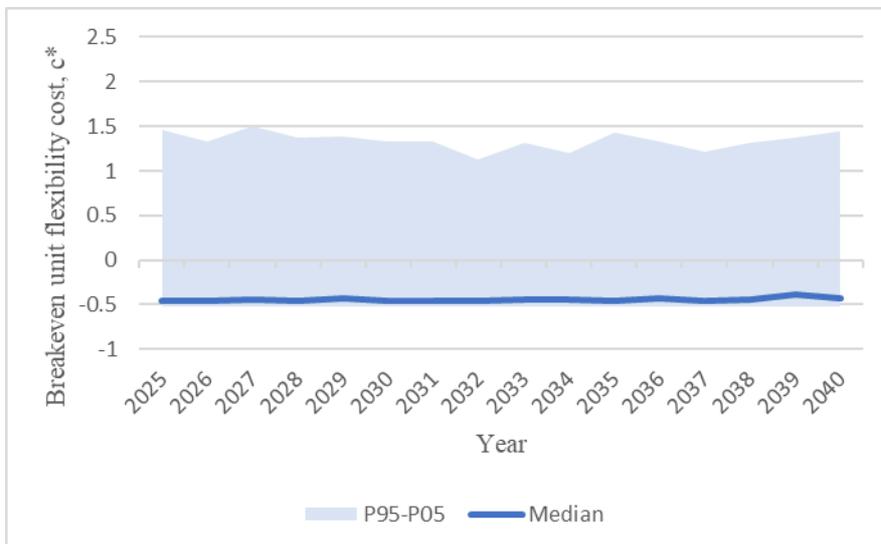
Figure 6. Percentile band and median of the breakeven values for the Protectionist trade environment scenario.

Within the framework, these trade environment scenario-dependent shifts in demand level and volatility represent the external trade-policy uncertainty that shapes the conditions under which flexibility may become valuable. The changes in input between the trade environment scenarios might seem small but as can be seen in figures above they have a big impact on the breakeven value comparing a flexible and non-flexible strategy. All three trade environment scenarios had the same trigger for the flexibility mechanism, but the value of that flexibility varied greatly between the trade environment scenarios. The median breakeven value and its dispersion shift greatly due to small changes in demand baseline and volatility. Baseline

demand changes only by 10% up, for the Liberalised trade environment scenario and 10% down for the Protectionist trade environment scenario, while volatility decreases by 20% and increases by 20% in the Liberalised and Protectionist trade environment scenario respectively. These shifts translate directly into differences in frequency and magnitude of service-band violations, which determines when flexibility is exercised.

7   Discussion

Chapter 7 addresses the research questions. Evaluating the observations from theories, result and analysis

7.1   How can export-allocation flexibility be conceptualized as real options under trade uncertainty?

The first research question focuses on the conceptualisation of supply chain flexibility in export operations and in the case of this study, how it can be modelled as a real option in the context of a forest company facing global trade uncertainty. In the model, this mechanism is implemented through the service-band and the reallocation option, which allow managers to adjust export volumes when shocks push demand outside the service-band. The results of the Monte Carlo simulations support the theoretical framework presented in Figure 1, where flexibility was interpreted as a managerial option rather than a fixed operational characteristic. In line with real options theory, flexibility is only exercised when realised demand is outside of the service-band, no action is taken when realised demand is within the service-band. This logic is consistent with the arguments of Trigeorgis and Tsekrekos (2018), who emphasize that the value of real options arises precisely from the ability to respond to uncertain future states rather than committing irreversible actions beforehand. This mirrors exactly the choice between the flexible and non-flexible strategy created in this thesis, either commit beforehand without any flexibility, no-flex strategy, or choose the option to have flexibility but at a cost, flex strategy.

As shown in the analysis chapter, the Liberalised, Status quo and Protectionist trade environment scenarios systematically shift both the demand and the dispersion of demand volatility. This causal chain closely mirrors the conceptual framework presented earlier, where environmental uncertainty affects managerial decisions through embedded real options (Huchzermeier & Cohen, 1996).

From a supply chain management perspective, the results also align with the notion that flexibility is a design choice embedded in the structure of the supply chain rather than a temporary operational adjustment. Christopher and Peck (2004) and Jüttner (2005) emphasize that resilient supply chains are those that are deliberately designed to cope with uncertainty. In this thesis, flexibility is explicitly modelled as such a design choice, with clearly defined costs, benefits, and exercise conditions, reinforcing the relevance of the real options perspective for export-oriented forest companies. However, the result of this thesis points to the fact that flexibility is not always the answer to dealing with uncertainty. Export-allocation flexibility is treated as a real option and the value of that option is dependent on trade environment scenario outcomes.

