The Impact of Green Metrics on Inventory Transshipment

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Abstract

The Impact of Green Metrics on Inventory Transshipment

Green is associated with life and is becoming increasingly engrained in not just life, but the way people do business as well. In recent years, a growing number of business operations have adopted various green metrics to limit their carbon footprints and environmental pollution, drive sustainable operations, contribute more to sustainability projects, and appear more socially responsible within the industry and host communities. While these initiatives target reducing carbon footprints, their impact on daily operations in a sharing economy is yet to be explored. In this thesis, I performed a thorough review of green supply chains, recent green practices, and metrics adopted in various organizations, followed by a comparative study to analyze the impact of operational decisions in inventory and transshipment when green metrics are considered. I extended the classical inventory transshipment model with two newsvendors' retailers by allowing the retailers to incorporate direct or indirect green metrics as part of the objective function. In this setting, I explored three central research questions: 1) How would the adoption of green metrics impact the expected profit and equilibrium order quantities under inventory transshipment? 2) Would green metrics negatively or positively impact the coordinating transshipment prices? 3) What is the impact of direct vs. indirect green metrics on expected profit and equilibrium order quantities? Based on extensive numerical simulation, I find that when the profit margin is high, the impact of green metrics is limited—there is almost no change to a slight decrease in expected profit and the equilibrium order quantity when green metrics are considered. However, when the profit margin is low, the green metrics may improve the expected profits while reducing equilibrium order quantities. Interestingly, introducing green metrics does not affect coordinating transshipment prices, irrespective of profit margins. Direct versus indirect metrics have a limited impact on equilibrium order quantity and expected profit. My study contributes to the research by identifying the operational benefits of adopting green metrics. As an extension, this work may create a foundation for further work to determine the cost and benefits of implementing green metrics in practice and the key trade-offs in sustainability or social responsibility.

Keywords: Green metrics, green practices, sustainability, green supply chain, inventory transshipment, newsvendor, supply chain coordination

Acknowledgments

"*Commit to the LORD whatever you do, and your plans will succeed. In his heart a man plans his course, but the LORD determines his steps" (Proverbs 16:3).*

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I acknowledge the love, support, and cheer from my 3-in-one husband, brother and friend, my children, family, and friends throughout my studies.

"Now to God be all glory, forever and ever. Amen" (2nd Timothy 4:18).

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Glossary

CO_2	Carbon dioxide
GHG	Green House Gases
ISO	International Organization of Standardization
NO_x	Nitrogen oxides
SO_x	Sulfur oxides
FMCG	Fast-Moving Consumer Goods

Table 1: Definitions in literature

Chapter 1: Introduction

The purpose of this research is to establish the relationship between green practices and their influences on inventory decisions leading to transshipment between vendors in a newsvendor model. Optimization of profit is the goal of any business, as is the choice of inventory management and transshipment policies. However, sustainable operations minimize environmental impacts and maximize resource conservation and reuse. Many businesses, corporations, small and medium enterprises, and even start-ups have engaged in green practices, abided by green laws, and made numerous other sustainable commitments, including publishing sustainability reports, advertising green images of the company, and initiating ongoing and future green projects. Before the emergence of green practices and laws (environmental efficiency), the use of sustainability in business decisions bothered on economic and social dimensions. According to the Brundtland Commission's definition of sustainable development, which triggered the 2001 European Union's Sustainable Development Strategy (SDS), Psaraftis (2016) reported that "sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs".

As established by previous literature, greenhouse gas (GHG) emissions from the supply chains of large corporations contribute about 20% of global GHG emissions, (Gopalakrishnan et al. 2020, van Hoek et al. 2019), and more organizations and large corporations are driven to inculcate environmental policies into their operations due to increased visibility, attention, and stakeholder engagement (Huang et al. 2019). Green laws, otherwise regarded as environmental and pollution abatement statutes (Garber 1986), are actions and regulations carried out to conserve the ecosystem, including marine wildlife (Schrope 2001). The role of green logistics is to not only provide a healthier and safer environment but also greatly contribute to improved supply chain performance and operational efficiencies. The impact is positive for both organization and its host community. It is an act of corporate social responsibility (Chopra 2017) while elaborating on key pillars of corporate social responsibility, reported that activities to reduce greenhouse gas emissions, amongst others, are activities that improve environmental pillars, which measure an organization's positive impact on the environment.

Many large supply chain corporations have incorporated both governmental green laws and internally generated laws into their operations to reduce the impact of GHG emissions within their supply chain and contribute their quota to building an overall sustainable environment. In achieving these goals, their green laws are heavily dependent on the corporate objectives of sustainable operations. According to Apple Inc., some of these environmental policies include achieving carbon neutrality in all operations by 2030, reducing emissions by 75%, creating products with net zero carbon, improving energy efficiency, and transitioning to a renewable energy supply chain (Apple 2021). Walmart and Amazon both have a net-zero emission target for 2040, with several other milestones before then. Walmart has a 2030 milestone to avoid 1 gigaton of GHG emissions in their global value chain through collaboration with suppliers and 100% renewable energy by 2035, among others. Amazon is also working towards a 2025 target to power operations with 100% renewable energy (Apple, 2021, Amazon 2022, Walmart 2023). These organizational green laws, whether adopted from governmental policies or internally generated by the organization, are implemented while considering their main sustainability target and the other milestones on the way to achieving their overall goal. According to Starbucks company statistics, 80% of its direct greenhouse gas emissions were attributed to stored energy sources. With green practices, its internal greenhouse laws achieved a major milestone in 2012-2013 when 65% of all new stores built met the standards of the U.S Green Building Council (Chopra 2017).

This thesis aims to investigate the impact of incorporating green metrics on inventory transshipment decisions in a newsvendor setting. The study will focus on two newsvendors, exploring how green metrics influence equilibrium order quantities and expected profits over a range of predetermined transshipment prices. Through MATLAB simulations, this research aims to address three key research questions and contribute to the current body of literature in this domain. The literature review chapter will provide a comprehensive overview of relevant studies related to the green supply chain, the newsvendor inventory model, transshipment, and the adoption of green metrics in supply chain management. In the other chapters, the findings of the simulations will be presented and analyzed to demonstrate the effects of green metrics on expected profits and equilibrium order quantities in the transshipment setting. The results will also be discussed in the context of sustainable operations, highlighting the trade-offs and potential advantages of adopting environmentally friendly practices. The study will also explore the impact of green metrics on coordinating transshipment prices between newsvendors. The study will investigate whether green metrics positively or negatively affect the prices set for transshipment operations, and how this might influence collaboration and supply chain efficiency. The conclusion will reiterate the main findings and emphasize the significance of the research. It will also outline the broader implications of adopting green metrics in inventory transshipment decisions and advocate for sustainable practices in the supply chain industry.

Finally, this thesis will provide valuable insights into the impact of green metrics on inventory transshipment decisions. This research seeks to offer practical recommendations for businesses to adopt sustainable operations while maintaining profitability. The findings will contribute to the existing literature on newsvendor transshipment and the integration of green metrics into supply chain management, fostering a positive shift towards more sustainable and environmentally conscious practices in the industry.

Chapter 2: Literature Review

Sustainable practices and environmental responsibility have become crucial considerations for corporations operating in today's globalized and eco-conscious world. In supply chain management, inventory transshipment plays a pivotal role in optimizing inventory levels, meeting customer demands, and minimizing transportation costs. Inventory transshipments help businesses make the trade-off between demand management and lost sales. However, with increasing environmental concerns, the integration of green metrics in inventory transshipment practices has drawn significant attention.

This literature review aims to explore the impact of green metrics on inventory transshipment and its implications for sustainability and operational efficiency. The first step was to understand and define the green supply chain and the various activities encompassing the subject matter, including green procurement, green manufacturing, green sales and distribution, and reverse logistics, as shown in Figure 2. Hervani et al. (2005) define green supply chain management as an environmentally conscious practice from product procurement to product end-of-life. A literature review was conducted to understand green metrics, laws, and practices and how organizations react to their adoption, as well as the impact of green metrics on the supply chain. Chopra (2017) analyze the potential benefits of a green supply chain, such as reduced transportation costs, decreased carbon emissions, and improved inventory turnover. Additionally, the literature explored challenges such as increased transportation distances, potential inventory damage, and additional handling requirements that may affect sustainability.

When discussing inventory transshipment, transportation is a key indicator as it forms the basis of transshipment. Green technology and innovations in transportation have emerged as enablers for sustainable inventory transshipment. Chen et al. (2020) explore the implementation of electric and hybrid vehicles in transshipment operations to reduce greenhouse gas emissions. They also discuss the integration of renewable energy sources into transshipment facilities to enhance sustainability. A qualitative and quantitative study was conducted, highlighting distinct types of metrics measured in the private and government sectors. This section identified recognized issues, indicators, and numerical metrics tracked. The further analysis explored how these metrics and direct/indirect metrics were defined and tracked in both the public and private sectors, utilizing existing literature from scholars and public articles published by organizations with a strong presence in North America.

Various existing literature on inventory models, with an emphasis on newsvendor models and transshipment between two newsvendors, was reviewed. Rudi et al. (2001) explore several types of transshipment, including intra-firm and inter-firm transshipment, and decisions on coordinating transshipment prices. The literature further discuss the benefits and challenges associated with each type. Additionally, Rudi et al. (2001) investigate the impact of inventory transshipment on expected profit and equilibrium order quantity in a competitive environment. On determining coordinating transshipment prices, Hu et al. (2007) show that coordinating transshipment prices do not always exist between two general retailers. The paper explains that prices can be affected by cost and demand parameters. Hezarkhani and Kubiak (2010) develop an implicit pricing mechanism that coordinates the general two-retailer decentralized system via General Nash Bargaining Solution. By this mechanism, the transshipment prices will depend upon retailers' order decisions.

Past literature reveals that many large corporations lean towards sustainable operations, zero carbon emissions, low-carbon design products, renewable energy, and green practices. Despite having short- and long-term sustainability goals, these corporations and supply chains continue facing regular operational and logistics decisions. The emergence of green laws has influenced many operational decisions, both short-term and long-term, toward company sustainability goals. The integration of green metrics in inventory transshipment involves measuring and evaluating environmental performance indicators. Srinivasan et al. (2019) discuss a framework for assessing carbon emissions, energy consumption, and waste generation associated with inventory transshipment activities. By quantifying these metrics, organizations can better understand their environmental impact and identify improvement opportunities. To assess the environmental impact of inventory transshipment, case studies have been conducted across different industries.

Apart from environmental considerations, the economic viability of green inventory transshipment is essential for businesses to adopt sustainable practices. Collaboration between transshipment partners can make transshipment an attractive strategy for inventory control, managing lost sales, or overstocking. Effective collaboration and information sharing among supply chain partners are critical for successful green inventory transshipment. Luo et al. (2021) discuss the importance of sharing sustainability-related data and practices to achieve mutual environmental goals. Collaborative efforts can lead to streamlined transshipment operations and collective environmental responsibility. This informs the rationale behind coordinating transshipment prices in the newsvendor model. The study suggests that integrating green metrics into inventory transshipment can lead to improved cost-effectiveness over time.

