THE ART OF AID AND WAR

IN SUPPLY CHAIN MANAGEMENT

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by

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Abstract

This thesis uses mixed-methods to study key areas of concern in supply chain management for the improved delivery of humanitarian aid and the fight against dark supply chains, specifically human trafficking.

The growing field of supply chain management finds some of its antecedents in the operations of war, business, and in the delivery of aid. These three areas employ similar supply chain management tools and are inextricably linked, yet prior research is compartmentalised with the study of one area at a time, often with the questionable assumption of altruistic objectives of the main actors. This thesis challenges such common notions by providing new insights on:

- supply chain vulnerabilities that span across industries,
- an objective of stopping a supply chain rather than improving it, and
- an understanding of how to disrupt human trafficking supply chains.

To begin, I perform a literature survey to outline the key humanitarian areas that can benefit from further research in supply chain management (Chapter 1). This extends the realm of humanitarian research to include dark (i.e. hidden) supply chains as a field of study. To better understand dark supply chains, I employ multiple methodologies which are introduced in Chapter 2. I provide an exposition of the operational methods of dark supply chains in Chapter 3. In Chapter 4, I use game theory to analyse established industry and government protocols to optimise the decisions that underpin supply chain regulation on forced labour. In order to combat human trafficking supply chains, I use econometrics to study historical supply chain failures and categorise their vulnerabilities in Chapter 5. Chapter 6 applies the findings from the previous chapters to the dark supply chains involved in the case of illegal gold mining in Peru. The thesis ends with discussion and relevant directions for future research in supply chain management.

Acknowledgements

This thesis does not belong to me any more than the air I breathe. The information herein represents an ongoing struggle for freedom that we all face, in its various forms. It is my sincerest hope that the information herein will be used for good, not evil. Peace, not war. Freedom, not chains.

This thesis does embody a journey that has spanned multiple years, continents, and career paths of my life. The completed work has been supported by numerous individuals and organisations, of whom there are too many to mention.

My deepest thanks go to my father, who has constantly supported my professional and personal growth. To my wife Karishma and her family, who inspired the second life of this work and endlessly accepted my "writing days." To my mother and sister, whose love and listening ears were always available and who reminded me of the important parts of life. To all of my extended family, and friends who became family, I treasured our shared learnings and journey together.

This work would not have been completed without my guiding lights, Dimitris Papadopoulos and Simon Lilley. It was their belief in my mission to expand the supply chain literature beyond its current boundaries that gave this topic wings. For their support and sage advice, words are not enough to thank them, but I will try.

Every so often in life, we have the opportunity to make a mark that will last for decades to come. That is the gravity of the impact Simon and Dimitris have had on me. To think by their side is to have been grounded by the roots of humility and wisdom intertwined. My appreciation for the opportunity to learn through both of you is an honour I will carry with me.

To my fellow researchers who took time from their own lives to contribute to mine, I salute you and the work you continue to do for the betterment of humanity. To Nicole, Vivian, Karthik, Kate, Ted, Kinkini, Nora, Anil, Precious,

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For all whom I have not named, and to all those who little know they impacted me, please know that you always have my gratitude.

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List of Abbreviations

3P	Prosecution, Protection, Prevention
CoW	Correlates of War
DRO	Disaster Response Operations
GFEMS	Global Fund to End Modern Slavery
HT	Human Trafficking
HumLog	Humanitarian Logistics
ILO	International Labor Organization
LPM	Linear Probability Model
NGO	Non-governmental organization
OLS	Ordinary Least Squares Regression
OR/MS	Operations Research / Management Science
SCFF	Supply Chain Failure Framework
SDG	Sustainable Development Goals
SCRM	Supply Chain Risk Management
UN	United Nations
UNICRI	UN Interregional Crime and Justice Research Institute
UNODC	UN Office on Drugs and Crime
WHO	World Health Organization

0.1 Introduction

This thesis begins by establishing the gaps in supply chain management research that, if filled, will aid with urgent global humanitarian issues. Though several topics are introduced that are in need of additional research, the analytical chapters will focus on combatting the growing scourge of illicit supply chains that require attention. Of particular interest is the analysis of human trafficking, which we refer to interchangeably as the supply chain of modern slavery.

Traditional supply chain research focuses on the improvement of corporate enterprises. Such research highlights the tangible benefits that can be reaped through business optimisation. However, there is a critical need for the application of supply chain tools outside of the corporate realm.

A subset of humanitarian research is referred to as humanitarian logistics, which involves the movement of aid for the benefit of human populations in need. Through a literature survey of the humanitarian logistics field, the key gaps in research are offered in Chapter 1. One of the core identifications from Chapter 1 is that the study of dark (i.e. hidden) supply chains deserves further attention because of their impacts on human life.

To more deeply understand dark supply chains, especially that of human trafficking, multiple methods are employed. Chapter 2 outlines the methodology used in this thesis, which includes game theory and econometrics, to analyse the underlying factors involved. The methodology includes acknowledgements of prior research in the field and articulates the contributions of the work herein to extend the current literature.

Prior to diving into the analysis, Chapter 3 lays the foundation for dark supply chains, including their basic mechanisms, types, and methods of operation. It focuses on human trafficking as a growing illegal business that is directly harming human life and sets the stage for the subsequent chapters which deploy distinct methods to combat modern slavery.

Chapter 4 analyses a government's optimal response mechanisms to prevent

modern slavery from operating in corporate supply chains. It is important to analyse this perspective because it offers insights into the main decisions at work within current government policies to prevent human trafficking. The chapter finds an optimal equilibrium where a government can incentivise companies within its jurisdiction to make an active effort to prevent modern slavery in their supply chains.

Chapter 5 shifts to the perspective of supply chain vulnerability. In doing so, the question is asked, "how do supply chains break?" This is answered through a categorisation of historical supply chain failures. Using a custom-coded dataset built for this thesis from war data, the chapter elucidates the most common forms of catastrophic supply chain disruption. Through this work, the Supply Chain Failure Framework (SCFF) is built, a tool that extends the literature in supply chain disruption and risk management.

Chapter 6 applies the learning from the SCFF to the case of illegal gold mining in Peru, a dark supply chain which relies upon human slaves. Through this example and by using the SCFF with the Principles of War, the chapter shows how dark supply chains can be broken.

In their totality, the chapters create a foundation for further research in humanitarian work to protect human life and to contribute toward an ongoing war against human slavery.

0.2   Research Motivation

The motivation of this thesis is to better understand how research methodologies can be harnessed to safeguard human populations and, through the application of rigorous tools, how we can inhibit the dark supply chain of human trafficking, also referred to as modern slavery. This is analysed from multiple perspectives including those of their underlying supply chain structure, current government intervention mechanisms, corporate supply chain efforts to avoid forced labour, and historically proven methods of supply chain intervention in war.

To accomplish this goal, this thesis extends the existing literature in humanitarian logistics and supply chain disruption to introduce and analyse dark supply chains, an important research area that holds critical importance. This thesis, therefore, offers analytical and historically-grounded perspectives on how to combat illicit supply chains and thereby protect human life from illicit businesses that seek to do harm through engagement with human slavery, among other forms of nefarious business. Furthermore, we outline specific areas that can benefit from future research and collaboration.

0.3   The Research Problem

0.3.1   Humanitarian Logistics

The introductory chapter will outline humanitarian logistics research, its purpose, and key areas of global need which could benefit from additional academic attention. The three critical areas for additional humanitarian research need can be categorised into (1) disaster response, (2) long-term capacity building, and (3) dark supply chains. This third area will frame the remainder of this thesis and is unique because of its historical underpinnings, its insidious modern growth, and as will be shown, its connection to corporate supply chains.

0.3.2   Dark Supply Chains

In order to place human trafficking intervention methods into the humanitarian logistics context, it is necessary to describe what such supply chains are at their core. In this thesis, they are referred to as a type of *dark supply chain*, which operates similar to corporate chains yet which seek to remain hidden due to their existence outside the rules of the law. Numerous dark supply chains exist, including the trafficking of drugs, weapons, and humans, and they have similar facets amongst them which enable them to operate while remaining hidden. Indeed, many dark supply chains are connected to each other due to mutually beneficial relationships or ownership structures.

By defining and reviewing the currently understood information on dark supply chains, including their vulnerabilities, we have the benefit of being able to compare them to other supply chain types. The exposition of dark supply chains in Chapter 3 creates a baseline with which to understand them from a business perspective and generate additional research on how business tools can be used to fight them.

0.3.3 Modern Slavery

Modern slavery is a dark supply chain in which the product is people. It is estimated that over 40 million people are currently enslaved worldwide (ILO, 2017a). People are most commonly trafficked for the purposes of forced labour, prostitution, and organ removal (ILO, 2014). Despite its negative human and capital impacts, it is the third most profitable global criminal business, generating profits of approximately $150.2B per year, surpassed only by the trade of drugs and weapons (ILO, 2014). Though we use *modern slavery* and *human trafficking* interchangeably throughout this thesis to refer to the same phenomenon, these are unique from *human smuggling*, which is further delineated in Chapter 3.

The operations of human trafficking supply chains can be distilled to a few key elements. Supply of persons usually begins with strong economic, social, and cultural factors which motivate individuals to migrate in search of work or better living conditions. These individuals are found by recruiters, who are entities that earn payment by capturing vulnerable individuals and taking them to others who can utilise them as products for economic gain. Often, individuals who fall victim to this supply chain are not aware of the trap until it is too late. For example, this process commonly begins with the promise of a job, followed by the confiscation of legal documents, and ends in indebted or forced labour. These types of situations often become inescapable for the people trapped by them (Bales, 2005).

Modern slavery exists in almost every country, but we cannot see it because it

is against the law and therefore there is an incentive for it to remain hidden in order to continue its operations (Dept-State, 2018). There are many groups of stakeholders interested in seeing it fail including governments, non-profit organisations, researchers, and private citizens. These stakeholders have taken individual and collective action to mitigate the occurrence of modern slavery. These responses include the Palermo Protocol, which outlines the "3P" approach of Prevention of trafficking, Prosecution of traffickers, and Protection of victims (United-Nations, 2003). However, modern slavery persists because of its continued economic incentives.

To better understand modern slavery as a business, this thesis does not delve into the criminal or ethical issues of slavery, and in fact avoids those important topics because they have been well covered by research streams in other fields such as law, history, and criminology. Instead, modern slavery is modelled, for the first time, as a business supply chain using quantitative research tools to understand the economic incentives and vulnerabilities which enable its operation and, as argued through these chapters, its targeted supply chain disruption.

0.4   Research Questions

Based on the research problems identified which merit further investigation, in this thesis we seek to answer the following research questions:

1. What areas need additional attention in humanitarian logistics research?

2. Of these areas, how can we better understand dark supply chains?

3. How can analytical tools be utilised to understand the dark supply chain of modern slavery?

4. How do supply chains break, and based on this, how can the supply chain of modern slavery be prevented from operating?

This thesis utilises multiple methodologies (separated by chapter) to answer these questions. Each chapter builds upon the previous toward establishing

paths for supply chain management to aid those in need, as well as creating a framework of fighting against dark supply chains, which are detailed in Chapter 3. A game-theoretic approach to understanding modern slavery is analysed in Chapter 4 and an enhanced framework of historical supply chain vulnerability is provided in Chapter 5. These are harnessed towards application against dark supply chains in Chapter 6, followed by concluding remarks in Chapter 7. A visualisation of the thesis by chapter is provided in the following figure.
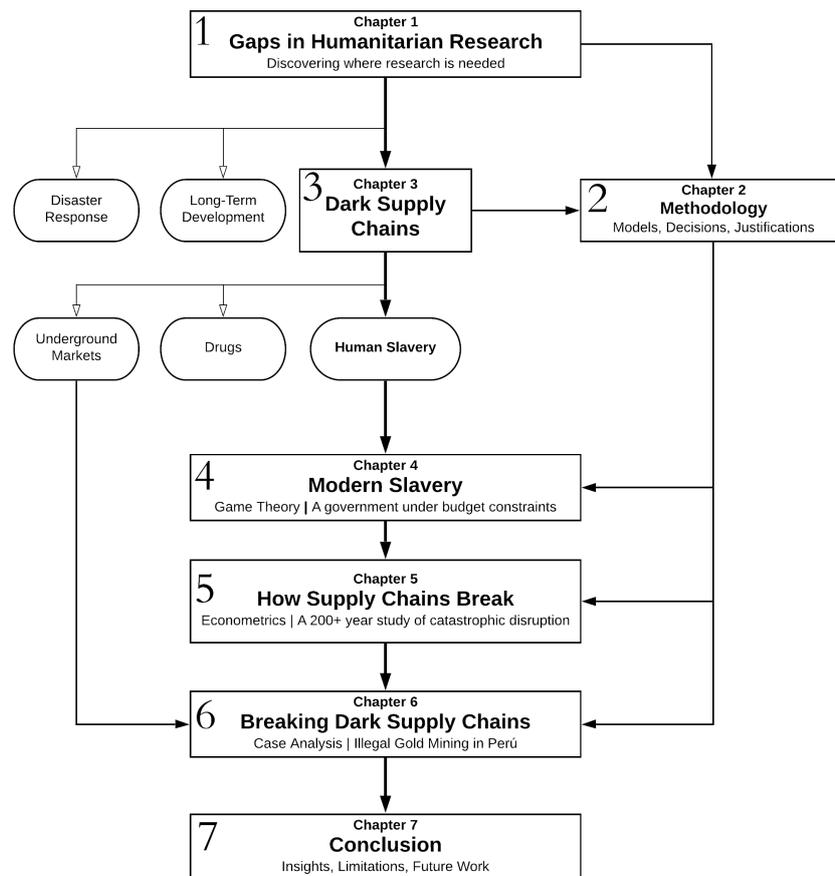
Figure 1: Thesis - Visual Navigation

1 Gaps in Academic Research

To answer the first research problem, that of finding critical areas in need of research, a survey of academic and industry literature was performed to compare humanitarian research with needs in practice. This survey has three key objectives.

1. The first objective is to provide an overview of recent supply chain management research in the humanitarian field in order to set a foundation of past (and potentially future) academic contributions.

2. The second objective builds upon this foundation by outlining the gaps between research and needs in practice in order to offer insights and motivate areas that could benefit from additional analysis and collaboration.

3. The third and final objective is to establish the main topic of analysis for the remainder of the thesis: an understanding of dark supply chains, and in particular the dark supply chain of human slavery.

Objectives 1 and 2 of this chapter have been published together in a journal paper (Bhimani and Song, 2016) and are taken abridged for this thesis as Sections 1.01 to 1.2.2. Objective 3 has been added to that published paper to create this chapter, an introduction to the gaps in humanitarian logistics research.

1.0.1 Summary of Literature

Recent global movements and disasters have given impetus to a growing body of research in humanitarian logistics (often abbreviated as "humlog"). One of the fastest growing research areas in the Operations Research / Management Science (OR/MS) field, a sister-field to supply chain management, *humanitarian logistics* is focused on enabling the mitigation, preparation, response, and recovery from natural and man-made disasters (Wassenhove, 2006). Due to a disaster's immense impact on life, infrastructure, and economies, the optimal

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delivery of aid and the efficient management of resources are of paramount importance.

This chapter takes a holistic approach to discuss existing supply chain management research in this area and compare it with the existing areas of focus for practitioners. Our goal is to establish prior and align future research directions. Such an alignment between research and practice has long been sought after in all manners of business practice. There is, however, a dichotomy between the research needs of corporate logistics and those of humanitarian logistics. Humanitarian logistics research is, in comparison, not as mature of a research field and has many opportunities for growth.

The specific humanitarian needs involved have given rise to two common areas of study in the field: disaster management and long-term development, both of which hold promise for research contributions. Therefore, these two areas help guide our chapter in the discussion of historical progress, examples in practice, and potential areas of future research. A third area, which is understudied but desperately needing attention, is that of protecting human life from the harm caused by illicit business activities. This third area inspires us to extend humanitarian logistics research to include the prevention of dark supply chains, such as those of human, drug, and weapon trafficking.

1.0.2   What is Humanitarian Logistics?

Common Definitions

We define humanitarian logistics by defining its two parts: humanitarian work and the logistics contributions to help achieve it. Humanitarian work is driven by individuals and organisations with the principal goal of improving the conditions of target populations (known as beneficiaries). Humanitarian aid, the general umbrella that our discussion usually falls under, has a presence that is felt by populations around the world because of its criticality and involvement with many stakeholders.

These stakeholders may include the populations receiving aid, organisations involved with its distribution, manufacturers that produce it, militaries, shipping companies, donors who sponsor the activities, governments that play many roles (financial, regional, or political), and many more. Logistics is concerned with the transportation of information, goods, and services between entities.

Humanitarian logistics is therefore considered to be the set of actions taken by organisations in an attempt to move information, goods, and services for the specific goal of aiding target beneficiaries, environments, and societies. This has an overlap with what is commonly referred to as humanitarian operations, which may include the entirety of processes within an aid and protection programmes. We acknowledge this overlap and focus herein on the logistics aspect (as defined above) of humanitarian operations.

Areas of Focus in Humanitarian Logistics

The actions taken by organisations practising humanitarian logistics can be considered in three distinct ways:

1. Actions regarding potential and actual disasters that may warrant humanitarian response, which we will call *disaster management* and which has been the major focus of past literature.

2. Actions with the goals of structural and sustainable development for an area/population, what we will call *long-term development*, which we go into more detail on in the section on potential research directions.

3. Actions to prevent the impact of illegal enterprises that seek to harm human life, what we will call *dark supply chains*, which is a nascent concept in the supply chain and OR/MS literature.

In this chapter, we use the word *disaster* to represent the various forms of man-made or naturally occurring events referred to as hazards, catastrophes, atrocities, etc. These types of events have the potential to negatively impact lives, communities, environments, and economies. Disaster management is therefore known to represent the set of activities performed before, during, and after a

disaster in order to diminish its impact (Altay and Green, 2006). Interestingly, within disaster management, it is estimated that 97% of disasters are man-made and only 3% occur as a result of natural phenomena Wassenhove (2006).

1.0.3   Existing Models

A quick Google Scholar search for "Humanitarian Logistics," at the time of this thesis submission returns over 97,800 results. The conundrum for introducing ourselves to this array of publications becomes: how do we cull through these results to find themes and true contributions from academia and practitioners? Although the field is relatively new, several researchers from various branches of academia have attempted to collate the libraries of knowledge on the topic, allowing us to use those indexes as a starting point to understand prior research.

Historically, research in disaster management has taken place mostly outside of the OR/MS field. We find that the social sciences have invested a great deal of time and effort in studying the effects of disasters on human populations. OR/MS papers began to grow in number around the year 2000 and have grown steadily since then, partly due to a growing need for expertise and recognition of the role researchers can continue to play.

1.0.3.1   The Humanitarian Lifecycle

Much of the research in disaster management can be separated into four parts of what is referred to as the humanitarian life cycle: Mitigation, Preparedness, Response and Recovery, with the majority of prior research being done in the Mitigation phase (Altay and Green, 2006). OR/MS humanitarian research has used many of the same tools as were used in classical research; therefore, existing models and methods were easily adapted and applied to the Mitigation phase for problems foreseen by humanitarian organisations. As breadth in this field grows, we are now witnessing more research into the Preparedness and Recovery phases. There is a strong correlation in growth to the field of Emergency

Response, which witnessed many contributions in the 1970s and has recently been revived (Green and Kolesar, 2004).

In order to provide a comprehensive understanding of the entire system, we briefly discuss each part of the life cycle using review information aggregated from Altay and Green (2006), Galindo and Batta (2013), and Ortuño et al. (2013). For each part, we include the areas of focus by academics, the type of research methods commonly used, and contributions made through analysis.

Mitigation

Until 2005, Mitigation constituted the majority of active work in humanitarian research. *Mitigation*, in practice, attempts to pre-plan for disaster relief by performing a risk analysis of potential threats and then focusing on gaps to ensure the proper planning and dampening of disaster effects. We consider the Mitigation phase as part of long-term planning. For example, setting up facilities that hold relief supplies are of paramount importance during Mitigation and this can directly impact the stages that follow it. This exemplifies the idea that no single phase exists in isolation; they are inter-connected and flow into one another. Another Mitigation example is early warning systems, which are implemented to alert first responders, agencies, and the general population of imminent disasters in order to assist with potential evacuations. Mitigation may also include the installation of protection systems such as police patrols and infrastructure strengthening.

Academic contributions to the Mitigation phase have included planning mechanisms for natural disasters (e.g. floods, earthquakes, hurricanes) and preventing industrial accidents (e.g. chemical spills, computer network vulnerabilities, hazmat transportation). The methods used in this research include (but are not limited to) simulations for vulnerability assessments, linear programming for facility locations, and set analysis for supply chain design and efficient distribution. Actionable insights obtained include decision support tools that use an integrated approach to measure disruption scenarios, such as those by Fiorucci et al. (2005) and Snediker et al. (2008), complemented by recommendations to coordinate with micro-retailers to distribute aid after predictable disasters occur

(Sodhi and Tang, 2014).

Preparedness

Following the Mitigation phase comes the *Preparedness* phase, which is principally concerned with action planning, protocols, and guidance to adhere to before a potentially imminent disaster. The idea is that by actively discussing steps and taking preventative actions before a disaster strikes, a community can put response plans in place that can be readily executed if necessary. In addition to human preparation, this phase also involves pre-positioning inventory and creating supply contracts with vendors.

Academic focus areas in this part of the cycle have been similar to those of Mitigation (e.g. floods, hurricanes, accidents) and also include other types of disasters such as warfare, wildfires, and nuclear response. Methods used include evolving multi-variable algorithms, modeling of network flows for evacuation, inventory modeling for strategic stock-pile placement, and spreadsheet-based modeling tools for on-site decision making. This part of the cycle has seen growth in recent years, representing 28% of academic contributions made from 2005 to 2010, up 7% from 1980 to 2004 (Galindo and Batta, 2013). Sample insights offered from this stage include the cost-benefit trade-off of pre-positioning inventory and the resulting response times (Duran et al., 2011), as well as an actionable framework with decision modeling tools for warehouse locations, capacities, and stock levels (Rawls and Turnquist, 2010).

Response

Response entails the required movement of aid after a disaster strikes. In this third part of the life cycle, the protocols that were developed in the Preparedness phase are used to mobilise resources to areas of need. Such resources are primarily concerned with protecting human life and stabilising the economic and physical infrastructure of the affected location. In addition, this phase requires the cooperation of multiple agencies and governments to deliver aid in an efficient manner, thereby minimising response time and duplication of effort.

Research focus areas in this stage are similar to those in the previous stages yet

also include papers on responses to terrorism. Theory used in this type of work mostly relies upon multi-period linear and dynamic programming, game theory, and routing problems (e.g. traveling salesman, vehicle routing, heuristics development). Similar to Preparedness, Response research has seen growth in recent years, making up approximately 34% of contributions made between 2005 and 2010 (Galindo and Batta, 2013). Sample insights gained from Response research includes the optimal assignment of resources to minimise the time of tasks such as rescue activities (Yan et al., 2009), and modeling solutions for rapid deployment in multi-priority response situations (Chiu and Zheng, 2007).

Recovery

The last phase in the field, *Recovery*, involves cleanup of debris, rebuilding of infrastructure, restoration of services, and planning for long-term housing and aid. This phase is both the area where practitioners could have the longest time invested and the stage with the least amount of research volume, accounting for only 11% of contributions made between 1980 and 2004 and only 3% of contributions made between 2005 and 2010 (Galindo and Batta, 2013). Reasons for this dearth of contributions are numerous but include lower availability of data, more complexity in models that depend on significantly more variables or assumptions, unique situations which are harder to generalise, and longer, more variable time horizons.

Academic focus areas in this stage are similar to those mentioned in the previous parts of the life cycle but also include infrastructure recovery (e.g. of road networks, health, financial systems). Modeling techniques used include linear and dynamic programming, spreadsheet-based tools, and simulations for infrastructure analysis and restoration considerations. One interesting example is simulating rebuilding frameworks based on how the human body and ant hills recover from damage. Insights gained in this phase include disaster waste management considerations with implications for local environments and economies (Brown et al., 2011) alongside heuristics for real-time restoration of infrastructure over finite horizons (Nurre et al., 2012).

1.0.4   Summary of Disaster Management Research

Altay and Green (2006) performed an exhaustive analysis of 109 humanitarian operations articles published in the literature related to humanitarian logistics between 1980 and 2004. We have taken their analysis by life cycle stage and created the figure below, which includes a summary of the preceding paragraphs as well as the volume of academic contributions (by total percentage) to each stage of the life cycle. We see that the majority of research performed took place in the early phases of the humanitarian life cycle, and a deeper analysis confirmed that much of it employed mathematical models, more than half of such research occurring after the year 2000. Subsequent to Altay and Green's analysis, Galindo and Batta (2013) published a follow up review of 155 papers, which showed strong shifts between 2005 and 2010, also depicted by percentage in the figure below.

Altay and Green: 1980-2004

Mitigation 44%	Preparedness 21%	Response 24%	Recovery 11%
• Risk Analysis • Early warning • Facility locations • Protection systems	• Pre-Position • Infrastructure	• Dist. Of supply • Air Transport • Inv. Mgmt. • Evacuation	• Waste Mgmt. • Network Restoration • Relief distribution

Galindo and Batta: 2005-2010

Mitigation 24%	Preparedness 28%	Response 33%	Recovery 3%	Multi-Stage: 11%

Figure 2: Research by Humanitarian Phase

The changing proportions of research focus indicates a more recent shift towards the middle of the life cycle, potentially in response to many natural disasters that have engaged the public eye and called for deeper analysis. We believe it is fair to say that our academic efforts in assisting with humanitarian organisations have been helpful, yet we can continue to learn from the needs of fast-moving practitioners. Therefore, as we dive deeper into humanitarian research, we must continue to do so while paying attention to shifts in this dynamic field.

Lastly, past literature reviews have separated research into three main contribution areas: Theory, Modeling, and Application. An increasing majority of

the research produced in humanitarian operations focuses on Modeling. Over time, Theory has declined as a focus area and Application has received the least amount of work, constituting only 5% of research contributions from 2005 to 2010. This lack of attention to Application makes us question if research is being performed in collaboration with or in response to practitioners, or if the research extends existing models. Throughout this chapter, we return to this question and offer recommendations to bridge the growing chasm.

Recap and Key Takeaways

The four parts of the humanitarian life cycle are categorised as Mitigation, Preparedness, Response, and Recovery. For each part, we have discussed the main focus areas and techniques through which previous contributions were made. We showed that Modeling has been a tool and contribution of focus in OR/MS humanitarian logistics research, while contributions to Applied research are significantly less in volume than those toward Modeling or Theoretical areas.

1.1   HumLog in Practice

To explore the directions research can go, we look to humanitarian operations occurring across the globe for insights into the needs of practitioners. In the sections that follow we review work being done by several organizations and discuss opportunities that are available for impactful research.

1.1.1   Disaster Management

Although each of the four phases of the life cycle is critical, it is important to note that international humanitarian organizations do not usually respond to a disaster until the affected country or local government declares a state of emergency and invites international aid (Wassenhove, 2006). When this happens, these organizations face many challenges (Kovács and Spens, 2007) depending on the:

- type of disaster (natural vs. man-made, warning time, probability),

- location (regional presence, topography, phase of relief), and
- stakeholders (internal, external, other relevant organizations) involved.

It is the combination of compounding variables, short lead times, multiple players, heterogeneity of disasters, and the relative recency of interest in this field that makes humanitarian logistics ripe with opportunity for discovery. While academics use qualitative and quantitative tools to understand and improve research, multi-national and global organizations are actively attempting to maximise humanitarian logistics capability, coordination, and efficiency.

1.1.2 Long-Term Development

Similar to the commercial industry, the coordination of multiple operating units in various regions is difficult to plan and manage. We begin to see the depth of difficulty faced by humanitarian organizations when we add the complexity of random shocks, stochastic inventory requirements, limited data or infrastructure, and other hurdles. This raises the question: how does the world navigate in this uncertainty, and are there protocols in place which make it easier?

To help answer this questions, we discuss the United Nations (UN) cluster system, the Sustainable Development Goals (SDGs), and provide examples of organisations performing work in long-term development through health and education programs.

United-Nations Cluster System

Humanitarian crises can be overwhelming for the populations impacted by, and organizations responding to, an event. Coordination amongst these organizations is critical to capitalize on synergies and thereby reduce the duplication of services. Along the same vein, a lack of coordination can lead to confusion, bottlenecks, and inefficiency.

In 2005, the UN cluster system was created as a standardized approach to the way in which humanitarian agencies would work in unison when responding to a crisis. The cluster system is organized into eleven thematic

areas: Nutrition, Health, Water/Sanitation, Education, Shelter, Camp Coordination/Management, Protection, Early Recovery, Logistics, Food Security, and Emergency Telecommunications. Each area is led by a focal UN organization tasked with coordinating the required activities within the purview of its assigned theme. A graphical representation of the humanitarian life cycle (as detailed by the UN), the clustered themes, and their respective lead organizations can be seen in the figure below.
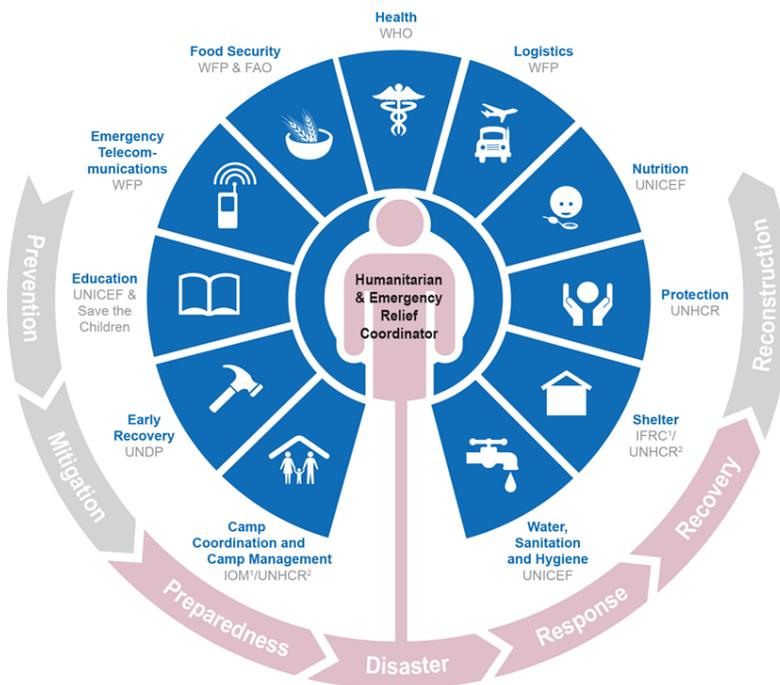
Figure 3: UN Cluster System (2018)

Envisioned in 1991, implemented in 2005, then updated in 2010, the cluster system will soon celebrate 15 years of being in operation and is currently being used in over 30 countries (United-Nations, 2018). We note that the cluster system has come under scrutiny for, what critics say is its inability to fully engage local government and citizens (Heath, 2014). According to these critiques, which have been acted upon, past cluster meetings failed to solicit participation from all relevant stakeholders and thereby unintentionally sacrificed buy-in from local groups.

Taking a step back, we can see that the successes and limitations of the cluster system also provide opportunities for research. Analysis can be considered in stakeholder collaboration, communication, game theoretic models with multiple agents, facility capacity sharing, inventory management, information flows, joint purchasing, coordination, and more.

We now provide brief examples of academic research towards collaboration. Balcik et al. (2010) discuss coordination challenges and offer potential applications of corporate coordination mechanisms to the humanitarian sphere. Tatham and Christopher (2018) take this thought further by analyzing and commenting on the multi-agency approach led by the UN cluster system. Related research outside of the humanitarian field includes Gui et al. (2015), who identify theoretical properties of fair cost-sharing mechanisms, and Meca and Sošić (2014) who provide a game theoretic model showing equilibrium of cooperation under certain conditions of shared costs.

It is important to recall that humanitarian logistics does not only involve disaster management, but also long-term development of regions in which populations receive assistance from organizations to improve their quality of life. This includes building sustainable infrastructure for the future such as programs involved with disease prevention, infant mortality rate reduction, permanent refugee camps, food programs to eradicate hunger, and safety of vulnerable populations.

Sustainable Development Goals

The Sustainable Development Goals in the figure above (United-Nations, 2019) encompass a spectrum of 17 long-term development goals through an incredible global push in development aid coordinated by the United Nations. The SDGs involve agencies from all parts of the globe and interface with academia on a multitude of projects. Similar to the UN cluster system, we believe that fieldwork geared towards the SDGs can benefit from additional supply chain expertise. There are many organizations with varying size levels making positive impact and progress towards these goals and it is within our capacity to learn from and contribute to their work.

Figure 4: UN SDGs (United-Nations 2019)

1.1.3   Dark Supply Chains

In addition to the work that is attempting to better the world, there is an ongoing attempt to undermine the global institutions described in the prior sections. This is being pursued by organisations who operate outside of established law and, in doing so, harm human life.

As business researchers and practitioners, we do not commonly study the actions of businesses who operate invisibly, beyond the scope of sight and everyday life. However, dark supply chains continue to persist, and as we describe in Chapter 3, impact the way even normal businesses operate.

1.2   Case Studies

This section contains case briefs that outline ongoing projects in Health, Education, and Human Rights as part of long-term development. The purpose of each case brief is to engender thought regarding potential areas that supply chain re-

search can contribute to.

1.2.1 Health

Health: Maternal Health Outreach

The Clinton Health Access Initiative (CHAI), a global health organisation founded in 2002, began with a focus on HIV/AIDS care and treatment. Today, it is involved with multiple SDG-oriented programs similar to those of more tenured organisations (e.g. IFRC, UNICEF). Despite its relative youth and size, CHAI is open to new directions, broad-spectrum engagement, and opportunities for rapid change.

One example of a program that CHAI is currently attempting to tackle within the 3rd SDG (good health and well-being) is a maternal health outreach program in Kenya. The program supplies expecting mothers with tools (in the form of medical kits) and awareness (through discussion, documentation, and point of contacts) regarding potential newborn issues. The program has engaged representatives with local clinics, making door-to-door trips to spread knowledge on the availability of life-saving resources available to the community.

An important question of interest is how programs, similar to CHAI's maternal health outreach program, are measured, optimised, and ultimately deemed as successful. In measuring success, we do not limit our scope to this one organisation, as CHAI is not alone in this type of work and all organisations are in some way accountable for fulfilling their mission. For an example of a similar program, see CARE (2019) in the thesis References.

Health: Anemia Response

We now provide an example of nutrition as part of delivering long-term development aid. It is known that a significant portion of the world's population (approximately 2 billion people) suffer from iron deficiency anaemia (IDA). Many international and grass-roots programs have collectively taken action to improve iron supplement access (LBWR, 2015) and continuing research shows

the negative economic and societal impacts from such nutritional deficiencies (Thomas et al., 2006). While there is access to data for many of these programs, organisations on both sides (supplement distribution and its analysis) do not always employ OR/MS expertise or approach their program from an optimisation (modelling, simulation, etc.) perspective. This constitutes a gap and therefore provides opportunities for our field to contribute, collaborate, and ultimately improve such projects.

Health: Summary

Despite their goals and promise, programs such as those mentioned above can benefit from improved measurement policies. Without supply chain best practices, last mile program delivery may be inefficient and could ultimately fall through. Part of the reason for a potential fall through may be due to the misalignment of goals with operational structure, a common issue faced in corporate and humanitarian sectors. Issues may also occur if well-intentioned resource allocations prove to be sub-optimal from Theoretic, Modeling, or Applied perspectives.

The health briefs discussed are examples of how academia can contribute to the long-term development of impactful health care: to build additional partnerships with organisations such as CHAI, CARE, and LBWR in order to understand where their pressure points are and how we can tailor our research to address their needs. Collaboration is common in all realms of academia; however, we believe that additional Applied work in humanitarian logistics can create substantial opportunities for understanding the supply chain and having a greater impact. We encourage readers to consider extending their thoughts beyond these examples to other areas related to health such as immunisation delivery, blood banks, food banks, and communicable disease prevention.

1.2.2 Education

Delivery of World-Class Primary Schooling in Africa

We now provide examples of education as a long-term development goal in Africa, a continent that is expected to have a burgeoning workforce of 924 million people, where the principal concern is robust education delivery to an expanding population.

The African Leadership Academy (ALA, 2019) is a school that aims to develop and connect the next generation of these leaders in Africa. In October of 2014, Fred Swaniker, the founder and executive chairman of the ALA, announced to the world via his TED talk that their academies would expand their impact by increasing their training capacity from 700 students to 250,000 students by opening 25 new university campuses (which will each train 10,000 students per campus). Adding up the math, this means that the ALA intends to train three million new students over the next 50 years. The ALA is not alone in their mission, as there are many other organisations working on the efficient dissemination of robust education.

One such organisation is the Aga Khan Academies (Academies, 2019), part of a network of agencies called the Aga Khan Development Network (AKDN, 2019), which works to create opportunities for low-income populations across the developing world. For example, the Aga Khan Academies are delivering an international standard of excellence in education to targeted populations in Africa and Asia who previously lacked access. By establishing cooperation agreements with a variety of international educational systems, the Aga Khan Academies are building institutions that can empower youth from multiple continents to lead and enact positive change in the communities they inhabit.

The ALA and the Aga Khan Academies are separately yet simultaneously attempting to train the next generation of leaders in some of the globe's up and coming economies. However, the population needs are high and these academies have a limited capacity network. This context opens the door to how research and OR / MS optimisation techniques can help fill the gaps in capacity and delivery of education.

1.2.3 Human Rights

Modern Slavery

Health and education are critical areas of focus, yet they necessitate a person's freedom to seek services and to learn. However, this underlying requirement of human freedom is at risk worldwide. This risk materialises when people become products and are bought or sold as part of a business transaction. In this case study, we look at the Palermo Protocol, an international agreement amongst over 150 countries to systematically fight the advent of modern slavery (United-Nations, 2003).

The Palermo Protocol is built upon what is referred to as the "3P" framework, an acronym for Prevention, Prosecution, and Protection. Prevention focuses on activities that can safeguard potential victims and make trafficking more difficult for perpetrators. Prosecution involves the legal activities to punish perpetrators and capturing those involved with selling humans. Lastly, Protection is the set of actions to rehabilitate and reintegrate victims back into society and ultimately prevent them from being trafficked again.

Though the Palermo Protocol embodies a common global effort against human trafficking, the nefarious underground business continues to operate across international borders. A recent ILO report estimates that over 40 million people are currently being trafficked at an estimated global financial cost of 21 billion USD annually (ILO, 2017a). Furthermore, it is the third most profitable global criminal business, generating profits of approximately $150.2 billion USD per year, surpassed only by the trade of drugs and weapons (ILO, 2014).

1.2.4 Business Human Trafficking Failures

In this sub-section, we provide examples of how corporate supply chains are inextricably linked to low-cost labour and how how that connection can lead to significant problems for companies.

It would be naive to presume that corporate supply chains utilise only willing labour, or in other words that all of the work that is accomplished for the products which are sold are manufactured by willing hands. It must be made clear that often such employees have no choice or freedom in their profession, at least not in the same way that many parts of the world's population may perceive job choice. In such situations, there is often little ability to say no to an opportunity, as some situations come down to the will to survive, the choice to live.

To make this clear, we can consider a hypothetical scenario. Imagine a person is stuck at the bottom of a well for days, weeks, or months. They are running out of food. Someone comes to the top of the well and says "I will help you get you out of there, but you will need to make it up to me," a quid pro quo. In such a situation, the person is compelled to say yes, because to say no could mean death and potentially the same for the family they seek to support (who may be in the well with them). Therefore, they say yes, not knowing that the bottom of the well may be exchanged for a cell. In that cell, they become trapped again, yet now into a system, legal or otherwise. They are often transported to work in another country where they are unable to communicate because of a purposeful language barrier. The UNODC estimates that 60% of trafficking victims are exploited in a different country than their country of origin (UNODC, 2016).

If the system they are placed into is legal, they may be manufacturing garments for long hours and little pay, garments which will eventually make their way to sell at our local super stores for bargain prices. If they are placed in an illegal system, they may be helping drug cartels, human slavery syndicates, or may themselves be exploited as slaves. The important factor here is that the choice was not necessarily their own, as they had no choice other than to be in peril or be trapped.