7.2   What is the effect of export-allocation flexibility under different trade conditions?

The second research question addresses the effect of supply chain flexibility under uncertain trade conditions, estimated in this case via a breakeven analysis made with Monte Carlo simulations for three different trade environment scenarios. The central empirical result is the distribution of the breakeven unit cost of flexibility across the Liberalised, Status quo, and

Protectionist trade environment scenarios. The results show that the value added by flexibility is highest in the Liberalised trade environment, slightly below zero in the Status quo trade environment scenario and negative in the Protectionist trade environment scenario. At first glance, this pattern may appear counterintuitive, as flexibility is often assumed to be most valuable under uncertain conditions. However, when interpreted through the theoretical and empirical lens developed in this thesis, the results are consistent with both real options theory and supply chain management Theory. For example, in the Liberalised trade environment scenario, demand is characterised by a positive drift in demand and lower demand volatility. This creates frequent but moderate upward deviations from planned volumes. Under these conditions, flexibility enables firms to exploit favourable demand realisations by reallocating capacity to high value markets while avoiding penalties from over- or undershooting the limits of the service-band. As a result, flexibility generates substantial upside value, which explains the high breakeven values observed in the simulations. This finding is consistent with the real options argument that options derive value not only from downside protection but also from the ability to capture upside opportunities (Trigeorgis & Tsekrekos, 2018).

The Protectionist trade environment has a negative shift in demand and higher demand volatility. Although uncertainty is greater, the overall demand level is lower, which limits the opportunities for flexibility to create value. In this scenario, reallocations often occur in response to adverse shocks rather than favourable ones, and the value gained from reducing penalties does not offset the cost of exercising flexibility. Consequently, the breakeven value becomes negative, indicating that flexibility does not justify its cost within the modelled trade environment. This outcome aligns with the findings of Huchzermeier and Cohen (1996), who show that the value of operational flexibility depends on the balance between uncertainty, expected returns, and adjustment costs.

The Status quo scenario occupies an intermediate position, with no changes in demand and volatility from the baseline. Here, flexibility does not create value on average, but the margin is small and breakeven values are positive around 45% of the time. This result highlights the importance of considering not only expected values but also the distribution of outcomes. The percentile bounds, 5% and 95% respectively, demonstrate that while flexibility may be highly valuable in general for a certain scenario, it may also destroy value in others. This reinforces the importance of a risk aware evaluation of flexibility and that although unlikely, any given breakeven value from the simulation might occur.

7.3 How do uncertainty, flexibility costs, and irreversibility affect flexible export strategies?

The third research question examines how uncertainty levels, costs of flexibility, and irreversibility influence the effectiveness and timing of flexible export strategies. The results clearly demonstrate that flexibility is not universally beneficial but highly dependent on the trade environment scenario and cost structure. Changing the set values of the variables can drastically alter the results, increasing fixed costs lower the value of flexibility while increasing service-band violations raise the value of flexibility. Of course, changes in set values affect the trade environments differently.

A central role in determining whether flexibility is exercised and whether it creates value is determined by the variables affecting flexibility. In the model, flexibility incurs both variable reallocation costs and fixed costs, reflecting the real-world reality that flexibility often requires investments in logistics, contracts, or organizational capabilities. This is consistent

with the discussion in the introduction, where flexibility was described as costly but potentially valuable under the right conditions (Chopra, 2019). Irreversibility is captured through the comparison between the flexible and non-flexible strategies, where the no-flex configuration represents full commitment and the flex configuration preserves optionality at a cost. The no-flex configuration represents a fully committed strategy, where export volumes are fixed in advance and cannot be adjusted once uncertainty is realized. The flex strategy, by contrast, preserves optionality at a cost. The breakeven analysis therefore provides a clear quantitative expression of the trade-off between commitment and flexibility that lies at the heart of real options theory (Trigeorgis & Tsekrekos, 2018).

The results show that when expected demand is sufficiently strong and volatility is moderate, preserving optionality is valuable. However, when expected demand deteriorates and volatility increases, commitment may dominate flexibility. This finding reinforces the argument made in the introduction that flexibility should not be viewed as a universal solution for uncertainty but as a strategic choice that must be evaluated in context.

RQ3 is answered by showing that the effectiveness of flexible export strategies depends on the interaction between uncertainty, expected demand conditions, flexibility costs, and irreversibility. Flexibility creates value when uncertainty coincides with sufficiently strong expected demand and when the cost of preserving optionality is low relative to the penalties avoided. When expected demand deteriorates and volatility increases, the benefits of reallocation are insufficient to offset flexibility costs, and irreversible commitment to a fixed export strategy becomes preferable.