The model in Figure 1 depicts, through boxes and arrows, the relationship between green practices, inventory decisions, and transshipment. Therefore, the hypothesis posits that green metrics impact inventory transshipment and, subsequently, overall expected profits and equilibrium order quantity using the newsvendor inventory business model as the focus.

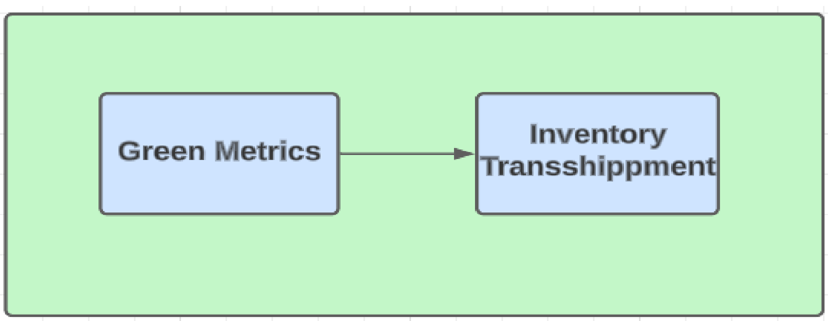

Figure 1:Research Model

2.1 Green Supply Chain Management

A green supply chain involves engaging green laws, regulations, and practices in all aspects of the supply chain, not only in the aspect of reducing greenhouse gas emissions but across all value chain activities, from manufacturing to products or services that reach consumers or target markets. All aspects and drivers of the supply chain must follow sustainability goals to achieve green supply chain management. In general, supply chain planning is an important operational decision that determines efficiency and reduces the need for last-minute decisions. Supply chain management starts with the procurement of raw materials, then manufacturing activities, sales, and distribution. All supply chain drivers are a result of all these activities. Some of its drivers include inventory, transportation, transshipment in the medium term, sourcing, information, product design, marketing, pricing, and facilities (warehousing and distribution centers).

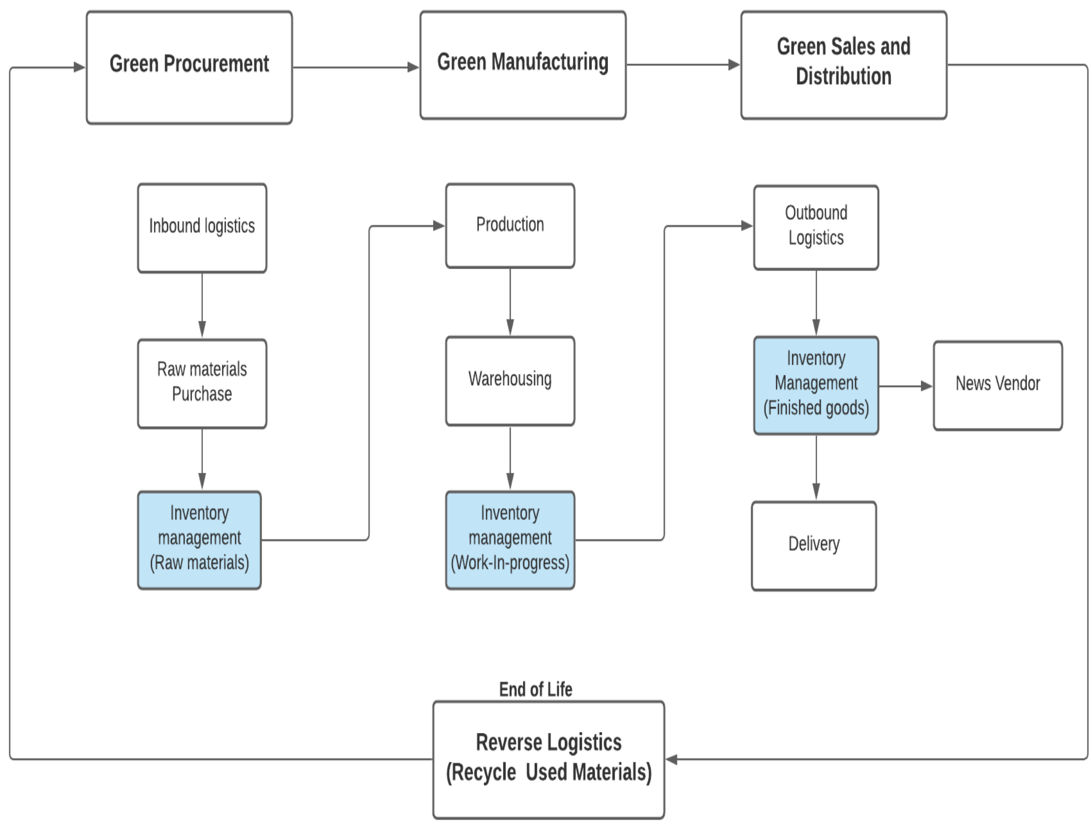

Figure 2:General Framework of Green Supply Chain

Hervani et al. (2005) simply define the green supply chain as "green purchasing" + "green manufacturing/materials management" + "green distribution" + "marketing" + "reverse logistics". This explains that the green supply chain addresses both forward and reverse activities on the value chain. Green practices must address both the present and future situation of a business or organization to eliminate waste both ways. The model in Figure 2 integrates the idea of Hervani et al. (2005) with this research work, which addresses the effect of green practices on inventory decisions in a newsvendor model.

2.1.1 Sourcing and Manufacturing

Green procurement, or green sourcing," involves the procurement of raw materials or parts that are eco-friendly. Saada (2020) find that with the emergence of a sustainable green supply chain, many organizations have adjusted company objectives and policies to include environmental concerns, beginning with the procurement of raw materials like reusable, recyclable materials, and products with a lower possibility of emitting toxic or poisonous substances. Green purchasing requires the active involvement of suppliers and organizations, including sustainable innovations and management practices. Chopra (2017) report that incentive systems may be required to get suppliers and sourcing agents to fully participate. Organizations must assist suppliers to ensure compliance with environmentally friendly services.

Green manufacturing starts at the source of raw materials and other value chain activities until production is completed. It involves production that minimizes environmental pollution and reduces waste which includes defects in production, scrap, and reworking. The emergence of green manufacturing has led organizations to adopt lean production thereby improving production efficiency. A holistic view of adopting green practices in manufacturing also reduces the cost and transportation of raw materials and increases the company's return on investment.

2.1.2 Facilities

Facilities in the supply chain are for production, assembly, and storage. The emergence of green laws has led to green warehousing and green distribution centers. Management of these facilities ensures compliance with internally generated and regulatory green laws in all operations within the facilities of the organization. Some of these include facilities that are built under green compliance, including the use of renewable electricity to power all activities, the provision of a safer and more environmentally friendly place for staff operations (e.g., air and water pollution-free centers), renewable water use, and others. In recent years, many large retail companies have adopted internal green laws and milestones to achieve sustainable facilities and operations within those facilities. Many facilities, especially large storage facilities, involve the movement of goods within the facilities and to various locations within the same organization. The green supply chain encourages the use of ecological transportation and logistics within the facilities to also encourage a safe environment for employees.

2.1.3 Inventory

Inventory refers to all finished goods, work in progress, and raw materials used in manufacturing within the supply chain. Inventory policies and decisions affect logistics and operational efficiency. It could invariably increase or reduce costs and profitability. Hence, in inventory management, good planning helps determine the correct replenishment policy, inventory levels, order size, re-order point, order cycle, safety stock, backorder, etc. Dekker et al. (2012) find that good planning in inventory management reduces or eliminates the need for urgent shipments, which have negative environmental impacts due to the smaller order quantity and faster transportation mode, which increase carbon emissions. Green inventory management reduces or eliminates inventory decisions that will negatively impact the environment. Such efforts involve reducing the inventory order cycle by reducing order frequency while meeting demand needs, choosing safer transportation means and vehicles, and partnering with suppliers and vendors on their choices of delivery and transportation. According to Walmart (2023), the focus of sustainable operations is on environmental and social issues as well as the availability of affordable, safer, and healthier products.

2.1.4 Marketing

Green marketing, sometimes referred to as sustainable marketing, environmental marketing, eco-friendly marketing, environmental marketing, and more, is a set of marketing activities and operations designed and implemented to satisfy consumers while maintaining sustainable environmental practices and causing minimal ecological risks. Mahmoud (2017) define green marketing as activities that include product modification, change in the production process, modification in advertising, and change in packaging. To achieve a truly green value chain, marketing practices might include boycotting printing paper posters, choosing electronic or digital marketing options, designing, and marketing green products and green promotional activities, and green pricing, which sometimes includes eco-fees for products that cause harm to the environment.

2.1.5 Transportation

Dekker et al. (2012) find that transportation is a major component of the supply chain and contributes immensely to greenhouse gas emissions. Transportation in the supply chain is the movement of raw materials and finished goods by various modes of air, sea, and land transportation. The choice of transportation and the distance traveled by vehicles or transmitting vessels heavily impact GHG emissions and environmental pollution. Saada (2020), while referencing Stern (2007) report that in 2000, transportation contributed at least 14% of global greenhouse gas emissions and is projected to continually increase over the next few years if decisive actions are not taken. Green transportation ensures the usage of eco-friendly vehicles and means of transportation to reduce emissions of greenhouse gases and air and sound pollution. The use of electric, hybrid (half electric and half mechanical), and vehicles that use biofuels has become prevalent in several supply chains around the world.

Green transportation in the supply chain is not limited to product delivery, it includes the movement of raw materials, distribution between warehouses, and transshipment between organizations and vendors. Gopalakrishnan et al. (2020) report that many large supply chains corporations like Walmart, Microsoft, Timberland, Dell, and others are assumed to be environmentally friendly, implementing various green laws including carbon pricing, carbon footprint tracking, publicized green index for products, environmental policies, and sustainability reports. They are however still faced with daily inventory and transshipment decisions that counteract their implemented green laws. Apple (2021) report that in 2020 out of the 22.6 million metric tons of combined GHG emissions, only 1% of carbon footprints were caused by direct emissions. Indirect emissions because of value chain activities were reported as 71% for product manufacturing and 19% for product use, with only 8% attributed to product transport. It is unclear whether other aspects reported are interdependent on other kinds of transportation and shipment within the supply chain. However, Apple (2021) also report that the comprehensive carbon footprint is done using a regularly updated lifecycle-based approach, ensuring a more accurate and transparent assessment. Other actions within the value chain not reported as product transportation are also accounted for using the life-cycle approach.