This brings us to the idea that major corporate supply chains may unfortunately rely on forced labour who did not seek that job, but rather sought any means by which to survive and guarantee the safety (and supposed prosperity) of their families. The issue herein is that they will continue to be taken advantage of,

and at that point, there is no way out. There is no person coming to the top of their work cell and telling them they will get them out. There is only a clock which tells them how much longer they must toil, and it is in this situation that they perhaps give up hope, because the clock only counts up, not down, thereby increasing time in their bondage.

Below is a sample review from a selection of multi-national corporate issues that have involved forced workers and the resulting loss of goodwill when journalists shine light in these cells of darkness. This is strongly related to Chapter 4, where we will cover the international community's approach to this problem and our analysis of its impact on companies.

Nike

In addition to its infrastructure woes near the turn of the millennium, Nike was also confronted with accusations of managing supply chains with inhumane labour conditions. Often referred to as "sweatshop labour," Nike was blamed for overworking employees, sometimes children. The company initially responded by confirming that they did not actually own the factories, but the public backlash was intense and threatened long-term degradation of the Nike brand. The company then rolled out a new strategy to work with their suppliers by incorporate procurement practices that ensured their supply chain members followed protocols of fair treatment and working conditions. Though the Nike brand took a hit in the short term, it has tried to become a leader in supply chain transparency. However, in 2017, the company was back in the spotlight again for sweatshop labour accusations (Briselli, 2017).

Apple

One of the biggest technology companies on the global market (by market capitalisation), Apple maintains rigorous systems to ensure Corporate Social Responsibility (CSR). However, despite their best efforts, it can be difficult to root out improper work conditions or underage workers from a supply chain without constant vigilance. In Apple's case, many of its woes started when its main production supplier, Foxconn, experienced employee suicides at its facility in Shen-

zhen, China. Workers were being worked for 70 hours per week and with militant management styles. At this Apple facility, between 2009 and 2010 thirteen workers had committed suicide. Furthermore, it was discovered that dozens of employees in Apple's supply chain were underage workers. It should be noted that though employees were subjected to these conditions (and some were underage), Apple's facilities were found to be better than most other supply facilities, which does not bode well for the remainder of the industry (Torres et al., 2012).

Costco

A neighbourhood name, Costco is a members-club that sells products in bulk to consumers and businesses. In an exposé published by The Guardian, (Hodal and Lawrence, 2014) reported the use of slave labour onboard Thai shipping vessels that were selling their catch to Charoen Pokphand (CP) Foods, who in turn was selling the byproducts to Costco, Carrefour, Walmart, and Tesco.

Costco has received significant public attention for this due to a lawsuit filed by one of its members alleging that the store knew of the slave labour and that she was harmed because she unknowingly consumed the ethically tainted product. Though this case was thrown out (it was proved the shrimp the customer ate came from a different supplier than CP Foods), the case may be brought to court again by a different consumer who did consume the tainted shrimp (Addady, 2016). Based on the reports and consumer feedback, Costco has said it is working with its supplier and the Thai government to prevent future issues.

Walmart

Wal-Mart is a name synonymous with value, and their growth from a rural store to a global force was in no small part due to their ability to leverage their supply chain. However, in 2005 a news story broke in Canada that some of Wal-Mart's products in that country were being made by children (10-14 years old), where each child was reported as being paid $50 a month as their wage (Torres et al., 2012). More recently, in 2013 it was reported that over 1000 workers died in the Rana Plaza collapse in Bangladesh, where manufacturing apparel for major

conglomerates (allegedly including War-Mart, JC Penney, Carrefour and others) was produced.

Within two years of the factory collapse, $19 million had been raised for the victims and their families. Yet, it was reported that up to 150,000 workers had already lost their jobs due to stricter auditing of supply chains and that up to 700,000 total people in Bangladesh might lose their jobs if this continued (Quadir, 2014). Though this can be seen as beneficial because those employees have been kept away from potentially unsafe environments, it begs the question to another political quagmire: where will those hundreds of thousands of people work now?

1.2.5   Potential Research Implications

The related questions we must pose to ourselves as a research community are: how can we help with health, education, and human rights? More specifically, can these systems be analysed, modelled, and positively impacted with targeted research? Furthermore, can this only be applied to a single continent or area, or can it be scaled up to enable action across the globe, or scaled down to a small town in India (see case learnings in Vachani and Smith, 2008), or near where we live? Our careful consideration of these questions is important, and their answers have the ability to impact the opportunities and quality of health, education, and access to freedom for current and future generations.

1.3   The Path Forward

In this chapter, we have detailed the streams of research in the four areas of the humanitarian life cycle and discussed some key focus areas that practitioners are currently engaged in. Overall, we believe that the OR/MS field has made significant strides in building a foundation of analytical knowledge in the area of humanitarian logistics. It is our hope to not only help align future research with practice, but also to inspire applied collaboration between humanitarian

researchers and practitioners. Successfully improving the efficiency of humanitarian logistics is crucial because it directly impacts human lives.

Three key areas we have pointed out in the figure above for the alignment of humanitarian logistics research are in disaster response, capacity building, and the prevention of dark supply chains. Examples of research opportunities in disaster response include data-driven decision support tools, efficiency metrics, and coordination mechanisms. Examples of opportunities in capacity building include the establishment of long-term camps/housing, infrastructure design, health/sanitation, building local capacity, and collaborating with organisations to reach the delivery of MDG goals. Examples of research needed in dark supply chains include assistance with current government and NGO programs, establishing economic freedom so that vulnerable populations do not get caught into human trafficking, and managing the risk of slavery through awareness, risk mitigation, and prevention mechanisms. These areas for further research are discussed in the Conclusion chapter's section "Further Research."

Through a discussion of current programs, we explored a variety of important paths that can benefit from applied research. We believe that the gaps between research and practice can be filled with targeted analysis in tandem with deeply understanding the needs in practice. Ultimately, addressing the needs of humanitarian logistics can create a substantial positive impact on beneficiary populations and the body of research in supply chain management.

The next chapters of the thesis turn toward the third humanitarian topic, dark supply chains, and specifically modern slavery. This will include models that utilise analytical tools to inhibit the supply chain of human trafficking from operating. In Chapter 4, this will involve considering the optimal decisions of a government who, under resource constraints, is attempting to prevent corporate supply chains from using forced labour. In Chapter 5, we use the lens of supply chain vulnerability to look at weaknesses in the actual movement of operations, thereby understanding optimal areas for targeted attack.

Author's Notes

As discussed in the introduction of this chapter, a portion of this literature survey was published during the completion of this thesis (Bhimani and Song, 2016), and the co-author of the publication (a previous doctoral advisor) has confirmed in writing that the entirety of the work was performed by the author of this thesis. All personal notes are written using the singular pronoun "I", though for consistency with supply chain literature, the body of the thesis is written with the plural pronouns "we" or "our."

In writing this chapter, I was fascinated by the plentiful amount of information that is publicly available on the web and have included such resources in the References section of this thesis. One resource I recommend for accessing data with regards to humanitarian logistics is the Emergency Management Database (EM-DAT, 2012). EM-DAT is an international, free to access website maintained by the Centre for Research on the Epidemiology of Disasters (CRED), and is an excellent source for disaster and development data. Through this website, researchers, practitioners and the general public can obtain valuable information on historical and current natural disasters, including data sets from which to analyse and perform humanitarian research.

2   Methodology

This chapter introduces and formalizes the research methods used in the remainder of the thesis. As discussed in Chapter 1, there are two key perspectives which require quantitative study, namely that of government resource allocation and supply chain vulnerability.

Based on the requirements of the topic, a multi-method approach was taken to achieve the research objectives. The set of decisions which led this approach are described in this Chapter (2). The analytical methods employed include game theory (Chapter 4), econometrics (Chapter 5), and a case-specific application (Chapter 6).

2.1   Development of Government Response Model

Chapter 4 will analyse the problem of modern slavery from a government's perspective. Specifically, we assume that a government seeks to prevent forced labour within its borders; however, it has limited funds with which to combat this scourge. This is, therefore, a resource allocation problem under the constraints of a limited budget.

In deciding how to approach the area of limited resource allocation, many areas of research science were considered. These include both the quantitative and qualitative study of fields including public policy, economics, business, law enforcement, and healthcare for their application toward similar anti-trafficking goals.

A key requirement of the methods considered was the ability to assess, with flexibility of dynamic decision variables, the trade-off between resource decisions being made and their resulting impacts on larger system-wide benefits. This requirement necessitated an economics-based methodology that allows for concise numerical conclusions to be reached based on two important factors:

1. In order to understand the dynamics of a system, specific variables can be

pertubated to understand their impact on a multitude of other variables, and,

2. the results should ideally be scalable to multiple contexts, i.e. for use in understanding such systems in a variety of geographies or situations.

Of the economics methods available, game theory and econometrics were primarily considered due to their ability of handling the relevant trade-offs and arriving at concise numerical conclusions. While econometrics has merits due to its ability to understand the outcomes of policy decisions, one of its limitations for the resource allocation chapter was a lack of flexibility to perturb the resulting model to various scenarios. Further, the lack of homogenous data would have made econometrics infeasible for a scalable analysis.

Game theory was found to successfully provide the required computation flexibility, as well as the to draw clear conclusions from model perturbations of trade-offs. Additionally, game theory allows for the inclusion of *steps*, whereby one player (e.g. a government) makes a decision, and the next player (e.g. a company) responds to that decision. The decision to use game theory was further supported by similar modelling techniques performed in the academic literature, which are highlighted in the following section of this methodology chapter.

There are some inherent weaknesses of utilising game theory, first and foremost in the abstract nature of any economics tool. Simplifying complex systems into variables or conditions can entail some loss of the nuances and therefore a potential loss in fidelity of the findings. Though this was recognised, it was determined that game theory minimized such loss as compared to other methods, as it allows for a range of different inputs and is not limited to existing data. In fact, the model used for the game theory model herein is agnostic to inconsistencies in data and therefore can cleanly probe at the heart of the decisions and trade-offs that governments must make. This, to the extent possible, mitigates the aforementioned loss of fidelity. To ameliorate the simplification of contextual elements in the core model, for example, external NGO intervention, additional analysis of these elements is considered in the Extensions section of Chapter 4.

A second weakness (indeed somewhat related to the first) of using game theory is the question of accurate representation. One must ask if game theory can accurately represent real-life choices and if the results of the model can be applied to multiple contexts. For both of these questions, the answer is quite similar to most areas of economics, that it depends. However, to ensure the accurate representation and applicability of our model several steps were taken. These include adapting the existing techniques of prior research to maintain literary consistency and speaking to practitioners in the field of human trafficking. Therefore, despite the weaknesses of game theory, it was chosen as the best method considered for the analysis herein.

Discussions with practitioners helped to ensure our base model reflects the real-world foundational elements of human trafficking. This involved speaking to individual experts at organisations including United Nations Interregional Crime and Justice Research Institute (UNICRI 2017), the Global Fund to End Modern Slavery (GFEMS 2016), The Why (2018), and the Urban Institute (2017). The organisations were engaged to provide practice-based insights in order to question, verify, and supplement what is written in the academic literature.

These discussions were two-way dialogues that took place before and during the analysis to inform the model employed herein. Discussion topics included the stakeholders involved, methods of intervention, protocols, legal frameworks, and urgent needs in practice. Notes were taken during the calls and, these insights provided a qualitative, practice-influenced backing to the model. For example, this dialogue influenced our use of the 3P approach, which is further discussed in this chapter. Furthermore, through dialogue with these organisations and presentations to the academic community at seminars and conferences, helpful feedback were obtained and improvement ideas were utilised for the extension areas employed at the end of our analysis.

It is worth noting that the words quantitative and qualitative may have different meanings depending on their area of academic use. To be consistent with the areas of supply chain and operations management, *quantitative* is used to signify numerical analysis and *qualitative* is used to signify non-numerical analysis.

Our chapter on the government response model is quantitative, yet noticeably improved due to the qualitative discussions held with the external organisations mentioned above.

A review of methods used in prior research, the building of the game theory model, and the novel contributions made herein are provided next.

2.1.1 Prior Modelling Techniques

Our analysis of the relationship between a government and a firm bears similarity to the modelling works of related fields such as supplier auditing (e.g. environmental regulation), responsible supply chain management, and optimal enforcement with penalties.

A key difference between the game theoretic chapter and the prior literature is the perspective we take on the objective function of the government (herein referred to as *she*, or *her*). In the majority of related literature, the government (sometimes referred to as the regulator or enforcer) is described to be a social welfare maximiser. Due to a limited budget, we instead model the government as a budget (or profit) maximiser. This is due to the realistic monetary limitations a government faces, as she collects funds through taxes while trying to minimise her costs, including the societal cost of human trafficking (i.e. Protection).

In the related supplier auditing literature, recent health and climate movements have led to tightening regulations on businesses and their respective supply chains. Setting appropriate standards can be challenging (Arguedas, 2008), and government monitoring (i.e. Prosecution, in our context) can be costly (Becker, 1968). The research has followed the two main paths that a business may take in response to government action: willful or unintentional misconduct (Cropper and Oates, 1992).

In the category of unintentional misconduct, Kim (2015) studies the trade-off between periodic and random inspections and finds that periodic inspections can be preferred in surprising circumstances. Additionally, when deciding be-

tween a responsible or risky supplier, socially conscious customers and supply chain transparency have been found to be drivers of an optimal procurement strategy (Guo et al., 2015). Recent work has also shown that supplier inspections can be outperformed by delayed payment after confirmation of non-defectiveness (Babich and Tang, 2012). In other work, optimal contract design is studied whereby a firm purposefully hides its non-compliance in an attempt to commit fraud (Baiman et al., 1991).

In the literature on responsible supply chain management, much focus has been placed on the numerous points of vulnerability in multi-tier supply chains due to the delegation of responsibility and lack of direct supplier oversight. This highlights the importance of relationship building in the supply chain, which can all too often devolve into a transactional orientation (Ellis and Mayer, 2001). Depending on the business relationship structure, some methods to handle the delegation of responsibility include supplier development, offering premiere supplier status, providing non-monetary rewards or delaying full payment (Chen and Lee, 2015).

It is also possible that suppliers may collude with auditors in their hiding effort and increased scrutiny on the part of the regulator may cause even further hiding. In contrast to the game theory model used in this thesis, Plambeck and Taylor (2015) study a case where a buyer exerts auditing effort on a supplier, and the supplier can exert two different types of effort: effort to comply or effort to hide. In their model, it can be beneficial to take counter-intuitive approaches such as reducing payment cost in exchange for higher wages, instead of levying penalties or public defamation.

In the closely related enforcement and penalties literature, several seminal economic works have laid a solid foundation for considerations in law enforcement, starting with the classic paper by Becker (1968), who looks at resources and penalties for crime enforcement. Malik (1990) and others find that setting a penalty as high as possible may not be optimal because it will simply drive offenders to engage in activities which reduce the probability of being caught. Instead, it can be beneficial to distinguish potential offenders through screen-

ing activities, and then set optimal fines based on the type of individual. There exists a moral hazard problem within the chain through which partners open themselves up to risk. In this case, penalties charged from external stakeholders to higher tiers can help to coordinate across a supply chain (Huang et al., 2015).

The potential for enforcement to backfire is a counter-intuitive yet common occurrence in the recent literature. It reinforces the notion that despite good intentions, auditing may inadvertently incentivise the same action it is attempting to prevent. For example, one recent paper found that increasing supply chain transparency may backfire and actually has the potential to induce the use of child labour (Cho et al., 2015). This is analogous to another result found where certain methods of auditing a supplier's effort may actually cause increased hiding (Plambeck and Taylor, 2015). Similar to the child labour case, Kambhu (1989) finds that increasing regulations against non-compliance may be detrimental to social optimality. In this situation, the two methods which can reinforce compliance are penalties for noncompliance and strengthening enforcement efforts, both of which have parallels to our work.

For an overview of historical research on optimal penalty structure, we recommend the reader to Lear and Maxwell (1998) and Decker (2007). A review of optimal law enforcement is provided by Garoupa (1997) and Polinsky and Shavell (1999), whereas Kim (2015) provide the same for more recent optimal monitoring work.

2.1.2   Game Theory Modelling Technique

Though similar at a rudimentary level to prior techniques, the model employed has been significantly modified and built-for-purpose to the context of human trafficking. Critical modifications from past literature include the new structure of equations to match the 3P protocol against human trafficking and the inclusion of new variables to cater to the real-life decisions that governments and firms are facing in this context. Therefore, although based on the learnings of prior literature, the model built herein stands on its own as a unique application

of game theory to the problem of modern slavery in corporate supply chains.

2.1.3   Elements of the Model

This thesis assumes that all players are *rational*, which means that each player will act in their own economic best interest given any set of decisions they are presented with in order to maximise their economic outcome (i.e. payoff). Furthermore, all players understand their complete decision set (i.e. all possible decisions they can make), how it is linked to their complete outcome set (i.e. all possible outcomes that could result from their decisions), and have common knowledge of other players sets. These assumptions match reality and are supported by the previously introduced literature, which presupposes that the economic person will seek to maximise their payoff function over time (Tadelis, 2013).

The moves made by players of the game can occur simultaneously or sequentially. *Simultaneous games* require all players to make their decision(s) at the same time. In *Sequential games*, the type of games used in this thesis, it is required that one player makes their decision(s) first, after which the second player can then make their decision(s). This sequential requirement was chosen because, for our context, it best matches the real-world order of events. Each player can make a decision over a *discrete* range of numbers (e.g. 1, 2, 3) or a *continuous* range (e.g. 1.1, 2.3, 3.8) to receive an expected payoff (Von Neumann and Morgenstern, 1944).

There is an element of chance in the game, whereby the resulting profit to each player will act similarly to a random variable. A random variable encapsulates the risk and reward trade-off decisions with unknown outcomes, as the payoff depends not only on each players decision(s), but also the decision(s) of all other players. Each outcome has a probability, and in sequential games, these are considered to be compound probabilities because of the sequential moves involved. Therefore, the order of moves matters, as it can influence the outcomes of the game. This type of sequential move game is known as a Stackelberg game (Von Stackelberg, 1934) and is solved with the use of backward induction.

Backward induction requires mapping out all possible steps for each player to determine their optimal moves to maximise their potential outcomes. Starting from the end of the game (at the potential profit outcomes) and working backwards, it is possible to determine the *dominant strategies* (i.e. optimal decisions) that each rational player will make, given their payoffs and the probability of achieving such payoffs (Tadelis, 2013). The end-point is used, therefore, as a starting point to walk backward through the game and determine the optimal decisions for moves that would occur for each player.

2.1.4   Application of Game Theory

Chapter 4 of the thesis uses a customised game theory model to analyse the optimal decisions of a government attempting to prevent forced labour and companies who are potentially using forced labour in their supply chains. Each player, namely the government and the company, take part in a Stackelberg game to maximise their outcomes, and this thesis shows the optimal decisions a government can make to incentivise companies to mitigate forced labour in their supply chains, in equilibrium. This provides insights into the decision frameworks of governments and, thus, postulates the impact of those decisions on firms. By modelling this dynamic as a sequential game, we are able to better understand the key trade-offs for both stakeholders.

After analysing the game theory model to better understand stakeholder behaviour, we now turn our attention to understanding supply chain vulnerability and disruption management.

2.2   Development of the SCFF

2.2.1   Supply Chain Disruptions and Failure

The main focus of academic research in supply chain disruption, which began ramping up with Svensson (2000), has been in risk mitigation and vulnerability

management. *Risk mitigation* is essential to the continuity of supply chain performance and the building of resiliency. Furthermore, it is an essential stepping stone to insulating an enterprise from the impacts of disruption (Craighead et al., 2007).

Altay and Ramirez (2010) report that disruptions may have been caused by a variety of events, including system disruptions (e.g. technology, electricity), natural disasters (e.g. hurricanes earthquakes), and man-made disasters (e.g. terrorism, political instability). Traditionally, risk mitigation can be segmented into the various levels of the supply chain. Peck (2005) describes these levels as product and information flow, infrastructure, overall business strategy, as well as the wider economic and natural environment. Among the numerous papers written on preparing for disruptions, Tang (2006) was one of the first to outline specific mitigation techniques in the literature.

Punter (2013) provides a business consulting report with case studies of selected supply chain failures; however, this does not synthesise such disruptions into a larger narrative, nor provide a framework of failure. Hayes and Upton (1998) provide insights into how knowledge of supply chain operations can be used to attack and dethrone long, entrenched supply chains for the purpose of market dominance by harnessing operations efficiencies.

This thesis utilises the Wagner and Bode (2008) definition for a *supply chain disruption* as "the combination of (1) an unintended, anomalous triggering event that materialises somewhere in the supply chain or its environment, and (2) a consequential situation which significantly threatens normal business operations of the firms in the supply chain." Wagner and Bode (2008) offer five classes of disruption (discussed in the following section), the final class being catastrophic, which they describe as having a severe impact. We concur with this large level of impact and furthermore believe it is an integral area of concern for understanding supply chain failure. Therefore, catastrophic disruptions are the main focus area for research herein.

Prior Disruption Frameworks

Several taxonomies of supply chain disruption have been proposed by researchers such as Mason-Jones and Towill (1998), Svensson (2000), Christopher and Peck (2004), Chopra and Sodhi (2004), Jüttner (2005), and Wagner and Bode (2008). There have been attempts to aggregate these framework contributions, such as Sodhi et al. (2012) and Heckmann et al. (2015). However, such aggregated frameworks were similar in construction to their predecessors and therefore are not further analysed herein, primarily because those latter iterations are well represented by their original sources.

Many of the prior frameworks have categorised themselves based on the source of risk in the supply chain. For example, Svensson (2000) sorts disturbances into two categories (quantitative or qualitative) and their impacts into small (atomistic) or large (holistic) disruptions. Mason-Jones and Towill (1998) refer to an "uncertainty circle" where supply chain vulnerabilities have four areas of uncertainty (manufacturing, supply, control systems, and demand). Christopher and Peck (2004) build on this to create five sub-fields (processes, controls, demand, supply, and environment) while Chopra and Sodhi (2004) outline nine such sub-fields (disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory, and capacity). Jüttner (2005) simplifies risk into three sources (supply, demand and environment). Finally, Wagner and Bode (2008) take this further by categorising risk into five 'classes' (supply, demand, regulatory including legal and bureaucratic issues, infrastructure, and catastrophic risks). We describe these frameworks in further detail in Chapter 5.

Wagner and Bode (2008) explain the last category, catastrophic risks, as those which would have a 'severe' impact. However, their understanding of catastrophic risks is quite broad. Furthermore, this category can overlap with any of their other classifications. In other words, there are catastrophic risks that impact the supply, demand, regulatory environment, infrastructure, or all of these areas of a supply chain. Thus, the current understanding of catastrophic risks remains unclear, as it acts as a "catch-all" to capture the worst types of disruptions.

This begs several questions. First, what types of catastrophic risks are there?

Secondly, what are their causes? Indeed, for a framework to be developed for catastrophic disruptions, it would need to build on the prior literature yet convey a deeper understanding of this specific category of vulnerability.

It is here that the idea of a supply chain failure is introduced, because by understanding what would cause a supply chain to break (i.e. cause a supply chain to fail), we can thereby create a better understanding of catastrophic risks. It is due to the severity of potential failures that a deeper understanding of this category of disruptions is warranted and indeed critical for understanding risk and vulnerability.

A *supply chain failure* is defined by this thesis to be a break in an organisation's supply chain that causes an inability to continue planned operations. The failure does not necessitate a collapse of the entire organisation, but it does significantly prevent its ability to move essential resources (such as materials, information, manpower) towards meeting the organisation's purpose. A failure may immediately immobilise a supply chain organisation, or if the organisation has some remaining capacity, then the failure will progressively weaken the organisation over time.

Finally, we place failure within the research area of supply chain vulnerability and specifically of disruptions which were defined by Blackhurst (2005) as "unplanned delays or stoppages of planned product flow." A failure can be synonymous with the worst type of disruption, that of a catastrophe. The key differences between a failure and a non-catastrophic disruption are the severity and time impact a failure has on an organisation. Compared to a failure, non-catastrophic disruptions are usually recoverable and have minimal impact over time. Conversely, a failure is difficult to recover from and has substantial consequences. Thus, a failure is not a separate type of risk, but rather is any type of disruption which meets the definition described above.

2.2.2   Development of the Model

Multiple research methods were considered to assess the types of supply chain failure and elucidate the ways in which supply chains break. Possible methods of developing this research into critical weak links in supply chains included discussions with business executives, performing focus groups, collation of prior industry reports or publications on the subject, and historical analysis of actual events.

The survey method was considered to have significant promise and was strongly considered. This may have included contacting individuals in supply chain positions to ascertain their understanding of failure and their expectations of where a failure could occur. It was seen in the literature that similar surveys, interviews, or focus groups had been previously conducted, which does provide credence to pursuing a similar approach. However, a consistent issue with these approaches was the human bias described by previous authors, such as Altay and Ramirez (2010). This bias has the potential to sway the findings based on speculations, a focus on recent events, or fears of future events which may have no factual basis. It was therefore decided that relying on interviews was not the ideal approach for this thesis.

The choice against using a survey method is distinct from the discussions with external organisations discussed in the Methodology chapter. Those discussions were used to inform our game theory model in Chapter 4. The difference between a survey method (not employed) and discussions with experts (completed for validation) is a projection of the future in the former, and an understanding of the current state in the latter. Due to our goal of understanding the current state, our approach for human trafficking enforcement is based on expert discussions, rather than based on speculation or conjectures of future events from survey methods.

Prior industry reports and publications offer helpful information on the subject. In particular, Punter (2013) presents an overview of supply chain complexity and risk through his analysis of 17 relevant supply chain disruption cases. Though

interesting, it is similar to standard industry reports in which the insights are anecdotal and not based on rigorous analysis.

To truly get at the underlying knowledge of how supply chains break, it was deemed necessary to study how they have historically broken. As much as possible, this sets aside opinions, conjectures, or anecdotes. Unfortunately for past research, though fortunately for the contribution herein, a database of supply chain failure did not exist. Thus, the decision was made to collect relevant operational data so that a rigorous analysis could be performed for the derivation of evidence-based insights on supply chain failure.

The creation of this dataset required collecting historical records, a process that began with collating supply chain failures in the business field. Two learnings were quickly realised. First, businesses do not tend to publicise their failures. This is intuitive yet problematic for data collection and lends justification as to why prior research has instead relied on selective case studies or managerial surveys. Second, outcomes can be inherently company-specific and required a heavy dose of subjectivity regarding the classification of 'outcome,' thereby raising several questions. For example, should the outcome be measured by a dip in profit? If so, was the profit loss short term or long term, and how does it relate to other products or services the firm and their competitors offer?

This quandary led to an exhaustive search of supply chain records. This would enable sensemaking of historical documents (Gasparin et al., 2017). The search culminated in the realisation that there is a specific sector which has definitive outcomes and historical records of supply chain movements and failures. This unique sector, that of military supply chains, was therefore found to be an ideal area of data collection and analysis. The justifications for this choice are explained below.

First, military supply chains have specific objectives, one objective being to win a war if called upon to do so. This introduces a concrete and measurable outcome variable, most commonly categorised as a win or a loss, though occasionally situations of a tie, stalemate, or ongoing battle (the latter of which are not analysed herein). It is worth noting that the study of war is a separate field in and of it-

self and the focus of this discussion is the supply chains of the countries that are at war, no further than that. We do not purport to have knowledge of every military machine or the intricacies of the war effort, those are beyond our scope. We are solely and specifically interested in the supply chain failures that have occurred and been documented as part of historical military operations.

The second justification is that military supply chain information is continuously recorded and, therefore, verifiable information is made publicly available for analysis. This is in contrast to corporate supply chain information, which is often obscured in news headlines and private firms must be tangentially analysed through annual reports and securities analysis for publicly traded firms. Though it can be argued that some military information is kept hidden, the focus herein analyses movements in historical wars that are in the public domain and already academically studied, thereby avoiding such concerns. Furthermore, as military supply chains were meant to be hidden, these types of supply chains provide relevant insight into another hidden type of supply chain, those of dark supply chains such as human trafficking.

Third, military supply chains have similar facets to corporate supply chains and the learnings from one can be transferred to the other. This similarity, what we refer to as shared learnings, is shown in the following section through the typology of supply chains.

2.2.3   Typology of Supply Chains

For the purposes of consistency and readability, we begin by reviewing common definitions of key supply chain terminology. We refer to a *supply chain* as the entire movement of information, finances, and materials to manage a product or service from its inception to its consumption. Mentzer (2004) describes these as integrated movements that usually occur between three or more entities and include raw material collection, manufacturing, shipping, storage, distributing, retailing, consumption, disposal, and recycling/re-purposing. A key differentiator of supply chain management from traditional firm management

is the extension of concern and interaction beyond the firm itself. This includes an extension to a firm's suppliers, customers, as well as the natural and socio-political externalities with which it must engage in its operations.

According to Mentzer et al. (2001), *Supply Chain Management* is defined as the management of two parts. First, it is collaboration across the entire supply chain. Second, it is the flow of products, materials, and information across the supply chain in an effort to produce value through actions such as reducing cost, ensuring on-time delivery, and increasing consumer satisfaction. This definition uses the commonly employed title *chain* to represent the collaboration and flow between participating entities. This chain is sometimes referred to as the supply *network*, for the purpose of conveying the depth of links (i.e. arcs) between entities (i.e. nodes) in a supply chain (Christopher, 1992). The title *supply chain* is used interchangeably with *supply network* as a matter of convenience for the remainder of the thesis.

Upstream and *Downstream* refer to the movement of a product up or down a supply chain, respectively. The easiest analogy of upstream and downstream movement would be a river. Water flow begins upstream at a source (e.g. a mountain or higher terrain area) and flows downstream (aided by gravity) to arrive at its destination (usually a sea or lake). Similarly, in a business supply chain, a product begins upstream at a source (e.g. a raw material like cotton) and flows downstream (aided by supply chain management) to arrive at its destination (usually a business or consumer). Alternatively, if a product moves from the consumer back to the manufacturer, this product would be considered to be moving upstream, a process that is commonly known as *reverse logistics* (Mentzer, 2004).

A supply chain mapping is a visualisation of the entities and their links across the chain. This is useful for understanding the interconnected movement of products across different types of supply chains. For example, for a consumer business (e.g. office supplies, toiletries, food) we can drastically simplify a basic retail supply chain to the figure below.

The *Manufacturer* in the figure represents the entity responsible for producing
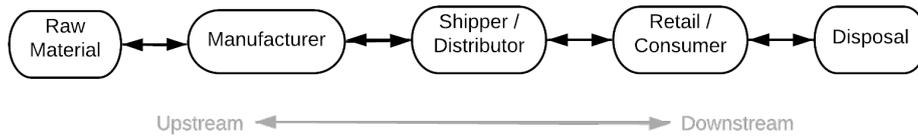
Figure 5: Supply Chain Mapping - Retail

the product from the *Raw Material* received. As the product is shipped down-
stream (along the right-facing arrows), the *Distributor* is then responsible for
moving the product to where it will ultimately be sold.

The *Retailer* provides the product to the final *Consumer* (business or individual).
The reverse (left-facing) arrows in the diagram represent reverse logistics flow,
which may signify the return of the product from the Consumer, back up the
supply stream, where the product can possibly be returned, refurbished, or re-
distributed. Additionally, at the final step of the supply chain, we capture the
end of life for the product, or when it is no longer of use and will either be dis-
posed of or re-purposed.

Building upon the above supply chain mapping of a consumer retail chain, we
can now consider mapping other chains. For example, in the following figure we
consider a military or humanitarian supply chain organisation. We categorise
these areas together because they have (at a high level) similar structured de-
signs.
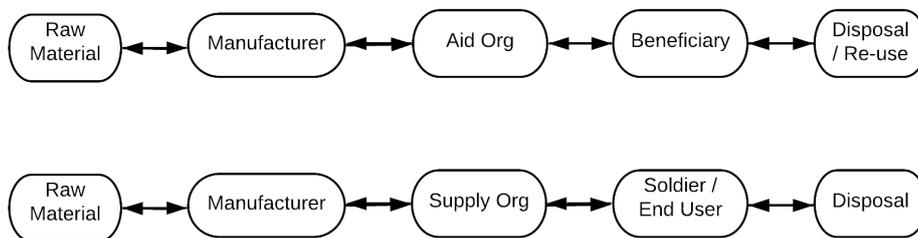
Figure 6: Supply Chain Mapping - Humanitarian & Military

There are two critical discussion points to be made here. First and most impor-

tantly, it should be noted that the military and humanitarian supply chains in the next figure are quite similar in structure to the retail supply chain from the previous figure. Thus, we can see that despite the difference in industry or purpose, there are common nodes and arcs that apply to a variety of supply chains.

Secondly, it must be pointed out that supply chains (i.e. supply networks) and their links are substantially more complex than we have visualised in the previous figures. For example, the links in a military or humanitarian supply chain may vary significantly in their method of delivery to end-users depending on a multitude of factors (e.g. organisation, geography, available infrastructure). However, we simplify these variations in our linear mapping for the purpose of highlighting the inherent similarities across supply chain structures.

To end this brief overview of typology, it is important to place our description of supply chain structures in its broader network context. Although the mappings we have introduced are useful and sufficient for the purposes of this thesis, they are only one-dimensional. Therefore it is important to note that not all supply chains are necessarily linear in design. In a true mathematical sense, supply chains are commonly multi-dimensional networks with nodes, arcs, and value-related design elements, as discussed by Christopher (1998). As such, network analysis is often used in the assessment of supply chain dynamics (commonly using network and graph theory). However, our mappings sufficiently reflect the concepts and flows used in our discussions. Therefore, a background on advanced network theory is not necessary based on the methods employed herein.

2.2.4 Shared Learnings Across Supply Chains

As shown in the previous section, the foundational elements of military and other types of supply chains are quite similar and therefore can have shared learnings. This similarity of structure is harnessed in this thesis to apply learnings from one area, namely military supply chain failures, to the areas of corporate and trafficking supply chains.

This application could, at first glance, be thought to be conceptually difficult in

its extrapolation from one type of supply chain to another type of supply chain. It begs the question, "does this work?" Admittedly, the author of this thesis had similar initial thoughts.

However, after further consideration, three facts led to the realisation that this is not only possible, but necessary:

1. All supply chains have a similar underlying structure. In business transactions around the world, while allowing for some differences to exist in purchase or delivery, the basic principles remain the same across geographies and industries. This is supported by the fact supply chains use similar technological tools (e.g. enterprise resource planning systems), industry standards (e.g. the International Organization for Standardization), as well as auditing and certification requirements (e.g. the Customs-Trade Partnership Against Terrorism), regardless of what they supply. Furthermore, organisations that offer supply chain qualifications and benchmarking (e.g. the Institute for Supply Management, the Supply Chain Operations Reference Model) have standardised core material, regardless of what industry their clients hail from, thereby reinforcing the idea that supply chain knowledge is not restricted to any single industry.

2. It is difficult to study supply chain failure because supply chains are commonly hidden. For example, military supply chains are hidden in order to protect their people and physical assets from attack or interference. Similarly, trafficking supply chains are hidden to avoid detection or attack from governments or rivals. Finally, corporate supply chains hide their supply chain infrastructure to protect from being copied and, indeed, from being attacked by competition or those who would seek to destroy it (e.g. protestors, terrorists).

3. Each step, from raw material to consumption, relies upon a shared approach and indeed, a shared genealogy. The concept of supply chain management is not new and hardly differentiated, and it coincidentally has antecedents in war itself.

It may be enough to state the three facts above, but it is important to give this commonality of structures a deeper consideration. Therefore, in the following section, this thesis provides a historical account on the genealogy of supply chains to lend further credence to the shared learnings across industries.

2.2.5   Historical Perspectives on Supply Chain Management

We set the stage for shared learnings by providing a brief overview of the history of supply chains. This history is not meant to be exhaustive, but rather a narrative which intertwines the three key types of organisations discussed in this thesis, those of traffickers, militaries, and corporations.

The supply chains of business, armies, and trafficking organisations have grown, changed, and advanced together over time, yet when we study supply chain management it is usually isolated to a single industry, field or area of assumed altruistic endeavour. The following discussion seeks to challenge this isolationism by taking a step back to connect the parallels of supply chains across these sectors, especially connecting the study of supply chains to underground criminal activities. Though there are some differences between these supply chains due to the objects they move, we argue they are more alike than they are different. Therefore, by understanding the history, structures, and failures of one area, we can better understand the supply chains in other areas as well.

Though the usage of the term 'supply chain' is commonly traced back to the early 1980s (Jacoby, 2010), the antecedents of supply chain enterprises go back centuries (Christopher, 2016). A rudimentary example is the dawn of modern agriculture when resources such as the autumn harvest were gathered for distribution and storage before the winter months. Following this, the colonisation of foreign lands for the purposes of trade, agriculture, and power led the way to supply networks that literally spanned the globe (Smith, 2006). Supply chains have since evolved dramatically, spurred forth by the industrial revolution and the intersecting wars which brought unbounded technological advancement in industrial engineering to enhance supply chain practices.

In recent history, modern logistics across supply chain areas has been catalysed by the combination of industrial science and military-related activities (Ballou, 2007). In wars, as countries and alliances raced to build the largest and most destructive armies, a reliance on supply chain innovation and efficiency was a key contributor towards success. These war-time innovations led to the creation of Logistics and Supply Chain Management as fields, in addition to introducing the precursors of radio frequency identification (Chawla and Ha, 2007), advanced cryptography, wireless communication, and a more holistic perspective toward scientific research in the field of Operations Management.

Later in the 20th century, military funding was used to help create the internet (Hafner and Lyon, 1998), with which computers enabled the near-instantaneous dissemination of digitised information that improved all sectors of supply chain management. This tradition continues, with militaries continuing to invest in scientific research in logistics, communications, and their applications.

In tandem with these historical progressions, the corporate and underworld supply chains we know today progressed with a similar focus on efficiency. Indeed, modern supply chains can be considered the descendants of those built alongside military advancement, and as we will show, there is a substantial amount of learning we can take from this shared ancestry.

This lineage can be seen in the example of Napoleon's army, a force that could traverse Europe at unprecedented rates of speed to capture foreign lands. This ability came from Napoleon's invention of the 'corps d'armée' (army corps), which separated his 'Grande Armée' (big army) into smaller groups. These smaller, self-sustaining branches could march, fight, pillage, and recover independently. This evolution of the army, from one large force to smaller self-sufficient forces was one of his keys to victory. The separation of forces has carried on from Napoleon and reflects much of the design of modern armies and their supply chains in the modern era (Smith, 2006).

The modularity Napoleon introduced incidentally matches the current structure of corporate giants such as Unilever, Coca-Cola, Google, and others who separate their supply chains into lean, optimised centres that can operate indepen-

dently. This evolution of structure has also been reflected in the evolution of the underworld as large trafficking cartels have shifted over time from vertically structured monoliths to horizontally connected organisations to be self-sufficient. Interesting, this makes underworld supply chains harder to catch, trace, or predict, the underworld's version of Napoleon's corps d'armée.

In tandem with the intersecting wars, the industrial revolution of the 19th century spurred the capabilities of textile manufacturing, steam power, rail systems, agriculture and more. This catalysed supply chain advancements across industries as goods could be produced and delivered more efficiently. These benefits were not only felt by upper-world companies. Additionally, military supply chains were now able to produce better weapons and move armies along railway systems at a historically unfathomable pace. These military advancements laid the path for Napoleon to march on Europe and was an enabler for World War I, as armies from multiple countries could now cross vast land distances quickly using railways (Smith, 2006). Criminal organisations thrived as well, given new modes of transport for their contraband, access to new markets in which to sell goods and services, as well as shifting country borders which offered opportunities to slip under the radar.

The supply chains of the upper-world, underworld, and militaries not only commonly benefit from advancements, but they learn from each other and evolve together. Technological advancement is a simple example of such a shared supply chain evolution. Whereas in the past, communication relied upon couriers or local informants, technology has upgraded these with instantaneous communication and satellite imagery. The ability to connect physically separated organisations has become even easier with automated information sharing, web portals for digital exchanges, and alert algorithms to warn of potential disruptions. All of these advancements have universal applicability to any supply chain interested in adopting them, and indeed, the best practices from one area are quickly replicated in others.

It is due to this idea, that the learnings from one area can be implemented in another, that we can consider multiple types of supply chains in tandem. This is

because, despite the differences in their purpose, they are similar in their underlying designs, an understanding which is enhanced given their common ancestry (i.e. the shared advancements in the movement of corporate, militaries and trafficking over time). Given this similarity in structure, analysing one type of supply chain can hold important learnings for other types as well.