7.4   Managerial and Policy Implications

From a managerial perspective, the results provide a clear and actionable decision framework. The breakeven unit cost of flexibility can be interpreted as a price ceiling for flexible capacity. If the market price of flexibility is below this threshold, adopting a flexible strategy is economically justified; if it is above, a rigid strategy dominates. The results further suggest that flexibility should be prioritised in favourable or improving trade environments rather than as a defensive response to adverse conditions. This insight challenges the common intuition that flexibility is primarily a risk mitigation tool and instead highlights its role as an opportunity enabling strategy. For export-oriented forest companies operating under global trade uncertainty, this implies that investments in flexibility should be aligned with expectations about market access and demand growth, as emphasized by OECD (2023) and FAO (2022).

At a policy level, the findings also have implications for how trade policy uncertainty affects firm behaviour. Within the modelling framework, a more predictable and liberal trade environment is associated with higher returns to flexibility, encouraging firms to invest in adaptive supply chain structures. Conversely, highly restrictive and volatile trade regimes may discourage such investments, potentially leading to more rigid and less resilient export structures.

7.5   Methodological Reflections and Limitations

Finally, the results must be interpreted considering the methodological choices and limitations discussed earlier. By combining real options theory with a supply chain allocation model and Monte Carlo simulation, the thesis provides a structured and quantitative evaluation of flexibility under uncertainty. At the same time, several limitations constrain the

generalisability of the results. Demand shocks are assumed to be independent across regions and products, which likely underestimates the value of flexibility in situations where shocks are correlated. Similarly, trade policy is modelled in reduced form through shifts in demand mean and volatility rather than through explicit tariffs or quotas. These simplifications were deliberate and consistent with the stated aim of balancing realism and tractability.

The result in this thesis is based on the parameters used in this specific case and would have to be changed to fit for other cases. The precision and accuracy of the model is dependent on the parameters that it is given, meaning that other businesses might get other results than the ones given in this study. Despite these limitations, the results remain internally consistent and aligned with the theoretical expectations outlined in the thesis. The findings should therefore be interpreted as illustrative rather than predictive, providing insight into how flexibility can be conceptualised, quantified, evaluated, and managed rather than forecasting specific future outcomes.

8 Conclusions

Chapter 8 presents the main implications of the study. Summarizing the overall assessment of result, analysis and discussion.

The results show that the value of flexibility is highly dependent on the trade environment. Under a favourable trade environment, flexibility generates substantial economic value and can justify relatively high flexibility costs. Under current trade conditions, flexibility is not valuable on average, but the difference between flex and no-flex is small. In contrast, under adverse and volatile trade conditions, flexibility does not create sufficient value to offset its costs, making rigid export strategies preferable. These results are conditional on the modelling assumptions and parameter values adopted in the study; alternative specifications may lead to different quantitative outcomes. These findings demonstrate that flexibility should not be viewed as universally beneficial, but rather as a context-dependent strategic choice.

This study contributes to the literature by operationalising export-allocation flexibility as a portfolio of real options in an export-oriented forest-sector context and by quantifying its economic value using breakeven flexibility costs. This approach links theoretical concepts of uncertainty, irreversibility, and managerial timing to a decision-oriented metric that is directly applicable in practice. From a managerial perspective, the breakeven flexibility value provides a clear decision rule. If the expected cost of flexibility is below this threshold, a flexible export strategy is economically justified; otherwise, a non-flexible strategy is preferable. Within the modelling framework, the results suggest that firms should align flexibility investments with expectations about future trade conditions, preferring flexibility in favourable or stable trade environment environments and exercising caution in persistently adverse trade environment environments.

This study is subject to limitations related to data aggregation and the reduced-form representation of trade policy uncertainty. Future research could extend the framework by incorporating firm-level data, modelling correlations across markets, or explicitly linking policy instruments to demand and cost dynamics. Such extensions would allow a more detailed assessment of disparity in flexibility strategies across firms and markets. Overall, the thesis shows that real options theory provides a valuable lens for understanding and quantifying strategic export flexibility in an increasingly uncertain global trade environment.

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Appendix 1

Asia	Europe	MENA	North America
China	Belgium	Algeria	Canada
India	Andorra	Egypt	United States of America
Japan	Albania	Iraq	
Republic of Korea	Austria	Israel	
Viet Nam	Belarus	Islamic Republic of Iran	
	Bosnia & Hercegovina	Jordan	
	Croatia	Kuwait	
	Cyprus	Lebanon	
	Czechia	Libya	
	Denmark	Morocco	
	Estonia	Oman	
	Faroe Islands	Qatar	
	Finland	Saudi Arabia	
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	Germany	Tunisia	
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	Greece	United Arab Emirates	
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	Malta		
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	Montenegro		
	Netherlands		
	North Macedonia		
	Norway		
	Poland		
	Portugal		
	Romania		
	Russian Federation		
	Serbia		
	Slovakia		
	Slovenia		
	Spain		
	Switzerland		
	Ukraine		
	United Kingdom		