Figure 3: Cycle of Green Supply Chain with green transportation by Saada (2020)

Notably, transportation is embedded in all aspects of the supply chain. From raw material procurement and movement to end-of-life transportation of used products either to recycle or reuse, transportation is required all the way through. Saada (2020) report that in general, transportation is the most prominent cause of increased GHG emissions, health hazards, and global warming. According to Buhang et al. (2009), transportation activities account for a total of 27% of global CO_2 emissions, with road transportation accounting for 21.3% of the distribution. 0.5% rail, 1.9% international aviation, 2.7% international shipping, and 0.65 domestic shipping. Figure 3 enumerates the percentages of global CO_2 emissions. Other aspects of the supply chain contribute enormously to global CO_2 emissions, with a good portion including manufacturing as well. Other types of emissions, such as sulfur oxides (SOx) and nitrogen oxides (NOx) are also important types of GHG contributing to global emissions. Figure 4 is a representation of how much transportation contributes to CO2 emissions.

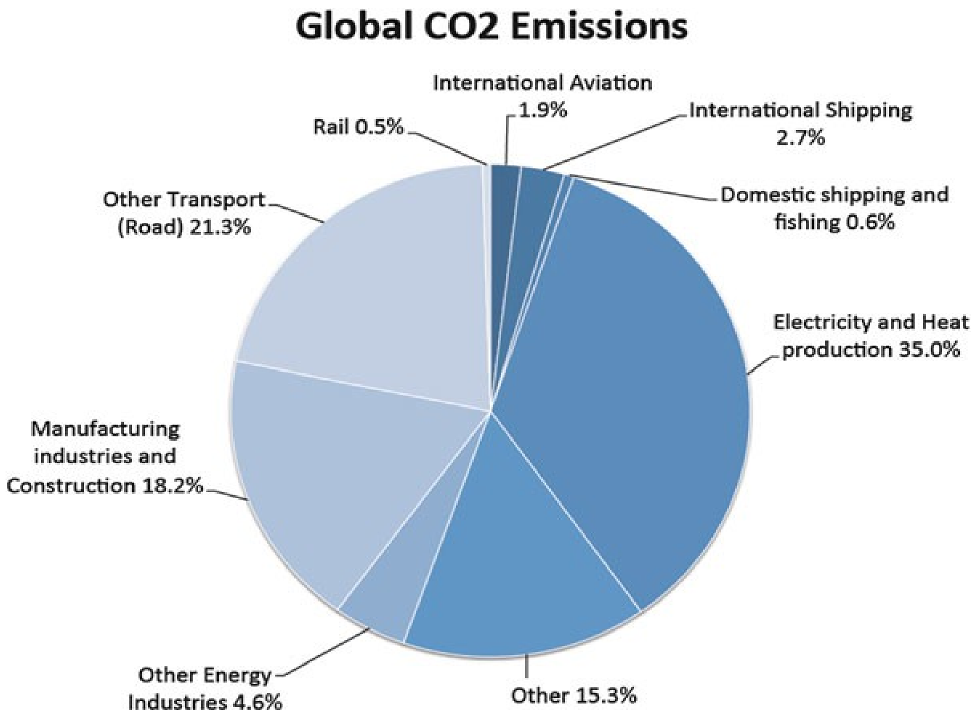

Figure 4: Global CO2 emissions, 2007 baseline year. Adapted from Buhaug et al. (2009)

2.1.6 Other value chain activities

Several other activities along the supply chain also contribute to sustainability and green practices. Some of these include sustainable product design, which has recently become popular in most production companies; environmentally friendly packaging with more reusable materials, which many large organizations have also adopted; and many more operational activities tilted towards sustainability. These practices focus on the 4 Rs, which are reducing, remanufacturing, reusing, and recycling.

2.2 Green Laws, Regulations, and Practices

It is important to note that adopting and implementing green laws and other emission-reduction activities are huge investments and impact organizations' finances at the initial stages. To this end, Chopra (2017) note that it is likely that most organizations will require incentives or mandates from the government or other regulators to make these adjustments. Many organizations have a positive resolve towards achieving sustainable supply chains and green logistics, however, the journey towards achieving a green supply chain may be painstaking. In addition to the capital, it sometimes involves major operational shifts that may also include training for the workforce. To successfully transition, corporations must align their management goals, practices, vision, and even their governance (board of directors and shareholders) with sustainability goals. Some of these laws are internally generated by organizations, either because of their responsiveness towards their corporate social responsibility, their corporate values of sustainability, or by the enforcement of government mandates or other regulatory boards of their host communities, while others are regulatory-based. A common example is carbon pricing and carbon taxes.

The goal of businesses is to maximize profit and report surpluses. The general goal of any operational decision, which includes inventory and transshipment decisions, is to minimize costs and increase profits. However, the supply chain represents just a tiny part of the overall ecosystem that achieves this business goal. Chopra (2017) find that to achieve sustainability in business, operational goals must be adjusted to include the health of the ecosystem. While many large corporations have gone green in logistics, this research will examine the relationship and impact of those green laws on operational decisions, including inventory and transshipment decisions.

2.3 Metrics for Green Supply Chain Practices

Despite the need to embed green practices into operational models, companies strive to not only make a profit but also maintain product quality and continuous improvement. The International Organization of Standardization (ISO), in collaboration with governments of different nations and host organizations, strives to ensure organizations and their supply chains contribute positively to environmental safety while keeping the quality of products and services within set standards. In addressing the environmental impact and green laws and regulations, various metrics can be either governmental or organizational. The metrics are needed to track and monitor the progress of corporate environmental sustainability goals. Many organizations use existing benchmarks, practices, and objectives to achieve this, while others develop a more adaptable metric in line with their organizational objectives in terms of their green laws and regulations. Dekker et al. (2012) find that metrics allow a clear and transparent assessment of environmental impact, including tracking the environmental impact of all direct and indirect value chain activities in the supply chain.

• By 2030, reducing greenhouse gas emissions to 40% below 2016 levels, Lowes Canada
• By 2030, achieve carbon neutrality in all operations by reducing GHG emissions by 75%. To meet this goal additional targets and milestones like investing in carbon removal solutions, low carbon design products, direct emission abatement, energy efficiency, and transitioning to a renewable energy supply chain, Apple Inc.
• By 2030, products with net zero carbon impact, Apple Inc.
• By 2030, avoid 1 gigaton of GHG emissions in their global value chain by collaboration with suppliers, Walmart
• By 2035, 100% renewable energy, Walmart
• By 2040, net-zero emission target, Walmart, Amazon
• Ongoing waste reduction by making packaging designs that eliminate waste, and ensure products arrive intact and undamaged, Amazon

Table 2: Ambitious Green Goals by Global Enterprises
Source: Curled from Dekker et al. (2012)

Many large corporations and supply chains have vowed to do better with their sustainability goals and improvements in green practices within their corporation while positively influencing partner firms, suppliers, and collaborating institutions to adopt green practices too. To achieve these sustainability improvements, goals, milestones, and green practices, key performance indicators and metrics must be set and used to measure progress in line with the targets set. Chopra (2017) report that some organizations have already achieved these goals, like Starbucks in 2012–2013, when 65%

of all new stores built met the standards of the U.S. Green Building Council. Apple has also achieved carbon neutrality for corporate operations since April 2020. Also, Lowes (2020) report that Lowe's Canada achieved energy savings in over 160 corporate stores in 2020, effectively reducing its GHG emissions by approximately 8.6% relative to 2016. Some of these ambitious green goals include but are not limited to, those listed in Table 2.

To successfully achieve these sustainability goals and improve green practices, a key factor is stakeholder collaboration, which includes governmental, non-governmental, and private parties. The main objectives of green practices are to improve environmental practices. According to Cohen et al. (2014), sustainability metrics quantify, measure, and benchmark environmental performance. So many environmental, social, and economic indicators and metrics have been identified since the emergence of green practices; however, not very many are used in practice, both in the private sector and government.

Issue	**Indicators**	**Metrics**
Environmental Pollution	Emissions	GHG emissions per city or corporation (tons/year) Carbon taxes (tons of GHG/year/corporation) Panagakos (2016)
Waste and Effluents	Waste disposal and management	Annual degradable, non-degradable, and recyclable waste per city (g/year) Methane gas (CH_4) * produced per year (ton/organization)
	Recycle waste	Annual recycled waste (%total of recycled waste/year) Hervani et al. (2005)
Resources Management	Water use and management	Wastewater produced (gallons/year) Fresh water used (gallons per year)
	Energy Use and Management	Energy consumption per organization/year (kWh per year) (Hervani et al. 2005, Panagakos 2016)

Table 3: Direct Metrics Measured by Government
Source: Adopted from (Hervani et al. 2005, Cohen et al. 2014, Panagakos 2016)

2.3.1 Government Measures

In some economies around the world, the government also acts as a regulatory arm, while the roles are separated in much larger economies, making the metrics of the government different from those of the regulators in checking sustainability and green practices. Indeed, the role of government is to uphold safer communities by ensuring sustainable practices from host businesses, individuals, and corporations. Therefore, performance measures and metrics are important to monitor the progress of goals set by individual nations and governments. In general, governments that strive for a sustainable environment have similar goals, even though timelines for achieving them may differ. Some of those metrics to measure performance are highlighted in Table 3.

2.3.2 Private /Organizational Measures

It should be noted that corporate or organizational performance metrics depend heavily upon the company's vision, goals, environment, host community, and strategies. Herveni et al. (2005) find that for large corporations, performance is always tied to financials, return on investments, profitability, market share, revenue growth, customer satisfaction, inventory performance, strategic performance, and many more operational, strategic, and business-level decisions. Performance measures and metrics also differ from one organization to another, and within the organization, departments, and business units also have different green practices, goals, and therefore different metrics to measure performance while maintaining the overall corporation. However, in general, most companies involved in green supply chains or that have adopted green practices in operations have similar sustainability goals. Hence, performance metrics are not too different from one to the next.

Issue	**Indicators**	**Metrics**
Social	Noise pollution	Percentage area affected above 50/55 db Panagakos (2016)
	Associated accidents	Annual incidents per organization/year. (Hervani et al. 2005, Psaraftis and Panagakos 2016)
	Corporate Social responsibility	Annual Sustainable projects initiated and completed per organization Annual community engagement activities per organization
	Buildings and Land use	Percentage of urban areas affected by environmental issues. Panagakos (2016) Percentage of corporate facilities certified green Hervani et al. (2005)

Table 4:Indirect Metrics Measured by Government
Source: Adopted from (Hervani et al. 2005, Cohen et al. 2014, Panagako 2016)

* According to USEPA (2018), Methane gas is a non-CO_2 gas that is released as waste decomposes; it also contributes to global climate change. Methane gas and emissions are a function of total waste, management facility location, design, and practices.