It is, therefore, with a common historical background and the underlying premise that all supply chains are at a structural level similar, that we seek to answer an overarching question: **how do supply chains break?** The answer to this question come from our econometric work in Chapter 5.

By understanding common failure points across areas, we can better understand supply chain vulnerabilities. This analysis can aid in classifying and studying failures, as discussed in this thesis.

However, it offers an added benefit: by analysing how companies and military supply chains break, we create strategies on how an illicit business can be pushed to break, as discussed in Chapter 6, "Breaking Dark Supply Chains."

2.2.6 Methodological Introduction

Based on the preceding notions of similarity in structure across militaries, companies, and dark supply chains, our analysis focuses on the supply operations in war. The choice of war was explained in the prior section. Going forward, we discuss the types of wars that are studied as part of the analysis. Prior literature has sought similar insights by utilising case studies (Punter, 2013), management surveys (Wagner and Bode, 2008), and natural disaster data (Altay and Ramirez, 2010). However, as far as the author of this thesis has found, no paper has specifically collated catastrophic supply chain disruptions to create a more robust understanding supply chain failure.

2.2.7   Inter-State Wars

Within the context of war, we specifically consider *Inter-State* wars, or in other words, wars where internationally recognized countries go to war with each other (Sarkees and Wayman, 2010). These wars can be due to desire, obligation, or compulsion. However, no matter their impetus, a war pulls military supply chains (and indeed, the countries themselves) into operational movement. It is that movement, specifically the failures that occur during the war, that we seek to study.

Civil wars (referred to as *Intra-State* wars) were considered outside of the scope of the data collection due to a perceived overlap between supply chain infrastructures that may have existed within countries, in addition to the complication of assigning clear sides during shifts and changes in country populations. Thus, the process of analyzing civil wars was ascertained to be unquantifiable for this specific endeavour, though this may be a potential area of future research. Despite this purposeful exclusion, our analysis does provide a secondary review of Intra-State wars due to their tangential relation to Inter-State wars. Therefore, though not analysed directly, multiple insights were gained from Intra-State wars and are included in our discussion of Inter-State wars.

For each Inter-State war between the years 1816 and 2007, data was collected from secondary sources of military supply chain operations. The wars analyzed are listed on the *Correlates of War* dataset (CoW) dataset (Sarkees and Wayman, 2010). The CoW dataset offers a robust list of Inter-State wars, the countries involved, duration, outcomes and battle deaths. There are other war databases which were considered for this chapter, such as those from the Peace Research Institute Oslo; however, those were limited in their time-horizon, (e.g. the Peace Research Institute Oslo and others cover 1949 onwards).

The CoW dataset has the benefits of breadth of duration (thereby increasing the scope of analysis), as well as being well-regarded and consistently updated by academics. Therefore, it was determined to be a sufficient dataset for this analysis.

According to the CoW project requirements, each war participant had at least 100 fatalities or at least 1,000 armed personnel on the ground per year for each war. Therefore, smaller wars that do not meet the CoW dataset criteria were not included. The dataset fields, with a full list of all variable descriptions, are provided in the following sections.

After our analysis of Inter-State war history, we validate our framework of failure types and causes with a comparison to business supply chain failures. This validation is important for two reasons. First, it connects us back to the ongoing literature in supply chain management that is focused on the business realm. Second, it serves to critique our war-based supply chain framework based on application to a more commonly practised field, thereby grounding this research in reality.

2.2.8 Empirical Analysis of War History

Utilising the CoW Inter-State wars dataset as the starting point, we conducted a review of military tactics and supply chain performance for each war. The specific goal of reading this history was to collate, document, and code cases of supply chain failures. These identifications were made using the definition of failure outlined earlier in this chapter, that a failure creates a cut in the supply chain network which impedes the flow of goods, services, or information.

The war reference materials were sourced from scholarly articles found in military and academic journals, as well as relevant historical reference books for each war. All wars on the CoW Inter-State dataset were researched, none were omitted. Care was taken to only include information which could be relied upon by multiple scholarly sources. When a supply chain failure was found in a specific war's history, a data entry was made using a pre-defined structure and a second source was used to validate the failure. The details of each failure were coded, along with the corresponding contextualised failure summary.

During the analysis of war failures, patterns began to emerge based on explicit strategies employed by armies, as well as the common failures incurred by their

supply chains. Additionally, implicit notions of failure were gathered during the course of cataloguing and coding which made further insights available for analysis. The coding and summaries are available in the chapter "How Supply Chains Break." The purpose of providing such background is not only to assist with replication, but also to provide the references and historical context to the reader for further information and research.

The resulting war failure data from operations was then combined with the CoW dataset. Specifically, supply chain failures were classified by an extended categorisation of their types and causes. Each failure in the dataset contains notes on its impact on supply chain performance and the corresponding war outcome. Unlike prior frameworks creations such as Wagner and Bode (2008), a Likert-type scale was not used in this analysis. Instead, we utilise a binary classification system, thereby purposefully limiting subjectivity or the impact of opinions on our results. This also negates the need for psychometric analysis or bias considerations from interviews. However, there is admittedly a subjective bias based on the coding of each war. To the extent possible, this was overcome through the two-source verification process discussed in the following section.

2.2.9   Finding Supply Chain Failures

This method of data collection was chosen after an exhaustive search for prior databases on supply chain failure was completed. Despite finding anecdotal stories, the search for datasets concluded that no sufficient collections of data had been generated on this topic, either publicly available or otherwise. The data of historical supply chain failures relies upon information culled from historical records of military events; however, business data was also collated for comparison and verification purposes. The business failure data was not used in any statistical analysis, yet it was used to bolster the applicability of the resulting framework and provides a unique set of references for further analysis (included in the Appendix).

War data for historical analysis was collected from scholarly records such as text-

books, historical volumes, and news articles. Each failure in the dataset required two reputable sources for validation prior to being analysed. This utilised structured content analysis of historical records to understand supply chain failures. Each record was analysed using a consistent procedure and coded into a standardised dataset as follows.

Coding Process

For each war, each state (i.e. country) contains what we refer to as an entry, or a row, in the dataset unique for the participation of that state in a war. The binary marker used was coded on a true/false basis. If no failure occurred for a state during a war, the state's binary failure entry was marked with a zero (0, false), as prescribed by the analysis design. Conversely, if one (or more) supply chain failure(s) occurred for an entry, the binary failure entry was marked with a one (1, true).

A reliability evaluation was then conducted through a two-step verification system. Initially, a recognized supply chain failure would be cited and added to the dataset. Next, the failure would require a second source to support the occurrence of that failure. A failure which could be verified by two sources received a verification coding of 1 (true), whereas an unverifiable failure was classified with a verification coding of 0 (false), and the original corresponding data for that entry was dropped prior to the econometric analysis.

Based on this contextual analysis, the following additional fields were changed or appended to the CoW dataset: Outcome (binary), SCFailure (binary), Failure-Type, FailureCause, FailureNotes, FailureReference. For the reader's reference, a full detail of each field in the original CoW dataset provided in the table below.

Table 1: Summary of Original CoW Dataset

Variable	Description
WarNum	The number assigned to the war
WarName	The name given to the war
State Name	The name of the state (i.e. country)

Variable	Description
Start M, D, Y	The date the fighting started
End M, D, Y	The date the fighting ended
TransFrom	The WarNum that transformed into this war
WhereFought	The region(s) of the world that had combat (1-19)
Initiator	Did this state start the war? Binary (1=Yes; 2=No)
TransTo	The WarNum this war transferred to
MultiOutcome	The outcome of the war (1 - 6); edited
BatDeaths	The number of fatalities attributed to battle

The result of the combined dataset is rich with information and homogenised across diverse war operations. It includes wars that spanned from five days to over ten years, war operations with zero deaths to 7.5 million, and coverage of almost every continent of the globe. Additionally, every failure followed the two-step verification process outlined in this section to limit historical bias or conflicting perspectives.

A summary of the data appended to the CoW dataset is provided below.

Table 2: Data Appended to the CoW Dataset

Variable	Description
Outcome	The binary outcome of the war (1 = Win; 0 = Loss)
SCFailure	A supply chain failure (1 = Yes; 0 = No)
FailureType	The type of failure that occurred
FailureCause	The primary cause of the failure
FailureNotes	Notes on the specific failure, if one occurred
FailureRef	The reference in which the failure was found

In summary, an existing academic dataset was appended with custom-coded failure data to understand the historical failures of military operations during

Inter-State wars. The original dataset comes from the Correlates of War (CoW), maintained by Sarkees and Wayman (2010). The CoW dataset includes multiple factors about each war and a numerical variable for the outcome of each war (e.g. 0 is a loss, 1 is a win).

The data appended to the CoW dataset adds a binary marker to signify the existence of failure on a true/false basis. If no failure occurred for a state during a war, the state's binary failure entry was marked with a zero (0, false). Conversely, if one (or more) supply chain failure(s) occurred for an entry, the binary failure entry was marked with a one (1, true).

Based on our coded dataset, the regression methodology for analysis will be introduced next.

2.2.10 Choosing the Regression Model

One possible method of predicting the impact of supply chain failure on war outcome is to use the Linear Probability Model (LPM) to perform a multiple linear regression. Such an approach has the benefit of direct inference, i.e. being able to directly interpret the results. The LPM uses Ordinary Least Squares for the calculation and the binary outcome variable takes the form:

$$Pr(Y = 1|X_1, X_2, ..., X_k) = B_0 + B_1X_1 + B_2X_2 + ... + B_kX_k$$

However, the LMP's flaw in our application is that it assumes the dependent variable is continuous and therefore does not restrict the probabilities between 0 and 1. While this is acceptable for many other types of analysis, it is a shortfall which limits the LPM's utility (Aldrich et al., 1984) and therefore makes it inappropriate for this study.

To accommodate for this specific constraint, the Logit and Probit regressions are considered, both of which work well within the binary space. The Logit regression utilises the cumulative standard logistic distribution function and takes the following form:

$$Pr(Y = 1|X_1, X_2, ..., X_K) = F(B_0 + B_1X_1 + B_2X_2 + ... + B_KX_k)$$

whereas the Probit regression utilises the cumulative standard normal distribution and takes the following form:

$$Pr(Y = 1|X) = \phi(B_0 + B_1X)$$

whereas both the Logit and Probit models appropriately handle binary outcome variables (Stock and Watson, 2015). Despite their slightly different approaches in the calculation, the Logit and Probit models also yield similar results. Therefore, as noted by Tadelis (2013), the choice between them is often based on ease of use for the researcher and on software preference.

In the enclosed analysis, the Logit method is used due to the convenience of its interpretation as the log-odds probability, which is intuitively clearer than the Probit result. However, a comparison is performed for robustness to ensure the calculations deliver similar numerical results, and therefore similar insights.

2.3   Application to Dark Supply Chains

Chapter 6 applies the learnings from all of the prior chapters (on intervention methods and supply chain failure) to the trafficking context. In this section we describe the rationale for this approach.

After the use of game theory and econometrics methods to find solutions to the research questions around human trafficking, it is necessary to apply these learnings. The necessity is born from the idea that by taking the theories beyond their conceptual form, we can show their tangible impact, enable future use, and inspire research.

As introduced in Chapter 1, the case of human trafficking is the main area of focus for this thesis. Though this remains a focus area, we must first take a larger scope to introduce and define these types of supply chains.

2.3.1 What is a Dark Supply Chain?

The previous sections of this chapter utilised a sample typology of supply chains to show the overlap that exists between retail, military, and other types of supply chains, including those of underworld (i.e. illegal) organisations. We now give those types of supply chains a name.

We use the term *dark* to describe a supply chain that operates outside of the legal or business frameworks of its area or jurisdiction. However, this does not imply that the supply chain is immoral. A *dark supply chain* purposefully exerts effort to remain hidden from legal purview, knowledge or surveillance.

A positive example of dark supply chains can be the migration businesses that smuggle people from dangerous nations or states to safety (e.g. the underground railroad which freed runaway slaves in the United States). Though illegal, this may not be immoral as it saves lives. However, there are many negative examples of dark supply chains as well, such as those of illegal drug distribution, forced labour, and the illegal sale of weapons.

For the remainder of this thesis, our discussion of dark supply chains will only refer to those enterprises which operate for nefarious, immoral purposes, putting aside more altruistic endeavours. Continuing with the prior mappings, we can visualise the supply chain of human trafficking as shown in the figure below.
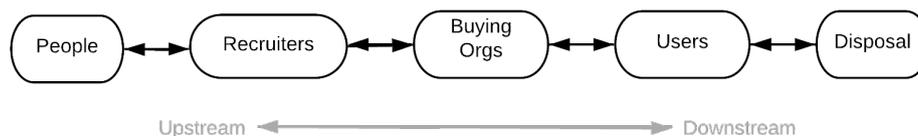
Figure 7: Supply Chain Mapping - Human Trafficking

In the above figure, we see that Raw Materials have been replaced by *People* and Manufacturers have been replaced by *Recruiters*. Recruiters are the entities responsible for finding and bringing persons into the supply chain of human trafficking. These persons are then bought by regional or global *Buying Organ-*

isations, transported to a distribution point where they are sold for a period of time to the *Users* (a person or entity).

The Users will utilise that person until they are eventually discarded or re-purposed. It should be mentioned that it may seem coarse to speak about people in this way (i.e. as a commodity); however, it is accurate and ensures that we understand how these supply chains work without the impedance of discretion.

This discussion is necessary to appropriately set the stage for later discussing vulnerabilities in this illicit supply chain. Most importantly, we see that the design of a trafficking supply chain is similar to retail and military supply chains, which presents the notion that their weaknesses may also be similar as well. We will return to the operations of dark supply chains in the following chapter.

2.3.2   Case Study: The Choice of Peruvian Gold

The use of a case study evaluation was deemed to be the best approach to this field of qualitative enquiry based on a comparison to ethnography, grounded theory, and quasi-experimental evaluations (Yin, 1992).

The choice of a case study, illegal gold mining in Peru, was chosen for three key reasons. First, due to its sufficient level of depth, which enables our analysis to be performed (Yin, 1984). Secondly, it has a connection to both human trafficking and corporate supply chains, which fits the quantitative chapters of this thesis. Third, the availability of data through a reputable report that is published, accessible, and sufficiently provides the necessary insights required for evaluation. In this case, minimal iteration was required due to sufficient theory built from Chapters 4 and 5, as well as to avoid theoretical saturation, as described by Eisenhardt (1989).

2.4   The Methodological Fit

The remainder of the thesis will dive deep into analysis on dark supply chains, and specifically that of human trafficking, through the use of the analytical methods reviewed in this Methodology chapter. The specific quantitative methods (game theory and econometrics) were chosen for theoretical analysis due to their specific fit with the research questions discussed in the Introduction chapter. These quantitative methods are especially useful because of their numerical flexibility. However, every effort was taken to do justice to the distinct quantitative and the qualitative methods employed and thereby limit the disjuncture between them. For example, each chapter has a self-contained analysis section based solely on the specific method used for the research question at hand. In Chapter 6, when applying the learnings from the chapters, there is also caution given to avoid combining assumptions or over-generalisations.

Furthermore, within each chapter there is a discussion on how the distinct model or data were analysed, thereby communicating the nuances in approach and highlighting areas of weakness for the potential of alternative considerations.

Based on this multi-method approach, it is worth noting that the contributions of this thesis are not only the findings but also the unique use of the methods themselves. Based on our literature survey, it is rare to find this combination of analysis, and it perhaps matches the rarity of such a supply chain study that seeks to break a business rather than optimise it. Thus, the unique combination of methods, though utilised as tools due to their ability to answer the specific research questions at hand, ultimately also delivers a product that perhaps can be considered itself novel.

3   Dark Supply Chains

This chapter defines dark supply chains as a critical area of study within the field of supply chain management. To build a foundation for research, we review the structure and operations of some common dark supply chains that are currently harming human life. We begin with a review of the dark supply chain of drugs, followed by our main focus for this thesis: the dark supply chain of human trafficking.

3.1   Introduction

In 1971, United States President Richard Nixon stood at the helm of the White House podium, looked into a live camera broadcast and declared to his nation that it was embarking on war. The war, he said, was a "War on Drugs." He would then go further by declaring drug abuse as "public enemy number one." In the almost 50 years since that declaration of war, the United States illegal drug industry has only increased. In its war on drugs, the United States has spent over one trillion dollars (Wainwright, 2016). Despite its investments in the war effort, the U.S. is losing. As of 2016, drug abuse kills over 170 people per calendar day in the U.S. alone (Hedegaard et al., 2017). Unlike the Cold War or any other wars before it, the country continues to bleed from this clash of wills between the dark supply chains of drug cartels and a government that seeks to bar its operation.

The war on drugs can be considered as an ongoing societal struggle with vice. Our wars with vice, or the participation in illegal or immoral habits, is innate and has alternating political ideologies. For example, Britain participated in the Opium wars to ensure that the Chinese continued to buy the drug, following which Britain banned the sale or production of it on its homeland (Booth, 1998). Currently, the annual global sale of illegal drugs is estimated to be worth approximately $300 billion per year (UNODC, 2018a).

There is, as shown in the previous chapter, another dark supply chain which operates in the shadows. It is dangerous because it is not only about vice, but also

bores into the heart of human economics: the sale of people, what we refer to as the supply chain of modern slavery. Slavery is unfortunately not a new phenomenon, yet the modern iteration of it is particularly horrid because it exists despite the fact that it is completely outlawed in every country. It is estimated that approximately 40.3 million people are currently enslaved today, more than at any point in history, of which 24.9 million are in forced labour (ILO, 2017a).

In this chapter, our objective is to answer the following question: *How can we better understand dark supply chains?* To answer this, we consider how dark supply chains are formed, structured, and how they operate to enable the illegal sale of materials and human beings.

As discussed in Chapter 2, illegal organisations have access to almost any supply chain tool currently used by companies and some militaries to date. We will establish an understanding of past supply chain failures in Chapter 5 and apply our learnings to consider how to counteract the supply chains of an illicit business (the 'underworld' of dark supply chains). For although human slavery and drug cartels are not the phrases that come to mind when we think of supply chains, they should be. The upper-world (i.e. legal) supply chains of major corporations (such as UPS, Amazon and Wal-Mart) do not exist or progress in a vacuum, as their underworld (i.e. illegal) counterparts similarly progress and learn from the movements of their upper-world brethren in their unyielding goal of delivering illicit products and services to global consumers.

There is a vital need to increase research in the activities of illegal supply chains. This is especially true in the business field which has the particular tools to holistically analyse global business trade. Despite what (or who) is being sold, these supply chains constitute businesses. Therefore they can, and should, be analysed using business tools.

Our analysis includes a detailed account of the structural properties of common dark supply chains, including an overview of their basic economics and logistics systems. To answer our questions, we create a foundational overview to classify dark supply chains along with their related vulnerabilities.

In this chapter, we focus on the illegal sale of drugs and humans because they constitute two of the largest illegal economies. The annual global spend on illegal drugs is estimated to be approximately \$300B (UNODC, 2018a). For human slavery, it is estimated to be \$150B (ILO, 2014), which is more than the £125B combined income of Apple, Berkshire Hathaway, Toyota, Alphabet (Google's parent company), and IBM (\$53B, \$24B, \$19B, \$16B, \$13B, respectively) in 2016 (Fortune, 2016).

The current illegal market size represents an increase from prior years (UNODC, 2018a). However, despite the massive amounts of capital involved and the growth in this sector, there is limited business literature on these topics. This gap can be partially attributed to the lack of accessible business information on dark supply chains. There is, however, information available from related fields, such as gold mining, that can shed enough light to ascertain a basic supply chain analysis, which the author of this thesis aims to provide in the latter chapter "Breaking Dark Supply Chains."

We note that there are many ongoing debates in the analysis and categorisation of illegal trade, and we do not seek to engage within or lean in any direction within those debates. Our goal is to offer insights and findings based on focused research on current human trafficking issues. We will use these findings to analyse supply chain vulnerability in Chapter 5. We hope that in the future others can take this further in similar endeavours to better understand these nefarious enterprises.

To the best of our knowledge, this thesis is the first establishment of dark supply chains in the business context. Furthermore, we analyse their structure and key methods of their operation. By understanding the underlying dynamics and incentive structures, we derive insights on what is required for a dark supply chain to exist and ultimately how intervention methods, some of which are currently in implementation, could hinder their operation.

Though the findings herein may have implications for governments, NGOs, and corporate programs that aim to effectively invest resources to combat illegal business operations, this research is primarily intended to fuel discussion and

debate and is not meant to be a prescriptive text.

3.2   Definitions

As introduced in the previous chapter, we define *dark supply chains* to be supply chains that attempt to remain hidden and operate outside of legal or business frameworks of the geographic regions they are in. Dark supply chains are often referred to by other names, such as *trafficking networks*, *transnational crime groups*, or *organised crime groups*. Such groups are commonly said to operate in the *black market*, a colloquial term used to refer to economies that are unregulated, informal, or operate in the shadows (Feige, 1990). However, no matter what these businesses are called or what the underground market is referred to, these are businesses like any other which operate to deliver products to consumers in exchange for compensation.

The following differentiation of terms is for the purposes of clarity and consistency.

Legal vs. Illegal

Dark supply chains have adapted well to the global economy. It is relatively easy to surmise what they do to protect themselves: look at major companies, their legal counterparts. By keeping a darker context in mind, it is possible to read reports or business journal papers on resiliency to understand how illegal enterprises may also be securing their operations.

Often, such businesses are referred to as *organised crime groups*, defined by the United Nations as "a structured group of three or more persons, existing for a period of time and acting in concert with the aim of committing one or more serious crimes or offences as defined in the United Nations Convention against Trans-national Organised Crime, in order to obtain, directly or indirectly, a financial or other material benefit" (UN 2010). This definition, although perhaps useful for reporting, is essentially the same as any other company, though the words "crime" or "offences" have been used instead of the word "business".

Thus, it can be inferred that organised crime groups are portrayed as villains because of their lack of lawlessness. This type of labelling may create a false narrative that there are two types of organisations: righteous or otherwise, similar to the common disparity between good and evil.

Often, however, there is a large area of grey between the black and white split that we see. To begin with, legality is a dynamic categorisation, as laws frequently change in their specification of admissible and inadmissible acts. Prohibition (of alcohol or other items) has gone in and out of fashion in many countries, where what was once legal became illegal, then became legal again and may continue to change in the future.

We can take the drug industry as an example. The number of global human deaths caused by tobacco, which is legal in almost every country, is more than 7 million per year. More than 6 million of these deaths are directly caused, whereas approximately 890,000 deaths per year are caused by second-hand smoke (WHO, 2017).

When compared to the estimated less than 1 million annual deaths directly caused by the most commonly used illegal drugs, including opiates, cannabis, and cocaine (UNODC, 2018a), the number of deaths by tobacco is substantially higher. So why is tobacco legal in most countries, whereas the others are not? Part of the reason can be the risk of an overdose with commonly used illegal drugs, which when taken in excess are linked to fatality and therefore rallied against. But this begs the question, is tobacco also not directly related to fatality? This is an example of the grey area between the black and white, between legality and illegality. For those who run businesses, it is hard to determine what may be made legal or illegal in the future and this is sometimes deemed insignificant compared to consumer demand.

This dovetails into the continuing issue of legality compared to practice. For example, slavery is outlawed in every major country in the world; however, slavery continues to persist and grow in numbers according to the ILO (2014). This can be seen across human history and persists to today. George Washington, America's first president, created the United States Navy to protect Americans

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from being put into slavery from Algerian pirates. Yet, until the end of his life, George Washington owned slaves (Ferling, 2010). Incidentally, he only allowed his slaves to be freed after his death because, though he knew human slavery needed to be stamped out in the future, he took advantage of its contemporary benefits.

Similarly, India currently has laws against slavery, yet its ongoing caste system directly creates a hierarchy of people, casting some as top-tier and others as bottom-tier (e.g. untouchables), thereby propagating inequality into societal function. This is mirrored in other countries which tie labour to citizenship rights, this being one of the ways conflict is created between living labour and labour power (Lilley and Papadopoulos, 2014). This is exacerbated when companies prey upon those who need work and are *willing* to accept lower income positions and poor working conditions, as seen in garment manufacturing in India (Ellis, 2015).

If legality is an ever-changing classification, where can one draw the line of what is right or wrong? In our analysis, we delve into the grey area to tease out meaning and structure. We purposefully limit our personal opinions in the hopes that the reader may come to their own perspective when presented with the information herein.

Trafficking vs. Smuggling

We use the Palermo Protocol (United-Nations, 2003) definition of trafficking: "the recruitment, transportation, transfer, harbouring or receipt of persons, by means of the threat or use of force or other forms of coercion, of abduction, of fraud, of deception, of the abuse of power or of a position of vulnerability or of the giving or receiving of payments or benefits to achieve the consent of a person having control over another person, for the purpose of exploitation. Exploitation shall include, at a minimum, the exploitation of the prostitution of others or other forms of sexual exploitation, forced labour or services, slavery or practices similar to slavery, servitude or the removal of organs."

In addition to this definition of trafficking, a delineation in terms that we seek to

clarify is the difference between trafficking and smuggling in the movement of persons. Both terms refer to an illegal movement of some kind; however, we use trafficking, especially in the context of humans, to signify a movement against the will of the person being moved (in addition to the illegality of the act).

Alternatively, we consider human *smuggling* to involve the willing movement of people. This can be related to autonomy of migration (Papadopoulos and Tsianos, 2013). Though smuggling may involve some violations of laws or human rights, it does not necessitate it for the purposes of illegally moving persons from one country to another (UNODC, 2011). Terms such as forced labour or exploitation (i.e. slavery) are used to signify forced work or actions upon people who are unwilling. These definitions are in line with the literature. For example, Salt (2000) and Wheaton et al. (2010) make the same delineation between trafficking and smuggling as used herein.

Demand-side vs. Supply-side

Demand-side refers to the consumers or participants who are purchasing from the market. Therefore, any programs or efforts to reduce demand-side participation will focus on the downstream portion of the supply chain. *Supply-side* refers to the procurement of raw materials into a dark supply chain in order to supply the process and market, where the focus is on the upstream.

Dark vs. Immoral

Although the word "dark" brings up connotations of illegality or illicit behaviour, this is not necessarily the case. For example, in this chapter, we will discuss dark (i.e. hidden) online activity, yet privacy researchers agree these are not necessarily immoral (Barratt and Aldridge, 2016). For example, the hidden parts of the dark web can be used to provide anonymity to journalists, facilitate freedom of expression, and remove barriers of censorship.

This is also true for businesses, where some businesses must remain dark in order to operate, yet they could be, by doing so, saving lives. An example of this would be smuggling people from war-torn areas to areas of safety. Smuggling is therefore differentiated from trafficking as willing movement performed with-

out force or coercion, whereas trafficking is done under force or coercion. However, such a comparison delineation is not exactly fair as there is a large grey area within the context of human smuggling, as there is often a lack of choice, alternatives, or knowledge (Anderson and Davidson, 2004).

For the remainder of this thesis, when we discuss dark supply chains, our analysis will focus on dark supply chains operating for illegal or immoral purposes, such as drug and human trafficking; however, it is important to explicitly state that dark does not necessarily mean immoral, just as immoral activities are not always dark.

3.3 Related Literature

The literature related to dark supply chains is vast and inter-disciplinary. It spans across the fields of law, political science, criminology, and economics. We call upon specific areas of each of these in turn to establish a grounding in related work. However, we do not claim to encapsulate or cover any field in its totality.

Underground markets and economies have long been a topic of study in the political science realm. Reuter (1985) lays a foundation for this research through his seminal work on the principles of industrial organisation, the movement towards illegality and the implications for crime control.

Through the use of nodal analysis, Campana (2015) details the communication links of a Nigerian human trafficking operation that trafficked women from North Africa to Europe. He found that most actors in the network are decentralised (i.e. arms-length consultants), each with minimal contact to other actors in the network.

Shelley (2003) discusses the underworld business model of trafficking, wherein she details its most common methods of operations into six distinct areas based on her analysis: repeated sale of women, labour smuggling, border smuggling, sex trafficking with violence, traditional slave trade, and the rational actor

model. Davidson (1998) complexifies our understanding of sex work and its relation to business, power, and freedom. Becker (1968) discusses the income and non-income (e.g. psychological) sources of profit from committing crime. Giles (1999) uses econometrics to form a method of measuring the hidden economy in size and value by connecting the hidden output to macroeconomic variables.

Wheaton et al. (2010) use rational choice theory to show how human trafficking operates as an economic market wherein traffickers operate in monopolistic competition. This includes the factors that lead to the supply of victims (e.g. vulnerability), the demand-side factors also detailed by Anderson and Davidson (2004), and the environment that affords the business opportunities for profit.

Criminology researchers have made great strides to understand and unlock the psyche of criminals and criminal networks, including their supply chains. Several previous studies were considered in our analysis, for example, Caulkins et al. (2009) performed an in-depth review of interviews conducted by Matrix Knowledge Group (2007) on drug traffickers captured for bringing illegal substances into the United Kingdom. The review outlines the various methods of entry, the organisation of drug networks at home and abroad, as well as the reasons people take up jobs in these networks.

3.4   The Structure of Dark Supply Chains

Trafficking organisations range from small to extensive networks and with local to global links. They utilise multiple modes of operating depending on their many products and each network relies upon multiple individuals to help with various tasks (Campana, 2015).

The network structure may vary depending on the business type, of which the top three are the sale of drugs, weapons, and humans (ILO, 2014). Though all supply chains transport three essential items (money, products, and information), the flow for each network may vary on the country of export, destination, or method of transport. There can, therefore, be unique methods of tackling

each type of business depending on those flows. In Chapter 6, we will discuss the case of the dark supply chains of Pervuain gold in detail, which in comparison to our prior analysis of human trafficking shows their unique yet similar structures.

Within transnational crime groups, it is believed that one form of criminality is commonly connected to another. Indeed, criminal organisations have been found to span across illegal activities including trafficking, prostitution, drugs, cars, and money laundering, as one type of illicit activity often begets another (Salt, 2000). In such circumstances, the financial activities may also be tied together, and unraveling one chain may eventually perturb or unravel its connected chains.

3.4.1   How to Stay Dark

Dark supply chains are structured like upper-world supply chains; however, they take purposeful steps to avoid detection or monitoring through a series of methods to hide their operations. The methods that dark supply chains use to stay dark may include the following:

Dark supply chains can avoid public financial records.

The transactions of buying, selling, and trading performed by dark supply chains are hidden or obscured from common bank ledgers. This is done through the use of hard currency (e.g. physical cash) or digital currency (e.g. digital blockchain variants without a public ledger), both of which offer a high degree of anonymity (Martin 2014). Dark supply chains may also open legitimate accounts in the names of others (e.g. with stolen identities), to have access to the global monetary system without directly connecting themselves to it.

The technological advancement of blockchain can, therefore, be considered a mixed blessing. On the one hand, blockchain enables dark supply chains to access financial markets in an anonymous fashion. However, on the other hand, it can also work against dark supply chains if implemented with regulatory over-

sight. An example of this is the current changes to the fishing industry to verify that fish being brought to market come from sustainable companies who are not using forced labour (Visser and Hanich, 2017).

Blockchain itself is relatively new. It was introduced in 2008 as part of the Bitcoin (a digital or *crypto-currency*) debut and although Bitcoin has had issues with its platform, the technology of blockchain holds significant promise (Iansiti and Lakhani, 2017). At its core, Blockchain seeks to be a unifying public ledger. A public ledger offers the benefit that it is universally accessible, can offer instantaneously verified transactions, and because it cannot be edited, all transactions are tracked and monitored. This seems like it could be a strong boon to financial transparency, yet it also works against it because transactions can be anonymous. As with any new technology, the methods of implementation will determine its level of legality. According to Iansiti and Lakhani (2017), it will take decades to truly understand the implications of blockchain; however, in the meantime, we can see it has already found a home across industries.

It is possible that in the future that crypto-currencies will be further regulated, but until then, Blockchain may be a double-edged sword that is holds the power to positively transform not only the companies we know, but also the dark supply chains we fight.

Dark supply chains can operate through intermediaries.

Dark supply chains can employ the services of reputable persons or businesses, with or without their knowledge. This may include paying a retail supply chain truck driver to intentionally hide their goods in a shipment, utilising extra capacity in air-shipment containers without the knowledge of the shipment consignee, or shipping illegal products via couriers (e.g. UPS, DHL) without accurately declaring the contents. In these examples, the dark supply chain is essentially feeding on established and legal supply chain operations (SOCA, 2006), yet perhaps without the knowledge of the registered supply chain operator (Ekwall, 2007).

Dark supply chains can operate on the dark web.

In order to take advantage of the benefits of the internet, without the risk of being easily identifiable on it, dark supply chains utilise dark parts of the deep web. The *deep web* is a lesser-known part of the internet that is not indexed by major search engines because the websites 'opt-out' or block indexing (i.e. searchability). The deep web contains reputable websites, for example, Facebook's non-public pages are not indexed by search engines are, therefore, part of the deep web.

However, parts of the deep web are considered *dark*, meaning that in addition to opting-out of indexing, the websites on the dark web purposefully take steps to remain hidden from tracking or surveillance. Such websites stay dark by requiring specific web-configurations to access them, utilising encrypted policies to anonymise their users and sometimes maintaining private network infrastructure. We refer to this private part of the deep web as the dark web.

Dark supply chains can use the dark web to communicate between organisations, advertise to consumers, sell products and arrange shipments, all in almost complete anonymity (Martin, 2014). Indeed, some dark supply chains avoid the internet altogether, instead relying on ad-hoc peer-to-peer digital communication networks which offer high levels of privacy (Campana, 2015).

We must reiterate; however, that dark does not necessarily mean immoral. Journalists and those seeking to avoid censorship use the dark web for freedom of speech, to learn, and to share knowledge.

3.4.2   The Supply Chain of Drugs

Overview

We begin with a description of the illegal drug trade, as it is estimated to be the largest illegal economy in the world (UNODC, 2018a).

The drug trade is an expansive industry that contains an ever-shifting number of major companies, smaller players and even recreational growers. The combination of these enterprises creates a panacea of options for customers and intense

competition between incumbents. The major cartels operate similarly to multi-national corporations, organising themselves across borders and continents to meet demand in their key markets, many of which are in the global north (Dittus et al., 2018).

Although logistics vary based on drug-source (i.e. plant growing areas), most major drugs (the two largest in trade being cocaine and opium) come from Central America, South America, and various parts of Asia (UNODC, 2018a). The source countries and trade routes will depend on the type of drug. Countries with tropical growing regions such as Columbia and Peru have been key suppliers of drugs derived from the coca plant, such as cocaine. Cocaine moves through land, air, and sea transportation corridors to its markets by using dark supply networks. A visualisation of the cocaine routes, from the UNODC's 2018 World Drug Report, is provided in the figure below.
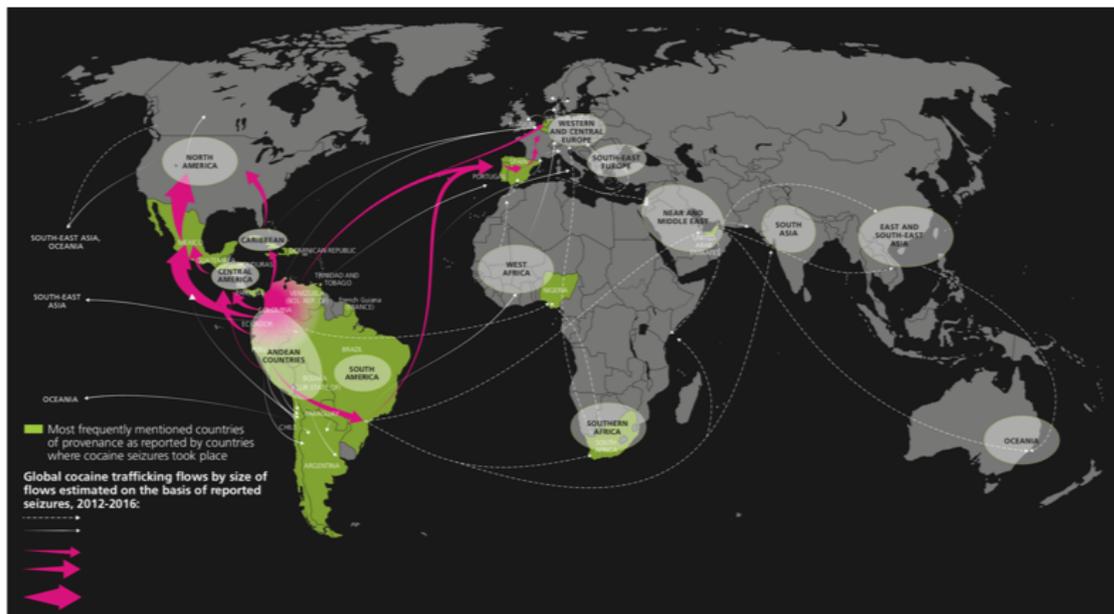
Figure 8: Main Cocaine Trafficking Flows (UNODC 2018)

Opiates, on the other hand, are estimated to have double the global land growing areas of cocaine, approximately 305,000 hectares compared to 156,500 hectares, respectively. Much of the worldwide supply of opiates is supplied from Central Asia, especially Afghanistan which in recent years has surged as a major culti-

vation region (UNODC, 2018a). Opiates come from the poppy plants, which are harvested, processed, and changed into a sellable product for worldwide distribution. The poppy plant can be transformed into opium, heroin, and morphine. It is estimated that in 2017, 652,000 people in the United States suffered from a heroin use disorder (CNN, 2017). A visualisation of the main 2012-2016 heroin routes, from the UNODC's 2018 World Drug Report, is provided in the following figure below.
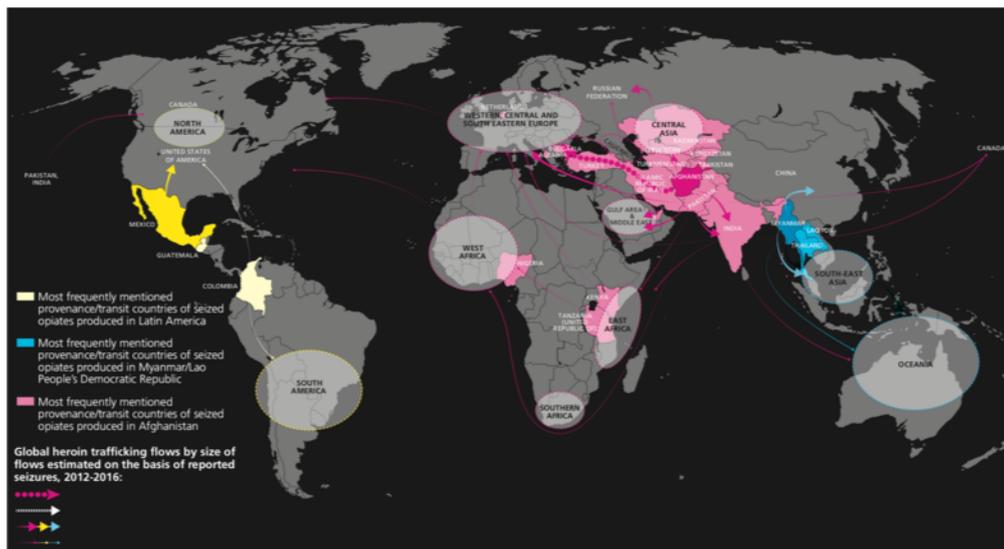
Figure 9: Main Opiate Trafficking Flows (UNODC 2018)

Plant-based drugs, such as those from coca and poppy plants, are accompanied by the supply of amphetamines, which are synthetic (i.e. manufactured) drugs, that are most commonly captured in the middle east, as well as central-to-mid Europe. One type, in particular, the drugs classified as methamphetamines, have had strong growth in North Africa and the United States, and in the latter, it is now the second most used type of drugs after heroin (UNODC, 2018a). A visualisation of the main 2012-2016 methamphetamine routes, from the UNODC's 2018 World Drug Report, is also included.