Table 4 lists a few metrics used by corporations to measure sustainability and other green practices. To achieve overall sustainability goals, all metrics and controls are important. This ensures continuously achieving positive results and successes in every milestone set towards the main goal of a completely sustainable ecosystem. However, a few metrics have been widely believed or accepted as more important. All participating companies, suppliers, and individuals must key into the sustainable goal to set achievable metrics. They must be responsive to all aspects of keeping GHG emissions low, from as little as tracking carbon footprints to as much as implementing internal green practices.

Issue	Indicators	Metrics
Efficiency	Cost	Annual Absolute and relative costs ($/tons/km) Panagakos (2016)
Service quality	Transport	Annual Commute time spent on the shipment or operational transportation (hours) Annual Distance covered (km/hour/shipment)
Environmental	Service reliability	% Shipments delivered within acceptable time and cost Panagakos (2016)
	Emissions	CO_2 (g/ton/km) Panagakos (2016) SOx (g/1000 ton-km) Panagakos (2016) NOx (g/1000 ton-km) Panagakos (2016) Carbon Pricing ($/tons/year)
	Recycle Materials	Percentage of recycled materials used in operations/production
Resources	Total energy efficiency	Energy use (kWh/year)
	Water use and management	Wastewater produced (gallons/year) Fresh water used (gallons per year)
Social	Corporate social responsibility Building	Sustainable projects assigned (Per host community) Sustainable projects completed (Per year/ carbon pricing) Percentage facilities certified green Percentage facilities upgraded to reduce waste and conserve energy.
	Associated accidents	Number of incidents directly or indirectly linked with environmental compliance Hervani et al. (2005)

Table 5: Corporate/ Organizational/private Metrics for Green Practices
Source: *Adopted from* (Hervani et al. 2005, Cohen et al. 2014, Panagako 2016)

2.4 Carbon footprints

Many researchers have raised several questions about carbon footprints. An important one is whether only carbon-based gases should count in measuring carbon footprints, or all greenhouse gases should be considered. Wiedemann and Minx (2007) find that carbon footprints, which are measured in tons, are the total amount of gaseous emissions associated with production and consumption activities that are relevant to climate change or environmental effects. This metric is used by large corporations and governments alike. To achieve this, the CO_2 calculator is used. The CO_2 calculator tracks and records the number of emissions from all transportation activities made by an organization. Boer et al. (2011) find that the CO_2 calculator uses simple formulas and average statistics like the total mileage driven or covered, load factors, type of equipment, and fuel consumption, which are then used to derive an estimated total emission.

2.4.1 Carbon Pricing and Carbon Taxes

Carbon pricing and carbon taxes are used interchangeably, and while they are similar in that they both attach monetary values to the measure of greenhouse gas emissions, they also differ. The carbon tax is a type of carbon pricing. Carbon pricing is a market-based approach that uses market mechanisms to pass the cost of emitting on to the emitters. This incentivizes the emitters to reduce their carbon emissions. The carbon tax is a government-regulated fee that fossil fuel-burning corporations pay. Fossil fuels include oil, coal, natural gas, and gasoline, which are also producers of greenhouse gas emissions when they are used or burned. The major difference is that carbon taxes are levied on emitters (corporations and individuals) by the government, while the emitting corporations internally generate carbon prices themselves. However, both carbon taxes and carbon pricing are used to fund sustainable and green projects for host communities.

2.5 Inventory Transshipment

Inventory transshipment is a fundamental aspect of supply chain management that refers to the process of transferring goods from one location to another within a supply chain network. The aim is to optimize inventory management and meet customer demands efficiently. As organizations increasingly focus on sustainability and environmental responsibility, the integration of green metrics in inventory transshipment practices has gained significant attention. A review of existing literature gives interesting insights. Inventory can be finished goods or work-in-progress items, therefore they are either end-user consumables or production consumables. To determine an optimal production transshipment in a situation with supply uncertainty, Hu et al. (2008) studied a multiperiod two-location problem in which the capacity at each site is random across the planning horizon, a similar situation with the Newsvendor inventory model. In studying vertical relationships in relevant distribution systems, Dong and Rudi (2004) consider a system with one manufacturer and n identical retailers. The model is under a single period like the newsvendor model. The study finds that a manufacturer's profit generally decreases with the demand correlation between the retailers and increases with the number of participating retailers. In particular, the manufacturer generally benefits from transshipment among the retailers. Zhang (2005) also researched vertical relationships in transshipment models however while Dong and Rudi (2004) mainly used the normal distribution to analyze the demands, Zhang (2005) further show that the results hold for general demand distributions.

Transshipment is an integral part of inventory management and transportation in operations management. Due to the variability in demand and supply, transshipment models can be used by retailers to achieve optimal inventory levels. Huang (2013) propose that transshipment models, whether virtual or physical, depend on the supply chain structure of the organization. They can either be centralized, where one parent enterprise manages all retailers or supply points, or decentralized, where each supply point or retailer acts on its own. Walmart, Loblaws, and Costco brands are good examples of organizations that offer centralized transshipment because operations are centrally controlled and managed. In this case, inventory is locally managed but centrally controlled. Slikker et al. (2005) consider a general n-newsvendor transshipment game in which cooperative decisions can be made on both order quantities and transshipment patterns. The paper showed that no group of retailers has the incentive to split off from the grand coalition and form a smaller coalition. Extending the centralized transshipment model to consider a partnership in luxury low-demand items and cost-benefit analysis, Grahovac and Chakravarty (2001) consider an extended supply chain consisting of a manufacturer, a distribution center, and a general set of retailers. Transshipment is triggered when the inventory level at one location is below pre-determined. The paper shows that transshipment may increase the total cost or the total inventory and that the stakeholders may not always benefit from transshipment. Axsater (2003) further consider a reorder point (R) and the order quantity (Q) replenishing policy for multiple locations facing independent Poisson demand. The paper derived transshipment rules by developing an approximation expected cost leading to heuristic solutions on the reorder point and fixed batch quantity for each location.

Huang (2013) also find that that in centralized transshipment models, retailers are always cooperative, while in decentralized models, it could be corporative or competitive. To clearly understand transshipment in decentralized-competitive models Anupindi et al. (2001) establish a general distribution framework with n retailers. The retailers first make competitive decisions on order quantities, and then after demand realization, cooperative decisions on the pattern of transshipment. The research finds that the dual solutions cannot induce a first-best order decision, however, certain fractional allocations can lead to a first-best order decision but lack other merits, and thus cannot coordinate the system either. Sosic (2006) suggest that value-preserving rules in decentralized models cannot induce a grand coalition when retailers only consider immediate payoffs after coalition formation.

In a green supply chain, transshipment model choices start with getting the inventory levels right. Since transshipment involves the element of transportation when it is physical, and in the eventuality that a virtual transshipment occurs, product or inventory movement is done by transportation means. While transshipment models are useful in achieving optimal inventory levels, the effect of inventory decisions made by organizations affects transshipment decisions. Still, under decentralized transshipment, Shao et al. (2011) investigate a single-period problem with two identical retailers and one manufacturer. The paper find that manufacturer prefers high transshipment prices between the retailers while retailers prefer the opposite. This leads to the manufacturer preferring dealing with centralized than decentralized retailers. Comez et al. (2012) further consider a similar single-period decentralized setting, allowing both physical and virtual transshipment. It studies a one-manufacturer-two-retailer system and assumes there is a single order opportunity for each retailer at the beginning of the season. The paper develops an optimal holdback policy for the retailers regarding whether a (physical) transshipment request shall be accepted and a heuristic transshipment policy under Poisson demand when there are more than two retailers. Wee and Dada (2005) did a comprehensive study on the choices of transshipment policies retailers might be able to consider by studying a network of one warehouse and various retailers. They identify various conditions that might impact the best transshipment policy retailers can consider.

Several literatures gave insight into transshipment, picking the right policies, centralized or decentralized a lot more focused sustainable practice too. While investigating the incorporation of green metrics in inventory transshipment and evaluating the environmental impact of various supply chain strategies, Jones et al. (2018) propose that eco-friendly practices can lead to reduced carbon emissions and resource utilization while highlighting the importance of sustainability in inventory management. Chen et al. (2019) also explore the optimization of inventory transshipment policies by considering carbon emission regulations. The study demonstrates how organizations can align their transshipment strategies with environmental regulations leading to more sustainable operations. Brown et al. (2017) report that there are trade-offs between economic considerations and environmental impacts in inventory transshipment decisions. The study highlights the need for a balanced approach that takes green metrics into account to achieve both cost savings and environmental sustainability. Garcia et al. (2016) propose that by incorporating green metrics in a multi-echelon supply chain, optimized transshipment strategies can reduce waste, energy consumption, and greenhouse gas emissions across the entire supply chain.

My thesis is more related to single-period inventory transshipment between two newsvendors, where transshipment plays a critical role in optimizing inventory levels and meeting customer demands efficiently. This literature typically employs newsvendor model (see Arikan 2011 for a review of the newsvendor model) which can be applied to seasonal fashion and textile industries, perishable goods like food and drinks, newspaper media, and prints, to capture the trade-off between the risk of excess stock and incurring inventory holding costs against the risk of stock-outs and losing sales. Related studies also investiage the impact on inventory performance, decision-making strategies, and the integration of sustainability practices because of transshipment. There is an established understanding of transshipment dynamics between two newsvendor and their implications on the overall supply chain. Transshipment between two newsvendors holds immense significance in the context of the modern supply chain. Rudi et al. (2001) extensively discuss local decision-making between two newsvendors. These included coordinating transshipment within an interfirm and intra-firm setting. Intra-firm is a situation where the two locations are managing transshipment within the same firm with the same vision, while inter-firm is not a centralized decision model. Both locations have different transshipment prices, goals, and corporate visions. Rudi et al. (2001) find that transshipment prices are managed locally, optimizing cost and overall performance rather than through a single central decision like in the intra-firm scenario. The integration of sustainable practices in transshipment between two newsvendors is gaining prominence in response to growing environmental concerns. According to Huang and Sosic (2010), there are a variety of concerns that have been extensively addressed by past research when inventory decisions, which may also involve inventory sharing and transshipment, are introduced. Some of those include profit allocation, stock-sharing formulas between participating retailers, and the frequency of the activity. A study by Wu et al. (2015) delve into the importance of transshipment as an effective approach to improving inventory performance and reducing operational costs. By redistributing excess inventory from one newsvendor to another experiencing high demand, the overall inventory carrying costs can be minimized, leading to improved supply chain efficiency. A significant aspect of transshipment between two newsvendors is the trade-off between economic benefits and environmental impacts. Liu et al. (2017) analyze the benefits of coordinated transshipment between two newsvendors. They find that sharing inventory can lead to enhanced product availability and reduced stockouts, resulting in higher customer satisfaction and increased profits. For proper planning, optimal order quantities may help reduce the need for transshipment and in turn factors that cause environmental challenges. Herer and Tzur (2001) analyze properties of optimal order and transshipment policies in a two-location system with dynamic deterministic demand. Additionally, coordinated transshipment enables the reduction of overstock situations, preventing inventory obsolescence and waste. This research work addresses these concerns regarding sustainable practices and established green laws and metrics among participating vendors and organizations. Altiparmak et al. (2018) present a comprehensive analysis that considers both cost-related factors and sustainability metrics. This approach enables decision-makers to strike a balance between financial gains and ecological considerations, promoting socially responsible transshipment practices. The impact of transshipment on inventory performance has been the focus of several research studies.

2.6 Research Questions

The main objective of any business is to maximize profits and minimize costs. This research work focused on newsvendor inventory models in two locations assumed to be symmetric and adopting green metrics with three central ideas.

- How would the adoption of green metrics impact the expected profit and equilibrium order quantities of newsvendors with inventory transshipment?
- Would green metrics negatively or positively impact the coordinating transshipment prices between the newsvendors?
- Would there be a remarkable effect on returns if direct metrics were considered over indirect and vice versa?

Chapter 3: Methodology

3.1 Data

For this research, data was carried out for stochastic optimization and the search for equilibria. Based on the model in Sec. 3.4, I conducted a numerical simulation using parameters from a classical paper on inventory transshipment, by Rudi et al. (2001). I assumed that the demand followed a normal distribution with a mean, μ =100 units, and a standard deviation, σ = 50 units. Assuming a symmetric approach, first without green metrics and with the probability density function specified, the unit cost price of the goods, c =\$20 per unit, unit sell price of the goods, r = \$40 per unit for high margin and r = \$25 for low margin, salvage value of unsold goods, s = \$10 per unit, penalty cost for lost sales, p = \$0 per unit, transshipment cost per unit, $\tau_{ij} = \tau_{ji}$: \$2 per unit. The range of transshipment prices randomly selected was computed by c_{ij}= [$s + \tau, r$].

3.2 Variable Definition

The central idea of this research focuses on how the inclusion of green metrics in transshipment in the newsvendor business model can affect expected profits, equilibrium quantity, and in turn newsvendor decisions. It is established that the impact of green practices in general influences costs at various levels of the supply chain. Concerning the impact of green practices in business models, tracking environmental metrics can be direct or indirect. Therefore, the dependent variables are no green metrics, which does not include the cost of any green metrics in the transshipment model; direct green metrics, which are the costs of metrics directly caused in both transshipment locations; and indirect green metrics, which are the costs of metrics indirectly caused in both transshipment locations but because of business activities between them. The independent variables include expected profit, which is the total profit earned from the overall transshipment business operations; equilibrium order quantity, which is the order quantity that maximizes the expected profit; and coordinating transshipment price, which is the price that returns the equilibrium quantity.

3.3 Parameters Definition

Parameter	Definition	Value
Q, q	total order quantity based on D	
D, d	unknown demand rate	
R, r	actual sale quantity	$R = min \{Q, D\}$
U	unsold inventory	$U = max \{Q - D, 0\}$
Z	unmet demand	$Z = max \{D - Q, 0\}$
c	unit cost	
r	the unit price sold	$r \geq c$
s	unit salvage value	$s < c$
p	shortage penalty incurred on every unmet demand	$p \geq 0$
m	the marginal value of every additional retail sale	$m=r + s$
N	Newsvendor	

^{T}	Transshipment	
$_i$	Location 1	
$_j$	Location 2	
c_{ij}	price charged by *i* for each unit transshipped to *j*	$[s + \tau, r]$
τ_{ij}	unit shipping cost by relocating a unit of inventory from *i* to *j* incurred by location *i*	τ
	the surplus obtained for each unit transshipped from *i* to *j*	$c_{ij} - \tau_{ij}$
T_{ij}	Quantity of items transshipped between *i* and *j*	
x	Direct metrics	
y	Indirect metrics	
A	High margin scenario	$(r\text{-}s) / (r\text{-}s) > 60\%$
B	Low Margin Scenario	$(r\text{-}s) / (r\text{-}s) < 35\%$

Table 6: Parameter Definition and Values

3.4 The Newsvendor Model

Newsvendor models have been around for a long time now. They have been extensively reviewed and researched by many past researchers. It is a fact that the newsvendor model is a single-period inventory control model where products are either perishable or useful during one season or sale period. As mentioned in the literature chapter, Arikan (2011) upheld that demands are unknown and random and based on long-period forecasting, and usually inventory replenishments are not done during the sale period to cover unexpected demands. Past research identified application areas of the newsvendor model in the seasonal fashion and textile industries, perishable goods like food and drinks, newspaper media, and prints. A classic newsvendor assumes the following, no transshipment, inventory quantity Q based on unknown demand D, salvage cost, s for every unit of excess inventory, and shortage penalty f for every unit of unmet demand in addition to some parameters listed in Table 6. Therefore,

Expected profit $\pi^N (D, Q) = E\,[rR + sU - pZ] - cQ$

Rudi et al. (2001) noted that although the newsvendor problem assumes no transshipment, it is still the basis of most existing transshipment literature. Surplus and stockouts in other inventory models could result in good or bad returns depending on how the company and vendor relationships work. However, in newsvendor inventory models, both stockouts and surpluses are very costly because inventory is perishable, and disposal is time-based. Stockouts result in lost sales, while surpluses lead to salvage. Salvage value may be lower than the cost of procurement, hence the importance of transshipment between businesses operating the newsvendor inventory model.

3.4.1 Transshipment Model

The transshipment model has helped several organizations operating the newsvendor inventory model achieve optimized inventory management. It has been extensively studied in supply chain management. It helps in inventory management, cost reduction, profit maximization, and overall operational efficiency. The transshipment model between two newsvendors involves the transfer of surplus inventory from one newsvendor to the other. Rudi et al. (2001) explained that for transshipment to occur between two locations, there must be an unmet demand at one location, excess demand at another location, and a willingness to transship between the two locations under agreed circumstances. The two newsvendors each have uncertain demand for a similar product. The goal is to determine the optimal inventory levels for each newsvendor and the optimal quantity to be transshipped between them to maximize expected profits. Existing literature finds that transshipment models can lead to significant cost savings and reduce stockouts. The assumptions for transshipment between two newsvendors are a partnership between them, surplus demand in one location and stockout in another location, coordinating transshipment prices, and an agreed transshipment quantity.

Two locations *i* and *j* with newsvendor inventory models and transshipment partnerships were considered. The objective function of each retailer will be to maximize total profits including those from transshipment.

$Z_i = (D_i - Q_i)^+ = max\ \{D_i - Q_i, 0\}$ is the excess demand at location *i*

$U_i = (Q_i - Di)^+ = max\ \{Q_i - D_i, 0\}$ the excess inventory at location *i*.

Then, the total transshipped from location *i* to *j*

$T_{ij} = min\ \{U_i, Z_j\}$

For location *i*, transshipment is profitable only if the surplus exceeds the salvage value $c_{ij} - \tau_{ij} > s_i$ while for location *j* transshipment is profitable only if a stockout situation occurs and the transshipment price is less than the marginal value of additional sales, $c_{ij} < m_j$ making transshipment mutually beneficial. The retailer *i*'s expected profit under the transshipment model becomes,

$$\pi_i^T (D_i, Q_i, D_j, Q_j) = \Sigma[(r_i R_i + s_i U_i - p_i Z_i) + (c_{ij} - \tau_{ij})\ T_{ij} + (r_i - c_{ij})\ T_{ji}]$$

3.4.2 Green Metrics Transshipment Model

The green transshipment model involves including green metrics tracked by participating transhipping partners in the transshipment activities. Depending on what kind of metrics each partner firm is tracking and considering, there are additional costs calculated as part of the transshipment cost. These costs however little have impact on overall returns, equilibrium order quantity, and even transshipment prices decided by both firms. Metrics could be direct or indirect. The direct metric considers the impact of environmental impacts directly caused by the transshipment. Expected profits for the location given Newsvendor profits, transshipment profits, and direct environmental impacts considered (Q_i, τ_{ij}) and is given by.

Location *i:*

$$\pi_i^T (D_i, Q_i, D_j, Q_j) = \Sigma[(r_i R_i + s_i U_i - p_i Z_i) + (c_{ij} - \tau_{ij})\ T_{ij} + (r_i - c_{ij})\ T_{ji}] - c_i Q_i - x_i\ (T_{ij})$$

Location *j:*

$$\pi_j^T (D_j, Q_j, D_i, Q_i) = E[(r_j R_j + s_j U_j - p_j Z_j) + (c_{ji} - \tau_{ji})\ T_{ji} + (r_j - c_{ji})\ T_{ij}] - c_j Q_j - x_i\ (T_{ji})$$

Indirect metrics consider the indirect environmental impact of doing business between locations *i* and *j* due to transshipment agreement between them (Q_i, τ_{ij}, τ_{ji}) and are given by,

Location *i:*

$$\pi_i^T (D_i, Q_i, D_j, Q_j) = \Sigma[(r_i R_i + s_i U_i - p_i Z_i) + (c_{ij} - \tau_{ij})\ T_{ij} + (r_i - c_{ij})\ T_{ji}] - c_i Q_i - y_i\ (T_{ji}) - x_i\ (T_{ij})$$

Location *j:*

$$\pi_j^T (D_j, Q_j, D_i, Q_i) = E[(r_j R_j + s_j U_j - p_j Z_j) + (c_{ji} - \tau_{ji})\ T_{ji} + (r_j - c_{ji})\ T_{ij}] - c_j Q_j - y_i\ (T_{ij}) - x_i\ (T_{ji})$$

Chapter 4: Results

These variables included an array of possible random demand with normal distribution, order quantity, unit price, unit cost, and salvage value. These variables constituted the foundation of the research and were employed to examine the validity of the assumptions underlying the research questions. Parameters were also sourced from an existing research article published by the Institute for Operations Research and Management Sciences (INFORMS), located in Maryland. This article was written by Nils Rudi, Sandeep Kapur, and David F. Pyke in 2001. The study provides extensive information regarding the two-location inventory model with transshipment local decision-making. The source provides data on newsvendor models with demand normally distributed and uniformly distributed, symmetric, and asymmetric inventory parameters, returns with high margins *(r-c / r-s) > 60%,* transshipment with central and decentralized coordination, and interfirm and intra-firm inventory decisions. A profit margin of over 60% indicates substantial profit generation which signifies that the original selling price significantly exceeds the cost of goods sold, resulting in a considerable profit. Setting a 60% threshold is an arbitrary choice, but it aligns with a substantial level of profitability used to differentiate the scenarios, and high and low margins for this research. I assumed data on symmetric inventory parameters and returns over a normally distributed demand.