Drug cartels run the major operations, many of whom are affiliated with criminal gangs. Although the cartels obtain most of their supply from Central and South America, they can easily adapt to external threats by relocating their ar-
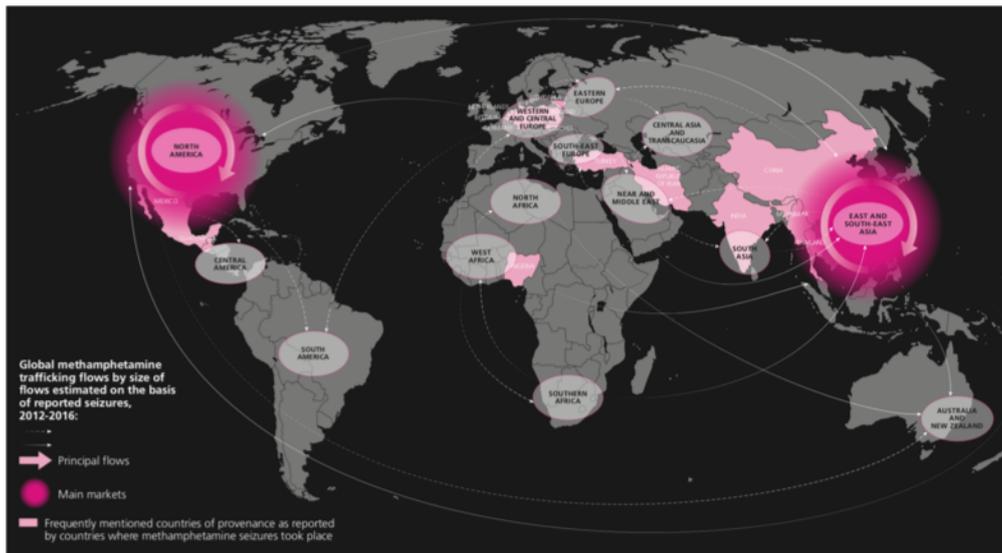
Figure 10: Main Methamphetamine Trafficking Flows (UNODC 2018)

eas of operation as needed to reduce detection and thereby continue production. The price of drugs remains fairly inelastic to production shutdowns, as the drug itself is relatively cheap to make and with such a high-profit margin (estimated to be in the tens of thousands of percent), the supply can be relocated and will continue to find new areas of cultivation (Wainwright, 2016).

Currently, the estimated annual business on illegal drugs is worth an estimated $300 billion per year (UNODC, 2018a), approximately double the annual sale of human beings (ILO, 2014), which we will discuss next. However, it is important to point out that these large profits come at a real cost societal and with the detriment of human health.

3.4.3   The Supply Chain of Humans

Overview

The supply chain of human beings has a similar structure to other common illicit supply chains (e.g. drugs, weapons), yet here the products are real people who are being bought, sold, and used against their will. Slavery is not a new

phenomena, as a reliance on forced labour in business and war has existed for a substantial part of human history; however, the startling truth of slavery today is that it is larger (in numbers), and cheaper to own a person, than it has been at any time in modern history (Wheaton et al., 2010).

Sourcing of human trafficking victims (i.e. products) usually begins with human need. People in need often look for help due to lack of resources, safety or opportunity in their home environment (Salt, 2000). Recruiters visit cities and villages advertising a way out, transportation and a job in another place. Consequently, it is estimated that 95% of trafficking victims are taken away from their home city (Salt and Stein, 1997). After leaving their origin point, the person (i.e. product) is transported to their use point. The UNODC estimates that 60% of trafficking victims are exploited outside their country of origin (UNODC, 2016). This transit could take days, months, or years depending on where the client who ordered the product is located and how long it takes to get there while taking precautions to avoid detection, as well as monitoring the product along the way (Salt and Stein, 1997).

Upon arrival to their destination, products are integrated into their new "life." This involves confiscating their identification documents such as passports, where they are told such documents will be kept until they pay back their *recruitment fees*, i.e. fees charged to the victims by their new owners to recover the cost paid for them. This step makes it almost impossible to escape their new location without a form of identity (Salt and Stein, 1997). The illegitimate fees that are levied upon the victim can be in the hundreds or thousands of US dollars and may increase with extortionate interest rates and additional fees for food, clothing, and board, making it even more difficult to pay back their growing debt (Hepburn and Simon, 2010). These fees are all on top of the fees paid to the original recruiter to help relocate them to the new job.

Products may remain with their clients for years, performing a variety of services including forced labour, prostitution, or unwillingly offering organs while being subjected to physical abuse (Salt and Stein, 1997). When products are no longer valuable to their clients, they are discarded, sold onwards, or if they have

paid their debt, they may be let go. In this latter situation, products sometimes return to the industry as recruiters or clients themselves, as they have grown accustomed to the system and find it difficult to leave (Campana, 2015).

Of the victims, it is estimated that 98% exploited for sex are female and up to 50% exploited for forced labour are children (Hepburn and Simon, 2010). As for the perpetrators, the risk of conviction for trafficking humans is lower than the conviction risk for travelling drugs or weapons (Wheaton et al., 2010). Often, this low conviction rate is due to the burden of proof required, historical lack of prior regulation on trafficking, and competing politics on the crime (Anderson and Davidson, 2004).

These are some common human slavery routes which are known by law enforcement due to the large amounts of people that transit through them. Generally, these routes include women taken from Latin America, Africa, and East Asia being transported to various parts of the northern hemisphere including the U.S. and Western Europe (Salt, 2000). One such route which gained substantial attention was the smuggling of Nigerian women to Italy (Campana, 2015). It is estimated that 12.5% of the over 40 million humans in slavery are currently forced into the sex trade, whereas 37.5% are in forced marriage and 50% are in forced labour (Alliance8.7, 2017).

Example: India's Brick Kilns

Though India outlawed debt bondage in 1972 (Economist, 2012), the financial practice continues to this day, thereby capturing individuals and families in a form of perpetual servitude. A particularly notorious industry for debt bondage is that of brick making.

The expedited industrialisation of India's economy has led to high demand for building materials such as bricks, and migrants are often lured to work in this manually intensive job with large upfront payments (Wainwright, 2014). However, absorbent fees and interest rates are levied upon migrants once they begin their work which can lead to a cycle of indentured servitude.

An estimated 2 million workers are employed for brick making in India who

each earn, at most, £0.125 per hour and are aged as young as four years old (Hawksley, 2014). The country has over 150,000 of these brick production kilns, many of them located in the region of Andhra Pradesh, with many of the migrants coming from the nearby state of Orissa in search of work (Wainwright, 2014).

Perhaps the worst part of this business is that it difficult for workers to leave due to the situation of bonded labour. The freedom to leave is directly blocked by financial obligation and escape can be disastrous. An example is the documented cases of those trying to leave heaving their hands amputated as punishment (Wainwright, 2014). Staying also creates further consequences as the health of workers and their families diminishes due to hard labour, unsanitary conditions, and the polluted air near the kilns. Thus, workers are captured and have no options to escape, only to work and potentially at their own detriment.

Relation to Migration

One facet of human slavery which is exemplified in the example of India's Brick Kilns is that of a human's need for survival. This need to survive, and often to support the survival of others, leads to the search for work and thereby the risk of capture into slavery. The migration of people across cities, regions, and countries is not atypical, as it is a phenomenon which has existed throughout history. However, there is a recurring theme of risk associated with migration and being caught into slavery. It is this link between economic migration and the risk of slavery that we must highlight. For without the vulnerability of people, the dark supply chains that sell people would have a more difficult time ensnaring its product.

3.5 Current Prevention Schemes

In the previous sections we reviewed dark supply chains, their operations, and the impact they have on human life. We now review the current methods in which governments and non-profits have taken action to stop them. These methods are separated into discussion on two areas: direct and indirect enforcement.

We pay particular attention to preventing the dark supply chain of human trafficking, as it is a key area of focus for this thesis. Following this, we compare the current intervention strategies with potential vulnerabilities.

3.5.1   Direct Enforcement of Dark Supply Chains

Currently, 176 countries around the world are party to the Palermo Protocol, which details the standardised government approach used to respond to human trafficking worldwide. Through the "3P" approach of Prevention, Prosecution, and Protection, governments have a basic framework for directing their anti-trafficking efforts. However, this is not straight-forward and indeed, the implementation of this basic framework has been difficult (Anderson and Davidson, 2004). Based on this critical problem, in Chapter 4 we will model the 3P framework and analyse an optimal budget allocation which requires forethought and an understanding of the structural dynamics that drive forced labour in supply chains.

Below, we provide some examples of specific implementations of anti-trafficking programmes.

The South Florida HT Task Force

In the 1980s, it was common for speedboats to make drug runs (i.e. shipments) from the Caribbean to Florida. This was shut down by the South Florida Task Force, an initiative created by President's Reagan and Bush which dried up the movement of drugs along that corridor and forced it through Mexico and other alternative maritime or air routes. The success of the South Florida Task Force for drugs led to the South Florida Human Trafficking Task Force (SFHTTF, 2019), which is funded by U.S. grants and works with a variety of stakeholders to protect victims of trafficking and combat organisations who seek to enslave persons. Similar human trafficking task forces have been created across the U.S.

The Barrier Model

The Netherlands has implemented a system known as the Barrier Model, named

as such because of the six barriers it seeks to build to prevent criminal organisations from human trafficking. The barriers are developed in: recruitment, entry, residence status, housing, work, and financial (Aronowitz and Dahal, 2014). The barrier model's approach to each of these is briefly discussed below.

The *recruitment* barrier addresses the illegal activities which take advantage of vulnerable populations in looking for labour, charge recruitment fees which may lead to debt bondage, and the use of deceit to capture persons into trafficking. These are addressed through awareness campaigns, creating clarity around jobs, accessibility of legal aid, prohibiting recruitment fees, and creating cross-border communication between recruitment agencies.

The *entry* barrier challenges immigration services to increase screening of migrants for signs of trafficking. This involves thorough visa screening, border checks and coordinating with embassies in origin countries to ensure entry data is valid. There are also roles played by labour inspectors who can be trained to identify forged documents.

The *residence* status barrier acknowledges that migrants may not be aware of the differences between governmental organisations. Due to this, traffickers can instil fear of inspectors, police, and other government services personnel into migrants. To overcome this fear, employment agencies and government ministries can work together to reach out to migrants, provide critical information on workers rights, and liaise with police as needed to ensure human safety.

The *housing* barrier capitalises on the fact that people need to sleep somewhere. This barrier places a critical burden on inspectors, employers, landlords, rental agencies, handymen, and communities to keep vigilance for persons that have cramped accommodations, are sharing a space with many others, or are living in other abnormal conditions. By looking for and reporting these signs, victims of trafficking can be found and their traffickers can be tracked down.

The *work* barrier seeks to enforce relevant regulations against illegal labour. This is accomplished through interactions with employers, performing workplace inspections, preventing conditions that are ripe for trafficking, working with

government suppliers, and communicating with migrants. The United States follows a similar approach with its use of H-2 visas.

The *financial* barrier seeks to prevent the economic incentive for human trafficking by eating away at its profits. A potential avenue for this is working with companies to identify suppliers or competitors who are using unfair businesses practices or preventing transparency. Working with police, this can involve tracking the financial accounts of current investigations to find others who may be involved, thereby disabling those assets.

3.5.2   Indirect Enforcement of Dark Supply Chains

Public Reporting

A concerted effort toward transparency has led multiple government and non-profit agencies to publicly report illegal acts. We will highlight three examples of this which relate to ethical labour practices.

First, each year the United States Department of State publishes a *Trafficking in Persons* (TIP) report (Dept-State, 2018), which compliments the UNODC's Global Report on Trafficking in Persons (UNODC, 2018b). The TIP report contains the U.S. view on human trafficking worldwide and details the individual efforts of other governments, described by country, to fight this dark supply chain. The TIP report is made freely available and publicly criticises governments who are not contributing to fighting human trafficking.

Second, the *JUST Index*, established in 2013 by the non-profit JUST Capital, ranks companies by their level of *justness*, a combination of socially-concerned ethical factors (JUST-Capital, 2018). The resulting index is a list containing hundreds of companies, rank ordered by their approach to ethical business. The list is publicly available and contains details on why a government received their rankings, in addition to outlining the areas of importance to ethical companies.

Third, the non-profit company Verite has established a platform entitled *Cumulus*, which enables companies to map their supply chain partners and see if the

entities in their supply chain have been linked to unethical labour treatment in the past (Verite, 2019). This can serve two key functionalities. Initially, it allows for clarity in past malpractice. However, it also helps companies to map out their current extended supply chains to better understand areas of risk. The database behind Cumulus is kept online and continuously updated by Verite.

Public Campaigns

Awareness is not limited to companies, governments, or NGOs. A key way of preventing human trafficking is also through awareness campaigns that push their way into the general public's perception of the problem. Such awareness campaigns help educate the public on the issues and warning signs of human trafficking, as well as provide resources to contact the relevant authorities if in need of help.

Worldwide campaigns have been launched to educate the public through advertising and engagement. For example, the Blue Heart campaign established by the UNODC creates involvement from multiple stakeholders to inspire action (UNODC, 2019). The blue heart logo offers recognition for the plight of those being trafficked and, more importantly, offers resources including funding for victim rehabilitation through the Trust Fund. The Trust Fund provides help to victims to be identified and given protective assistance. The Blue Heart campaign is mirrored in local regions, for example in the United States, the Department of Homeland Security runs the Blue Campaign to spread awareness of human trafficking (DHS, 2019).

One way to reach vulnerable populations and even potential customers of victims trafficked for prostitution (referred to as *Johns*), is by providing knowledge to populations that are vulnerable or ill-informed. The Prevention Project does this through teaching middle and high-school students the fundamentals of trafficking, the signs to be cautious of, and how to act as abolitionists in their own localities (Prevention-Project, 2019).

Corporate Training

Due to consumer backlash and legal requirements, many corporations have be-

come aware of human trafficking and how it can infect their own business structures. To prevent this, corporate training exists to map out supply chain vulnerabilities (see Verite Cumulus example above), and how to identify victims who may be in the process of transportation through supply networks, such as travel routes through air, train, or bus.

The non-profit Airline Ambassadors accomplishes this through training airline staff to keep, in their words, "eyes open" to persons who may be moved against their will during the transportation process (Ambassadors, 2019). This has resulted in success stories, such as a flight attendant who recently saved two girls that were being smuggled on a short-haul flight within U.S. borders, from Seattle to San Francisco (NBC, 2017). The same type of training is happening at border control stations and train depots in the hopes that victims can be recognised and assisted to safety by a more vigilant corporate workforce.

Protect Victims

One of the more sensitive issues with fighting human trafficking is the protection of victims who have been rescued from these dark supply chains. This is important not only because of their humanity but also because it prevents victims from potentially being pulled back into the same position again.

Limited budgets can make governments focus on demand-side reduction rather than supply-side reduction due to the higher efficiency of funds in the latter. However, missing out on this supply-side reduction is also critical for eliminating the problem (Wheaton et al., 2010). In the human trafficking field, it is often noted that governments should take the 3R approach of Rescue, Rehabilitation, and Reintegration into society (Konrad et al., 2017). This, of course, begins with finding the victims, an area where the interface of breakthrough technology can help through the combination of social media, data analytics, and facial tracking. Rescue is performed with the help of law enforcement and non-profits (Bales, 2007).

Rehabilitation and Reintegration into society seem straight-forward, but these are actually very dangerous points in the 3R process for a victim. This is due

to the fact that, in order for the victim to have initially been enslaved into the system in the first place, they may have been vulnerable beforehand. Thus, if being rehabilitated, long-term protection against recidivism into slavery must be considered and implemented as well (Bales, 2012).

3.5.3   Previous Dark Supply Chain Failures

The Online Drugs Market

Online shopping has changed the way society sells and buys products, and this is no different for illegal goods. One such product line which is ubiquitous on the internet is illegal drugs. Whereas in the past drug sellers would need to meet their customers in person, now the entire transaction can take place virtually and across continents. A recent study of popular online drug markets has concluded that the majority of online transactions occur in the country of demand rather than the country of production. For example, research has found that a majority (approximately 70%) of online buyers and sellers of cannabis are located in Western countries which are consuming a majority of the drug (Dittus et al., 2018), a departure from the days of old.

The most infamous example of an online dryg marketplace is the Silk Road, a dark web platform which is estimated to have sold approximately $200 million worth of drugs in its two and a half years of operation before the platform was shut down (Wainwright, 2016). Often referred to as an eBay for controlled substances, the Silk Road sold a wide range of items from sellers mostly based in the U.S. to buyers located across the world who paid for the goods using Bitcoin (Christin, 2013).

An integral part of the Silk Road's operation was that access was made by using the Tor browser, often called the 'onion browser' due to its multiple layers of anonymising traffic management, a technology originally created by the U.S. government to create anonymity for online users (BBC, 2015). The Silk Road required the Tor browser for access to its site and therefore users and administrators of the online market maintained anonymity for over two years. However,

due to a lapse in security prior to the launch of the site, the owner of the platform was identified, arrested, and the site was shut down in 2013 (BBC, 2015).

However, the Silk Road was only the beginning of large, openly accessible markets for the dark supply chains of drugs. Multiple sites sprung up after the shutdown, two of the biggest being Alphabay and Hansa. By 2017, Alphabay was estimated to have ten times the amount of sales of the Silk Road and was using the same technologies, Tor and Bitcoin, for anonymous access and transactions. To combat this, governments across continents coordinated an infiltration strategy where the site's servers were taken over and the system was monitored to capture user data, passwords, and transactions. After months of surveillance, the sites were shut down (Gibbs and Beckett, 2017).

Following this, the tactical knowledge of shutting down online markets was shared across countries and methods for finding and attacking future sites were standardised between governments (Gibbs and Beckett, 2017). However, law enforcement agencies admit that they will need to continue this work for future versions of sites which continue to open up. The reason for this continued existence, we surmise, is due to the continued existence of demand and supply for illegal products which the conventional marketplace cannot satiate, harkening back to our wars with vice.

Human trafficking between Northern Africa and Europe

Our summary below is focused on the trafficking of victims between Nigeria and Italy which were detected by government officials. The information herein is based on a research paper by Campana (2015) who used Italian police records on a human trafficking group to perform a network analysis and determine the structure of the organisation.

The route between Northern Africa and Europe is common because of proximity, economic and cultural factors in Northern Africa, combined with the demand for prostitutes in Europe. The case examined by Campana began in 2005 at a refugee camp in the Netherlands. Authorities found that over 100 women had disappeared from the camp, which led to an investigation with Italian au-

thorities. The authorities used hidden surveillance and phone taps to learn that the girls had been trafficked by flight to Italy to work as prostitutes. The specific structure of the trafficking group was quite large, as Campana estimates they would traffic approximately 200 women per year, typically two to three per flight on major airlines to avoid detection.

This specific trafficking group was intercepted by the police through targeted surveillance and monitoring of telephone conversations. The surveillance used by police allowed authorities to identify others involved and take the case forward for prosecution.

Human Trafficking in California

In the city of Los Angeles, police forces have increased their online presence to find potential victims, johns (clients), and recruiters of human trafficking. According to Bermudez and Mejia (2018), authorities have set up automated social media accounts which will pose as young girls, communicate with people who message them, and then tell that person what they are doing is illegal. Using this and other sources of information, police in Los Angeles recently arrested more than 500 people and rescued 56 victims as part of Operation Reclaim and Rebuild (Bermudez and Mejia, 2018).

3.5.4   Limitations of Current Schemes

In this sub-section, we discuss some key issues with the current approaches. This is done specifically within the topic of victim protection because of its importance and potential for improvement. The United States and almost every country around the world consider human trafficking is a crime; however, the protection of victims is made difficult because the laws have conflicting priorities. We provide two examples.

Our first example is with regards to the U.S. Immigration and Customs Enforcement (ICE) group. ICE has conflicting priorities because it is not only responsible for protecting the victims of human trafficking, but also for deporting illegal

immigrants. This is a multi-layered conflict because ICE also maintains a certain number of detention beds for persons it holds in custody, and it is expected to use those beds as part of a quota-like system to ensure that ICE deports as many people as possible (Miroff, 2019). The ICE budget is directly tied to the number of beds they maintain, and therefore they are economically incentivised to deport, and perhaps not necessarily to go through the aforementioned 3R process properly. Furthermore, potential victims are instilled with fear by traffickers and told that ICE will arrest them rather than save them, and therefore victims are less likely to seek help from ICE.

Our second example is victim protection. Unfortunately, a significant amount of focus (even in this thesis) is given toward crippling the business of trafficking. This is difficult and clearly not enough progress has not been made because the number of people being trafficked continues to grow over time. However, such intense focus on the trafficking organisations has often led to a neglect of the victims at the heart of it. This may include emotional or physical recovery, safety, and even the ability to live. Finally, the vulnerability that leads that person to slavery may continue to persist. This is described by Bales (2012) as rescuing people from slavery so that they can die, simply because slavery may have been the only thing keeping them alive, as their original vulnerabilities continue to exist. Thus, getting at the heart of human vulnerability is important, and also protects the relapse discussed in the prior section.

3.6 Chapter Conclusion

This chapter defined dark supply chains and provided an overview of their structure, operations, and steps that governments are taking to fight them. Through the use of examples, we also created an exposition of what dark supply chains look like, how they impact the economy and human life, and how they might be better understood.

This latter point, the need for being understood, drives at the core of this thesis's purpose. We seek to lay a foundation on which quantitative and qualitative

analysis can be performed to better understand dark supply chains. This would enable us to aid our fellow humankind that is being hurt by these organisations, quite possibly by going to war with the supply chains themselves.

Furthermore, this seeks to fill a glaring gap in the supply chain management literature. In our businesses, journals, and classrooms we, as business leaders, have a standardised curriculum that teaches the best practices in supply chain management. However, it is woefully inadequate at making the world aware of the other side of the coin: the dark supply chains that exist and infiltrate our economies without our knowledge. When we neglect to consider or share this darker side of supply chain management, it presents a false narrative that paints the practice of business in an overwhelmingly positive light. This chapter illuminates the other sides of business which need analysis, attention, and most critically, warnings to be delivered in order to raise awareness of the full picture at hand.

Finally, though it is repeatedly noted that *dark* does not necessarily mean immoral, the majority of the discussion focuses on illicit enterprises because this thesis, in the chapters that follow, builds on those foundations. For within this area of illicit activity, particularly in the dark supply chain of human trafficking, there is significant opportunity and need for the rigorous application of supply chain management tools.

4   Modern Slavery

In our Introduction chapter, we discussed three key areas of humanitarian research, that of disaster response, capacity building, and dark supply chains — specifically modern slavery. Modern slavery is an evolution of the insidious and age-old global business in which human beings are sold as products. The prior chapter classifies this business as a type of dark supply chain because it operates outside the boundaries of the law.

The slave industry is growing, currently valued at $150.2B in revenue per year (ILO, 2014) and an estimated 40.2 million people enslaved (ILO, 2017b), more than at any other time in history (Wheaton et al., 2010). This chapter will go deeper into the dark supply chain of modern slavery by analysing how to prevent its ability to infiltrate corporate supply chains.

When considering the multitude of areas for analysis within modern slavery from a supply chain lens, there are multiple perspectives in which to approach it. These perspectives may include the sourcing of victims (i.e. products), transportation, logistics, storage, inventory management, purchase, delivery, use or consumption, recovery, recycling, and disposal. Essentially, all areas of the supply chain are worthy of consideration. We must admit that these applied principles of business to human life sound grim, almost devoid of human emotion. However, this is the crudeness with which this dark supply chain operates. Therefore, to diagnose and disturb this disease, we must cross the lines of our own comfort and confront its true nature in order to find solutions.

While solutions can be found in any of the supply chain facets mentioned above, in this chapter we specifically consider *use*, because this is what drives the demand-side of human trafficking in the first place. If humans were unable to be used against their will, then the purpose of trafficking would be nonexistent.

According to the report *Profits and Poverty* (ILO, 2014), modern slavery capitalises on humans for three main uses: forced labour, prostitution, and organ removal. While all forms of slavery are deplorable, sexual exploitation is partic-

ularly heinous. The report states that prostitution earns the highest amount of profit per human, and accounts for an estimated 22% of victim population use. Organ removal represents the smallest use case (approximately 10%). Forced labour commands the majority, almost 70%, of humans used in modern slavery.

As forced labour motivates the lions-share of business for modern slavery, it is the area this chapter focuses on for intervention. The majority of this forced labour, approximately 90%, occurs in the private economy in the key industries of agriculture, construction, domestic work, manufacturing, mining and utilities (ILO, 2014). Therefore, the businesses we know and patron may be unknowingly capitalising on forced labour to produce the products they sell in its global supply chains. Companies, therefore, can be directly connected to modern slavery through their supply chains. This chapter will consider how governments can inspire companies to enforce ethical labour practices in their supply chains.

4.1 Modern Slavery in Corporate Supply Chains

Apple, Costco, and Wal-Mart have recently been charged with using slave labour in their supply chains (Bang, 2014; Hodal and Lawrence, 2014). When a firm's supply chain is linked to human trafficking (i.e. forcing humans to work against their will), the company is subject to significant media scrutiny and brand damage. If found guilty of this crime, the firm is subject to legal penalties, brand loss and may need to discontinue use of that supply chain link (Magnan et al., 2011). For example, Patagonia sets explicit labour standards for their suppliers, and if these standards are not met it may lead to a discontinuation of that business relationship (Patagonia, 2016).

The risk a firm incurs of unintentionally using human trafficking in their supply chain depends on their effort to enforce responsible labour practices. Government's have not been able to effectively motivate firms to exert that responsibility effort (Locke et al., 2007), and thus labour breaches continue to occur.

Governments have begun working together to fight human trafficking in a uni-

fied way. Implemented in 2003, the United Nations (UN) Palermo Protocol creates a global definition for Human Trafficking and establishes the 3P approach for government action (United-Nations, 2003). The three P's stand for Prevention, Protection, and Prosecution, and they have become the accepted framework for action against human trafficking. However, there is little uniformity, guidance, or analytical study on the implementation of the three P's.

This chapter provides guidance for a regulator using the 3Ps with limited resources to prevent or cure human trafficking within a firm's supply chain. Government agencies, similar to businesses, operate in the interest of the stakeholders they represent. Regulators face a problem, as citizens and nongovernmental organisations (NGOs) seek action to force companies into following laws which stop modern slavery in corporate supply chains. Recent findings of human trafficking have vocalised the need for additional government enforcement and action, along with penalties against the perpetrators (Bang, 2014).

This chapter also provides an explanation for why additional enforcement may not help alleviate trafficking or prevent future occurrences. To accomplish this, we model the 3Ps (Prosecution, Prevention, and Protection) used by over 170 governments to incentivise a firm to comply with human trafficking laws (United-Nations, 2003). This is accomplished by optimising a government's anti-trafficking budget allocations amongst the 3Ps.

Given a limited budget, a government must decide the allocation to be used for Prosecution effort, whereas the remainder of the budget will be used for Prevention effort. Protection, the third P, is modelled as a a non-allocatable societal cost that is incurred by the government if trafficking is found.

Prosecution effort typically consists of investigations and subsequent criminalisation to punish trafficking in persons, whereas Prevention effort may include awareness campaigns for migrant workers, laws for labour protection, enhanced business protocols, and reporting structures (Dept-State, 2018). This combination of a government's effort is aimed at reducing trafficked victims in their jurisdiction, currently numbering over 40 million people worldwide, from being forced to work. The difficulty, of course, is that modern slavery is underground,

pervasive, and growing (ILO, 2017a).

A firm (i.e. company, such as Apple) operates under the legal purview of the government and is bound by the laws and penalties which the government has set. The firm intends to operates a legitimate business, however, the firm's supply chain is susceptible to infection by trafficked labour and therefore requires effort by the firm to ensure adherence to the government's laws, such as the (*California Transparency in Supply Chains Act*, 2012) and the United Kingdom (*Modern Slavery Act*, 2015).

This effort can be delivered in the form of supply chain certifications or audits, working in collaboration with NGOs (Plambeck and Taylor, 2015), improving working conditions (Locke et al., 2007), as well as contracts and programs set up with multi-tier suppliers to ensure fair labour practices (e.g. contingent payments), visibility (Holcomb et al., 2011), and supplier development or incentive schemes (Chen and Lee, 2015).

Therefore, we analyse the situation where corporate supply chains are susceptible to infection from modern slavery and governments are utilising limited resources towards the Prevention, Protection, and Prosecution of human trafficking within their jurisdictions. The methodology chapter discussed prior research, such as an auditors efforts to ensure supply chain compliance with international laws; however, there has been a gap in the research of a government enforcing firm supply chain compliance against modern slavery. The Methodology chapter (2) further describes the game theory model used herein to fill this important gap. Though similar models have been used in the Supply Chain Management field in the past, our approach is different because it is tailored to the specific modelling of the 3P approach to human trafficking through the lens of government intervention.

This chapter shows that the optimal government effort towards prosecution is increasing with the prevalence of trafficking in the firm's industry, yet surprisingly decreasing in the firm's revenues. Even more striking is our finding that without external (e.g. NGO) auditing, the government's effort towards prosecution decreases as the societal cost of trafficking increases. We present our analy-

sis and the key levers in government effort in Section 2 of this chapter. Section 3 validates our findings with a numerical study of comparative statics in equilibrium. We adapt our model with alternate assumptions in Section 4. Section 5 concludes with a discussion and potential areas for future research.

4.2 Analysis

In this section, we use the game theory model introduced in the Methodology chapter to characterise how the government's allocation of funds towards Prevention e_g vs. Prosecution $(1 - e_g)$, as well as how the selection of a penalty p, affects a firm's effort to comply with human trafficking laws.

The following analysis depicts the decision trees for both players, along with the probabilities of reaching each respective payoff. We see that the government and the firm both face decisions and profits that are inextricably linked. By inspection of these decision trees we can better understand the potential for revenue and penalties, dependent on the players optimal decisions. Our assumption is that the firm knows, with perfect knowledge, the actions that the government will take with respect to Prevention, Prosecution, and penalty structures (i.e. e_g, p). If all decisions were binary (as we show in this chapter), the expected payoff path would be clear. However, efforts can take a range of values between 0 and 1 (modelled as probabilities), and thus we also analyse the continuous case in the subsequent section.

4.2.1 Introduction of Variables

The two-stage Stackelberg game employed in this thesis is displayed in the following figure. In stage one, the government (*she*) allocates a portion of her budget towards Prosecution effort as $e_g \in [0, 1]$, and decides the trafficking penalty p. By choosing e_g, the government is simultaneously also setting the budget allocation $(1 - e_g)$ for Prevention activities. In stage two, after observing the

government's decisions the firm (*he*) follows by choosing his effort $e_f \in [0, 1]$ to comply with human trafficking laws.

The efforts e_g, e_f are chosen within $[0, 1]$ because they correspond to probabilities. With probability e_g, the firm will be inspected by the government. For example, if the government chooses $e_g = 0.5$, then there is a 50% chance that the firm's supply chain will be inspected for forced labour violations. Government inspection may yield only one of two results: the firm will either be compliant or non-compliant with human trafficking laws. With probability e_f, the firm will be "safe," meaning that the inspection showed no signs of forced labour within the supply chain. For example, if the firm chooses $e_f = 0.25$, then there is a 75% $(1 - e_f)$ probability that the firm will be unintentionally using forced labour. A firm, therefore, faces a compound lottery. First, there is the probability of being inspected by the government. This is followed by the conditional probability of being inspected and then being found in non-compliance.
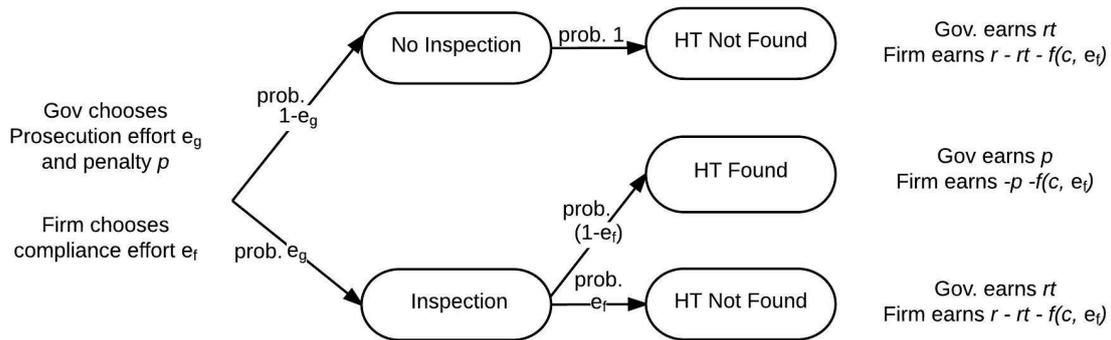
Figure 11: Model of Human Trafficking Prosecution and Compliance Effort

If trafficking is not discovered, the firm earns revenues r on products sold and pays taxes rt, $t \in [0, 1]$ to the government. The government thereby receives rt as its own "revenue" in the form of taxes. If trafficking is found, the firm will sacrifice revenues (this loss signifies the costs of brand damage, fixing their supply chain, and an inability to sell the products touched by slave labour). The likelihood that the government does not Prosecute the firm is $1 - e_g$ and the likelihood that she inspects the firm and finds no human trafficking issues is

$e_g(1 - e_f)$. If she finds human trafficking issues, the government incurs the social cost of Protection for victims s, and charges the firm a penalty p for non-compliance. We assume the supplier is able to make positive revenues such that:

$$r - rt \geq f(c, e_f)$$

and is able to pay the penalty p if discovered using slave labour. No matter the game outcome, the firm will pay his cost of production, denoted by function $f(c, e_f)$.

The cost parameter $c > 0$ is related to the firm's industry type and thereby susceptibility to trafficking infection. In an industry with a higher potential for trafficking, c would be larger across firms that participate in that industry. Conversely, c would be lower across firms in an industry with a very low probability of trafficking. For example, in the high-technology industry, unintentional use of forced labour may be quite low, whereas for the agriculture industry unintentional use may be significantly higher. The function f is increasing in industry parameter c and the effort e_f that he puts into compliance.

This is a single period game, for when the government chooses a new level of budget allocation and penalty, any firm previously caught with human trafficking has already taken action against it. All three P's can occur in this period, as the government sets her effort for Prosecution and Prevention, and then pays the cost of Protection if trafficking is Found in the firm's supply chain. Our model utilises Prosecution effort e_g as the probability of being inspected, and the remaining budget goes towards programs to prevent the potential for trafficking. This is one of the central questions and inspirations for this chapter: to determine what level of effort should be expended to Prosecute an infected supply chain (i.e. implement a cure with effort e_g), whilst leaving the maximal amount possible for Prevention activities $(1 - e_g)$.

Although tasked with maximising social welfare, the government faces resource limitations and thus budget constraints. Therefore, we model the government (due to budget constraints) and the firm both as profit maximisers. This is natural as many municipalities operate similar to companies, with multiple goals,

stakeholders and a desire to maximise their performance. Legally accepted examples of this include the sale of government weaponry, foreign and domestic investments, sovereign wealth funds, and municipalisation programmes.

The government chooses inspection effort e_g to maximise her expected profit (i.e. budget):

$$\pi_g(e_g, p \,; e_f) = (1 - e_g)rt + e_g e_f rt + e_g(1 - e_f)p - e_g(1 - e_f)s,$$

and the firm chooses his compliance effort e_f to maximise his expected business profit:

$$\pi_f(e_f \,|\, e_g, p) = (1 - e_g)(r - rt) + e_g e_f(r - rt) - e_g(1 - e_f)p - f(c, e_f),$$

where s is the government's Protection cost if trafficking is found and p is the penalty the firm pays to the government for not complying with supply chain slavery laws. Therefore, we have included the social welfare cost of prior research through the social cost s, yet allowed our game to reflect the reality of a limited resource, budget maximisation requirement. Through this approach, we analyse modern slavery in the context of a relationship between an unknowing firm and a government attempting to maximise compliance under budget constraints. In the last analytical section of this chapter, we compare our results to the case when the government's profit function is adapted towards the maximisation of social welfare rather than budget maximisation.

By increasing his effort toward compliance e_f, the firm will lower the probability of an issue (and thereby lower the potential for legal consequences) but will increase his cost of production $f(c, e_f)$, assumed to be a concave and twice-differentiable function. Production cost concavity is appropriate in this context because of economies of scale in supply chain alterations. For example, to increase compliance the firm could: lead additional audits of suppliers, implement employee training, conduct interviews along the supply chain, hire a third-party

agency to audit suppliers, among other remedial activities. Assuming that the firm will prioritise the activities which most substantially increase his effort level e_f, these changes would require a higher upfront investment (yet would be sustainable). Less-impactful activities would have a lower increase to the effort level and therefore would be implemented later, and would have a decreasing marginal cost $f'(c, e_f)$ in comparison.

We assume the firm's best response effort $\hat{e}_f$ exists (i.e. $\exists \hat{e}_f \in [0, 1]$) for all $e_g \in [0, 1]$ and $p \geq 0$. A government's goal is to incentivise the firm into full compliance in equilibrium ($e_f^* = 1$) whilst using the least amount of her normalised budget towards Prosecution activities (allocation e_g), so that she has expendable resources for Prevention efforts (allocation $1 - e_g$).

To find the optimal solution, we search for a unique equilibrium (e_g^*, p^*, e_f^*) given by the unique solutions to the first order conditions:

$$(1) (\partial/\partial e_g)\pi_g(e_g, p\,;\, e_f) = (1 - e_f)(p - s) - rt + e_f rt = 0$$
$$(2) (\partial/\partial p)\pi_g(e_g, p\,;\, e_f) = -e_g(p - s) + e_g rt = 0$$
$$(3) (\partial/\partial e_f)\pi_f(e_f\,|\, e_g, p) = -e_g(1 - e_f) = 0$$

furthermore, $\hat{e}_f$ is continuous in e_g. The government knows the firm's profit function (2) but cannot observe his compliance effort. Conversely, the firm knows the government's profit function (1) and also knows the government's decisions for her effort e_g and the penalty p. This is expected, as governments are responsible for publishing their laws, budget allocations, and the penalties that a firm would face if breaking the law prior to the infraction. This leads us to search for a Nash equilibrium in a sequential move game that is the unique solution to the first order conditions above.

We allow the government and firm's compliance effort in equilibrium to be either an interior or corner point solution (i.e. $e_g^*, e_f^* \in [0, 1]$). Conditions for the existence of a unique equilibrium are:

$f'(c, 0) = 0,\ f'(c, 1) <= r - rt,\ \pi_g|_{(e_g, p, e_f) = (e_g^*, p^*, e_f^*)} \geq 0,$

and

$$\pi_s\big|_{(e_g,p,e_f)=(e_g^*,p^*,e_f^*)} \geq 0.$$

We allow corner point solutions because a government would ideally want to incentivise full compliance effort from the supplier in equilibrium $(e_f^* = 1)$ and, in unfortunate yet realistic situations, the alternative is possible that one or both players could exert zero effort (Gupta 2009), i.e. $e_i = 0, i \in (g, f)$.

Prior to the game beginning, there are exogenous variables known to both players. This includes a exogenous marginal tax rate $t \in [0, 1]$, which we consider fixed. There is a fixed social cost of s that the government incurs if the firm is found to be using trafficked labour. We consider this cost to represent Protection, the third P of the Palermo Protocol introduced in Chapter 2, that is not included in the governments anti-trafficking budget. It is not included in the budget decision because it must be paid no matter the outcome. The social cost of s is used to protect and rehabilitate the livelihoods of the victims being used as slaves within the firm's supply chain, i.e. the cost of the 3R approach.

Table 3: Game Theory: Summary of Variables

Variables:	
π_g	Government profit function
π_f	Firm profit function
e_g	Government effort for Prosecution
$1 - e_g$	Government effort for Prevention
e_f	Firm effort to stay in compliance
c	An industry-related cost parameter
$f(c, e_f)$	Firm production cost function
p	Penalty levied by the Government
r	Firm revenue
t	Firm marginal tax rate
s	Government social cost of Protection

4.2.2 The Discrete Case

To understand the key dynamics in our model, we begin with a base case in a discrete setting. In this case, let us assume that the government and firm decisions are binary; in other words, e_g, p, $e_f \in \{0, 1\}$. We can thus analyse the game using backward induction to understand the equilibriums that would be reached. The following figure portrays all potential outcomes which can be achieved in the discrete game.
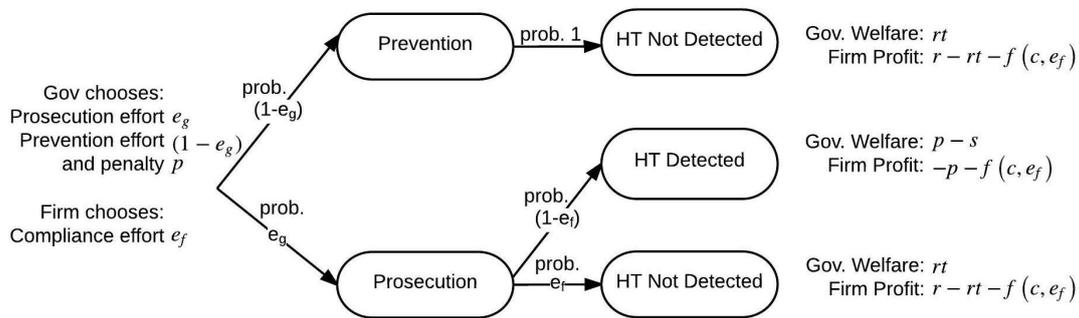
Figure 12: Discrete Model of Human Trafficking Prosecution and Compliance

Proposition 1: The government and the firm are guaranteed to make revenue, regardless of other actions, if $e_g = 0$.