To compute equilibrium order quantities for two newsvendor locations where orders are placed simultaneously and independently. The transshipment price is independent of demand and inventory levels at either location and remains constant irrespective of the quantity of transshipment required or available in both locations. Two were investigated with a normal distribution, with a mean, μ =100 units, and a standard deviation, σ = 50 units.

$$Di \sim N\ (100,\ 50)$$

The scenarios considered with high and low margins per unit product *(r–c / r–s)*. All parameters are assumed to be symmetric. In each unique scenario, various transshipment prices $c_{ij} = c_{ji} = (s+ \tau,\ r)$ were considered. A baseline equilibrium quantity $q_1 = q_2$ and expected profit $\pi_1 = \pi_2$ were obtained and used to determine the coordinating transshipment price, $c_{ij} = c_{ji},$ and expected profit, π indicated in tables 7 and 8. Two conditions were also considered to measure the effect of green metrics on equilibrium quantities $q_1,\ q_2,$ and expected prices $\pi_1,\ \pi_2$. The conditions were both vendors applied direct green metrics x on every transhipped item. The second was if indirect metrics y were considered on every transhipped item. It is difficult to put a monetary value on metrics charges because they vary by governments, businesses, corporations' sustainable goals, general industry standards, and other internal firm decisions based on revenue, cost, and growth. However, given the same parameters and including green metrics tracked by locations *i and j*, we assume symmetric values where $x=y=5\%$ of transshipment cost, $\tau_{ij} = \tau_{ji}$

4.1 Scenario A High Margin

In this case, high margins per unit product > 0.60 was considered. Transshipment prices, $c_{ij} = c_{ji}$ ranged between integers of \$12 being the floor and \$40 being the ceiling price. The unit cost price of the goods, $c_i = c_j$ = \$20 per unit, unit sell price of the goods, $r_i = r_j$ = \$40 per unit, salvage value of unsold goods, $s_i = s_j$ = \$10 per unit, penalty cost for lost sales, $p_i = p_j$ = \$0 per unit, transshipment cost per unit, $\tau_{ij} = \tau_{ji} =$ \$2 per unit.

Three instances were considered, first with no green metrics, second with direct metrics, *x,* and third with indirect metrics, *y*. In all three instances, the integer coordinating transshipment price of $23 with the highest expected profit, $\pi_i = \pi_j$ = $1594.4 was obtained, there was however slight variation in the equilibrium quantity of 116.6 when no green metrics are considered and 116.5 where direct and indirect metrics was considered units as reported in Table 7.

	No metrics		Direct metrics		Indirect metrics		
$c_{ij} = c_{ji}$ ($)	$Q_i = Qj$ (units)	$\pi_i = \pi_j$ ($)	$Q_i = Qj$ (units)	$\pi_i = \pi_j$ ($)	$Q_i = Qj$ (units)	$\pi_i = \pi_j$ ($)	
12	107	1579.6	106.7	1578.7	106.8	1579	
18	112.1	1591.1	112.1	1591.1	112.1	1591.1	
20	113.9	1593.1	113.9	1593.1	113.9	1593.1	
23	**116.6**	**1594.4**	**116.5**	**1594.4**	**116.5**	**1594.4**	**Coordinating**
24	117.4	1594.4	117.4	1594.4	117.4	1594.4	
26	119	1593.7	119.1	1593.6	119.2	1593.6	
35	127	1579.8	126.7	1580.6	126.7	1580.6	
38	129.2	1573	129.1	1573.3	129.2	1573	
40	131	1566.6	130.6	1568.1	130.7	1567.8	

Table 7: High Margin Scenario A >0.6

4.1.1 No Metrics v Direct Metrics A

Comparing the consideration of direct metrics against no metrics, we see from Table 7 that there is a similar trend with minimal variations. Concerning the coordinating transshipment price, we see a slight, almost negligible decrease in equilibrium order quantity that has a negligible change in expected profits. It indicates that direct metrics do not negatively impact the coordinating transshipment prices between newsvendors. At higher transshipment prices $35 \leq c_{ij} = c_{ji} \leq 40$ we notice a slight increase in expected profit and a slight decrease in equilibrium order quantity showing that direct metrics do not have a remarkable impact on the expected profit and equilibrium order quantities of newsvendors with inventory transshipment, coordinating transshipment prices also remain unaffected by the change.

4.1.2 No Metrics V Indirect Metric A

Unlike with direct metrics and no metrics comparison, the indirect metrics, and no green metrics shows some fluctuations in expected profits and equilibrium order quantity. At the floor transshipment price of $c_{ij} = c_{ji} = 12$, indirect metrics return a slightly lower equilibrium order quantity and expected profit. For most transshipment prices the equilibrium order quantity and expected profit remain unchanged with minor increase and decrease indicating no effect in the choice of no metrics or indirect metrics.

4.1.3 Direct, Indirect Metrics Comparison A

Deciding between which of the two green metrics to apply as part of transshipment operations between the newsvendors. The values of equilibrium quantity for direct and indirect remain the same throughout the various transshipment prices with few minor deviations when $c_{ij} = c_{ji} = 12$, the floor transshipment price, and a few above coordinating transshipment prices.

Observing expected profits there is almost no change between direct metrics and indirect metrics as with equilibrium order quantity. This demonstrates that the expected profits for both scenarios, i.e., with direct metrics and with direct metrics are remarkably close throughout the transshipment price range. This implies that the choice between direct and indirect metrics does not significantly impact the returns of newsvendors in the high-margin profit scenario.

To further analyze this choice and a general overview of what metrics are right to adopt, I performed a comparison of the use of direct or indirect metrics over no green metrics, by finding the differential between direct metrics and no metrics i.e., (QDM-QNM and πDM-πNM), and indirect metrics and no metrics i.e. (QIM-QNM and πIM-πNM) over a range of transshipment prices and for equilibrium order quantity and expected profit respectively. This was done for the two scenarios with high and low-profit margins. In both line graphs in Figures 5 and 6 for equilibrium order quantity and expected profit, we observe positive and negative differences. This indicates that the adoption of green metrics can either lead to an increase or decrease in expected profits and equilibrium order quantity depending on transshipment prices used. We see a negative or zero differential in both line graphs in transshipment values $c_{ij} = c_{ji} \leq 23$ which is the coordinating transshipment price. However, the patterns change for equilibrium order quantity differential and expected profit differentials.

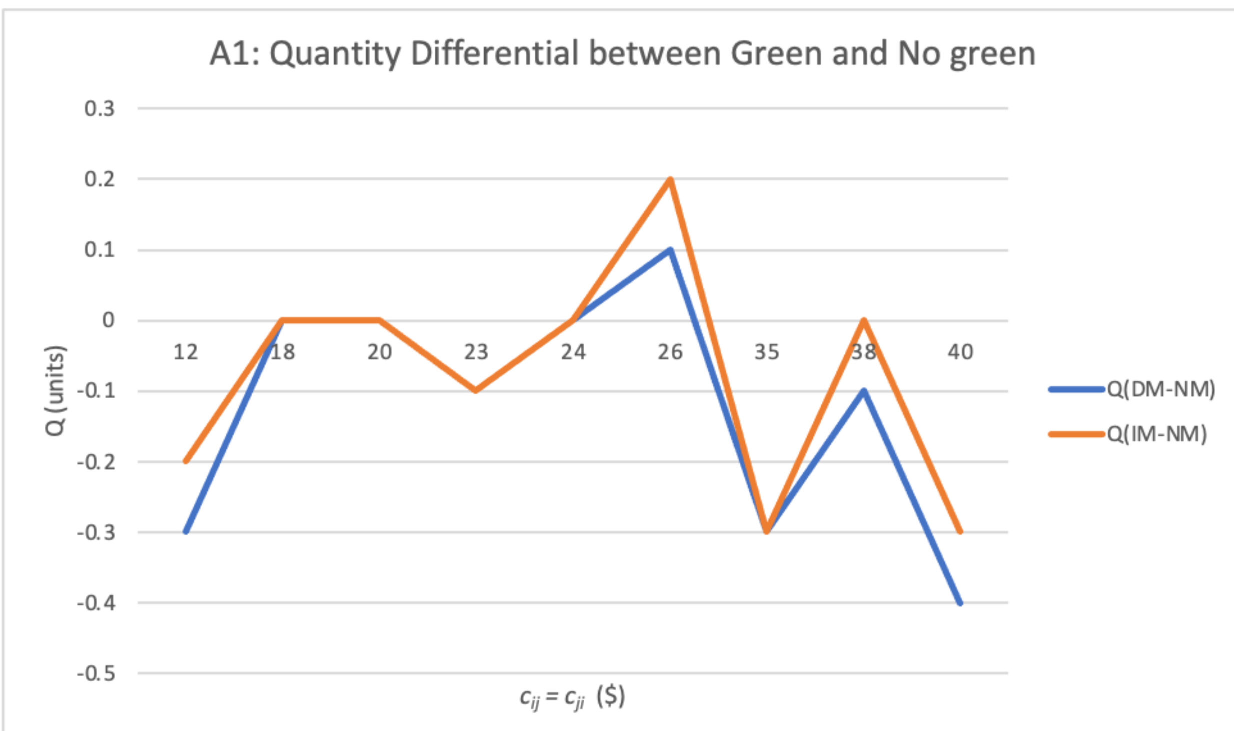

Figure 5: Scenario A1, Differential in Q when green metrics are considered.

For equilibrium order quantity in Figure 5, we observe a slightly different trend. The highest differential is $Q = 0.2$ at $c_{ij} = c_{ji} = 26$, and the lowest is $Q = -0.4$ ceiling $c_{ij} = c_{ji} = 40$ for direct metrics differential. The trend starts low with floor $c_{ij} = c_{ji} = 12$ and increases gradually till $c_{ij} = c_{ji}$

= 18 with the next decrease in order quantity differential seen at $c_{ij} = c_{ji} = 23$, which is the coordinating transshipment price. The only positive differential in equilibrium order quantity however is seen between ranges $24 \leq c_{ij} = c_{ji} \leq \sim 30$, indicating that over a larger transshipment price range, there is a negative differential in equilibrium order quantity. While the patterns are similar in the differential between no green and direct and no green and indirect, there is a visible difference between the two lines with a constantly higher differential when indirect metrics are the choice over direct metrics. In a classic newsvendor model, because the optimal order quantity is used to determine ideal inventory levels for a perishable product with uncertain demand, a higher or lower equilibrium order quantity does not necessarily imply that one is better than the other. The optimal order quantity depends on several factors, such as the cost, demand uncertainty, and the trade-off between holding costs for excess inventory and stockout costs. Since the overall objective is typically to maximize profits, it will be logical to make conclusions based on expected profits and not equilibrium order quantity. However, this could inform the right inventory level to reduce transshipment activity in the newsvendor model because of overstocking or understocking in any of the locations.