Proof: In this case the firm will rationally choose $e_f = 0$. In this case, zero effort will be directly exerted toward finding current human trafficking issues from both, the government and the firm. □

Intuitively, the government's profit will be rt if she sets $e_g = 0$, effectively not inspecting firms who may be in non-compliance, and dedicating all available budgetary funds towards Prevention. Whether or not the government imposes a penalty is irrelevant in this case, as it has zero probability of being levied upon the firm. Therefore, the firm's best response to the government setting $e_g = 0$ would intuitively be to set $e_f = 0$. In this case, human trafficking would potentially continue to operate uncurbed by firm intervention and any action would rest solely on government Prevention mechanisms.

Unfortunately, this "do nothing" approach is the current situation in multiple countries, where governments allocate little to no resources towards Prosecution, and instead rely on international campaigns, at best. As can be imagined, firms then have no incentive to search their own supply chains and the industry for forced labour may continue to propagate unchecked.

Let us consider the alternative, if the government sets $e_g = 1$, i.e. full intervention and Prosecution with no prevention effort. The question of a penalty selection now becomes of importance. Using backward induction, with a penalty of $p = 0$, there is a zero-probability risk of her earning $\pi_g = -s$ because the firm's best response would be $e_f = 1$. Thus, the government will continue to make tax revenue and will now force the firm to put effort into compliance or face a potential loss of revenues from trafficking. Indeed, we see that the firm will choose $e_f = 1$ to maximise his profit in this situation because $r - rt - f(c, e_f) \geq -p - f(c, e_f)$, based on our assumptions on profitability.

Proposition 2.1: In the binary case, if the government chooses to implement Prosecution with a penalty, she is guaranteed a positive profit and incentivises the firm to expend effort in compliance.

As seen in the previous figure, we also highlight the fact that the government has the potential to make revenue so long as a penalty is enforced; however, in most situations the government's revenue is derived from continued business operations. Conversely, with $e_g = 1$ and $p = 0$, the government can still force a firm into the situation where he will make revenue through an unintentional labour breach even without her use of a penalty (i.e. $p = 0$), unless he rationally exerts compliance effort ($e_f = 1$). If the irrational choice ($e_f = 0$) is made (though we assume rationality), it would sacrifice the government's profit stream as well. Thus, from a simple binary perspective, the use of a penalty actually incentivises the government in addition to incentivising the firm, because an appropriately chosen penalty would guarantee government profitability.

By inspection, we can see that if multiple firms exist in the market with one government, and the government chooses a standardised effort level with all firms,

then the results would remain the same. In other words, the actions between a government and a firm stay the same with multiple firms because a government's Prosecution level would not change under the assumption of a uniform effort level, and therefore each firm would respond according to their best action set. A necessary assumption here is that as new firms are added to the industry, the government's budget increases (due to an increase in tax revenues), and thus she can afford to inspect a new firm at the same effort level as the previous firm, which is fair and in line with budget economics (i.e. the larger a coverage district, the larger the budget to monitor it), and vice-versa.

4.2.3   The Continuous Case

The discrete case considered a binary decision; however, a firm's decision is not usually black and white. This section analyses the continuous case of the problem faced by governments and firms where $e_g, e_f \in [0, 1]$ and $p \geq 0$. We make the same assumptions as the previous section (i.e. rationality, perfect information, and risk-neutrality).

We have considered many potential forms of the firm's cost function. For the remainder of this chapter, we employ the tractable and differentiable form of the firm's cost function as: $f(c, e_f) = \frac{c}{2}e_f^2$.

We have chosen this concise form above all others for two key reasons. First, it matches the key intuitions and the pre-existing research behind a firm's cost function: it is increasing, concave, twice-differentiable, and reliant upon the firm's effort. Secondly, it can be readily computed as needed when calculating comparative statics. During our analysis, we tested more complex quadratic forms of the cost function and found that our resulting insights held. To consider a general form of f, one may use the Implicit Function Theorem; however, throughout this chapter we will assume that the firm's production cost function $f(c, e_f)$ takes the aforementioned form in order to calculate precise, closed form results.

As discussed in the introduction of variables, the firm's cost function is pred-

icated on two key attributes: his effort towards compliance e_f, as well as his industry-related cost of production, symbolised by c. The higher the constant c, the greater the cost the firm incurs for production. Similarly, as the firm increases his compliance effort e_f, his production cost also increases. We now consider how a government's anti-trafficking budget allocation decisions impact the firm's effort.

We begin by taking the first order condition of the firm's profit function to find the critical point at which the firm makes his decision to maximise profitability.

Theorem 1: The firm's best response is $\hat{e}_f = \frac{e_g(r - rt + p)}{c}$.

Proof:

First, we check the concavity of the firm's profit function:

$$\pi_f(e_f \mid e_g, p) = (1 - e_g)(r - rt) + e_g e_f(r - rt) - e_g(1 - e_f)p - f(c, e_f)$$

by calculating it's Hessian to ensure that the function is concave, i.e.

$$\pi_f'' \leq 0.$$

Expanding the profit function:

$$\pi_f(e_f \mid e_g, p) = r - rt - e_g r + e_g rt + e_g e_f r - e_g e_f rt - e_g p + e_g e_f p - \frac{c e_f^2}{2}$$

We now take the first order partial derivative with respect to the firm's effort e_f to check the coefficient in the second order derivative:

$$(\partial/\partial e_f)\pi_f = -c e_f + e_g p + e_g(r - rt)$$

$$(\partial/\partial p)\pi_f = -(1 - e_f)e_g$$

$$(\partial/\partial c)\pi_f = -\frac{e_f^2}{2}$$

As can be seen, the profit function has a negative coefficient in the second order derivative by the firm's production function. This makes the Hessian of the firm's profit function negative semi-definite, thus providing the result that the function is concave.

With this knowledge, we can now take the first order condition of the profit function with respect to the firm's effort to obtain the result:

$$\frac{\partial \pi_f}{\partial e_f} = e_g(r - rt) + e_g p - e_f c$$

$$e_g(r - rt) + e_g p - e_f c = 0$$

$$e_g(r - rt) + e_g p = e_f c$$

$$e_f(e_g, p) = \hat{e}_f = \frac{e_g(r - rt) + e_g p}{c} \quad \square$$

Based on the above result, we see that the firm will optimise its effort to comply with human trafficking laws in direct response to: the government's decisions of effort e_g and penalty p, his own cost function parameter c, and the exogenous tax rate t. We can also see the firm's effort e_f is increasing in government effort e_g and the penalty p, which matches our intuition. We also see that an exogenous increase in the tax rate t or production constant c would reduce firm effort e_f, which can be understood because it increases cost constraints and therefore increases incentives to seek methods to reduce costs.

Knowing that the firm will maximise his profit by choosing the effort level $\hat{e}_f$, the government will intuitively choose her effort and penalty accordingly. Using standard game theory procedure, we employ backward induction and solve for the resulting system of equations. We find an interesting result when taking the first order condition of π_g with respect to e_g, noted below in the next proposition.

Proposition 2.2: In the continuous case, if the government exerts inspection effort with an appropriate, non-zero penalty, she is guaranteed a positive profit and incentivises the firm to expend effort in compliance.

Similar to the binary case, because the government is the leader and can thereby set her effort and penalty first, she can incentivise the firm whom she knows will operate in his best interest based on her actions. As long as the government correctly sets her effort and penalty levels, she can force the firm into an equilibrium that ensures her profit and his compliance.

Theorem 2: The government's optimal effort and penalty in equilibrium are $e_g^* = \frac{c}{r+s}$ and $p^* = rt + s$, respectively.

Proof:

We calculate the optimal penalty and effort for the government to employ. We take the first order condition of the government's profit function to find the critical points.

Therefore, we find the optimal e_g^* and p^* by substituting the firm's best response, $\hat{e}_f = \frac{e_g(r-rt+p)}{c}$ and again taking the first order condition of π_g with respect to e_g and p:

$$W(e_g, p; \tfrac{e_g(r-rt+p)}{c}) = (1-e_g)rt + e_g(\tfrac{e_g(r-rt+p)}{c})rt + e_g(1 - \tfrac{e_g(r-rt+p)}{c})p - e_g(1 - \tfrac{e_g(r-rt+p)}{c})s$$

$$\frac{\partial W}{\partial p} = -\frac{e_g^2(p-s)}{c} + \frac{e_g^2 rt}{c} + e_g(1 - \frac{e_g(p+r-rt)}{c} = 0$$

$$\frac{\partial W}{\partial e_g} = -rt - \frac{e_g(p-s)(p+r-rt)}{c} + \frac{2e_g rt(p+r-rt)}{c} + (p-s)\frac{e_g(p+r-rt)}{c} = 0$$

We consisdered two possible methods of solving the above equations with the constraints that $e_g, e_f \in [0,1]$, and $p, c, r, t \geq 0$. One method is to solve the equations sequentially, and the other to solve them simultaneously. As the government makes their decision for p and e_g in the same move, i.e. simultaneously, we solve the equations simultaneously to find the Stackelberg solution for the government's optimal e_g^*, and p^*:

$$e_g^* = \tfrac{c}{r+s} \; ; p^* = rt + s \; \square$$

Proposition 3: In equilibrium, the government's optimal inspection effort e_g^* is only reliant upon the firm's revenue r, his production cost function parameter c, and the social cost s (i.e. Protection cost).

In Theorem 2, we showed that the optimal effort the government expends is reliant upon the firm's industry-related cost rate c, the firm's revenues r, and the social cost s incurred when finding non-compliance. We consider these to

be the key levers which may be moved up or down to shift the government's Prosecution effort. Later in sub-section 4.2 we discuss these three levers one at a time to understand their intuition and impact on a government's effort.

The firm-specific results above harken to the idea that optimal enforcement effort may depend on the characteristics of the firm and industry as opposed to a standardised approached. This is analogous to the idea behind the work of Ayres and Braithwaite (1992) who establish a framework for responsive regulation, i.e. regulation based on the characteristics of the regulated community, and the work of and Toffel et al. (2015) who describe the importance of the context the firm operates in.

Proposition 4: In equilibrium, the government's optimal penalty p^* is reliant upon the firm's profit function, the marginal tax rate t, and the social cost s which would be incurred by the the government in the event that trafficking is found.

Interestingly, p^* equates the government collection of the social cost s to the cost of lost tax revenues rt, which shows that the government, as a rational player, will protect her profit given any potential game result. This is similar to the results of Lear and Maxwell (1998), who show that the optimal penalty is described based on the characteristics of the entity being inspected.

By substituting e_g^* and p^* into the firm's profit equation and solving, we find in the subgame perfect equilibrium, the firm's optimal effort e_f^* is a corner point solution:

The firm's optimal action (given the government's optimal decisions) is $e_f^* = 1$. This leads us to our next proposition.

Proposition 5. In equilibrium, a government who optimally chooses her positive effort and penalty structure will incentivise a firm to exert full effort towards compliance.

Based on the dynamics of our model, a firm will exert full effort towards com-

pliance if a government chooses her optimal decision set. This has direct implications for governments and NGOs around the world who are concerned with the proper structure of their trafficking response.

Our solution is simple yet drives a powerful message: the key decisions rely upon an understanding of the three critical features of the context the firm operates in. Specifically, it hinges on:

1. *Industry type*: a firm in a riskier industry would incentivise governments to increase the effort made toward inspection, thereby decreasing the effort toward prevention mechanisms.

2. *Potential revenues of the firm*: all else equal, a firm with increasing revenues would require less inspection effort and a government would, therefore, increase her effort toward prevention mechanisms, presumably trusting that the firm will seek to ensure its profit by remaining in compliance.

3. *Estimated social cost of trafficking:* this is tied to the optimal penalty and causes a government to decrease inspection while increasing prevention, hoping to dissuade the discovery of forced labour.

Now that we have established the optimal decisions for both players, we calculate the overall system profit.

Theorem 3: The system-wide profit (surplus) in equilibrium $= -\frac{c}{2} + r$

Proof:

$$\pi_g(e_g, p\,;\, e_f) = (1 - e_g)rt + e_g e_f rt + e_g(1 - e_f)p - e_g(1 - e_f)s$$

Substituting e_g^*, e_f^*, p^* , we have:

$$\pi_g(e_g^*, p^*;\, e_f^*) = (1 - \tfrac{c}{r+s})rt + \tfrac{c}{r+s}(1)rt + \tfrac{c}{r+s}(1 - (1))(r - rt) - \tfrac{c}{r+s}(1 - (1))s,$$

which simplifies to:

$$\pi_g^* = rt, \text{ in equilibrium.}$$

$$\pi_f(e_f \,|\, e_g, p) = (1 - e_g)(r - rt) + e_g e_f(r - rt) - e_g(1 - e_f)p - \frac{ce_f^2}{2}$$

Substituting e_g^*, e_f^*, p^* , we have:

$$\pi_f(e_f^* \,|\, e_g^*, p^*) = (1 - \tfrac{c}{r+s})(r - rt) + \tfrac{c}{r+s}(1)(r - rt) - \tfrac{c}{r+s}(1 - (1))(rt + s) - \tfrac{c(1^*)}{2},$$
which simplifies to:

$\pi_f^* = -\frac{c}{2} + r - rt$, in equilibrium.

Summing the profit functions together, we have the result:

$\pi_g^* + \pi_f^* = -\frac{c}{2} + r$ $\square$

Interestingly, the system-wide profit does not rely upon the tax rate t (which can, therefore, be considered as a transfer cost), nor the social cost of Prevention s. Instead, it is only decreasing in the firm's cost function parameter c and only increasing in his revenues r.

The key to understanding the intuition behind this result is through the perspective of the government's optimal decision. By choosing a penalty which guarantees maximum profit for her and full compliance from the firm, the government's profit is centred on obtaining the equivalent of tax revenues (rt) from the firm. In equilibrium, tax revenues are zero-sum, in other words, the firm will pay this amount regardless of the outcome (whether through operations or through the payment of the penalty p). Thus, the system-wide profit is reliant solely upon the firm's ability to make a profit above his production cost.

In the following section, we display the impacts of changes to exogenous variables (such as tax rate t and societal cost s) on player efforts and profits in equilibrium.

4.2.4 Government Levers

This section contains a discussion of which elements of our model should be focused on in order to impact government Prosecution of international human trafficking laws. This is of specific use for policy makers and NGOs attempting

to curb trafficking through government intervention. We do not consider the variables regarding the firm's compliance because, with the correct effort and penalty, a firm will exert full compliance effort in equilibrium.

4.2.4.1   Firm's Cost Function

As discussed in the introduction of variables, the firm's cost function is predicated on two key variables: his effort e_f towards compliance as well as his industry's cost of production symbolised by c. Based on the government's best response e_g^*, the government's effort is increasing in the firm's cost of production. In other words, a higher cost of production for the firm's industry incentivises the government to expend more effort towards inspecting the firm. This is intuitive, as a firm which has higher costs has more incentive to cut costs, ceteris paribus.

Examples of cost-cutting by a firm could be in the form of sourcing/auctioning from lower-cost suppliers with unknown supply chains, neglecting to properly assess the supply base, or decreasing inspections of the current supply chain. The government reacts to the firm's decrease in effort with heightened vigilance by increasing her auditing level, thereby avoiding any collection loss on her part, either from taxes lost or penalties paid.

Therefore, these results regarding the parameter c have implications for government and NGO action. This industry-related parameter can be a proxy for industries with less incentive to comply and therefore more deserving of government and NGO attention. For example, this proves that a priority of focus should be given to manual-labour sectors that are hyper-competitive on cost, therefore having a higher risk of forced labour in their supply chains due to cost pressures and thereby necessitating compliance checks.

4.2.4.2   Firm's Revenue

In equilibrium, the firm's revenue (r) is decreasing in the government's effort, i.e. as the firm's revenues grow, the government may have less incentive to exert

effort towards Prosecution. We note that we are not discussing profits (or the maximisation of them), as this analysis is of the firm's revenue before costs, and therefore his ability to sell products or services.

There are two main intuition take-aways from this result: First, a company with higher revenues has less incentive to cut costs, ceteris paribus, than a company with lower revenues. Furthermore, when a company has less incentive to lower costs, the company would be less likely to use unknown of labour or neglect proper inspections of his supply base or supply chain. Secondly, seeing a firm's higher revenue stream, the government will thereby lower her inspection level whilst adjusting her penalty to ensure the same profit in equilibrium. This matches our intuition, as a firm who has grown in size is more stable and has more to lose by risking inappropriate behaviour. Therefore, he will require less government inspection effort than firms who are smaller and not as established.

4.2.4.3   Social Cost

The social cost s, incurred by a government if a firm is found in non-compliance, is tied to the impact on society and incurred through the Protection of victims of human trafficking. The government's effort e_g in equilibrium is decreasing in the social cost s, i.e. as the social cost becomes larger, the government has less incentive to exert effort towards Prosecution of the firm.

This is counter-intuitive, yet we can understand the meaning by inspecting the earlier result for the government's optimal penalty structure. The optimal penalty for the government directly passes through the social cost incurred by the government to the firm. Therefore, the government places less weight on expending effort because the heightened incentive to comply now becomes the firm's burden.

Effectively, the social cost is transferred completely to the firm, raising his effort level e_f and thereby reducing the government effort e_g needed towards Prosecution.

A key learning from this result is that NGO's who lobby governments for higher

vigilance on the basis of increasing societal costs from human trafficking may not necessarily be increasing government Prosecution effort at all. The government, who maintains the exact same profit in equilibrium, may actually raise penalties while lowering Prosecution with an increased social cost. In summary, a rising social cost would lead to increased penalties which places a larger potential burden on the firm, not the government.

4.2.4.4   Zero-sum Variables

As discussed with the social cost s in the introduction of variables, the penalty p allows potential government costs to be passed through to the firm. For example, one such cost (if non-compliance is found) is the loss of potential tax revenue (rt) collected by the government.

We can see that the exogenous tax rate t has no effect on the government's effort because it essentially gets passed through directly to the firm through the equilibrium penalty ($p^* = rt + s$). Thus, the tax rate t, similar to the social cost s, has no incentivising implications for the government and surprisingly only impacts the potential penalty paid by the firm. Therefore, a tax rate change in equilibrium would cost the Government nothing and takes additional profit directly from the firm, who may already be in full compliance.

One could argue that increasing the corporate tax rate allows for additional funding of anti-trafficking because the budget has grown in size with the same allocation. This may be true (as are many arguments for increased tax dollars); however, our analysis is for a fixed budget without consideration of budget expansion. Additionally, there is a non-zero probability that an increase in tax rates may instead be made to fund new programs or activities.

4.2.4.5   Avoiding the Penalty

It is important to note that there exists a realistic situation outside of the scope of our model where the government may go into negative profit with a positive probability. This occurs when she chooses $e_g = 1$, $p = 0$ and the firm then

chooses $e_f = 0$. Logically, this is the equivalent of a search with no bite. In other words, the government will fully prosecute a firm with 100% probability; however, she will not charge a penalty to a firm who is caught in non-compliance. Thus, a firm will only comply due to fear of lost revenues (brand damage, being able to sell the product touched by forced labour, etc.).

In our model, this is never a best response for the firm; however, based on discussions with human trafficking experts, we have learned that some businesses may utilise a legal loophole. Their strategy is to use zero effort on compliance, and if caught then to declare bankruptcy and re-establish themselves under a different corporate name. We do not consider this strategy (a firm's re-incorporation) as part of our model; however, our analysis would be incomplete without acknowledging the potential for negative profit for the government from this action set. For a full treatment on a firm's ability to avoid penalties, we recommend the reader to see Kambhu (1989), as well as Nowell and Shogren (1994).

Using the mechanisms described above, we can better understand the key levers that should impact a government's enforcement of human trafficking laws: The firm's industry (through parameter c), the firm's revenue r and the counterintuitive result regarding the government's awareness of the social cost s incurred if trafficking is found.

4.3   Numerical Analysis

We now present some numerical examples to verify our analysis, offer comparative statics, and seek to more deeply understand the relationship between a government and firm. We vary specific exogenous variables of interest in order to understand their effect on the resulting equilibrium. Unless otherwise described, the parameters for the figures below are given as $r = 10$, $s = 20$, $t = 0.4$, $c = 10$, and $e_g = e_g^*, e_f = e_f^*, p = p^*$, to fit as described in the equilibrium analysis.

4.3.1   Impact of Firm's Cost Function
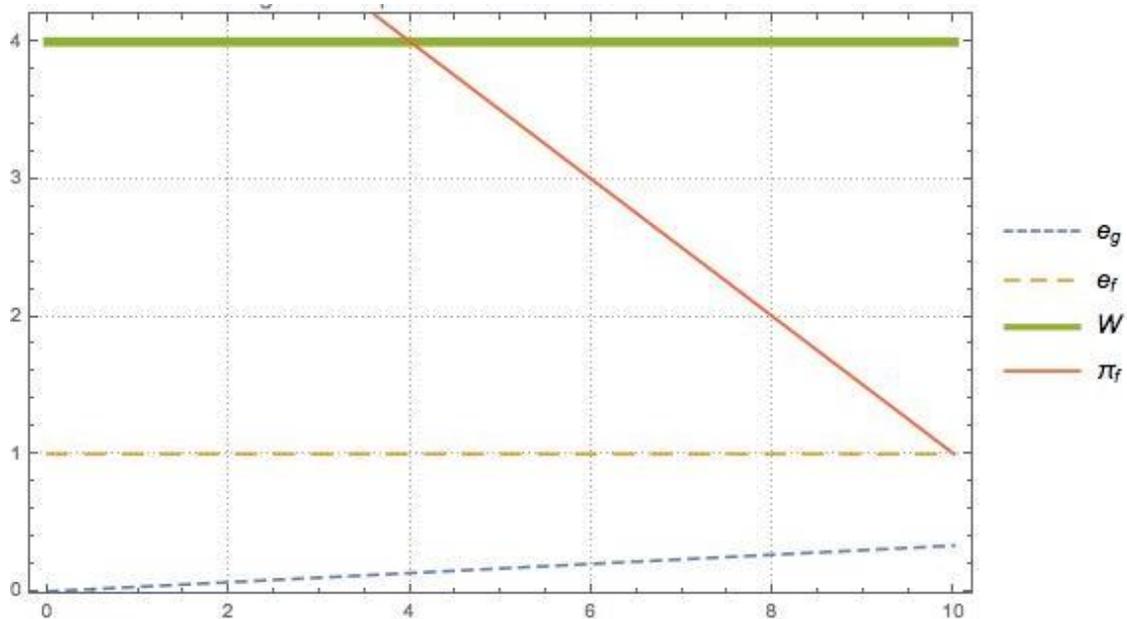
Figure 13: Impact on Firm's Cost Function

In this figure, we illustrate the effect of the firm's cost parameter c on the effort and profit of both players. This visualisation confirms our analysis as we see that a change in the firm's cost parameter between 0 and 10 will cause a decrease in firm profit, which will thereby incentivise an increase in the government's effort towards Prosecution.

4.3.2   Impact of Social Cost

Figure 15 shows the effect of varying the social cost s on the government's effort e_g and the firm's effort e_f in equilibrium.

The graph is consistent with the findings in Proposition 5 which discusses incentivising a firm's full-compliance. As the exogenous social cost s increases increase from 0 to 10, the government decreases her effort level from 1 to 0.5. As
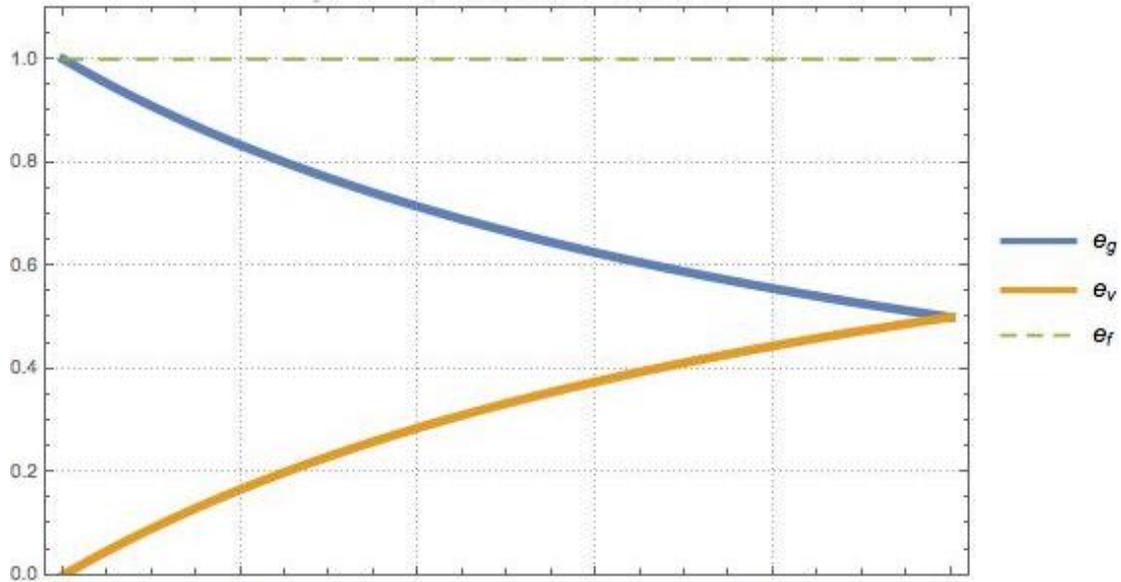
Figure 14: Impact of Social Cost on Effort

discussed in our analysis, this is due to a simultaneously rising penalty p being imposed on the firm if found under non-compliance. As the firm takes on this potential burden by raising his effort level e_f, the government has less incentive to enforce and therefore re-allocates her effort from Prosecution to Prevention.

4.3.3 Impact of Zero-Sum Variables: Penalty and Tax

Proposition 6: Tax rates are zero-sum variables which have no incentive impact.

In Figure 16, we keep all parameters fixed and show what could happen as the exogenous tax rate t varies between $[0, 0.5]$, symbolising a tax rate anywhere between 0% and 50% on revenues. The graphic shows that taxes are a zero-sum cost in the game which is passed between the players. That is, for an increase in the tax charged (and thereby profit decrease) to the firm, there is an equal revenue increase (and thereby profit increase) in the revenue collected by the government.

This zero-sum relationship is impervious to changes in penalty p, social cost s,
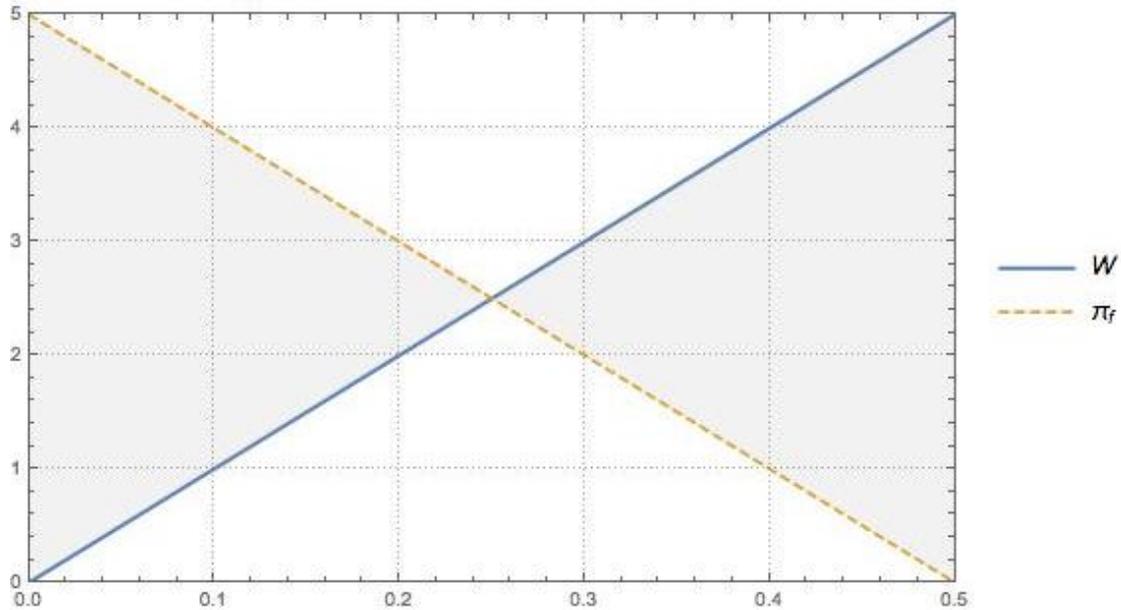
Figure 15: Zero-Sum: Tax Rates on Profit Functions

and adaptations to the firm's production cost (i.e. more complex quadratic forms of f) because it is simply a give and take between the two entities due to their intertwined relationship. This visualisation is consistent with the optimisation analysis section, as the exogenous tax rate t, similar to the endogenous penalty p, is zero-sum. Although this chapter does not make the tax rate a variable of interest, it is included in our model to explicitly show the multitude of ways in which a firm and government are connected.

4.3.4   Numerical Analysis of Total System Profit

The final figure of this chapter (Figure 17) shows all potential system profit states by summing the profit functions of the government and firm together and plotting them against the effort levels of both players between 0 and 1 (i.e. across all effort possibilities, from no effort to full effort). As characterised by the equilibrium calculations in Theorem 3, the equilibrium profit is $-\frac{c}{2} + r$ when the firm exerts full compliance $e_f = 1$.
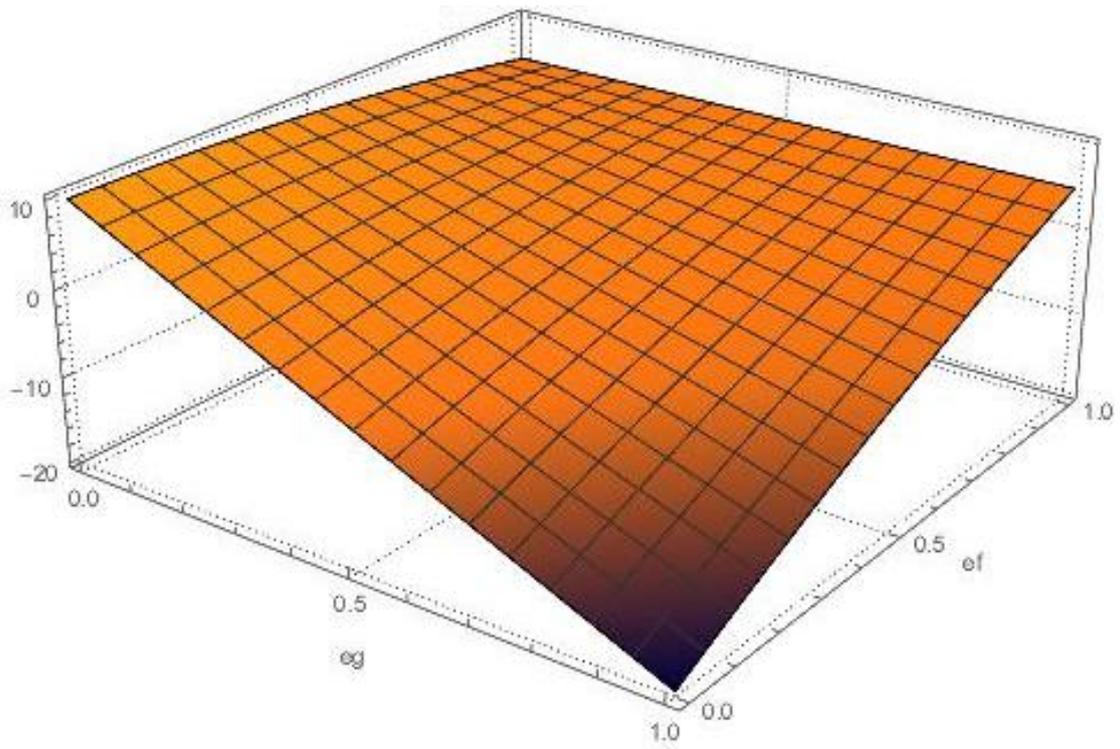
Figure 16: Potential System-wide Profit

However as detailed in Proposition 1, when $e_g = 0$ is also when the greatest combined profit is achieved. Though the closed-form equation is reliant on our assumption of the firm's production cost function, it visualises the previously mentioned consideration: governments and firms have incentive to expend zero effort towards the dark supply chain of modern slavery because ignorance actually increases their respective profits and, as can be seen above, it can maximise the system profit as a whole.

If we were to take the perspective of an unbiased social planner (as seen in the following section, Extensions), we would find this to be the best route to maximise system utility because, despite the ethical considerations to society, system profit is maximised in this alternative equilibrium where $e_g, e_f = 0$.

4.4 Extensions

This section seeks to compare and contrast our results to other interesting areas of analysis by adapting key assumptions in our model.

4.4.1 Social Welfare Model

We compare our modelling approach to two alternate approaches in modelling social welfare based on prior research (Vickrey 1960). The following subsection considers a utilitarian or "Benthamite" social welfare adaptation to our existing model. After that, we then take the position of a risk-averse social cost minimiser.

4.4.2 Maximisation of Surplus

Traditionally, social welfare is calculated by the sum of stakeholder surplus, with a central planner being tasked with the utilitarian maximisation of total surplus across all players in the game. Within the social science literature, it is common

to use Quality Adjusted Life Years (QALY's) or Disability Adjust Lifted Years (DALY's) to calculate the impact of a program or policy (Sassi, 2006).

The difficulty with calculating impact in the human trafficking context is that the consumer surplus (or impact of a program or policy), especially in an applied setting, is difficult to enumerate. Numbers around the actual cost of an incident vary, as each incident may have involved various quantities of victims and levels of life impact. To be able to measure such impacts may require multi-country data analysis and this would eventually become a mathematical approximation. For the purposes of creating a feasible comparison, our analysis considers previous branches of literature whilst staying within tractability by using a side by side comparison to our framework described herein.

We adapt our model to consider a slightly different role that the government can take, the role of a social planner intent on maximising welfare. Therefore, we make the government a social planner who attempts to maximise the profit of both players simultaneously (herself and the firm**).** By combining both profit functions we see that the government, as a social welfare maximiser (subscript sw), seeks to maximise the following profit equation:

$$\pi_{sw} = (1 - e_g)r + (e_g e_f)r - e_g(1 - e_f)s - f(c, e_f)$$

By inspection we can see that π_{sw} is maximised when $e_g = 0$. This is where, unfortunately, the social welfare maximisation becomes the equilibrium in some global contexts. A government that is resource constrained has little to no incentive to enforce human trafficking laws, and therefore firms exert little to no effort in this context. Thus, without external auditing, the dark supply chain of human trafficking continues unchecked in its exploitation of forced labour.

4.4.3 Government's Minimisation of Social Cost

An alternate formulation is when the government's profit function changes to prioritise the minimisation of social costs (subscript sc), namely the social cost s in our model. This may transform her profit function from:

$$\pi_g(e_g, p\,;e_f) = (1 - e_g)rt + e_g e_f rt + e_g(1 - e_f)p - e_g(1 - e_f)s$$

to:

$$\pi_{sc}(e_g, p\,;e_f) \quad = \quad (1 \; - \; \alpha)\left[(1 - e_g)rt + e_g e_f rt + e_g(1 - e_f)(p - s)\right] \; - \; \alpha\left[e_g(1 - e_f)s\right]$$

where the parameter $\alpha \in (0, 1)$ determines the level of the government's priority on maximising social welfare. In our base model (described in our initial continuous analysis), we assumed $\alpha = 0$ and, therefore, only the first part of the equation held. Now we see that if the government pursues social cost minimisation by setting $\alpha = 1$, then the government's profit equation simplifies to:

$$\pi_{sc}(e_g, p\,;e_f) = -e_g(1 - e_f)s$$

In this case, the government is pursuing full maximisation of social welfare by minimising the social cost. By inspection, it is clear to see that in order to minimise s the government will choose $e_g = 0$. Using the same backward induction steps (as followed in our discrete and continuous analysis), we confirm that there are indeed two critical points where $e_g = 0$ is the only Positive possibility. This is also directly related to our numerical result which shows that $e_g = 0$ is a critical point for analysis, and that a government may, therefore, have a disincentive to prosecute trafficking incidents because of the resulting social cost s she would incur.

4.4.4 Simultaneous Game

In this sub-section, we consider the case where a government and firm must make their decisions at the same time. We use the same profit functions detailed in our analysis and solve the game using simultaneous moves to compare our original results to this alternate setting.

We find the the firm's best response remains the same in the simultaneous game (denoted sg), i.e. $\hat{e}_{f(sg)} = \frac{e_g(r - rt) + e_g p}{c}$. The change in effort in the simultaneous

game is on the part of the government, which now becomes:

$e^*_{g(sg)} = \frac{-rt+(p-s)}{2(p-s)(\frac{-rt+p}{c})}$, as compared to the sequential game optimal response of $e^*_g = \frac{c}{r+s}$.

Similar to our analysis of the sequential game, we now search for the optimal penalty for the government to take in the simultaneous move game. We begin by taking the first order condition of the government's profit function:

$$\pi_g(e_g, p \, ; e'_f) = (1-e_g)rt + e_g e'_f rt + e_g(1-e'_f)p - e_g(1-e'_f)s$$

$$\frac{\partial \pi_g}{\partial e_g} = -rt + e'_f rt + (1-e'_f)p - (1-e'_f)s$$

Setting this equal to zero for the first order condition, we have:

$-rt + e'_f rt + (1-e'_f)p - (1-e'_f)s = 0,$

$rt - e'_f rt = (1-e'_f)p - (1-e'_f)s$, which simplifies to

$rt(1-e'_f) = (1-e'_f)p - (1-e'_f)s$, where the common term $(1-e'_f)$

can be removed to find $rt = p - s$, and thus $p^*_{(sg)} = rt + s$.

Therefore, we see that the penalty remains the same between the simultaneous and sequential game. Based on this and the result for $e_{g(sw)}$, we learn that the government's effort level continues to be reliant not only on both parameters of the firm's profit function, yet also on her own decision for the penalty (p) imposed upon the firm. Therefore, we have shown that despite a change to simultaneous moves, the optimal penalty structure of p continues to equate lost tax revenue rt with Protection (the social cost s) of human trafficking victims.

4.4.5 Government Effort with External Auditing

In our analysis we assumed that the government is the only entity auditing the firm for misconduct. We now adapt our model to the case where an external agency (subscript ea), for example an NGO, performs their own audits and have

the ability to publicise their findings on the firm. With this, the government's profit will change from:

$$W(e_g, p \, ; e_f) = (1 - e_g)rt + e_g e_f rt + e_g(1 - e_f)p - e_g(1 - e_f)s$$

to:

$$W_{(ea)}(e_g, p \, ; e_f) = (1 - e_g)rt + e_g e_f rt + e_g(1 - e_f)p - a\left[(1 - e_f)s\right]$$

where $a \in [0, 1]$ is the probability that an external audit may trigger the social cost. In this context, the social cost s is no longer an outcome triggered by the government's action and is reliant upon the audit rate a of the external agency, as well as the effort level $e_{f(ea)}$ of the firm.

In this comparison, the firm's profit function does not change, and therefore neither does his best response function $\widehat{e}_{f(ea)} = \frac{e_g(r - rt) + e_g p}{c}$.

Similar to the government's original profit function W, we use backward induction method to solve for $W_{(ea)}$. The government's optimal effort level in this context is:

$$e^*_{g(ea)} = \frac{1}{2}\left[\frac{as}{p - rt} + \frac{c}{(p + r - rt)}\right]$$

The first major change we note in the government's best response with external auditing is that the social cost s has changed from decreasing in e_g to increasing in $e_{g(ea)}$. This is the result of an external agency having the ability to trigger the social cost s and therefore the burden can be incurred by the government without her control. In this extension, as the social cost rises, the government's effort will also rise, which may be considered realistic given the context. The penalty $p_{(ea)}$ and firm effort $e_{f(ea)}$ in this context are highly dependent on the size of the social cost s in relation to the parameters a and c. Thus, a closed form expression is not included in this extension. For a full treatment of supply chain impact with NGO scrutiny, including the overlap of auditing effort between a regulator and NGO, we recommend the work of Chen et al. (2015).

4.5 Discussion

This chapter is one of the first projects in the supply chain literature to directly and quantitatively analyse the occurrence of human trafficking with game theory. Our design is inspired by discussions with NGOs who work on international projects with governments to incentivise business compliance with trafficking laws. The analysis explains the interconnected relationship between a government and a corporate supply chain in the context of modern slavery to prevent the dark supply chain of forced labour from infecting corporate supply chains.

The analyses finds that maximising penalties or inspection effort may not help governments to incentivise compliance of a firm who may unknowingly be using forced labour. Instead, we find and discuss the levers by which a government should change her effort and penalty decisions (namely firm revenue, firm cost of production, and the Protection cost of trafficking), thereby impacting the resulting actions in a firm's effort to comply. Further, we characterise the optimal allocation of a government's anti-trafficking budget between Prosecution and Prevention to ensure a firm's full compliance with human trafficking laws in equilibrium.

One viable option which has been discussed is for governments to use a customised level of effort depending on the firm's industry-related cost of operating (parameter c, which is related to industry vulnerability) and estimated firm revenues to effectively allocate government Prosecution effort. A categorisation of companies by industry would not be difficult to create, and indeed already exists in many forms (McCarthy, 2011). Thus, governments can set inspection levels on a per industry basis to optimise their Prosecution mechanisms.

Furthermore, we offer advice for NGOs based on the key levers that drive government effort. However, we find that in the absence of external auditing, NGOs should be careful to heighten awareness of the Protection costs of trafficking, as it may backfire and lead to less government effort in Prosecution. In this case, NGOs should instead lobby based on the potential for business damage, and

thereby a potential loss of government tax collection due to a reduction in firm revenue.

The customisation of the government's profit function is an important feature in our analysis and insights, as it focuses on the perennial problem of governments under resource constraints. Although authorities are tasked with ensuring industry compliance with set laws, our model and results highlight the incentive that exists in opposition to enforcement. Specifically, authorities acting as social welfare maximisers have an incentive (in the form of tax collection and a minimisation of social cost) to allow businesses to operate undeterred, without exerting effort towards Prosecution.

One recent supply chain example was when Costco, a highly acclaimed retailer based in North America was sued for selling prawns procured from Thai fishing boats employing trafficked persons (Hodal and Lawrence, 2014). Costco's code of practice states it does not tolerate human trafficking, but this begs the question: did it have government-driven incentives to ensure that its suppliers were adhering to the same standards? Perhaps not. In Costco's response, the chain has now said it is working with the Thai government and the fishing industry to address these uncovered issues, a costly and public endeavour which may disrupt their ability to sell products.

Low government effort, as seen in the Costco example, can be a slippery slope to social acceptance that further breeds the violation of basic human rights. For example, the Thai fishing industry notoriously uses trafficked migrants beyond acceptable employment standards in duration and treatment (Hodal and Lawrence, 2014). Although Prevention mechanisms (e.g. laws, training) are in place, enforcement is limited in part due to corruption and a high level of social acceptance.

These issues of modern slavery are mirrored globally and across industries. In discussions conducted while writing this chapter, the highest-incident industries included agriculture, fishing, mining and textiles, with less prevalence in industries such as technology or education.

As consumers, we consider ourselves insulated from these issues, yet this could not be farther from the truth. The aforementioned high-incident industries have supply chains in which we drive demand for companies to provide products. Thus, we as consumers have a critical part to play, we are commonly yet unwittingly part of the problem, and we are potentially part of the solution. By purposefully buying products sourced from transparent supply chains, insisting on fair labour practices from suppliers, and voting for proper enforcement of laws and penalties, consumers can make a substantial impact on business compliance effort within their respective societies.

This chapter has provided a framework for modelling the relationship between a budget-constrained regulator and a firm responsible for compliance with human trafficking laws; however, further quantitative research is now needed.

One approach would be to collect data on the multiple approaches taken by governments to prosecute trafficking and their resulting impacts on firms. If there are certain approaches that were more (or less) successful, evidence-based findings could supply further insight into government strategy. A second empirical approach could take the form of NGO analysis to ascertain which lobbying efforts have caused the most positive movement on government intervention on the dark supply chain of human trafficking. Finally, it would be of interest to perform analysis of events which should have motivated firms to heighten compliance in their supply chains (e.g. slavery findings). These can be correlated to actual qualitative increases in firm inspections/disclosures of supply chain audits to find effective search mechanisms.

In this chapter, we analysed the allocation of budget mechanisms for incentivisation of ethical management of corporate supply chains to reduce the need, or use, of humans as unwilling forced labour. This analysis was based on the Palermo Protocol framework to ground the research in real practice and provide insights for current government policy implementation.

We can now think back to the dark supply chain of modern slavery. Though it is true that governments can protect corporate chains from being infected by this type of business, it begs the question if this is the best way to attack these types

of dark supply chains. As modern slavery operates as a supply chain, it is conceivable that we can also attack it using its inherent supply chain vulnerabilities. This notion, of taking advantage in the vulnerabilities of a supply chain is where our attention turns to in the next chapter. By better understanding core supply chain vulnerabilities that can result in business failure, we can more efficiently target and disable such businesses from operating.

4.5.1 Authors Notes

The dark supply chain of modern slavery has the ability to infect corporate supply chain systems if there is not a well-implemented government framework to incentivise firm compliance effort. Governments are building global momentum towards curing current occurrences and preventing future infections through the implementation of the 3P Palermo framework, yet much work remains to be done.

There are countless organisations helping in the fight against the sale of humans for business purposes. Based on current global events, this chapter offers timely insights that have applicability to academics, law-makers, and a growing community of practitioners who are attempting to use constrained budgets in the most effective way possible to combat forced labour in corporate supply chains.

The author of this thesis acknowledges feedback for this chapter from discussions with the Global Fund to End Modern Slavery (GFEMS), the Urban Institute, the WHO, amongst other organisations combatting this nefarious system on multiple fronts. Additionally, our modelling framework and each of the Extension areas were improved by feedback given to the author based on presentations of this chapter at international conferences. For all of the insights and feedback received, much gratitude is due.

5   How Supply Chains Break

In this chapter, our approach flips the perennial research goal of optimising a supply chain's performance. Instead, we focus on its duality for dark supply chains: how a supply chain can be purposefully hindered.

In the previous chapters, we introduced the supply chain perspectives which may be used to understand dark supply chains, including sourcing, transportation, logistics, storage, inventory management, purchase, delivery, use or consumption, recovery, recycling, and disposal. These may be analysed individually as *use* was individually modelled in Chapter 4 to understand the dynamics of forced labour in corporate supply chains. However, analysing them together, and over time, may be of even greater value. In doing so, it is possible to show the key areas of vulnerability and this may influence our understanding of how to disrupt dark supply chains.

Purposeful disruption does not exist in the supply chain management field, as causing damage to a supply chain has never been the goal. However, it is related to existing network interdiction models of the industrial engineering field. For example, Malaviya et al. (2012) assess how to model the interdiction of criminals in the dark supply chain of drug trafficking. Papers such as this customise mathematical models to simulate the relationship between law enforcement and criminals to find intervention methods.

The supply chain management field, on the other hand, has consistently taken the perspective of avoiding disruption and minimising risk, or in other words, improving profitability and ensuring stable performance. The absence of purposeful disruption from the supply chain literature is problematic yet understandable. It is problematic because it shows that researchers have not invested the necessary time to create tools that can aid in the disablement of illegal businesses, such as human trafficking, from a business perspective. It is understandable because with the use of traditional supply chain management tools, there is no known dataset, historical foundation, or need for this. That changes now.

This chapter presents the findings of an analysis of 200-years of historical supply chain failures to develop what we refer to as the Supply Chain Failure Framework (SCFF). This provides an enhanced understanding of catastrophic vulnerabilities and we connect this to the existing literature of supply chain disruption. Through our analysis of failure types and failure causes, we offer insights to better understand, prevent, and inflict supply chain failures. This is useful for preparedness and continuity of operations in corporate, military, and humanitarian supply chains, which can save resources and lives. The applications of this research include predicting supply chain failures, strengthening existing supply chain robustness, and outlining historically weak areas for use as adaptive threats. It may, most critically, be useful in law enforcement for creating failure in dark supply chains.

5.1   Introduction

The past two decades have seen a rise in the study of supply chain risk and disruption management (Kilubi, 2016). Much of this attention has been due to the widely publicised impacts of disruptions which have caught the public and academic eye (Wassenhove, 2006).

In the early 2000s, multiple frameworks were introduced to categorise disruption, such as those by Christopher and Peck (2004) and Wagner and Bode (2008), and analysis was conducted to ascertain the magnitude of those disruptions (Hendricks and Singhal, 2005). However, there has been limited depth in research on the worst types of disruptions, specifically those that are, in the words of prior research, *catastrophic*. These types of disruptions can cause a *failure*, which we define as the prevention of a supply chain's ability to operate, an event we also refer to as a *break* in the supply chain.

It is unfortunate that relatively little is known about catastrophic disruptions and what causes them. They are shrouded in mystery and often act as a last-resort description for cataclysmic events that have no other risk categorisation. However, additional research on catastrophic disruptions would enlighten our

understanding of supply chain risk and is severely needed for multiple reasons. Primarily, it can help organisations prepare for the worst possible outcomes, thereby avoiding potentially significant losses of resources. This is especially true in the humanitarian field, where preparation is an integral part of mitigating damage and protecting lives (Bhimani and Song, 2016). Similarly in corporate supply chains, understanding vulnerabilities that can cause failure enables companies to ensure continuity of operations and provides the potential for a competitive advantage through resiliency (Holcomb and Ponomarov, 2009).

Finally, as it becomes obvious that severe disruptions are becoming more frequent (Altay and Ramirez, 2010), the need to understand the types of disruptions that can cause failure becomes all the more critical.

The hard part is knowing where to start. Previous frameworks have mapped a general foundation for disruptions; however, without a depth of knowledge in catastrophic disruptions (i.e. sources of supply chain failure), organisations are shooting in the dark on where to focus their efforts to avoid large-scale risk. Therefore, managers require a cohesive understanding of supply chain failure types and their causes to better prepare for these risks. Furthermore, as law enforcement agencies attempt to create disruption in dark supply chains, it must be ascertained if they are aiming for their most vulnerable parts.

This chapter has two objectives. First, it provides the empirically-derived Supply Chain Failure Framework (SCFF) that adds new depth to the prior literature on disruption management, specifically on catastrophies. Second, it analyses these severe risk areas to historical outcomes to demonstrate the significant impacts supply chain failures have reaped and may provide in the future.

The Methodology chapter has defined the econometric study for this analysis, including the model employed and the relevant literature on supply chain risk, vulnerability, and the study of military supply chains that are an integral part of the quantitative analysis. The following section provides an overview of relevant nomenclature and previous frameworks in risk management. Following this, we complete the analysis, provide an exposition of the supply chain failure framework, detail the findings, and discuss the limitations of this study. We end

with the implications of our results, as well as recommendations for practice and further research.

5.1.1 Contribution to the Literature

A critical feature of this paper is the sourcing of war history to better understand how catastrophic supply chain failures have occurred. Reporting these findings frequently calls upon key failures in war operations to draw inferences and add supporting examples to our results. For this, we utilise existing academic research and historical records of war strategy and outcomes.

The Correlates of War (CoW) datasets (Sarkees and Wayman, 2010) offer a detailed foundation for our analysis of war history. This includes the types of war, countries involved, duration, relation to later wars, outcomes, and battle losses. This chapter uses data from the Correlates of War Inter-State dataset for its full range of years (1816-2007) as a starting point.

A paper with a similar foundation was created by Arreguín-Toft (2001), who presents an empirical analysis with the paper *How the Weak Win Wars*. Toft also utilised the CoW data in his analysis of past wars to understand how weak actors can overcome larger opponents. He argued that major powers can win wars by having two types of war capability: a normal standing army for relatively symmetric conflicts and a secondary army built specifically for the unique facets of asymmetric conflicts. His paper shows war strategies that have a higher likelihood of success or failure in a war setting. In a similar research approach, we seek to elucidate the key causes that catastrophically disrupt a supply chain in war and business settings. To accomplish this, similar to Toft, we append the CoW dataset with binary indicators of war outcomes and perform statistical analysis to build our understanding. Therefore, our work is aligned with the methods in the literature.

Our collection of causes are based on supply chain failures that occurred throughout the wars listed in the aforementioned CoW dataset. Specifically, our econometric analysis of previous supply chain failures, including the

categorisation of their types and causes, highlights those disruptions which were significant and impactful. In effect, we detail the types and causes of supply chain failure that were most catastrophic, i.e. had the ability to break a supply chain.

Although the prior research across the aforementioned fields is robust and voluminous, a substantial gap exists at the intersection of vulnerability and actual supply chain failures, or what can be referred to as historic supply chain vulnerability.

Simply put, to our knowledge there is almost no research which directly answers the question: how do supply chains break? The answer to the question is critical because it can enlighten where future breaks may come from, and potentially how we may understand past vulnerabilities to cause failure in dark supply chains.

We answer this question through an econometric study to analyse approximately 200 years of supply chain failures in war operations. We also compare and fit our findings with prior academic assessments of vulnerability.

This chapter, therefore, contributes to a growing literature on supply chain risk and vulnerability management. Much of the prior research on this topic relies on surveys of firms and executives who are asked to provide their opinions on what they perceive as a future risk in their supply chains (e.g. Wagner and Bode, 2008). Although this may provide insights on future events, it does not assess actual events which have impacted supply chains. Furthermore, surveys have limitations including respondent perceptions, temporal recency, confidentiality, bias, and more (Altay and Ramirez, 2010). Our approach of considering actual supply chain failures that have historically occurred can provide insights into ongoing weaknesses, key areas of intervention, analysis and purposeful attack, as we discuss in our case application in Peru in the chapter "Breaking Dark Supply Chains."

Though there is a deep extant literature on the assessment of weakness in supply chains, our research contributes a novel approach with the study of key histori-

cal catastrophic disruptions. Specifically, we study past failures in business and in war to critically analyse how supply chains actually break. Together, these sectors offer clear evidence on failure occurrences from which we learn and apply to dark supply chains.

In this chapter, we seek to answer the following questions:

- How have supply chains broken in the past?

- What learnings can we infer on supply chain vulnerability based on previous failures?

- How do our results compare to existing frameworks on supply chain disruption?

5.2 Supply Chain Failure Framework

In our Methodology (Chapter 2), we introduced prior supply chain disruption frameworks in the related literature. This created a backdrop of disruption and risk management classifications. Similarly, it introduced the connection between the concept of a catastrophe and that of a failure. A summary of prior frameworks is provided below.

5.2.1 Summary of Existing Frameworks

To answer our question of how supply chains break, we first sought to choose a framework with which to categorise failures. This was completed through an extensive sampling of prior vulnerability frameworks. Prior frameworks were collated through an extensive review of academic literature on supply chain risk management. Definitions for supply chain risk and vulnerability were also sourced from similar academic sources.

Following this, draft categorisations for our framework (including their relevance, wording, common usages, and potential overlap) were considered based

on preliminary testing with our findings. A draft framework for supply chain failures was thereby developed. During this process, we sought to maintain literary consistency whilst simultaneously remaining aligned with our research questions.

We now discuss and assess previous supply chain vulnerability frameworks. While the selection of frameworks described in this section does not exhaust the many contributions that have been made, they do cover some of the commonly discussed variations. The frameworks discussed below are therefore a sampling of key publications over time as opposed to a complete listing. In the tables below we summarise the six supply chain vulnerability frameworks and their categories that are commonly referred to and referenced in the related literature. The first three seminal frameworks in this area are:

Table 4: Frameworks 1-3 in Supply Chain Vulnerability

1. Mason-Jones and Towill (1998)	2. Svensson (2000)	3. Christopher and Peck (2004)
Supply; Manufacturing; Control; Demand	Quantitative; Qualitative	Process; Control; Demand; Supply; Environment

The frameworks described above were followed by three additional works, thereby creating a total of six core disruption frameworks considered in our analysis. The three works that followed are:

Table 5: Frameworks 4-6 in Supply Chain Vulnerability

4. Chopra and Sodhi (2004)	5. Jüttner (2005)	6. Wagner and Bode (2008)
Disruptions; Delays; Systems; Forecast; Intellectual Property; Procurement; Receivables; Inventory Capacity	Supply; Demand; Environmental	Supply-Side; Demand-Side; Regulatory, Legal, Bureaucratic; Infrastructure; Catastrophic

We now discuss the design, strengths, limitations, and uses for each framework.

Framework 1: Mason-Jones and Towill (1998)

Before the study of supply chain vulnerability came to the fore, Mason-Jones and Towill provided an indicator of its promise with the study of what they referred to as the uncertainty circle. In their discussion, the authors provide a glimpse of two forthcoming areas in supply chain study: information disclosure and supply chain vulnerability. For the latter (as related to our research), they outline the four areas of uncertainty as manufacturing, supply, control systems and demand. From a manufacturing perspective, they recommend the implementation of lean principles to improve quality while reducing waste. On the supply side, they consider applying the same lean approaches to upstream members to achieve the same benefits as were expected in the manufacturing area.

The authors used simulations and actual examples to show that better control over processes and demand can be achieved through information sharing (such as electronic data interchange) and cross-collaboration across the supply chain, similar to the findings of Stank et al. (2001). One of the notable points of this study is its focus on lean manufacturing and supply. These, however, can be dangerous as they may exacerbate supply uncertainty if an adverse event occurs.

Framework 2: Svensson (2000)

One of the seminal contributions towards building a framework of supply chain vulnerability was offered by Svennson with his empirical analysis of the Volvo supply chain. There are certain limitations of this early framework. To begin with, it was narrowly focused by three filters: only one part of the supply chain (inbound logistics), one industry (automotive), and one country in its geography (Sweden). Though it was tested against three other Swedish industries (retail, furniture, and pre-manufactured homes), these comparisons were on a small scale and the author noted that his classification was basic in its exposition.

Specifically from a framework perspective, Svensson sorts disturbances into two categories: quantitative or qualitative. He defines quantitative disturbances as a lack of material availability downstream and qualitative disturbances as a lack of accuracy or reliability in materials. Going further, the author separates the consideration of supply chain disruptions as either atomistic (direct, smaller in scope such as firm level) or holistic (indirect, spanning the chain). Though this study was admittedly nuanced, it helped usher in the dialogue of what he called supply disturbances, or what is now referred to as supply chain disruptions.

Framework 3: Christopher and Peck (2004)

Calling upon the foundations of Mason-Jones and Towill (1998), Christopher and Peck further the idea of resiliency in supply chain management. The authors categorise supply chain risk into five sub-fields: processes, controls, demand, supply and environment. By processes, they refer to the activities reliant on assets or infrastructure such as transportation and communication. Controls are the rules and protocols that manage the processes, including but not limited to procedures on assets and inventory. Demand risk includes impacts to the delivery of resources locally or downstream in the supply network. Supply risk is the complementary to demand risk for the upstream portion of the supply network. Environmental risks are external risks that may directly or indirectly impact the supply chain. Furthermore, the authors mention visibility as a major factor towards vulnerability, though it does not make it into their framework as a category.

Based on the above considerations, Christopher and Peck provide recommen-

dations on building resiliency into the supply chain, including strategies for organising the supply base, maintaining multiple options for services, increasing collaboration with information and visibility, and maintaining agility to shift or recover operations when disruptions occur.

Because their framework towards resiliency is based on recent studies performed for the UK government, the structure is thereby limited by the scope of those studies. Furthermore, there may be duplication across the categories. For example, a disruption in communication could be considered as a process disruption or a controls disruption, and it is unclear where the line would be drawn for such an event. However, the framework provided a more robust consideration of potential disruptions than those that preceded it. Following this, a similar framework was introduced by Manuj and Mentzer (2008), though those authors included security as a category and specifically focused on the manufacturing industry.

Framework 4: Chopra and Sodhi (2004)

In the same year as Christopher and Peck's paper on resiliency, Chopra and Sodhi followed a similar theme with a paper on preventing supply chain breakdown. According to the authors, there were nine categories of risk for a supply chain: disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory, and capacity (all briefly described below). They argue that by catering for these areas of risk, managers can mitigate potential issues before they occur. Finally, the authors recommend considering 'what if' scenarios and then creating risk management approaches to prepare for such events.

According to Chopra and Sodhi, supply chain disruption risk manifests itself with an impact on the flow of materials. Delay risk occurs on the upstream side (due to issues with a supplier) and can be mitigated through the balance of excess capacity and inventory. Risk of system breakdown increases with the interconnectivity of systems (except those of backup systems, which reduces the risk). Forecast risk comes from an error in estimating actual demand (e.g. the result of the bullwhip effect) and a method of prevention is collaborative planning, forecasting and replenishment.

The risk of intellectual property issues comes from maintaining a company's proprietary information from competitors, which may involve keeping it from suppliers. Procurement risk involves mitigating the disadvantages of currency shifts or supplier price hikes. The inability to collect debts owed constitutes receivables risk. Inventory risk is derived from the costs of holding excess inventory and can be mitigated through inventory pooling, standardisation or postponement. Finally, capacity risk involves the cost of having too little or too much capacity, which can be solved through flexible production.

Chopra and Sodhi's paper provides a helpful structure and historical anecdotes in the early consideration of supply risk. However, while their multiple categories of risk provide interesting considerations, there are some limitations. First, their category of disruption can be seen as one that is not mutually exclusive. Based on the definition employed by the paper, other categories (e.g. delays), could also be classified as a disruption. Furthermore, a majority of the risks exist on the supply (upstream) side of the chain as opposed to a holistic consideration of all internal or external (e.g. environmental) risks. It should be noted that the disruptions category contains some (but not all) of the essential building blocks that Wagner and Bode (2008) would later use in their categorisation of supply chain vulnerability.

Framework 5: Jüttner (2005)

Following the framework of Mason-Jones and Towill, Jüttner contributes to the literature by adding a practitioners perspective on Supply Chain Risk Management (SCRM). Based on her fieldwork from an industry survey and multiple focus groups with supply chain management professionals, Jüttner outlines how companies saw risk mitigation, their critical issues, and outlines the philosophical, principal, and key processes involved with SCRM issues. Furthermore, she adapts the Mason-Jones and Towill paper to create a simplified framework for risk, through three categories: risk in supply, demand, and environment.

In supply risk, the author refers to inbound flows of goods from upstream. In demand risk, she refers to issues with outbound flows downstream. For environmental risk, she refers to externalities that can impact both supply or demand,

and thereby creates an overlap between her three categories of risk. The empirical results of the paper show the risk areas that managers conveyed for their supply chains.

Jüttner's paper provides an important perspective on disruption research by utilising industry contributions. Additionally, the paper lays out clear and concise definitions for SCRM and potential areas for future analysis. There are, however, some limitations to the research. Regarding the framework, the simplification of the three risk categories (supply, demand, and environment) is quite broad and therefore creates an overlap between the categories while also avoiding important nuances in each risk area. Regarding the empirical method, survey data is a double-edged sword because though it can collect helpful insights, it can be subjective and therefore requires bias considerations. Despite these limitations; however, Jüttner's contribution to the supply chain disruption risk area was integral for the papers that followed.

Framework 6: Wagner and Bode (2008)

With a foundation similar to Jüttner (above), Wagner and Bode (2006) provide their own adaptation to the study of supply chain vulnerability by collecting empirical (survey-based) data of perceived risk. The authors categorise risk into five categories (what they refer to as classes): supply, demand, regulatory (including legal and political issues), infrastructure, and catastrophic risks.

According to the authors, supply risks may involve upstream risks with suppliers, relationships, purchasing, and more. Demand risks refer to potential issues with downstream operations, including distribution, transportation, and fulfilment. Risks related to governing authorities (i.e. legal risks) includes approvals to operate and comply with applicable laws. Infrastructure risks may jeopardise the usability of equipment (e.g. information technology), machines and other assets that the supply chain requires. Finally, catastrophic risks include all other severe events (e.g. natural disasters, strikes) that can negatively impact a supply chain. With their framework, Wagner and Bode performed a cross-industry survey to understand the perceived impact of each risk category on supply chain performance.

A key contribution of Wagner and Bode's paper is their creation of an empirical survey apparatus. They execute this tool to test the link between risk categories to potential impacts and show the existence of such a relationship. There are, however, some limitations. First, similar to Svensson (2000) this paper relied upon data from one country (Germany), which questions the ability to scale the results. Second and more importantly, the paper lists catastrophes as its own type of disruption. This creates a severe overlap with the other categories in the framework. Due to the overlap, any large-scale disruption to a supplier, customer, transporter, government, would be difficult to place in their respective category (or in the category of catastrophe).

Further Frameworks

Following the above frameworks, there were many iterations written that were variations of the previous categorisations of supply chain risk. Additionally, the word *risk* began presenting itself with multiple definitions in the literature over time, often tied to the mitigating strategies of *resiliency* (Sheffi and Rice Jr, 2005). There have also been attempts to aggregate these frameworks and contributions (Heckmann et al., 2015; Sodhi et al., 2012).

Through our discussion of previous disruption frameworks, it is evident that a significant amount of research has been done in building a structure with which to understand SCRM. Through the years, one can observe a progression of thought, nuance, and indeed collective feedback. Additionally, our synthesis of benefits and limitations of each framework has influenced the choice of categorisation for this chapter.

Based on our analysis, as well as to be consistent with the related research that followed these streams of disruption analysis, we utilise the Wagner and Bode (2008) framework as a foundation for our categorisation of failure *types*, with two notable changes:

1. The first necessary change is to remove catastrophes as a specific type of disruption, as we would argue that a catastrophe is a measure of severity and not a disruption type.

2. We utilise the term *environment* rather than the previous authors use of 'regulatory, legal and bureaucratic' to encompass all external environmental factors (e.g. natural disasters, antagonistic threats), which would otherwise be neglected.

In creating our framework, we have also sought to present these categories to external researchers for their advice and feedback, so that we may continue to maintain the applicability of this failure framework now and in the future.

Below, we provide detail on each of the four categories of failure-types we employ, which is followed by an introduction of the failure-causes. This offers consistency with the prior literature and extends it using historically-based research to dive deeper into catastrophes, i.e. failures.

5.2.2   SCFF: Failure-Types

In building an enhanced framework of catastrophic vulnerability through the Supply Chain Failure Framework (SCFF), the following failure types were adopted from the literature (as discussed in the previous section):

1. *Supply failures* refer to upstream failures that can be due to issues in manufacturing, inbound logistics, supply-side complications, resource acquisition, or other supply-based catastrophes. They are solely focused on the upstream of a supply chain. These failures are primarily concerned with receiving products from raw materials or manufacturers and incorporating them into the supply chain process. Failures may occur when materials become unavailable, manufacturers experience delays or shutdowns, or when the transportation to bring in supply is blocked, along with a myriad of other events. The inability to source material is compounded if there is limited safety stock in the supply chain to cope with shortages, or if the manufacturing line is reliant upon constant supply and thus the entire stream of flow can be brought to a standstill, often referred to as the bullwhip effect (Lee et al., 1997).

An example of such a supply vulnerability was when Land Rover's key supplier for chassis shut down overnight, essentially halting their ability to continue car production. This cut in the supply chain was remedied only when Land Rover was able to contact the supplier's bank, work out a financing agreement to continue their operations, and temporarily launch the supplier back up until a suitable alternative could be put into place. Other examples may include the inability of auto manufacturers to procure supplies due to disruptions in their suppliers, as described by Thun and Hoenig (2011) and Thome et al. (2014).

2. *Demand failures* refer to the inability to plan, solicit, or deliver to demand. These occur downstream when there is an inability to meet demand due to issues relating to logistics (e.g. distribution), demand planning, poor forecasting, or a surge in demand without the ability to fulfil it due to internal supply chain issues. A classic case of such demand issues occurs after major hurricanes ravage cities. In the aftermath of such storms, it is difficult to deliver supplies to the affected populations due to a lack of active transportation networks or knowledge of where the demand is most needed.

   Utilising the example of a hurricane, this may occur when aid stagnates due to an inability to physically move materials to hospitals, shelters, and government facilities. This is different from an environmental or infrastructure failure because the main cause of failure is not the result of a lack of resources. More critically, it is the inability to plan ahead of the disaster for the demand which required prediction and pre-placement of materials (Bhimani and Song, 2016).

3. *Environmental failures* refer to external failures with environmental underpinnings. These may include events in law, socio-political changes, regulation, or the impacts of a natural disaster. They occur due to shifts in the natural, political, or other relevant environments that can impact the supply chain.

   A recent example of an environmental failure that compelled international

fervour was the Syrian refugee crisis. In that specific situation, a massive migration of families from a war-torn country were visibly seen attempting to get to safety but could not always find asylum because of anti-immigration laws in many potential host countries. In such a situation, there was a plentiful supply of persons willing to work in other countries and there was proper infrastructure to physically take them (and the employer demand may even be supported), yet in-country laws prohibited mass influxes of people. The Syrian political failures caused turmoil for these refugees and many Syrians turned to smugglers to escape (Achilli, 2018). Also, this as been related to their subsequent mistreatment and the documented capture of many migrants into the dark supply chain of human trafficking, moving them across Europe, Asia, and the Middle East for economic gain (UNODC, 2018b).

4. *Infrastructure failures* refer to internal failures relating to physical or human assets in the supply chain including equipment, machinery, telecommunications, and labour. These involve the internal organisation's capacity of physical supply chain assets, including machines, telecommunications, and physical labour. An example of this was when General Motors spent billions of US dollars on robots to automate their key U.S. factories. The robots were meant to streamline the production process for tasks such as painting and pre-assembly. However, the robot's programming failed and instead of painting the cars, the robots were found to be painting each other (Pfeffer, 1996).

5.2.3   SCFF: Failure-Causes

Each failure-type outlined above can have one of numerous causes. During the course of our analysis, we found six causes to be pervasive throughout the historical records we analysed. In other words, there are six specific vulnerabilities that repeatedly caused supply chain failures to occur. The six are:

a. *Assets* refers to a failure caused by an inability to use internal assets which

were previously under the control of the supply chain. This may include equipment (e.g. machinery, vehicles), land, and facilities (e.g. manufacturing, airports).

b. *Trade* refers to a failure caused by an inability to buy and sell goods and / or services. This may include an inability to procure due to trade wars, natural disasters, embargoes, or blockades.

c. *Information* refers to a failure caused by miscommunication, lack of coordination, or loss of information. This may include lapses in information transfer, unintended transmissions, or data hacking.

d. *Delivery* refers to a failure caused by an inability to deliver to demand. This may include poor forecasting, loss of external delivery routes, demand surges, and lack of disaster planning.

e. *Logistics* refers to a failure caused when resources cannot be transported through an organisation's supply chain. This may be induced by weather, war, transport network issues, or other external events.

f. *Workforce* refers to failures arising from a loss of usable labour to continue operations. This may include worker strikes, a permanent loss of workers, or an inability to recruit workers.

5.3   Analysis

5.3.1   Hypotheses

This chapter analyses historical events to develop a previously unavailable framework on how supply chains break. The primary area of analysis is military supply chains in war. This context was chosen for multiple reasons which are detailed in Chapter 2, Methodology. The first of those key reasons is that militaries experience definitive war outcomes (e.g. a win, a loss, a truce), whereas business outcomes do not necessarily have specific end-states and therefore an 'outcome' in the business context is often temporary, subjective,

or arbitrary. The benefit of having a definitive outcome in war enables a direct comparison between militaries which had supply chain failures in war and those which did not. This leads to our first hypothesis.

H_1: *The occurrence of a supply chain failure has a negative impact on operational outcomes.*

Secondly, military supply chains often work together, as do companies. This enables the evaluation of whether having supply chain partners impacts the likelihood of a failure.

H_2: *Having at least one supply chain partner reduces the occurrence of a supply chain failure.*

Third, military operations during war operate on a fixed time horizon, specifically from the beginning of the war to the end of the war. Therefore, unlike a continuous business operation, this context allows us to test if the measurable duration of an operation is related to supply chain failure.

H_3: *A longer duration of supply chain operation is associated with the occurrence of a failure.*

Fourth, we have an account of the number of resources lost (i.e. battle deaths) by each military for each war operation, therefore, it is possible to test if there is any relationship between resource expense and supply chain failure.

H_4: *A higher number of resources expended is associated with the occurrence of a failure.*

There are numerous other benefits in the analysis of military supply chain failures discussed in Chapter 2, including the existence of repeated historical accounts of supply chain failures. This benefit cannot be understated, as business supply chains do not contain historical repetition and companies do not often disclose the details of their supply chain failures, nor the ultimate impacts they have caused.

Furthermore, substantial historical records exist which account for the success and failure of military supply chains, therefore the occurrence can be verified

and relies upon commonly accessible facts. This is quite unique from previous risk management literature which relies upon financial impacts (Hendricks and Singhal, 2005) and managerial opinions (Wagner and Bode, 2008). Finally, supply chain learnings from one sector can be applied to other sectors (Maon et al., 2009). Therefore, we believe the application of these learnings has utility for use in corporate, humanitarian, and other types of supply chains.

5.3.2 Data Summary

A summary of the dataset used is provided the table below. This dataset includes wars across geographic regions, time durations, battle deaths, and with a range of partners.

Table 6: Summary of Data used in Regression Analysis

Summary of Data		Entries	Percent of Total
Supply Chain Failure	Occurred	39	15
	Did not Occur	235	85
Region of Operation	W. Hemisphere	31	11.31
	Europe	106	38.69
	Africa	7	2.55
	Middle-East	50	18.25
	Asia	54	19.71
	Multi-Region	26	9.49
Duration	Less than 1 Week	10	3.65
	1 Week - 1 Month	30	10.95
	1 - 6 Months	122	44.53
	6 Months - 1 Year	31	11.31
	1 - 2 Years	28	10.22
	2 - 3 Years	7	2.55
	3 - 4 Years	13	4.74
	4 - 5 Years	14	5.11

Summary of Data		Entries	Percent of Total
	5+ Years	19	6.93
Resources Lost (Deaths)	Less than 100	26	9.52
	100 - under 1,000	72	26.37
	1,000 - under 10,000	94	34.43
	10,000 - under 100,000	49	17.95
	100,000 - under 1 million	24	8.79
	1 million and more	8	2.93
# of Partners	No Partners	119	43.43
	1 Partner	28	10.22
	2 Partners	21	7.66
	3 Partners	16	5.84
	4 Partners	15	5.47
	6 Partners	14	5.11
	7 - 9 Partners	16	5.84
	10 - 19 Partners	24	8.76
	20+ Partners	21	7.66

5.3.3   Sample Evaluation

We briefly provide a sample war failure to show the method of coding and categorisation used for our econometric analysis. In doing so, we highlight the inherent subjectivity (i.e. bias) in the categorisation of failure types and causes, as well as methods employed to overcome it.

In this example, we consider the Bangladesh War of 1971 which led to the creation of Bangladesh (previously East Pakistan) as a separate country. During the war between East and West Pakistan, India became involved on the side of the future Bangladesh. India strategically blocked West Pakistan's ability to re-supply troops by destroying Pakistani ships in four major ports and blockaded key maritime access. These actions severely impacted West Pakistan's ability to supply its troops in East Pakistan and helped force the country towards peace

talks.

Based on the abridged history above, we first consider the categorisation for the failure-type incurred by West Pakistan. Our four failure-types are Supply, Demand, Environment and Infrastructure. For this specific case, we have chosen Supply as the main type of failure due to Pakistan's inability to resupply its troops in West Pakistan due to a loss in maritime access, which directly led to a loss of control in key areas. It is also possible that we, and other researchers, could have chosen Infrastructure as the potential failure-type in this situation due to the loss of ships. However, given the action which most directly contributed to the outcome, we have chosen Supply over Infrastructure, as a lack of Supply was the type of failure incurred.

With the failure type decided as Supply, we now turn to categorise the cause of the failure. When deciding the categorisation of failure-cause, the natural choices are between Blockade and Logistics, both of which have a portion of overlap. Although we chose Blockade in this example, Logistics would could have may have also had justification for the failure cause (though we would argue that Blockade was more influential).

This example was chosen specifically because of its ambiguity to show the inherent subjectivity of categorising historic events. To account for this and to enhance replicability, a summary for each coded decision used in our data analysis is included in this chapter. This is intended to convey the related history and the rationale behind the categorisations based on the details and impacts of each supply chain failure. A summary for the remaining failures is included in the Appendix.

5.3.4   Regression Model

With the finalised dataset, we utilise logit regressions to test the hypotheses. This method of analysis is the most appropriate for our data for two main reasons, as introduced in the Methodology chapter (2) and briefly discussed below.

First, this type of regression analysis suits the binary classification of the war outcome variable (coded with the number '1' for a win, and the number '0' for a loss). This type of data classification (binary between 0 and 1) is the ideal space for using the logit regressor. Furthermore, though a standard regression analysis (e.g. OLS) could be used instead of a logit regression, it would lead to numerical outcome possibilities beyond the binary outcome range (i.e. outside of 0 and 1), which does not fit our binary outcome variable.

Second, unlike other regression methods, a logit analysis does not rely upon linearity between the covariates and the outcome variable due to its log (non-linear) transformation, while being able to accept ordinal and nominal data to predict an odds ratio. Therefore, the use of non-continuous variables in the covariates is acceptable in logit analysis, which is the case with our dataset.

Finally, it must be stated that the result of wars is due to a multitude of factors that we do not attempt to cover herein and are, indeed, covered by multiple other streams of literature. While we understand this, we do purposefully and cautiously follow a similar approach to other authors who have utilised the CoW dataset for similar insights (Sarkees and Wayman, 2010), including a similar econometric approach followed by Arreguín-Toft (2001). Therefore, we do not suggest that our results can unmistakeably approximate all aspects of warfare as that is not our intent; however, the model and results herein do capture the aspects of supply chain failure we seek to understand through our unique historical analysis of wars.

5.3.5 Statistical Analysis

Our research into Inter-State wars provides valuable information on the types and causes of failure (i.e. catastrophic disruptions) in supply chains. Supply chain failures have a positive probability of occurring and can be described by their types and causes.

As detailed in the data summary, we align these to the prior framework offered by Wagner and Bode (2008), as the disruption can occur to (1) the upstream

(i.e. supply), (2) downstream (i.e. demand), (3) the environment, or (4) the infrastructure of a supply chain. Further to the types (i.e. categories) of failures, there are specific causes (i.e. impetuses) of failure. Based on our analysis, we divide these into six causes: (a) Assets, (b) Trade, (c) Information Security, (d) Delivery, (e) Logistics, and (f) Workforce.

To consider the real impact of supply chain failures, we first consider the impact of failures on the outcomes of war. Our hypotheses are accepted at the statistically significant level of 0.05. An accepted hypothesis would give more credence to the impact of supply chain failures and incentivise further study to understand outcomes in related fields. If a hypothesis is rejected (or in other words if the null hypothesis is true), then supply chain failures may not necessarily have a tangible impact on war outcomes, yet we would still find their occurrences interesting for qualitative review. The hypotheses are rejected if they do not meet the required significance level.

The logistic regression model to test our first hypothesis takes the following form:

$logit(E[Outcome_{ic}|X_{ic}]) = \beta * X_{ic} = \beta_0 + \beta_1 FailureSC_{ic} + \beta_2 Initiator_{ic} + \beta_3 BatDeaths_{ic} + \beta_4 WarDur + \beta_5 Partners$

where the subscript *ic* refers to war *i*, belligerent country *c*. FailureSC (existence of a failure), Initiator (first aggressor), BatDeaths (number of fatalities), WarDur (duration of war), and Partners (number of partners) are explanatory variables for the Outcome (win or lose) for each country *c* in each war *i*. A summary of the correlations between the variables is provided in the table below.

Table 7: Correlation of Variables

Variables	(1)	(2)	(3)	(4)	(5)
(1) Supply Chain Failure					
(2) Initiator	0.01				
(3) Resources Lost (thousands)	0.26	0.05			
(4) Length of Operation	-0.04	0.32	0.24		

Variables	(1)	(2)	(3)	(4)	(5)
(5) Number of Partners	0.12	0.13	0.29	0.23	
Mean	0.14	1.68	108.32	449.03	4.87
Standard Deviation	0.35	0.47	551.81	692.33	5.76
Max	1.00	2.00	7500.00	3734.00	21.00

5.4   Results

Below we provide a summary of the supply chain failures, their types, and their causes. From our study of 95 wars (consisting of 274 military supply chains), 77 wars had a definite outcome (i.e. a win or a loss). Of those with a definite outcome, we summarise the 39 with verified supply chain failures in the second table.