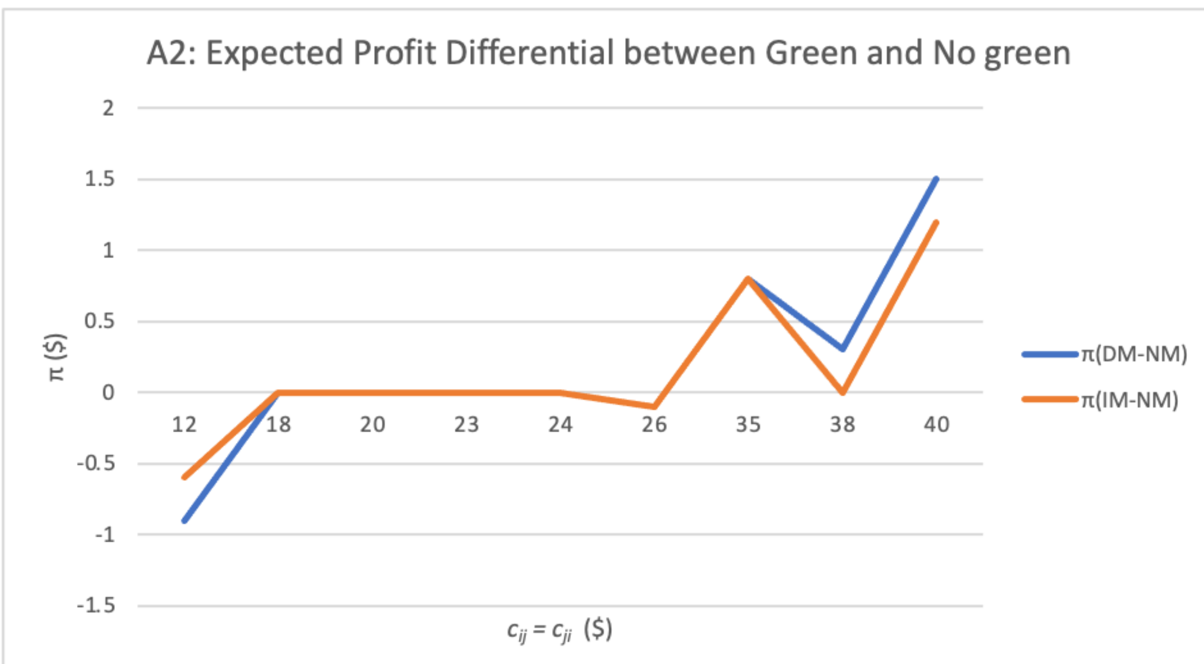

Figure 6: Scenario A2, Differential in π when green metrics are considered.

For expected profits in Figure 6, we observe a slight decrease in expected profit between $c_{ij} = c_{ji} = 24$ and 26, before a sharp increase between $26 \leq c_{ij} = c_{ji} \leq 35$ and a constant positive differential despite the rise and fall. While the patterns look the same in the differential between no green and direct and no green and indirect, there is a visible difference between the two lines. At floor transshipment price 12, and over range $12 \leq c_{ij} = c_{ji} \leq 18$, it is visible that adopting indirect metrics gives a better increase in expected profits over that range of transshipment prices than adopting indirect metrics. At $35 \leq c_{ij} = c_{ji} \leq 40$, ceiling transshipment price, adopting direct metrics gives a much higher differential even with the rise and fall trends. There is however a stage of indifference between the choice of direct and indirect metrics between $18 \leq c_{ij} = c_{ji} \leq 35$, because of the equality in the differentials of the two lines. Since the differential values for expected profits consistently show positive differences across various transshipment prices $18 \leq c_{ij} = c_{ji} \leq 40$, when direct metrics are applied, it suggests that the adoption of green metrics especially direct metrics positively impacts expected profits. Conversely, negative differences would indicate a potential negative impact on those transshipment prices. However, if the newsvendors stay within the coordinating transshipment prices, the choice between direct or indirect metrics does not matter.

In general, over a larger range of transshipment prices, we report 0 differential, indicating that whether green metrics are considered or not expected profit remains unchanged. This translates that over high margins there is almost no financial impact in considering green metrics in the transshipment activities.

4.2 Scenario B Low Margin

Considering the same probability density and low margins per unit product < 0.35 Transhipment prices, $c_{ij} = c_{ji}$ ranged between integers of \$12 being floor and \$25 being ceiling price. The unit cost price of the goods, $c_i = c_j =$ \$20 per unit, unit sell price of the goods, $r_i = r_j =$ \$25 per unit, salvage value of unsold goods, $s_i = s_j =$ \$10 per unit, penalty cost for lost sales, $p_i = p_j =$ \$0 per unit, transshipment cost per unit, $\tau_{ij} = \tau_{ji} =$ \$2 per unit. Three instances were also considered, no green metrics, direct metric, *x,* and indirect metric, *y*. In all three instances, the integer coordinating transshipment price of \$20 which is slightly lower than scenario A. Expected profit, $\pi_i = \pi_j =$ \$307.23 was obtained, and a slight variation in the equilibrium quantity of 87 when no green metrics are considered and 86.6 where direct and indirect metrics were considered as reported in table 8.

	No metrics		Direct metrics		Indirect metrics		
$c_{ij} = c_{ji}$ (\$)	$Q_i = Qj$ (units)	$\pi_i = \pi_j$ (\$)	$Q_i = Qj$ (units)	$\pi_i = \pi_j$ (\$)	$Q_i = Qj$ (units)	$\pi_i = \pi_j$ (\$)	
12	73.05	293.99	73.5	294.91	73.5	294.91	
14	75.33	299.56	76.91	299.83	76.68	300.23	
15	78.11	301.75	78.1	301.87	78.2	302	
18	83.21	306.22	83.1	306.27	83.2	306.32	
20	**87.01**	**307.23**	**86.6**	**307.23**	**86.6**	**307.23**	**Coordinating**
22	90.2	306.32	89.9	306.47	90.2	306.32	
23	93.22	304.22	94.29	303.23	92.57	304.45	
24	93.17	303.05	95.92	301.95	93.4	303.82	
25	96.19	300.6	95.4	301.44	95.5	301.3	

Table 8: Low Margin Scenario B <0.35

4.2.1 No Metrics v Direct Metrics B

In analyzing the results of not implementing any green metrics over implementing direct metrics in Table 8, we observe a similar trend. There is an increase in expected profit and values of equilibrium quantity for both situations green and no green increase as transshipment prices. The direct metrics increase slightly above the no metrics values as transshipment prices rise, and the difference becomes clearer for equilibrium quantity and expected profits.

4.2.2 No Metrics v Indirect Metrics B

For the comparison between applying indirect metrics and not considering any green, we observe a steady increase in equilibrium order quantity and expected quantity as transshipment prices increase. There is however a decline in both values after coordinating the transshipment price, $c_{ij} = c_{ji} = 20$ is reached. The indirect metrics value increases above the no metrics after the coordinating transshipment price, $c_{ij} = c_{ji} = 22$. Indicating higher transshipment prices may result in higher expected profits.

4.2.3 Direct, Indirect Metrics Comparison B

There is a slight increase in the indirect metrics line for both equilibrium quantity and expected profits until the transshipment price hits $c_{ij} = c_{ji} = 20$. For indirect, equilibrium quantity and expected profits lower a bit after coordinating transshipment price is reached, indicating that considering indirect metrics may result in slightly lower order quantities compared to direct metrics. Therefore, the effect of using direct metrics suggests higher order quantities and potentially more efficient inventory management decisions.

Using the differentials to further analyze as in scenario A, line graphs in Figures 7 and 8, we can observe that the adoption of green metrics has varying impacts on expected profit and equilibrium order quantities. Unlike in scenario A, with high margins, we notice the trends in low margins do not follow a similar pattern. Increase and decrease in differential values do not occur at the same time and with noticeable changes seen. This indicates that the adoption of green metrics can either lead to an increase or decrease in expected profits and equilibrium order quantity depending on transshipment prices used. Contrary to scenario A, the differentials for low margins start at positive values at the floor transshipment price $c_{ij} = c_{ji} = 12$ and does not necessarily report a negative value for equilibrium order quantity or expected profit at coordinating transshipment price of $c_{ij} = c_{ji} = 20$.

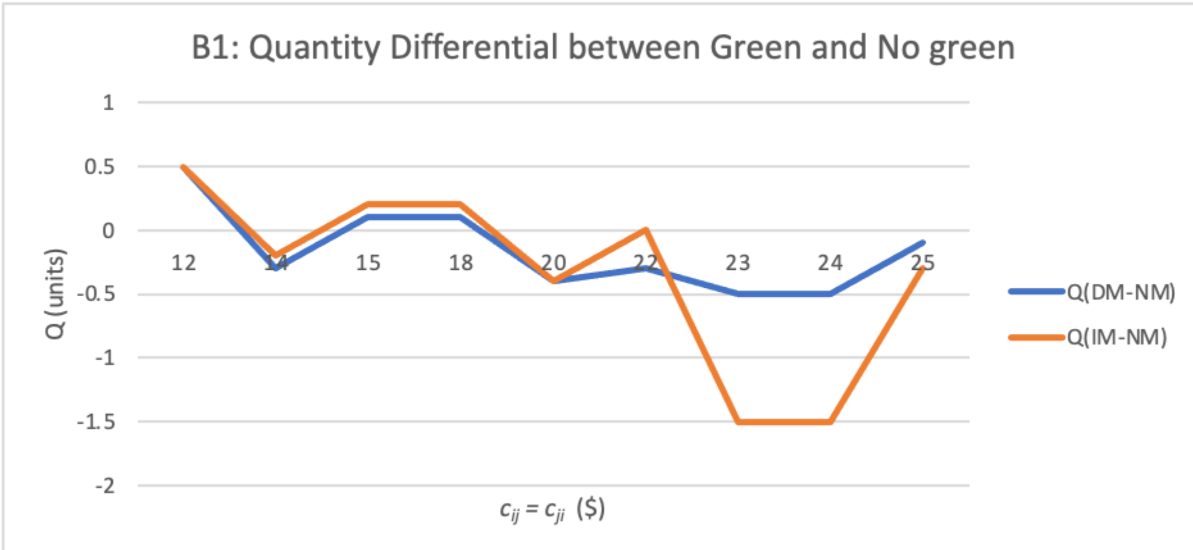

Figure 7: Scenario B1, Differential in Q when green metrics are considered.

For equilibrium order quantity in Figure 7, we observe a slightly different trend with more values < 0 over a range of transshipment prices. The trend is slightly different from the expected profits differential. At coordinating transshipment, we observe a -0.4 differential for both direct and indirect metrics differential and a low differential in the Indirect metrics line for $23 \leq c_{ij} = c_{ji} \leq 24$. As discussed earlier, the classic newsvendor model has uncertain demand, a higher or lower equilibrium order quantity does not necessarily imply that one is better than the other. The objective is to maximize profits therefore, we make conclusions based on expected profits.

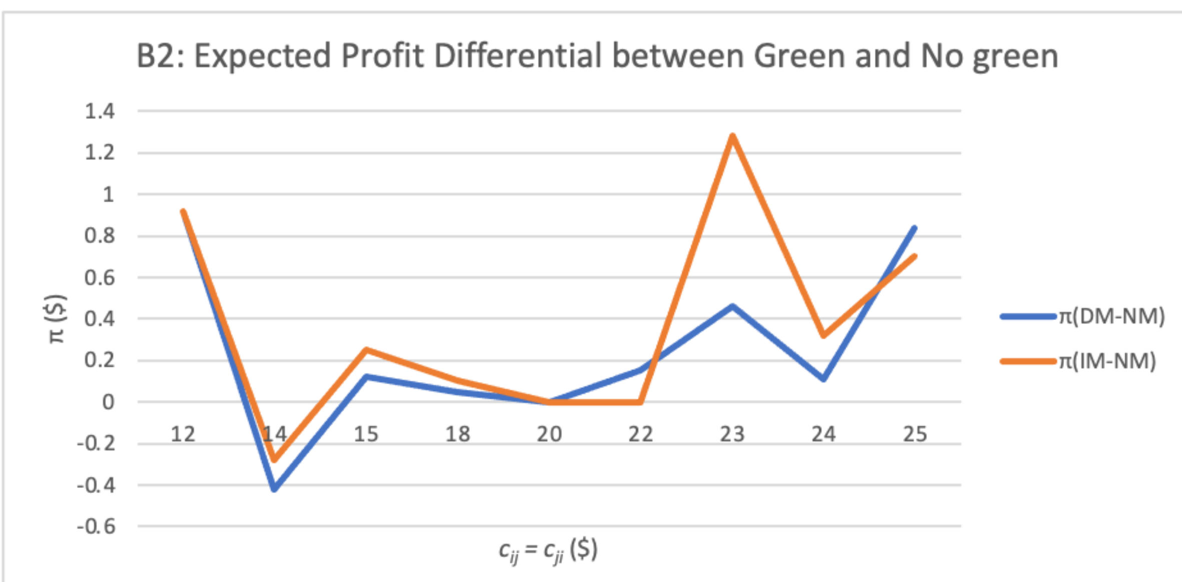

Figure 8: Scenario B2, Differential in π when green metrics are considered.

For expected profits shown in Figure 8, we observe a sharp decrease in expected profit at $c_{ij} = c_{ji} =\sim 13$. The trend follows an almost similar pattern. At $c_{ij} = c_{ji} = 20$, coordinating transshipment price, we observe a cross between the two lines at 0. However, the no metrics, indirect metrics differential slightly decreases and rises sharply above 0 for the other range of transshipment prices up till ceiling price $22 \leq c_{ij} = c_{ji} \leq 25$. The no metrics, direct metrics differential line however increases above 0 after $c_{ij} = c_{ji} = 20$ and stays within a positive differential throughout the rest of the transshipment range with an all-positive rise and fall above 0. It is visible that adopting indirect metrics gives a better increase in expected profits over that range of transshipment prices than adopting direct metrics. There is a positive outlook whether the choice is direct or indirect. Since the differential values for expected profits consistently show positive differences across various transshipment prices $12 \leq c_{ij} = c_{ji} \leq 25$ except 14, when either metric is applied, it suggests that the adoption of green metrics especially indirect metrics positively impacts expected profits. Conversely, negative differences at $c_{ij} = c_{ji} =14$ would indicate a negative impact on expected profit if that transshipment price were used.

4.3 Observations

In general, there is a steady increase in equilibrium quantity over the various transshipment prices irrespective of whether green metrics are considered or not. Observing the results graphically with comparative analysis one over another, we observe a similar trend for all situations irrespective of high or low margins represented as scenarios A and B. There are no deviations in trendlines. This indicates that the adoption of green metrics positively impacts the equilibrium order quantities of newsvendors with inventory transshipment. The higher the transshipment prices, the more the newsvendors are incentivized to order larger quantities, which leads to a more efficient supply chain. There is also a slight decrease in equilibrium order quantities at the coordinating transshipment prices for scenarios A and B. This suggests that green metrics tend to narrow the gap between the coordinating transshipment prices for newsvendors. Therefore, the adoption of green metrics can have a positive impact on coordinating transshipment prices, in a corporative situation as opposed to competitive.

In high-margin scenario A, where unit profit is greater than 0.6, all values of π ($) consistently remain close or unchanged. This suggests that the adoption of green metrics does not have a significant impact on the expected profit from transshipment. In a similar vein, the equilibrium order quantities, for all conditions, green, and no green are almost consistent and unchanged too. Therefore, it can be inferred that the adoption of green metrics in a high-margin scenario does not substantially affect the equilibrium order quantities.

In the low-margin scenario B, comparing expected profits for green metrics applied, we notice that indirect metrics generally give higher expected profits for most transshipment prices suggesting that considering indirect metrics may result in slightly higher expected profits compared to considering direct metrics. Conversely, direct metrics may lead to slightly lower expected profits compared to considering indirect metrics. However, the difference in expected profits between the two is relatively small, suggesting that the choice between direct and indirect metrics has a modest effect on profitability.

Chapter 5: Discussion and Conclusion

This thesis focuses on the impact of green metrics on profitability and operational decisions, specifically in the context of inventory transshipment. I implicitly examined the impact of green metrics on expected profits and equilibrium order quantities, the influence of green metrics on coordinating transshipment prices, and the effects of direct versus indirect green metrics on expected profit and equilibrium order quantities. This investigation provides valuable insights for decision-makers in business on inventory and transshipment. The conclusions drawn from numerical simulations conducted shed light on the implications of incorporating green metrics into inventory management, especially in different profit margin scenarios. This paper aims to justify the importance of the study and outline its managerial significance, providing practical use case scenarios for various industries.

5.1 Importance of the Study

In business and supply chains, effective inventory management is pivotal in achieving operational efficiency and sustaining business growth. As environmental sustainability gains significance, integrating green metrics into inventory decision-making has become a crucial activity for organizations across various industries around the globe. This study fills the existing research gap by examining the intersection between transshipment and green metrics, offering practical insights for decision-makers. By understanding the implications of adopting green metrics, companies can align their inventory management strategies with sustainability goals, while also enhancing profitability.

5.1.1 Managerial Insights and Use-Case

1. Decision-Making in Low-Profit Margin Scenarios: The findings indicate that in situations with low-profit margins, the adoption of green metrics can lead to improved expected profits and reduced equilibrium order quantities. This insight is valuable for managers operating in industries where margins are tight. For instance, grocery retailers like Walmart and Loblaws may have low-profit margins due to various factors such as intense competition, low switching costs for consumers, seasonality, or product types, as compared to high-margin industries like fashion apparel. The adoption of green metrics in transshipment can be a strategic decision for these businesses. The study suggests that integrating green metrics as a competitive strategy can enhance profitability when the profit margin is low.

2. Sustainability in Retail and FMCG Industry: In the retail and fast-moving consumer goods (FMCG) industry like perishable food items including fresh produce, vegetables, baked goods, or bottled water, where inventory turnover is high, incorporating green metrics can bring multiple benefits. By leveraging the conclusions of this study, managers can optimize inventory decisions to reduce waste, minimize environmental impact, and simultaneously enhance profitability. This can be achieved by implementing sustainable practices such as minimizing overstocking and improving demand forecasting accuracy.

3. Supply Chain Collaboration: In industries where supply chains are complex and involve multiple stakeholders, collaboration is vital for efficient inventory management. The study

reveals that introducing green metrics may further enhance the expected profit of competing newsvendors who share residual inventories. This finding emphasizes the importance of collaboration within supply chains. Managers can leverage transshipment opportunities to optimize inventory levels without compromising sustainability objectives. By collaborating closely with suppliers, distributors, and logistics partners, companies can establish efficient transshipment networks that enable cost-effective inventory management while considering environmental factors.

This research provides valuable insights into the impact of transshipment on newsvendor inventory, specifically focusing on the adoption of green metrics. The conclusions drawn from numerical simulations highlight the influence of profit margins and the potential benefits of integrating green metrics in inventory decision-making. The study's findings hold significant managerial implications for businesses, including opportunities to enhance profitability, align inventory strategies with sustainability goals, and foster supply chain collaboration. By embracing these insights, organizations can make informed decisions that balance financial and environmental objectives, driving sustainable operations across industries.

5.2 Summary

The conclusions drawn were compared over high and low values of standard deviation and high and low transshipment cost per unit, $\tau_{ij} = \tau_{ji}$. However, because the impact and variations are low, more research is needed to determine the cost and benefits of implementing these green metrics in practice, especially in the high-profit-margin scenario. It is also worth noting that the equilibrium quantity decreases slightly when considering green metrics, indicating that there may be trade-offs between profit and other factors such as sustainability or social responsibility. From observations of tables and graphical illustrations, the results suggest that there is a remarkable effect on returns when direct metrics are considered over indirect metrics and vice versa. However, the values of equilibrium order quantity for direct and indirect metrics are similar, indicating that the choice between direct and indirect metrics does not significantly impact the equilibrium order quantities and expected profit of newsvendors.

Based on a comprehensive analysis of the results, the following conclusions were drawn. In low-margin scenarios, considering green metrics can have a positive impact on expected profits while reducing equilibrium quantities. In the high-profit scenario, the impact of green metrics is not felt. There is almost no change to the slight decrease in expected profit when green metrics are considered. Introducing green metrics does not affect integer-coordinating transshipment prices, irrespective of vendor margins (high or low). However, if non-integer values are considered, coordinating transshipment prices for no metrics and green metrics (direct and indirect) may vary slightly within the same integer values. The findings could be used to inform the adoption of green metrics in supply chain management and improve the performance of vendors. The results also provide insights into the importance of coordinating transshipment prices and the role of green metrics in achieving this. The adoption of green metrics has a slightly positive impact on the equilibrium order quantity of newsvendors, but it has negligible effects on coordinating transshipment prices and returns. Therefore, newsvendors can benefit from the incorporation of green metrics in their inventory management strategy without any significant negative impact.

However, the results suggest that the impact of green metrics on the expected profit may not be substantial, and further research is required to assess their effect on other aspects of the supply chain.

Finally, the results support the thesis research question that the adoption of green metrics has a positive impact on the expected profit and equilibrium order quantities of newsvendors with inventory transshipment, irrespective of the unit margin earned. The results also suggest that green metrics positively impact the coordination of transshipment prices, while the choice between direct and indirect metrics does not significantly impact returns. The research reveals that the integration of green metrics in inventory transshipment is a critical aspect of sustainable supply chain management. The results emphasize the positive impact of adopting eco-friendly strategies, by incorporating green metrics into inventory transshipment practices, organizations can enhance their environmental performance while achieving efficient and cost-effective supply chain operations. These findings highlight the need for businesses to consider sustainability as a fundamental aspect of inventory management and logistics decision-making processes. These findings could be used to inform the adoption of green metrics in supply chain management and improve the performance of vendors.

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