We calculate that over 97% of wars which were won had no supply chain failures found, whereas over 29% of the wars that were lost had at least one occurrence of a supply chain failure.

Table 8: War Failures by *Type*

Failure Type	%	Won	Lost	Total
Supply	20.5%	1	7	8
Demand	28.2%	1	10	11
Environment	5.1%	0	2	2
Infrastructure	46.2%	2	16	18
Failure Total	100.0%	4	35	39
No SC Failure		151	84	235

Table 9: War Failures by *Cause*

Failure Cause	% of Failures	Won	Lost	Total
Assets	10.3%	1	3	4
Delivery	20.5%	1	7	8
Information	20.5%	0	8	8
Logistics	17.9%	2	5	7
Trade	28.2%	0	11	11
Workforce	2.6%	0	1	1
Failure Total	100.0%	4	35	39

Statistical Analysis: Understanding Failure

The below tables show the results our logit regressions on the appended CoW Inter-State war data spanning all (approximately 200) war years with all supply chain failure types and causes.

Table 10: Logit Regression on War Outcome

Variables		Coefficient	Std. Error	z value	p
	Supply Chain Failure**	-3.59	0.75	-4.77	0.000
	Initiator**	-1.61	0.34	-4.72	0.000
	Resources Lost	0.00	0.00	0.93	0.350
	Partners**	0.22	0.04	5.12	0.000
	Operation Duration*	0.00	0.00	-1.9	0.058

N = 274; LR chi2 = 102.58; Prob > chi2 = .000; Pseudo R-Squared = .273

The model results summarised in the table above explain 27% of the variance on war outcomes and provides support for Hypothesis 1, that supply chain

failure has a statistically significant and negative impact on the log odds of war outcomes.

Table 11: Logit Regression on Supply Chain Failure

Variables	Coefficient	Std. Error	z value	p
Initiator	0.22	0.41	0.53	0.598
Resources Lost**	0.00	0.00	2.72	0.007
Partners*	-0.08	0.04	-1.86	0.062
War Duration	0.00	0.00	0.69	0.489

N = 274; LR chi2 = 19.35; Prob > chi2 = .001; Pseudo R-Squared = .086

The model in of independent regressors on Supply Chain Failure predicts 8.6% of the variance of a catastrophic disruption; however, it does not support Hypotheses 2 at the 0.05 significance level (though it does at $\alpha = 0.1$), that having supply chain partners influences the log odds of failure. Therefore, we are unable to draw a conclusion that having additional supply chain partners would decrease the log odds of failure.

Hypotheses 3 is also not supported, as there is no statistical significance to show that a longer duration of operation impacts the likelihood of a supply chain failure. This is surprising, as we would have expected the length of an operation would expose a supply chain to additional chances of failure. However, this is not the case at all, and in fact the coefficient is rounded to approximately null.

Interestingly, Hypotheses 4 does provide support to surmise that a higher number of resources lost is statistically significant for the log odds of supply chain failure. However, with a low coefficient, the impact of this may be minimal. We carry these findings forward into our discussion of results.

5.5   Discussion

The results shed light on the relationship between supply chain factors and operational outcomes. Specifically, our analysis of historical events confirms a relationship between supply chain failure and war success or failure. This connection by itself is indicative of the critical importance of supply chain failure, yet it has potential conclusions for business and dark supply chains as well.

We found that the supply chain failures which occurred had similar failure-types to previous research and could furthermore be categorised by their causes. Of the factors considered, including the initiator country, war duration, and how many battle deaths were involved, supply chain failure had the highest statistical significance on the log odds of war outcome. This is important because it emphasises the point that a catastrophic supply chain failure can have a direct and substantial impact on the outcome of an operational endeavour.

Counter-intuitively, the duration of an operation (H2) and the number of partner countries involved (H3) do not have a statistically significant bearing on the existence of a supply chain failure. This is surprising because intuition would state that a longer operation or a higher number of partners would help reduce the chance of failure, yet this is not supported by our results.

One way of making sense of the former (duration of operation) is that supply chain failures can happen just as an operation is beginning, or due to some type of disruption to an ongoing operation with no apparent or common timeframe. The latter (influence of partners) is significant at the 0.1 level with a beneficial effect on the log odds of failure, yet not significant enough to meet the 95% confidence interval set in the research design. Therefore, though intuition might dictate that partnering makes a supply chain resilient to failure, this is not always the case and is not supported (at a significant level) in our analysis.

Almost half (46%) of historical supply chain failures in the study have been due to Infrastructure-type catastrophes. Following this, failures in the category of Demand represents a third (28%) of all failures. Together, Infrastructure and Demand make up the majority (74%) of failures. The high occurrences of Infras-

tructure failures are interesting because this category relates to assets under the supply chain's control, not external assets. This highlights the integral nature of infrastructure for supply chain operation and, when it is diminished, the organisation is put into peril as a result. The prevalence of Demand failures is intuitive because in the business field, we may associate an inability to deliver products as a sign of forecasting or supply chain naivety.

The combination of Trade, Information, and Delivery failures-causes make up more than two-thirds of all catastrophic supply chain disruptions in our dataset. For the failure-cause of Trade, we can derive insight as to the vulnerability areas of choice for external intervention. For example, world powers have frequently relied upon blockades to disrupt national supply chains, and the analysis shows how impactful this can be.

Similarly, lack of access to markets is a result of common sanctions imposed by the United Nations onto countries who feel the reprimand of UN resolutions. This is for good reason, as we can see that Trade-caused disruptions have a historical grounding in war manoeuvring. Therefore, it makes intuitive sense that world leaders already use this failure type as part of their arsenal. For the failure-causes of Information and Delivery, the high occurrences of these underline the inherent dangers of sale and procurement, as well as the vulnerability of the physical movement of goods and information.

As 85% of the military supply chains in our dataset did not experience a supply chain failure, we have also captured a fascinating background on the unique occurrences of catastrophic disruption as part of a richer contextual history. This highlights areas for use as *adaptive threats*, or in other words, areas where supply chains can be best forced to break and where underlying vulnerabilities may already exist. Furthermore, the study includes all major regions and therefore represents supply chain failure on a geographically global basis.

This also has direct implications for resiliency planning. For example, in verifying the impact of supply chain failure on ultimate outcomes, as well as the causes of those failures, this study provides a roadmap for companies to reanalyse their current operational structures to prepare for vulnerability.

5.5.1   Comparison to Business Failures

Equipped with an analysis of supply chain failures in war, as well as the resulting framework of supply chain failure introduced in the previous sections, we test our results on actual business failures. To accomplish this, we analyse 24 failures across multiple industries to test for our frameworks fit, applicability, and limitations.

We qualify a supply chain business failure using the same definition as our analysis of military failures. Specifically, a failure constitutes an inability to continue operations as planned as a direct result of the failure event. Similar to a military failure, it does not necessarily imply that the organisation shut down or "lost;" however, the supply chain's operations were inhibited due to the failure event.

Our method of finding business failures differed from that of military occurrences (which was grounded by a war dataset). An exhaustive search led to the conclusion that a cohesive dataset for business supply chain failures does not exist in the academic sphere, nor in the realms of industry. Therefore, we embarked on the task of drafting and creating such a collection.

To source material for this endeavour, we utilised supply chain journals, exp ert forums, industry publications, and thereby performed analysis of business failures which may have had supply chain underpinnings. Based on availability, our resulting dataset contains information on business failures which span the past few decades. From this list, we compared the results of our analysis of military supply chain failures to those of business failures to test for fit, applicability, and areas of difference.

In our comparison, we found some fascinating insights. First, we learned that while war is dominated by the Infrastructure supply chain failure-types, business failures were dominated by the Supply failure-types. Furthermore, a notable portion of business failures were caused by issues with Trade causes, which relates to our war finding on the war impact of Trade.

The comparison in types and causes of supply chain failures between war and

business is fascinating because it shows the possible similarities and differences between the two areas. This is natural, as the data comes from different time periods and the business data has minimal sample size. This size is due to a lack of pre-existing collation and the issue that companies may seek to not publicise their failures. This is contrasted by the war data which is publicly available and is continuously improved when new findings are uncovered. This is part of the reason why war data is seen to be more robust and further justification on why we used in the econometrics herein, though a detailed explanation is provided in the Methodology chapter.

Despite the differences, the history of failures across both areas has provided us with a backdrop of historical precedent and the details with which have created our Supply Chain Failure Framework (SCFF). This is a tool necessary for our next endeavour: approaching war with the businesses of drugs and slavery.

5.5.2 Falling Forward

The summaries of failure data in the appendix provide the history, context, and methods for analytical coding that were used in this chapter. Through our collation and analysis of documented supply chain failures, our results led us to create the Supply Chain Failure Framework, a theoretical foundation on which to better understand catastrophic disruption. In Chapter 6, we apply this, along with learnings on war strategy, to understand how dark supply chains can be pushed to break.

5.6 Chapter Conclusion

Through the analysis of catastrophic supply chain disruptions in war operations between the years 1816 to 2007, we categorically outline the types and causes of failures of the past into the Supply Chain Failure Framework (SCFF). Doing so imparts multiple contributions, namely the creation of an empirically based theoretical framework of supply chain failure and an appreciation for their impact

on operational outcomes, and a better understanding of supply chain vulnerability.

The first (the SCFF) is a contribution to the literature which has missed a quantitative treatment of supply chain failure. We offer this through the historical study of 274 military operations, of which 39 failures were identified and analysed. Through this thorough treatment, direct comparisons were made between military operations which enabled an empirical analysis to quantify the impact of supply chain failures on operational outcomes, thereby overcoming some limitations of previous studies, including interview bias and indirect analysis.

Second, this study offers new insights into the potential effects of operational facets due to supply chain failure. This includes the surprising results that the duration of an operation and the number of partners does not help, nor harm, with a significant probability, the event of a supply chain failure. Nor does the duration of an operation, a counter-intuitive result.

Third, we offer an enhancement to the previous taxonomies in the literature on supply chain risk. Specifically, we remove 'catastrophes' as a separate category of risk because a catastrophe can impact any type of disruptive risk, from supply, demand, environment, or infrastructure. Furthermore, we offer a cohesive framework with which we answered the integral question with a hitherto evasive understanding, how supply chains break.

5.6.1   Limitations of this Study

Perhaps the biggest limitation of our analysis is the reliance on historical records as secondary data. Though this is difficult to avoid, there are at least a few issues that arise from this.

First, history can be written with bias which can influence the clarity around how events occurred. This is the key reason it was important for us to second source each war failure.

Second, for each war operation analysed, there are innumerable lines of data

and text across hundreds, if not thousands, of historical volumes. Due to this, it is possible that not every failure which may have occurred is captured in the dataset. Similarly, it is also possible that there may be personal subjectivity regarding what historical factors should be considered a break in a supply chain. This could challenge the replicability of the study; however, the author has attempted to overcome this with pedantic multi-sourcing and an included summary (in the thesis appendix) which captures the decision process for each record.

Third, there is a relevant notion in the literature that the level of a supply chain's complexity can contribute to the probability of a failure (Perrow, 2011). This study does not directly take into account the depth of complexity in each military supply chain, though it could be partially considered through the included analysis of resources and partners for each engagement.

Finally, no study is perfect. Though the past is often heralded as a predictor of the future, this is not always the case. There are catastrophic disruptions which may break supply chains in the future which we have not seen, though it was our attempt to create a flexible taxonomy which is open to such eventualities.

5.6.2   Future Research

In writing this chapter we sought to open a window to additional research in a darker side of supply chain management. Much of the previous literature focuses on how to help supply chains succeed, yet there is limited work on how supply chains fail. While collating war operational data for the analysis, we also collected business failure data for comparisons to ensure the resulting framework translates well to corporate supply chains. It is through the process of trying to collect such data that we realised a database of business supply chain failures does not exist, which might be the perfect place to start for future research. Building on this, humanitarian logistics failures, such as the recent events of Hurricane Maria in Puerto Rico (Swaminathan, 2017) and the 2010 earthquake in Haiti (VanRooyen, 2013), are similarly worth collating for learning lessons

and analysis, similar to the work of EM-DAT (2012) from Chapter 1.

Also, it is worth considering how actual events compare to the preparation for disruption in practice. For example, are companies prepared for high-probability scenarios, or instead for the scenarios which they fear the most? Also, how do recent theoretical insights into supply chain resiliency address these concerns? There also may be space for work in the gaps between the perceived causes of risk versus the actual occurrences of them.

6   Breaking Dark Supply Chains

This chapter applies our learnings from how supply chains break, as well as common military strategies, in order to provoke failure in dark supply chains. It is through this qualitative analysis and a case application that we show how the fruits of our labour can be harvested.

6.1   Introduction

In the following sections, we apply the results from our review of past cases of supply chain failures, military tactics, and government attempts to dismantle dark businesses. Our initial goal is to maintain a broad perspective on the dismantling of a targeted supply chain, whereas later in this chapter we will discuss nuanced approaches as part of a case study.

The existing literature in supply chain management contains limited discussion on how to impair a supply chain; however, this area requires investigation as it is by analysing this duality that we can better understand supply chain management holistically. The underlying purpose of this is to challenge the notion that supply chains are altruistic or at worst neutral, for there are supply chains which are nefarious and their vulnerabilities should be understood.

The methods used herein are those of qualitative, case, and historical analysis, as discussed in Chapter 2. The implications of this research are a more complete view of supply chain risk and potential adaptations for law enforcement. To the best of our knowledge, this chapter is the first study to utilise the findings of past supply chain failures to tackle illicit business operations.

Often, it is common for managers to go after the low hanging fruit, or the easier projects, which give the largest results for minimal effort. This is in agreement with our analysis, as we believe that such an approach would work for our purpose of hindering a supply chain by utilising minimal resources (i.e. with economy of effort). The goal of this approach would be to target the weak points,

commonly referred to as the "weakest links in the chains," for intervention.

The applications of this topic are intended to be toward nefarious chains. Though it could be expected that such knowledge could also be adapted for competitive purposes, that is not the intent, purpose, or hope. Instead, the goal of this chapter is to show how dark supply chains, such as modern slavery, can be prevented from operating.

In the next section, we discuss applications of the SCFF failure-*types* (from Chapter 5) toward understanding how to break a dark supply chain. Following this, we will introduce the Principles of War, a common military doctrine, and detail how it can accompany the SCFF in order to combat dark supply chains.

In this chapter, we seek to answer the following questions:

- How can we apply our learnings on failure (from the previous chapter) and war strategy toward understanding the vulnerabilities of dark supply chains?

- What parts of dark supply chains are being targeted by governments and non-profits, and do these match our analysis on catastrophic vulnerabilities?

6.2   Harnessing the SCFF

In this section, we will discuss each of the six failure-types from the prior chapter to expand on the understanding of each. Specifically, each failure-cause will be extrapolated upon to show they can be weaponised to create failure. As a reminder, these causes are based on the readings of war history and their respective military operations from Chapter 5. Throughout the following discussion, our learnings are specifically harnessed for application against the dark supply chain of human trafficking. However, we seek to keep the discussion broad and therefore scalable to other dark supply chains, as we will use this for the chapter's case analysis.

6.2.1   Assets

By seizing a trafficker's assets, governments can turn the resources which were accessible to traffickers against them. This can be done by selling commandeered real-estate, capturing illicit funds, and utilising victim testimony against their captors. This transformation of an enemy's resources is not unique, for as we have discussed in Chapter 5 (War Summaries), it is used in military strategy as well.

Furthermore, taking these actions would reduce strains on a government who has a limited budget. This bolstering of a government's 'war-chest' through acquisitions of assets would help bring human trafficking to a higher priority according to Wheaton et al. (2010), thereby further fuelling the efforts to eradicate it.

6.2.2   Delivery

A supply chain exists to deliver products or services and an inability to achieve this raison d'être cuts directly at the heart of its existence. In a demand attack, the supply chain suffers a loss in its ability to deliver to consumers. To be clear, this may occur despite the continued existence of end-user demand and only refers to an inability to deliver.

One way this can be caused is due to poor demand estimates. However, it can be forced to occur by creating a cut in the delivery service of the supply chain. In military terms, this would be considered a blockade or encirclement.

An application of this to trafficking would involve policing the available delivery routes of products to market. By preventing the delivery of illegal products, a supply chain will be strained from its own weight of inventory and infrastructure. Furthermore, it can cause the supply chain to redirect to another market or, if the blockade is effective enough, simply fail altogether.

6.2.3   Information Security

Communication infrastructure, especially those for underground organisations, can be a critical vulnerability. When an external actor intercepts, alters or disables the transmission of information, a supply chain's ability to respond or continue can be damaged. We discuss each of these three actions below.

Information security can be compromised by intercepting (i.e. line tapping, listening in on) the communications of an organisation. This may include communications on analogue devices (e.g. phone calls), digital devices (e.g. messaging, computers, enterprise systems) and non-device communication (e.g. shipments of products, letters, parcels). Being able to tap into these systems enables external actors (such as governments) to collate a mapping of people, locations, and data, many of which can expose the vulnerabilities of a supply chain.

Once a supply chain's information systems have been compromised, there is a potential for data, signals, and communications to be purposefully altered to the benefit of an external actor. Finally, the disablement of communication could significantly impede a supply chain's ability to continue operations.

It is worth noting that underground organisations purposefully minimise traceable communications due to the issues discussed above. However, communication continues to occur through mail, messengers, or other rudimentary methods. Though more difficult to intercept, these information transfers are not without vulnerability. For example, placing individuals within the organisations (e.g. undercover agents) serves as a way to understand the organisation's design, collect information, and compromise even informal information security.

6.2.4   Logistics

In the context of dark supply chains, attacking logistics can involve preventing the use of legal transportation networks for smuggling illegal products (Ekwall 2007).

This requires a better understanding of what is in our global transportation systems, a task where technology is increasingly helping with transparency. This is being heightened even further with the introduction of blockchain technology to verify shipment details and product sources. Despite this, there is still the potential for illegal items to make their way into transparent transportation systems. Thus, inspections and road checks become key methods of identifying and detecting illegal products in transit.

6.2.5 Trade

We discuss two components of the larger trade context, specifically regulation and consumers.

With regards to regulation, governments employ a variety of tools to increase the difficulty of illicit trade. These may include embargoes, identification checks for the purchase of related products, and preventing the procurement of ingredients or tools used for illegal transactions.

Consumers play an integral role in trade because they create the demand which allows trafficking networks to sell products. Both private companies and governments can assist with this swaying consumer demand. An example of how private companies can assist is through programs such as FairTrade, whereby supply chains are verified to pay fair wages, not use trafficked labour, and this information is presented to consumers to make an informed buying decision between a verified product and an unverified product. Though FairTrade has had criticisms, programs like it are paving the way toward supply chain transparency. Examples of this are the smartphone applications offered by Provenance (2019) and EWG (2019), which enable a consumer to view a detailed supply chain history of a variety of products they may consider to purchase.

Combining changes by regulators and consumers, governments can incentivise a consumer shift by creating a legal option to substitute the illegal flow of products. This can be seen with recent shifts in consumer regulations in countries such as Portugal and Canada to legalise the purchase of certain drugs, thereby

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undercutting the illicit market. Furthermore, legally approved rehabilitation clinics have been set up to help ween users away from drugs without fear of law enforcement reprisal (Kristof, 2017).

6.2.6   Workforce

The will of the people connected to an organisation is a will which holds significant power. This has been shown time and time again in revolutions and coups. Similarly, the human aspect of a supply chain requires acquiescence to the task, at the very least, to continue operations. However, when this is changed, or in other words, the will of the workforce turns away and no longer agrees to continue operations, an entire organisation (or even country) can topple.

There are entire streams of literature dedicated to workforce and employment; however, we briefly discuss a few salient points regarding the impacts that can be had on dark supply chains.

One example is the provision of alternative work opportunities. As discussed in Chapter 3, persons trafficked are commonly in situations of economic difficulty with minimal access to opportunity, and thus they seek opportunity elsewhere, a search that can lead to being trafficked. This breeding ground for trafficking can be stymied by providing alternative options to people such as employment assistance, support, training, or other types of economic engagement. Such programs increase the economic cost of being trafficked and risking capture into forced labour (Wheaton et al., 2010), thereby decreasing the will of persons to enter the system whether inadvertently or otherwise.

For people who are currently enslaved in a trafficking system, helping them implies assisting with the escape and protecting against the future return to it. Finally, for persons who are employed by such dark systems, workforce intervention involves changing the economic cost of playing a role. For example, increased prosecution of traffickers and their associates would de-incentivise would-be traffickers from becoming involved because of the increased risk of imprisonment, fines, or both.

6.3 The Principles of War

Knowing how to attack or defend an enterprise is of paramount importance. The learnings from wars over the centuries have led to a vast accumulation of related methodologies, tactics, and protocols. Through partially incorporated into the SCFF; war strategies have also been contributed to, and compiled by, military leaders, tacticians, scholars, and governments. They have coalesced into the *Principles of War*, adopted in multiple country-specific variations across the world to represent the maxims or key learnings from past warfare.

Many scholars have contributed to the core principles over time, including Machiavelli (1532) in *The Prince*, Carl von Clausewitz (1940) in *On War*, and specific histories of which have been summarised by others (Reid, 1993). Similar to the history of supply chain management described in our Methodology chapter, the Principles of War have gone through their own historical transformation and are now applied by modern military apparatuses.

As part of our research, we have reviewed and distilled the Principles of War from multiple countries into a simplified framework usable for understanding the context of battle. The synthesis of these common war principles are offered as part of this chapter as a tool for understanding the current situation of warfare. Thus, these principles also have direct application to combatting dark supply chains because they espouse the main methods through which military force has been harnessed towards specific goals. Specifically, they critically highlight the ability to identify or exploit vulnerabilities in war. We now consider some of the common principles and explain their utility toward supply chain efforts. Additionally, we outline the relation these principles have to our failure framework and the extent to which they call upon causing supply chain failures.

We must mention that the Principles of War at not uniform globally, as each military takes its own approach to them. However, they are very closely aligned across most major militaries, and in our aggregation of these, we have summarised the following common principles for use in our analysis:

6.3.1   Aim or Objective

Every operation must have a clear and realistic objective or aim in order to plan for its accomplishment, work towards it and assess eventual success or failure. Without this guiding light, an operation is navigating in the dark, perhaps with an idea of directions, yet without a path to get there. This would involve a military declaring a clear end goal for their operation, after which there is a plan to withdraw or stabilise operations. A historical example of this was the UN coalition's invasion of Kuwait during the Gulf War. The objective was clearly stated to expel Iraqi forces from Kuwait, which was accomplished and the mission deemed successful. Due to the existence of a clear aim, the military was not swayed by some stakeholders who sought to perform a full invasion of Iraq to overthrow the military or government at that time (Freedman and Karsh, 1993).

6.3.2   Initiative or Offensive

The opportunity to be the initiator in action can have positive results as the opposing force may take a reactive or defensive position. By taking initial action, a force seeks to quickly achieve their objective and overrun an enemy's defences. An example of initiative is the planning of a surprise military excursion into foreign territory, strategically and tactically planned to disable the initial ability of the enemy to counter-attack. A military example of this was Israel's invasion of Egypt during the Six Day War. Israel's initiative allowed for the almost complete disablement of Egypt's air force in one fell swoop before Egypt could counter. However, Egypt would learn from this and attempt a similar offensive manoeuvre during the Yom Kippur War (Herzog, 1982).

6.3.3   Economy of Effort or Means

One of the cornerstone principles espoused by military strategy is often referred to as the economy of operations. Indeed, economy is a critical component not only for in the Principles of War of many modern militaries, but for businesses

as well. It refers to the minimal use of resources (e.g. effort, resources, time) to achieve the desired objective. Sample applications could include only using the number of soldiers required to maintain the defence of fortifications or only supplying the amount of ammunition that could possibly be used by the forces in a specific area. A historical example of this was during the Sinai War when Israel was able to land a limited number of paratroopers undetected and accomplish its mission with minimal force (Herzog, 1982). This was achieved before an internationally brokered cease-fire could be put into effect, yet without the need to deploy a large force.

6.3.4   Mass, Unity or Concentration

The three types of physical forces (land, sea, and air) amassed together towards a decisive goal can have a powerful impact. Such a concentration of power has seen itself used frequently in history and advances in communications have assisted with the coalescing of forces for devastating effect. An example may include the joint planning of forces with air strikes being pinpointed by ground forces whilst a naval strike occurs from the sea. A historical example of this was Germany's blitzkrieg, or lightning strike, which focused the entire military's might to break through defences using the sheer mass of firepower in a small, localised area. We note that this is not necessarily an amassing of assets, but rather a concentration of forces.

6.3.5   Security

This is the ability to keep information secure and freedom of action maintained. It also necessitates knowledge of where future attacks may come from (intelligence gathering) and the limiting of vulnerability. An application of security could be scouts who stay ahead of army divisions to feed information back regarding enemy whereabouts, safe areas, of exploration or potential risks. A military example on a large scale can be seen during the Cold War between the U.S. and the USSR. During this time, both countries used air (e.g. the U2) spy planes

or sponsored their space races to obtain satellite imagery in order to ascertain enemy military installations, troop deployments, and potential vulnerabilities.

6.3.6   Manoeuvre or Flexibility

In a shifting environment, the ability to remain agile is essential for adaptation to new threats, fronts, and opportunities. Therefore, a common Principle of War is maintaining flexibility of operations. An application of this would be the ability to separate forces to different theatres depending on strategic needs. A historical example of this was the invasion at Inchon during the Korean War, when coalition forces were on the brink of destruction, yet they were able to use their naval capacity to cut off the North Korean army and thereby open a new front with which to drive the enemy back (Haruki and Baldwin, 2013).

6.3.7   Learning from Failure in Drugs Markets

As an example, we can apply our earlier learnings on supply chain failure to the dark supply chains of human and drug trafficking. To accomplish this, we align the failure types and causes to the business model of trafficking. We then utilise one of the modern military doctrines, introduced as the Principles of War, to ascertain how intervention by force is used and how the trafficking contexts currently stand compared to a war footing.

Failure on the Silk Road

The online platform Silk Road did not fail due to the infiltration of its servers. It failed specifically because before the site was launched, the owner, who interacted online using the pseudonym Dread Pirate Roberts, posted on a public website asking how to set up an online marketplace. This posting was later found and, when the internet activity of the original poster was cross-checked with Dread Pirate Roberts, the police found it to be the same person. This can be classified as an *information security* failure, where the platform's owners were

kept available on the public web in a forum post which tied him to the market-place. Therefore, despite secure encryption protocols and infrastructure, the Silk Road was brought down by a lack of covering their tracks.

Failures of online drug markets

When the major online marketplaces Alphabay and Hansa were shut down, it was an example of an *asset* failure. Though there was an information security component to some extent, the critical failure was when the servers of these websites were taken over by authorities and thereby repurposed to cause catastrophic harm. In this case, the illegal servers were repurposed by governments to spy on users, similar to the war strategy of how enemy airports and resources are commandeered and used against their previous owners. A critical vulnerability involved was the co-location of servers, which made it easier to capture them. Methods of preventing this would obviously include distributing assets to minimise risk, but more importantly using technologies such as blockchain which runs authentication tests to ensure that the multiple parts of a system are verified and intact.

Failure for Human Trafficking route to Europe

Ultimately, it was an *information security* failure which toppled the human trafficking network moving people from North Africa to Italy studied by Campana (2015). This was an information security failure because their phone conversations and movements were recorded and used to shut down the group. Yet, this is only one of many networks trafficking persons between North Africa to Europe for nefarious purposes, and the route continues to operate despite the efforts of authorities against it. With easier access to encrypted communication protocols, it is becoming more difficult to decipher messages, especially if they are coded in encrypted languages. However, private enterprises have worked to break through the encryption used by major firms, creating a game of 'cat and mouse,' where new protocols are repeatedly created and decoded.

Comparison of similarities and differences

In the above examples, we can see the impact of attacks on information security

and assets on dark supply chains. These failures were created as a result of painstaking work by law enforcement. A common theme among them is the use of compromises in information security, a key way that a supply chain can be exposed and analysed. The information involved becomes a vulnerability which can be targeted, thereby becoming a critical weak point.

It is possible to attack supply chains by using the methods of war, as discussed in the next section. These can also be ways in which supply chains can be protected, ways in which preventative measures can be taken to block against attacks as well as protect against (and antagonise) vulnerabilities.

6.3.8   Applying the Principles of War to Trafficking

In the above descriptions, we have seen some of the work performed by governments to curtail illegal activity. We now apply our learnings from the Principles of War to consider other actions that can be taken.

To begin, we ask if a government's efforts against trafficking are to be considered a "war," how are both sides performing based on the common (and aforementioned) Principles of War? The following table summarises our answer to the success of each by each principle (Y = successful; N = unsuccessful) .

Table 12: Performance with Principles of War

Principle	Governments	Traffickers
Aim	N	Y
Initiative	N	Y
Economy of Effort	N	Y
Mass or Unity	Y	Y
Security	N	Y
Flexibility	N	Y

The comparison in the table above should not be surprising, for it is clear based

on our analysis that government efforts have not been completely effective at reigning in illegal enterprises. Indeed, it can be considered that the two sides utilise different sets of operating rules. Whereas government agencies are limited to standardised police or military tactics which are limited in funds, public support, and methods of engagement, traffickers play by a different set of rules. Specifically, a trafficking enterprise is dependent on the continuation of the business. Thus, funding the enterprise is a priority, unlike a government which has multiple simultaneous objectives. Furthermore, traffickers may have less moral obligations to themselves and to society, thereby opening a larger spectrum of options for engagement. Simply put, governments are often obligated to play by a set of rules, while traffickers may not be obligated to do the same.

However, this comparison does illuminate some of the ways in which traffickers stay one step ahead, and perhaps areas where governments can make traction. We now discuss these principles individually to provide our assessment for each.

Aim.

Illegal enterprises have a clear aim, which is to continue to operate and thereby continue to make economic profits. However, what is a government's desired outcome of what could be a "war on trafficking?"

The answer is not as easy as an elimination of trafficking, as there are many situations where the impacts (e.g. financial, safety) of such an elimination would decimate a country (e.g. consider when Pablo Escobar declared war on Columbia) and the persons connected to the supply chain. Furthermore, governments may not have the resources to completely eliminate trafficking and, thus, focus their efforts where they are thought to do the most "good." Finally, populations may depend on illegal enterprises for work, migration, and sustenance which are not provided in the traditional economy, and the elimination of such sources could be argued as harmful.

This can place a government in a difficult position. On the one hand, there are illegal enterprises clearly operating outside the established law. On the other

hand, there are populations being serviced by these illegal enterprises, some of whom are dependent on such goods or services. Therefore, defining an aim or a desired end-state is tricky.

It is in this difficulty of setting an attainable goal that a government's progress is lost. For in order to reach a destination, an aim or objective must be set so that that real effort can be exerted toward it. Such a lack of clarity may, therefore, be limiting the effectiveness of progress, not allowing for the proper dedication of resources or enforcement of laws, and ultimately creating less than optimal effort towards a fight where traffickers have a clear advantage in knowing what they want.

Initiative.

It can be understood that governments create, enforce, and amend laws based on past events which they seek to preclude. Unfortunately, this reactive stance necessitates that a government would be reactive instead of proactive. Similar to the game-theoretic settings analysed in Chapter 4, this means that illegal acts can occur without the knowledge of the government. Therefore, the illegal enterprises, due to their initiative (no matter how horrid of illicit) are sequentially one step ahead of a government's action.

Having the ability to be one step ahead gives traffickers the ability to hide, innovate, and control the game to evade governments who are attempting to catch up and learn the latest information. Thus, our above chart awards initiative to traffickers, because despite the danger of being caught they are ultimately controlling the interactions while governments react to them.

Economy.

In an ideal setting, democratic governments operate with the support of their citizenry and through the collection of taxes (among other forms of income) collected. In each year, an allocation of funds occurs which dedicates some portion of a government's annual budget to fight the trafficking of drugs, humans, or other dark supply chains. These funds can be considered capped as part of that year's budget and are spread across a series of ongoing or new initiatives

which may include border control, airport checks, immigration reviews, product screenings, corporate engagements, and other programs. The amount spent across all of these initiatives can add up and increase quickly. For example in 2018, the U.S. government was budgeted to spend approximately $23.8 million USD solely on the cost of protecting victims of trafficking, which is a 27% increase from the prior year and a 142% increase from their 2011 budget (ACF, 2018).

While governments need to cast a wide net to catch traffickers, traffickers expend costs to maintain their businesses and circumvent government detection. However, a trafficker's costs to operate will not be as high as a government's costs to defend, for a government must defend across every possible avenue while traffickers only need to use one or few. Thus, traffickers have an innate advantage in economy of movement, similar to guerilla fighters opposing a larger force, thereby expending less energy by hiding, not searching.

Mass.

Governments and traffickers alike have the control to mass their respective forces where needed. Thus, we can consider both as being able to focus resources where they are most useful, though it can be said that governments must allocate across a much larger area to do so.

Security.

There are two parts of security we focus on due to their significance to both governments and trafficking (though undoubtedly more could be covered). The first is secure communications and the second is physical security.

For secure communications, governments and traffickers are both able to communicate as needed within their respective organisations by utilising secure technologies such as digital encryption. If the case for vulnerabilities were to be made, it would be true that both have experienced breaches at some point from a communications perspective.

For physical security, traffickers take the advantage due to the small footprint

with which they operate compared to governments. For example, for a government to monitor a country's borders it is a constant herculean task, and thus despite best efforts, they are porous to the movement of undocumented people and products. Compared to this, a trafficking organisation maintains multiple layers of insulation between the 'on the ground' operatives and the central organisation (i.e. leaders). Thus, even if the first layer is breached, the organisation remains intact and can continue to operate unhindered (Campana, 2015).

It is due to a government's inability to maintain constant protection of its physical boundaries that we see it as performing poorly in security. An argument could be made that governments can send undercover agents to infiltrate criminal organisations; though, the same could be said for trafficking organisations who infiltrate governments through corruption or force.

Flexibility

As mentioned in the comparison of Economy, traffickers are a smaller force and, therefore, need to exert less effort to hide. Similarly, for flexibility, traffickers have agility in the methods and locations they operate in compared to governments. For example, when a government program intervenes in the growing of specific crops overseas, traffickers can move the crops to another area to continue operations. In comparison, government's are relatively inflexible with their location, operations, and budgets. Once an allocation of any of those is made, a government carries through with it. Thus, traffickers can constantly shift their modus operandi to match the vulnerability in governments while governments are unable to move as quickly.

Summary

As we can see in the above comparisons, traffickers have the advantage with the Principles of War in ways that a government cannot match with their current approaches. That does not mean that hope is lost for those who seek to safeguard their borders and enforce the code of law, but they would need to change the way in which the system operates. The Principles of War provide a good starting place to understand how traffickers are staying one step ahead, and how the

systems may need to be shifted to give governments the advantage.

Combining the SCFF and the Principles of War provides a two-prong approach to obtain such an advantage in a war-like setting. The Principles of War acts as a starting point which, when applied, provides an assessment of the current situation from the critical dimensions of warfare. Such an assessment highlights the contextual setting, as well as the advantages and disadvantages for each entity involved.

Our SCFF then moves forward from this defined context to articulate the areas for attack (based on proven past precedent). In the preceding sections, we have explained each element of this two-prong approach for use against dark supply chains. We will now take both of these into a specific application setting in our next section, the dark supply chains of gold mining in Peru.

6.4   Case: Gold Mining in Peru

In our case study, we analyse the supply chains of gold mining in Peru which operate both in the light and shadows. Through our analysis, we will understand the current local context, the relation to dark supply chains such as human trafficking, and apply our Supply Chain Failure Framework (SCFF) with the Principles of War to this specific context. We complete this case study by articulating the targeted actions that can prevent the dark side of gold mining from operating.

6.4.1   Case Selection

The case of Gold was chosen for three reasons: (1) the supply chain for gold derives materials from legal and illegal sources, thus making it easier to study than a strictly dark supply chain, (2) connections have been established between illegal gold mining and human trafficking, and (3) there are a wealth of programs currently aimed at limiting illegal gold mining, thereby offering sufficient data for analysis.

Other cases considered were garment manufacturing, agricultural farming, offshore fishing, and high-tech manufacturing. Though any such cases could have been interesting for analysis, gold has particular usefulness due to its intrinsic connection to topics discussed in this thesis. These topics include government interventions, human trafficking, and dark supply chain practices.

We base our discussion in the country of Peru. Peru was chosen due to its current bout with illegal gold mining and the active attempts by the government to prevent it. Though other countries in South America and Africa were considered and could have been similarly scrutinised, the Peruvian case held a fascinating mix of features regarding law, government oversight, remote terrain, labour, and international trade. Most importantly, as mentioned earlier, illegal gold mining in Peru has been verifiably linked to human trafficking and forced labour (Verite, 2016).

6.4.2   Data Sources and Collection

We analysed two secondary sources of data for this case study: a field report conducted on behalf of the U.S. government and a series of geological files provided by the government of Peru. Although we rely on secondary data, our use of both sources is novel from their original purposes. In addition to the two data sources, we also utilised existing analysis from news articles, journal papers, and government reports in the compilation of this case study, and those are cited accordingly.

The first and most important data source is based on published fieldwork conducted in Peru by Verite with sponsorship from the U.S. government, as well as with support from Humanity United (Verite, 2016). Between 2012 and 2013, Verite conducted 207 interviews with a combination of related experts, in-country workers and others involved in the supply chain of Peruvian gold mining. The organisation has made its methodology, analysis, findings, and recommendations publicly available.

The second source is Geographic information System (GIS) data available

through the Peruvian Dirección General de Ordenamiento Territorial Ambiental (translated as the General Directorate of Environmental Territorial Planning). The data geographically maps areas of active illegal mining and the resulting environmental impact (such as deforestation) which has occurred in Peru. This source allows the government to visually inspect the operations of the gold supply chain and thereby provide a contextualised understanding of where it is occurring.

Therefore, we contribute a unique perspective to this existing data with our theoretical application towards this dark supply chain. For clarity, it should be noted that not all gold supply chains are dark. As we will explain later in this chapter, this specific occurrence in Peru was chosen because of its existence outside of the laws of the country and, on top of that, because of its connection to human trafficking.

6.4.3 Background on Gold Mining

A scarce natural resource, gold is known the world over for its shine, opulence, and timeless demand. Unlike any other precious metals, gold has been exalted for thousands of years by civilisations who seek to use, gift, and exchange it. Among other utilities, gold is used today as jewellery, an investment, and in producing many high-tech devices due to its high conductivity.

As a naturally occurring metal, gold can be found in waterways through alluvial mining and in rock formations through hard-rock mining. Gold mining is arduous work which requires intense labour in potentially unsafe conditions. Though machinery may be used, mining also occurs by hand using rudimentary tools. This manual work is often referred to as *artisanal* mining. Both methods (mechanical and artisinal) are meant to be undertaken within legal requirements and, with the permissions of the owners of the land (or mineral) rights, seek to isolate gold from its surrounding earthen elements.

Major companies exports are supplemented by artisanal miners and small-scale mining companies who work in different fields using smaller or limited equip-

ment. Artisanal miners can work together in a cooperative and seek legal approval for their work by performing the same steps as major companies, such as registration and payment.

The International Labor Organisation (ILO) estimates that between 80 and 100 million people worldwide depend on the proceeds from artisanal mining (ILO, 1999). To contextualise the size of this population, it means that at the time of their report, more people depended on small-scale gold mining for their livelihoods than the combined populations of the United Kingdom, Belgium, and Denmark (CIA, 2017).

6.4.3.1   Gold Mining in Peru

Legal mining involves a company being properly registered within their country, paying their employees, and paying for the land-rights to mine gold. Large-scale companies legally mine using heavy machinery and now control a majority of the economic markets through which gold flows. Large-scale mines in Peru are classified by extracting over 25 tonnes of earth per day on over 1,000 hectares, whereas extraction on a space smaller than this is considered a small-scale mine (Hinton, 2006).

The following graphic from Fortune (2016) outlines the major large-scale mining companies in Peru along with their 2013 annual production in metric tons. The combined production of these five mines (70 metric tons) was approximately one-half of Peru's 150 metric ton output in that year.

In the same year (2013), Peru's total exports across all products were estimated to be $41.9 billion USD, of this, $8.1 billion USD (approximately 19%) were legal gold exports (SUNAT, 2017). In comparison, the same report shows that total petroleum exports from Peru were $5.2B and exports of coffee totalled $700M. From these figures, it is clear that gold is an key part of the Peruvian economy.
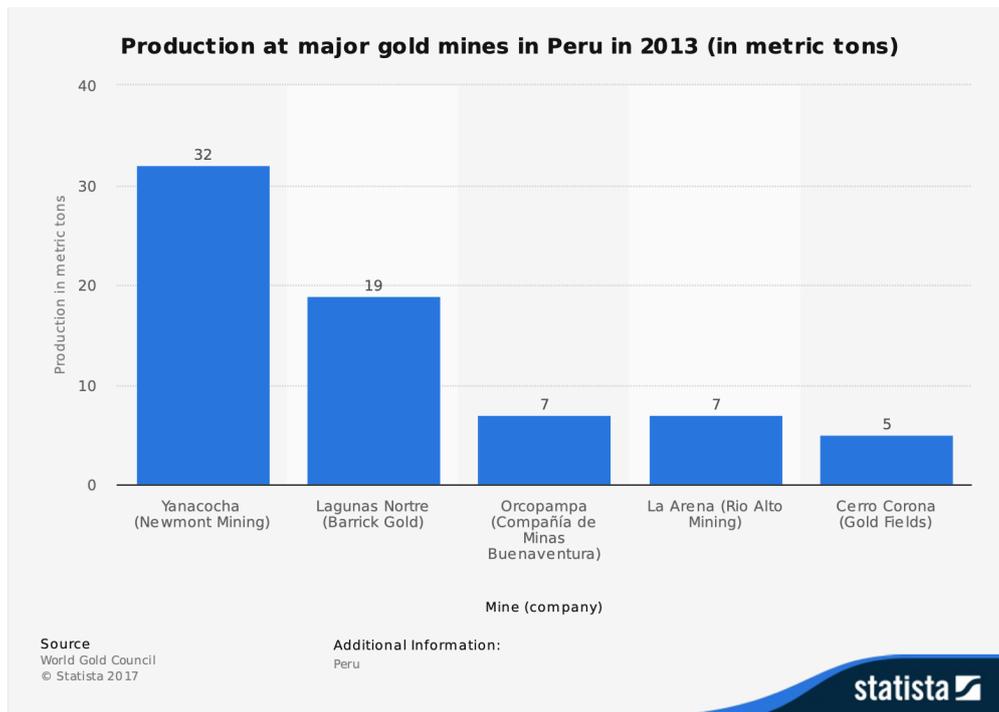
Figure 17: Production in Peru's Gold Supply Chains

6.4.4   Darkness in Peru's Gold Supply Chains

Despite a thriving legal mining business, the multitude of supply chains which ship gold out of Peru are not impervious to darkness. The lucrative work of gold mining can attract criminal organisations for many reasons. For one, gold is often found in remote geographies with limited enforcement oversight. This is useful to criminal groups who seek to avoid detection whilst performing their work. Once extracted, gold can be easily converted to cash or used as a mechanism for storing large amounts of wealth due to its high global demand as a currency in its own right (Hentschel et al., 2002).

Furthermore, because artisanal gold mining can be manually intensive, criminals use the victims of human trafficking to perform such work. Such victims are often forced or tricked into assisting with extraction in artisanal or small-scale mining for little to no pay, often in a vicious financial cycle they cannot escape from, thereby propagating their indentured servitude (Banchirigah, 2006).

Though major companies dominate the legal trade of gold, illegal mining constitutes a substantial portion of its capture (Hilson, 2008). In discussing illegal gold mining in the Peruvian case, we refer to mining which occurs on lands not designated for mining, or without permission from the land-rights owners. To transition from illegal to legal mining (a process known as formalisation), permissions need to be obtained from the government and the landowners, which often comes at prohibitively high prices (Hinton, 2006).

Thus, illegal mining attempts to remain in the shadows, utilising mineral fields without the knowledge of land-owners, and taking steps to avoid detection from enforcement agencies. In this effort to remain hidden, illegal mining often takes place in dynamically changing locations and in more dangerous conditions than legal mining (Banchirigah, 2006). As we can see, illegal mining groups fit our classification of a dark supply chain. With an understanding of the organisations behind illegal mining, we now introduce the primary stakeholders involved.

Accopiadores: The Middle-Men

As illegal mining utilises human labour (and small scale machinery) to find gold in prohibited areas, it cannot report where such gold was found. This is important because, in order to sell gold, they need to obtain mining receipts which verify origin and legality of the mineral. Receipts are a legal requirement to sell the gold in-country or to international companies.

To avoid such verification requirements, gold from illegal mines often goes through intermediaries known as *accopiadores* (a word used to refer to the 'middle-men') who purchase the gold without receipts at a discount and then use their back-channels to sell the gold to governments (Hilson, 2008) or onto the global market (Verite, 2016). These middle-men can perform many more tasks than simply buying gold. Often, accopiadores provide loans for small-scale mining, chemicals and tools for digging, as well as camp food and accommodations, all through loans and fees which can lead to the indebtedness of workers forced to perform the mining (UNIDO, 2005).

The Workforce

Miners for illegal mineral fields are found by recruiters (who may sometimes be family members or acquaintances) visiting small towns promising work and payments in gold. These personal and monetary aspects of their pitch incentivise persons with limited economic means to say yes. However, once they begin work they can be levied with 'finders fees' and forced to work to pay such recruiting fees back. Between 2012 and 2013, it was estimated that at least 100,000 labourers directly worked in illegal mines spanning across 21 regions of Peru (Verite, 2016).

Gold mining jobs can be strenuous and dangerous. It is common for miners to work seven days a week in physically taxing conditions. Miners are often paid a small portion of their illegal gold findings and are therefore forced to go through the sale process with accopiadores who offer less than market value. Furthermore, miners are not provided with the necessary personal protective equipment for mining and are thereby exposed to higher health risks. This is especially true due to their work with harsh chemicals used to mine such as mercury, a potent neurotoxin used to amalgamate gold (ILO, 1999).

Governments

As an indication of the physical scale of mining in Peru, it is estimated that 14% of the national territory has been granted to legal mining companies. Furthermore, taxes collected from gold production make up the majority of the government's corporate tax income (Verite, 2016).

To its credit, the Peruvian government has taken numerous actions to limit the pervasive underground economy of illegal gold mining, as we will discuss in detail later in this chapter.

Connection to Other Dark Supply Chains

Although gold mining is a profitable business on its own, it has been found to have connections to other dark supply chains such as human trafficking, money laundering, and child labour, wherein the latter more than 50,000 children are estimated to work within illegal gold mines in Peru (Verite, 2016).

6.4.5 Mapping the Supply Chain of Gold in Peru

Similar to the supply chain mappings of the previous chapters, the figure below provides a visual summary of the material and financial flows in Peru's gold supply chains.

A Tale of Two Flows

As can be seen, the gold supply chain begins with a choice between two network flows. On the one hand, we see on the top horizontal nodes the large scale mining companies who are registered with the government and manage the flow of gold as an export. On the other hand, we see on the bottom horizontal nodes are the artisinal and small scale miners, some of which are legal and some of which are dark. The small scale miners who sell to global buying organisations do so with receipts; however, those who go through accopiadores do not. Instead, they operate as a dark supply chain. This is a clear example of how dark supply chains infiltrate common corporate supply chains.
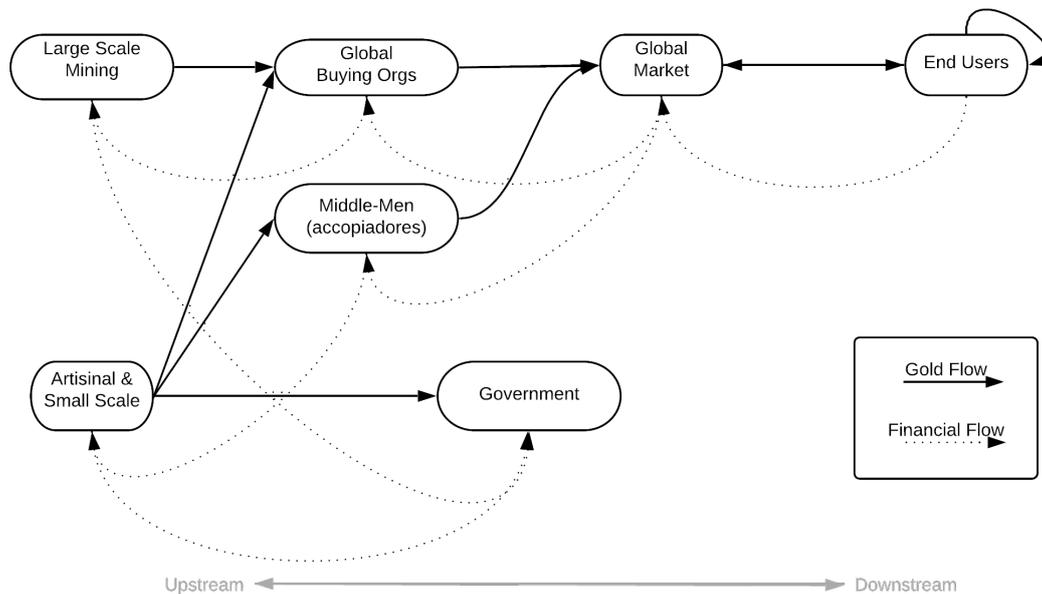
Figure 18: Mapping of Peru's Gold Supply Chains

In this chapter, we focus on those that are working in hiding, without permission or permits, and are therefore considered the dark supply chains. Ultimately, the gold will either make it out of the country in one of the two routes or, if illegal, may be intercepted by the government in the last stage.

Moving Gold and Money

For the large scale mines, gold transfers to global buying organisations located in Europe and are distributed to the global market. Eventually, they will arrive at the end users and money will flow back, through the markets, to the large companies.

For the artisinal mines we consider, the gold may be snuck out of Peruvian borders and sold to global buying organisations in another country, or these small scale mines may turn to accopiadores (the middle-men) to sell the gold on the global market for them.

It is worth noting that "dark" gold is not only moved by small firms. For ex-

ample, on 18 June, 2019 (a day before this thesis was submitted), the Wall Street Journal released an investigative report that the government of Venezuela was utilising dark supply chains to liquidate its gold assets in order to stay afloat. The process involved chartering flights from Venezuela to Uganda, whereby the gold was cleansed (i.e. made undifferentiable from legal gold), and then sold onwards to the Middle East (Steinhauser and Bariyo, 2019).

6.4.6 Current Intervention Methods

In this section, we discuss, and thereby create an understanding of some of the methods the government of Peru uses to find and prevent illegal gold mining. We structure our discussion of these attempts by using the Supply Chain Failure Framework categorisations of failure-*causes*.

Assets.

In an effort to physically prevent illegal mining, the Peruvian government performs raids on illegal operations to destroy pumps and equipment. However, the reaction to this is that mine workers are instead tasked to work at night to avoid being found and having their equipment destroyed. Similar to the issue with limiting gasoline, the high-profit margin of gold also means that new pumps and equipment can be purchased for a relatively low cost compared to the profits earned from continuing operations. Therefore, the raids can be considered non-effective actions (Verite, 2016).

Trade.

In areas known to have illegal mining operations, the government has implemented efforts to limit the amount of gasoline allowed. The idea is that small machines such as pumps rely on gasoline to operate and by blocking that trade it would prevent illegal activities. Though the intention is laudable, a critical issue with this is that gold's high-profit margin allows for illegal companies to pay for gasoline to be brought from other areas (Verite, 2016). This is the same logic which allows illegally mined gold to be sold through middle-men despite

the selling of gold without receipts to be against the law. Furthermore, these blockades of trade also detriment local residents who may not be involved in gold mining.

A limitation of blockading trade is that the departments (i.e. areas) of Peru where illegal gold mining is occurring are protected by armed criminal organisations who defend the mining operations from the police. For example, in the department of Madre de Dios (translated as 'Mother of God'), an area which in its own right is roughly the size of Ireland (approximately 33,000 square miles), police will not enter without military support, which is extremely infrequent (Verite, 2016), and therefore illicit trade is able to continue unimpeded.

Information Security.

Finding illegal mining can be difficult because it often occurs in remote terrain, a similar issue to the case of drug (e.g. cocaine) farming. An exacerbating issue is that Peru's topography is varied due to the sheer size and density of the Amazon rainforest. Therefore there are many areas where it is difficult for law enforcement to reach (Verite, 2016).

However, there are certain identifiers that mining leaves on the surface of the earth, one of them being damage to forests and trees due to flooding. Thus, one method that has provided valuable results are satellite scans which can show changes to the landscape where illegal mining may be taking place (SUNAT, 2017).

Delivery.

As far as we can tell, minimal efforts have been taken to attack the demand portion of the gold supply chain. In quite the opposite direction, gold demand generally goes up over time, especially with increasing demand from China and India (Larmer, 2009). Internationally-led discussions have taken place to create a 'fair trade' gold practice. A few practices have gained traction, such as 'Standard Zero' by the Alliance for Responsible Mining (ARM) and 'No Dirty Gold'; however, these have not have a wide-spread impact due to some impracticalities in implementation (Hilson, 2008).

Logistics.

Preventing the movement of mining materials and minerals is of key consideration in the physical extraction of gold from Peruvian lands. The government attempts to search individuals going to mining areas for dynamite, gasoline, or other signs of material movement (Verite, 2016). Despite these efforts, illegal gold mining continues as mining camp owners find ways around the searches by simply sending more supplies to buffer against interdiction (similar to cocaine supply heading to the U.S.), as well as using uncommon or under-policed routes.

Workforce.

Intervention initiatives to protect and intercept workers exist but with minimal effect. For example, in 2010, though 50,000 children labourers were estimated to have been working across gold districts in Peru, only thirteen were intercepted by the Peruvian Ministry of Labor (Verite, 2016). Furthermore, the government set up a human trafficking hotline which received over 1,000 reports of forced labour; however, this system could not receive calls from mobile phones and only resulted in thirteen total interventions (Semana Economica, 2011).

Despite infrequent successes, the government has now ramped up its ability to attack forced labour with new laws, and in 2013 had 100 ongoing investigations with 59 findings (Verite, 2016). However, increased police scrutiny led to protests among workers who were forced into more difficult situations and experienced further exploitation. This is the double-edged sword of policing underground businesses, the effect that they will go deeper underground, and thereby further endanger vulnerable populations.

6.4.7   Application of the Supply Chain Failure Framework

Despite the Peruvian government's efforts, illegal gold mining in Peru continues to operate. Using our learnings from Chapter 5, we now analyse potential methods of intervention with the application of our Supply Chain Failure Frame-

work.

The methods discussed below are based on our analysis of historical precedent and are not meant to be prescriptive. Furthermore, we would expect that some of the methods are already being covertly employed and some may have limited application; however, this does not negate their potential utility in this context and others. Finally, we make an assumption that it is in a government's best interest to eradicate illegal gold mining, though this may not always be the case. For example, it is being used to keep thousands of Peruvians alive through informal work, a dynamic that would need to be replaced.

Similar to the prior section, we discuss each strategy within its category of the SCFF failure-*causes*.

Assets.

Similar to the tactic of blocking trade, the Peruvian government's attempts to destroy the pumps and devices which enable mining. This is futile because their cost to replace is so low compared to the profits garnered from continuing operations (Verite, 2016). A better method of attack could be to instead focus on the items which are more difficult to replace; namely: communications, chemicals, and land.

By attacking communications, we refer to blocking radio or cellular communications in areas of suspected mining. This can be accomplished with jammers or similar digitally impeding devices. This method relies upon the fact that illegal mining is happening in remote areas and thus such jamming would have limited impact on local populations while having a significant impact on illegal gold operations.

By tracking chemicals, authorities can study the companies and routes that chemicals (such as mercury) take to arrive at gold mining areas and thereby attack these routes. In this way, rather than attempting to police for commonly available items, the focus would be to identify infrequent and difficult to obtain items, thereby increasing disruption.

Furthermore, one intrinsic difficulty with illegal mining is that it must stay in the areas where gold is located. Thus, if the land where gold is known to be to located is protected, it creates a barrier for criminal organisations from operating. It is undoubtedly difficult to police vast areas of land and forests, yet a similar problem is mitigated with oil through the granting of land rights to private companies of unprotected areas. By doing so, a government can outsource the work of protection while collecting tax revenue from limited legal mining.

On protected land, this becomes significantly more tricky because it is undoubtedly important to maintain natural areas, though they are being degraded by illegal activities. In such a situation, a warfare strategy would be to clear one portion of the land at a time, utilising force as needed to establish defences against illegality and environmental destruction. As each area is cleared, it is held and protected by locals with communication lines and incentives from the government. In this way, the recapture starts small yet strategically and accumulates over time.

Trade.

Currently, the government of Peru is attempting to intercept materials which support illegal mining such as gasoline and dynamite (Verite, 2016). This is similar to a blockade manoeuvre in war. The issue in this context is that without the ability to cast a wide net of such interceptions, mining material can continue to filter through and around a porous blockade and, therefore, has little impact.

Conversely, the reverse could be more effective. Instead of blocking the imports of supporting materials, it could be better to prevent illegal gold from being as valuable. By focusing on intermediaries, the government would have a much more direct impact on the economics of mining by taking away the incentive or ability to buy and sell illegal gold.

The direction of attack here is to remedy the currently informal gold buying system that illegal mining relies upon. This can be done through policing the intermediaries, especially given they could be easier to find than miners. An alternative method of attack is to set up new government intermediaries who

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either work to identify illegal operations or better support small-scale miners who are meeting labour requirements and are in process to establish themselves legally through formalisation.

Information Security.

Though the government is using satellite imagery to inform them of where illegal mining is operating, their efforts could be further served by breaking through actual the communication systems of the miners. We discuss two conceivable methods of accomplishing this.

The first method is infiltration. Similar to spies in war, if an illegal mining group can be infiltrated by agents, an ongoing operation's location, supply chain, connections to other criminal enterprises, and methods of maintaining secrecy (what we have referred to darkness in Chapter 3), can potentially be exposed.

The second information method is deciphering communication. Though underground businesses attempt to keep secure messaging to operate, many methods can be intercepted such as cell phone calls, radio signals, and digital footprints. A major concern in pursuing this is the privacy of non-criminals. However, a benefit in this situation is that the communications to be deciphered are occurring in remote regions and, thus, are mostly isolated from common civilian communication systems. By deciphering communications, authorities can approximate the identities of the individuals involved, including their operations, routes, locations, hours of operation, and the potential added informational value obtained from the conversations themselves. Even if deciphering is not used, various transmission spectrums can be monitored to identify areas of concentration (i.e. traffic), thereby providing another layer onto the map of mining that may be occurring illegally.

Delivery.

An inherent issue with gold is that when it is mixed with other metals it becomes difficult to differentiate from any other gold. This creates an inability to identify whether gold was legally or illegally mined after it enters the global market. International campaigns have attempted to set up traceability programs where

companies can receive documents of the initial source of the gold and therefore make the informed decision to avoid supporting illegal mining. A critical flaw with such systems is that illegal gold can be cleansed (i.e. made legal) with falsified documentation such as fabricated receipts.

Furthermore, once mixed with other materials, illegal gold can be made undifferentiable from legal gold. The expertise to cleanse illegal gold is an entire market in itself, not too dissimilar from the markets for fake identification documents that are used to transport human trafficking victims.

If documents can be forged and gold cleansed, perhaps the only way to help block the delivery of Peruvian gold to markets is to physically block the transactions from happening. This would first require mapping the entire supply chain of routes, mechanisms, and brokers who buy illegally mined gold. We understand the gravity of such a monumental task; however, it is a necessary step and, though it may not be completely visible, a significant portion of the supply chain could be analysed.

Once such a mapping is created, a blockade can take effect. Such a blockade would require holding the middle-men accountable, as they are the critical conduit through which illegal gold flows. Such accountability would not only include performing clear audits but also undercover work to determine the levels and locations of corruption.

By blockading this layer from illegal gold flow, the movement would be disrupted, thereby necessitating transit to other regions or areas. This shift of transit would be easier to detect and stop, which leads us to attacking the logistics of the supply chain.

Logistics.

Once common routes are disrupted using the techniques above, the logistics infrastructure of illicit operations would be easier to detect due to changes in movement patterns. It is imperative to identify these changes and monitor potential routes which could be used. For example, a key route to monitor would be rivers which can be used to transport supplies, gold, and people on their way

to and from mining operations (Verite, 2016). As is the case in war, the prevention of movement grinds the entire supply chain to a halt.

Workforce.

A foundational component of winning a war against trafficking is winning the support of the people who support and are involved in it. Until now, the government of Peru has had limited progress with preventing illegal gold mining, part of which comes from those who rely upon gold mining as their only source of income. There are multiple ways to approach this and below, we discuss a few select methods.

Gold mining is a way of life for some workers, families, and villages. However, it can be done legally and the process with which to pursue legal mining can be made easier. The current system makes it extremely difficult and costly for small-scale miners and therefore, though some have attempted to go through it, others go around it and pursue illegal mining through the dark supply chain route. An improved registration system which is sufficiently accessible and accepted by small-scale miners, landowners, and the government is necessary to diminish the public support for the darker side of mining. An improved small and medium enterprise system would enable small scale mines to qualify for permits and work with the government, rather than operating in secrecy of it.

If the prior method proves too difficult to implement or needs to be supplemented, a separate initiative could be to provide alternate work. This attacks the economic incentive of the reliance on gold mining, for if there were alternative forms of pursuing work (i.e. other jobs to be done), then workers would avail themselves to those opportunities instead of the risks of illegal mining. These alternative opportunities may include construction, environmental conservation, monitoring the land, education, and subsidies for agricultural farming.

There are many stories of people being lured to work in illegal mines only to find that they are unable to leave and the job conditions are tantamount to slavery. To prevent this, awareness programmes can be initiated to share such stories of entrapment and knowledge of potential working conditions, thereby dampening

the incentive to participate.

Finally, there is a need to track and trace corruption in Peru which helps the continuation of illegal mining. This could be done at all levels, from the middlemen to the enforcement officials, to stamp out the allowance of illegal work. A key message worth pointing out is that policing often relocates illegality, whereas a change in economic incentive makes it less valuable to pursue and, thus, less prevalent. Therefore, by removing the reason for pursuing illegalities, we instead redirect effort to improved systems.

This concludes our application of the SCFF to illegal mining in Peru. By performing this analysis, we can see how specific, targeted changes can disrupt the dark supply chains of gold. In the next section, we contrast these with the applications of the Principles of War in the same context.

The key difference between the two is that the Principles of War are useful to understand the current "war" situation, i.e. who has the upper-hand, whereas the SCFF can be applied to change the situation and cause supply chain failure.

6.4.8   Application of the Principles of War

Following our discussion of the Principles of War, we now briefly seek to understand how each might apply to the case of illegal gold mining in Peru. By considering these applications, we also understand which side, the government's or the illegal mining groups, may have an advantage.

Aim or Objective.

The objectives of illegal gold miners is simple: extract gold from the ground, pay the lowest price in doing so, and not be imprisoned. Their supply chains are optimised to accomplish this by paying little-to-no labour cost and utilising cheap transportation (mules, rivers). However, the government's aim may be a bit more difficult to pinpoint and therefore harder to follow. Of course, a government would prefer to stop illegal gold mining, yet by doing so it also endangers

its soldiers, citizens, and puts people out of work. Therefore, although the gold miners have clarity, governments or municipalities may not.

Initiative or Offensive.

Illegal gold miners are on the offensive and are constantly shifting through private land looking for gold without paying usage rights. Governments, on the other hand, are playing catch up. It is a 'cat and mouse' game where the governments are at a constant disadvantage, and we will see this transpire through the remaining principles.

Economy of Effort or Means.

The economy of effort for governments is quite low because their resources must spread out across large land masses in the hopes of preventing illegal mining. Conversely, small scale gold miners are fairly efficient about their effort and where their resources are invested.

Mass, Unity, or Concentration.

In comparison to a war setting, this may be one of the only areas where the government has an equal footing. Once an area is located, the government has the ability to concentrate its forces and drive illegal mining out. However, this is also a strength shared by the dark supply chains that pursue gold. Their strength is due to the fact that they have a first-movers advantage and mass all of their physical forces immediately from the beginning, in an economically viable way to pillage an area before government intervention arrives.

Security.

There are multiple aspects of security worth considering. From an information security perspective, governments and illegal gold miners may be on an equal footing. However, from a freedom of action perspective, governments can have an advantage based on their sheer size and strength.

Manoeuvre or Flexibility.

For flexibility, illegal miners have an obvious advantage of being able to operate

in a guerilla-warfare type of setting. They can move around quickly and hide when needed because of their relatively small size and using the cover of vegetation. Governments, on the other hand, are overloaded by size and may be unable to move as quickly. However, this opens the door to a possibility that was discussed in Chapter 2's discussion on the history of supply chains: when Napoleon created his corps d'armée, the idea was to break the army into several smaller, self-sufficient armies. Though this may already be underway in Peru, the army also has the potential to interface with locals to act as their eyes and ears while the army is canvassing areas in their attempt to break this dark supply chain.

6.5   Chapter Conclusion

In this chapter and through our case application, we have harnessed our learnings from the thesis, as well as from military doctrine, and applied them toward the dark supply chain of illegal gold mining in Peru. Specifically, we were able to understand the local context in Peru through the application of the Principles of War and potential government actions using the Supply Chain Failure Framework (SCFF).

The SCFF is critically important for showing how the vulnerabilities of the past are able to elucidate possibilities in the present. By focusing individually on each of the six failure-*causes* (i.e. ways that supply chains fail), which were made available through the analysis and results from Chapter 5, we ascertained steps the Peruvian government could take as additional action against this scourge in the country.

It is possible that we could have chosen another dark supply chain for analysis. However, this specific case has the trifecta of (1) corporate, grey, and black markets that co-exist, (2) a strong connection to human trafficking that could be exposed, and (3) multiple programs aimed at stopping it, allowing for analysis and interpretation of the data. Therefore, it was an ideal setting for this qualitative discussion and framework application.

Going forward, a similar approach can be taken to other dark supply chain settings. This combination of the SCFF and the Principles of War, therefore, creates a foundational approach for considering how to prevent dark supply chains from operating. We admit, however, that these tools do not encompasse all facets of the problems in trafficking. Indeed, they are based on recorded history and aggregated military strategies, and therefore situational context and local requirements would take prescedence. Ultimately, it is our intention that this combination of tools acts as a starting point for discussions on dark supply chain intervention mechanisms and current programme assessments, as this type of starting point has been missing from the supply chain literature.

6.5.1   Authors Notes

The focus of this work is on criminal organisations who perform illegal, but more importantly immoral operations. However, it has been noted in the previous chapter and must be mentioned again that there are dark supply chains which can be, except for their legal classification, considered good. For example, human smugglers who help migrants escape from war-torn countries or dangerous areas provide a valuable service which governments sometimes cannot. Additionally, such acts of deviance can be considered sensible, for from a rational perspective they offer profit, moral righteousness, and the delivery of services to a willing and eager market. In such cases, it is fair to question if "conformity, not deviance, should be questioned" (Decker, 2008).

7   Thesis Conclusion

7.1   Introduction

This thesis utilised a multi-method approach to analyse the supply chain of modern slavery as a burning humanitarian aid topic. The multiple lenses used to accomplish this include qualitative research on the foundations of human trafficking, the introduction of dark supply chains as an area of business study, and quantitative research using game theory and econometrics to understand two critical parts of the problem.

Game theory is used to study the decisions involved to arrive at an optimal equilibrium where forced labour is not used in corporate supply chains. Econometrics is employed to understand the vulnerabilities of modern slavery and how to fight this nemesis as a supply chain instead of as a criminal activity. The mixed methodology used herein is based on choosing the best tool for the research questions involved. Each section of the analysis is therefore customised to better understand the various stakeholders involved including governments, businesses, and the dark supply chains themselves.

In this chapter, we bring together insights from the entirety of the thesis. In collating these points, we discuss the research questions raised across the chapters, as well as provide implications for theory and practice. Finally, we discuss the limitations of this work and outline areas for future research.

7.2   Research Insights

In Chapter 1 of this thesis, we outlined the gaps between research and practice in humanitarian logistics that require additional attention. Humanitarian logistics is described through three key areas: disaster response, long-term development, and dark supply chains. We introduced modern slavery as a primary topic of focus for the agenda in the subsequent chapters. At the end of the first chapter,

the following question is raised: How can we utilise analytical tools to better understand the supply chain of modern slavery?

In order to answer this question, Chapter 2 detailed the research methodologies used in our analysis. Three main tools were chosen due to their fit with the initial research question, specifically game theory, econometrics, and a case application on illegal gold mining in Peru.

Chapter 3 defined dark supply chains as a sub-topic within the supply chain management field. Initially, we reviewed the structure and operations of dark supply chains and showed their connection with other global supply chains. Following this, we provided overviews of two of the largest dark supply chains in the world, those of drugs and human trafficking. This, for the first time, provides a name and recognition for hidden supply chains as an area that needs further business study. Through the discussion of government intervention mechanisms and previous darks supply chain failures, we also outlined areas for future work.

Chapter 4 utilised a game theoretic model to analyse how a government with a limited budget can optimally allocate resources towards the prevention or prosecution of human trafficking in corporate supply chains. The analytical model is based on the current United Nations 3P Palermo Protocol and discussions with non-profits fighting human trafficking. The results exposed the complexity of decisions faced by a government, the potential reaction of firms, and the situational contexts which may require alternative approaches dependent on scenario-specific characteristics. These characteristics have hitherto not been quantitatively analysed in the literature and therefore the model provides a novel structure for incentivising corporate compliance with anti-slavery laws.

This is important because major corporate supply chains have faced brand damage and legal scrutiny due to the unintentional use of human trafficking in their supply chains. We provided insights on what a government with budget constraints should do to prevent or cure (i.e. remedy) a forced labour issue within major corporate supply chains. Specifically, Chapter 4 characterised the optimal budget allocation of a government who uses the United Nations 3P strat-

egy (Prosecution, Prevention, Protection) to motivate companies to exert effort in stopping forced labour issues from infecting their supply chains.

The results of Chapter 4 showed that common government efforts such as maximising inspections or standardised penalties may not help. Instead, Prosecution effort should be based on the revenue and relative concavity of the firm's profit function, both of which determine the optimal resource allocation and penalty to successfully incentivise a firm to comply with human trafficking laws in equilibrium. We also discussed an alternate equilibrium where a government and firm are incentivised to exert zero effort against modern slavery and offer insights to NGOs working to incentivise government action. These insights may also apply to environmental and labour law enforcement.

In Chapter 5, we provided an enhanced framework on supply chain vulnerability to understand how supply chains break, a critical research question raised in the first chapter. Though there was considerable academic work on supply chain disruption performed in the early 2000s, recent years have had a respite in this type of research and there is a noticeable omission in the consideration of how catastrophic disruptions can break a supply chain, or in other words, cause a supply chain to fail in its ability to move goods, finances, or information.

Through our analysis of war and business failures, Chapter 5 provided new ideas on the types of disruption which can severely impact a supply chain's ability to operate. This is characterised by the Supply Chain Failure Framework (SCFF), supported by approximately 200 years of catalogued evidence. The SCFF elucidated the four *types* of failure (supply, demand, environment, infrastructure), which are consistent with the literature. Critically for application, the SCFF goes further to offer the six *causes* of supply chain failure (assets, delivery, information, logistics, trade, workforce), a result which was previously unknown in the supply chain literature because a dataset of failures did not exist prior to its compilation herein.

Finally, the global approaches to warfare, known as the Principles of War, are connected to the SCFF to consider mutual alignment toward supply chain attack in Chapter 6. The chapter built on our preceding findings to understand

how the supply chains of modern slavery can be broken in general and in a specific context. Due to the difficulty of analysing the entire dark supply chain of human trafficking, the findings of the SCFF and Principles of War were applied to a related field which uses slaves in its workforce, the case of illegal gold mining in Peru. A focused case application of our study in Chapter 5 (of how severe disruptions occur) is performed and, additionally, a discussion on drug trafficking is considered. Through these applications of the SCFF and the Principles of War, a deeper understanding of how modern slavery can be pushed to fail is, for the first time, provided from a supply chain perspective.

7.3   Implications of this Research

7.3.1   Implications on Theory

The implications for theoretical practice are many and are organised by chapter below.

First, Chapter 1 outlined many key areas for research in humanitarian aid including disaster response, long-term development, and dark supply chains. Chapter 2 details the methods used to further this study.

The exposition of dark supply chains in Chapter 3 created a foundational look at the part of the supply chain management field that has been mostly absent from quantitative business analysis. Similar topics have been studied in law, criminology, political science, and in critical business studies. However, this chapter bridged the gap to the field of supply chain management. This made the topic accessible for the foundational analysis herein, as well as future analysis and applications using additional quantitative methodologies.

The game theoretic analysis in Chapter 4 made a novel contribution to the study of the principal-agent problem. In the environmental context, Plambeck and Taylor (2015) have done similar work, yet the application towards modern slavery herein provides a nuanced understanding of the unique decisions faced by governments and firms in the forced labour context.

Second, the implications for supply chain vulnerability are critical. Chapter 5's supply chain failure framework built upon the prior literature (Wagner and Bode, 2008), yet with a focus solely on the area of catastrophic disruptions. This is integral to the study of supply chain risk because it deepens the understanding of the high impact, low probability scenarios which have had limited analysis or historical aggregation. Furthermore, though others have analysed the impacts of disaster (Altay and Ramirez, 2010), we provided a data-science approach to a field which has frequently relied upon survey methods, thereby creating differentiation in our methodological approach and novel insights through an extension of vulnerability frameworks.

Following the quantitative analysis performed in Chapters 4 and 5, we see Chapter 6 bring dark supply chains to life. This is accomplished by transforming the topic from a theoretical concept and giving it teeth as a case analysis. Though criminal enterprises have been tangentially studied from a criminology and political science perspective for decades (Becker, 1968), the use of supply chain principles has had rare application to illegal enterprises.

Therefore, the case study in Chapter 6 purposefully complicates the common understanding of business, how it should be studied, and ultimately how the business tools we develop can be leveraged in alternative ways. Specifically, in this case, the chapter outlined how an illegal business that involves human trafficking can be purposefully targeted, harmed, and broken for the purpose of saving lives.

7.3.2   Implications on Policy and Practice

Common legal policy around modern slavery uses a globally consistent approach, the United Nations Palermo Protocol, often referred to as the 3Ps: Prevention, Prosecution, and Protection (United-Nations, 2003). However, this generalised method does not necessarily fit uniformly across countries or sectors. Based on feedback from anti-trafficking non-profits groups, it is also important to consider the unique characteristics of each situation. Thus, the

model in Chapter 4 delivered an analytical tool based on the industry, company, and local factors which influence the risk of modern slavery.

The utilisation of our model herein has now been considered by NGOs in multiple contexts, including overseas workers in the Philippines (OFWs) and factory workers in Vietnam. For the former, this was considered during discussions with GFEMS on how the model could be adapted and utilised for better undering the OFW systems. For the latter, the game theory model was part of a 2018 grant application to improve government budget disbursements against human trafficking. Though neither project is ongoing, the mere consideration of a theoretical model in real life practice situations is of note. Therefore, we highlight that the tool not only has academic insights, but also the potential for use in practice. Furthermore, these have lead to a 2020 National Science Foundation (NSF) grant with the title "How Supply Chains Break."

The combination of the chapters in this thesis provided a tangible structure and analysis of hidden businesses, which we defined and analysed as dark supply chains. This structure provided new, historically grounded information to be used in the consideration of how to disrupt illicit activities that harm human life.

The analysis also contained an econometric aspect that emphasises the significance of failures (i.e. catastrophic disruptions) on supply chains. The direct utility of this research can be easily seen in law enforcement. Furthermore, the insights from it can be considered to prevent corporate supply chains from falling victim to those types of vulnerabilities in the future. Finally, it forces each of us as global citizens to look inward and decide how much of a role we play in the aid or harm of those in need.

7.4 Research Limitations

Multiple chapters acknowledge the known limitations of this research, two of which are highlighted below.

1. The study of past supply chain vulnerabilities may be subjective due to interpretations of history. Though every conceivable effort was made to maintain impartial coding of historical records, it is inevitable that future researchers may have their own interpretation. However, this should not affect the insights obtained and all decisions were documented with justifications for replicability.

2. The study of the dark supply chain of human trafficking is limited by the simple virtue of it being "dark," i.e. hidden. Therefore, current details of current slave operations are difficult and often dangerous to obtain. To accommodate for this, the case study of illegal gold mining was chosen. This case study was suitable because illegal gold mining has significant amounts of public information available due to its high spectre in recent years and the release of reports which detail its ground-level operations in specific countries that are related to modern slavery (Verite, 2016). A similar rationale was used to include the discussion on drug trafficking, which has parallel structures to human trafficking, and similar to gold mining, also has publicly accessible information. Thus, although it would have been preferable to use additional human trafficking data, the level of detail for analysis is not currently available to the same extent as drug trafficking and gold mining data.

7.5   Future Research Opportunities

Opportunities for future research are detailed by chapter below. It is the intention of the author to pursue these areas, particularly furthering the understanding of the interaction of modern slavery with global supply chains.

Humanitarian logistics research, though having grown in recent years (Wassenhove, 2006), requires further consideration in the area of long-term development to serve vulnerable populations. Specifically, the availability of alternatives for needs (e.g. safety, work, education) can alleviate some of the risks of being captured into indebted servitude and other societal dangers. Though this work

is being considered by humanitarian organisations, it also fits and deserves to be considered for further business research. This is because new opportunities (e.g. those offered by business enterprises) can have a positive impact on providing alternative futures for the vulnerable populations involved.

Humanitarian logistics, as reviewed in the first chapter of this thesis, provides a connected field of study to supply chain management with regards to the severity that disasters can have on people and businesses, as well as the methods with which to respond to them. This has undoubtedly fuelled the rise in the research areas of disaster management and disaster response operations (DRO). Similarly, it has influenced the categorisation of the humanitarian lifecycle to include phases reserved for preparedness and response to disasters, both integral to that framework. As a major portion of this area is covered by the literature review in the first chapter, we must mention that the related research, journals, and conferences in the humanitarian field very strongly align themselves with the humanitarian lifecycle framework and our analysis, though slightly critical in approach, also purposefully mirrors that alignment.

We see from the discussion in Chapter 1 that there is ample opportunity for engagement between academia and the humanitarian field. Below, we discuss a few potential directions this collaboration can take to help spark the research imagination.

Our review of current literature and challenges faced by practitioners indicated many areas where supply chain research can assist. A significant portion of these potential areas fall under three categories: disaster response (the third stage of the humanitarian life cycle), capacity building (part of the long-term development process), and the study of the dark supply chains that are negatively impacting human life. We have simplified our findings of these research opportunities in the table below.

Table 13: Opportunities for Humanitarian Research

Disaster Response	Capacity Building	Dark Supply Chains
Decision support tools	Food and aid collection	Human rights enforcement
Connection between transparency, inter-agency performance and data collection	Infrastructure and local resource development	Preventing the proliferation of drug and weapon sales
Implementation of best practices from industry	Alignment with SDGs for the optimal distribution of aid	Partnering with law enforcement to protect human life

We are reminded that capacity building is not only an important structural building block for society. As part of the recovery phase, it is also one of the most ignored parts of disaster management research and a critical opportunity area for future contributions within long-term development.

In addition to the table above, we highlight three streams of potential research which can have important impacts on communities: policy evaluation, education, and human rights.

Opportunity: Policy Evaluation

We first consider the series of agency policies that maximise the delivery of aid. A sweeping problem in humanitarian logistics is whether aid is actually delivered to its intended receipts, or if it is lost, spoiled, or misdirected in the process. Ultimately, the efficiency measures of any organisation focus on delivery to its customers, yet a common complaint from practitioners is that much of the aid sent never makes it to its destination or that it arrives in an unusable form. This has tenets analogous to those of the corporate world, which may include back ordering, shrinkage, spoilage, etc.

In our context, organisations can benefit from customisation of performance met-

rics to humanitarian systems such as policy evaluation (e.g. using simulations, dynamic programming), last-mile delivery (e.g. linear and dynamic programming), and large scale distribution problems. It may also involve combining methods from other fields to create externally valid solutions.

Opportunity: Education

Generalising the earlier introductions of school systems in Africa, we seek to explore how we can optimise the global delivery of quality education for the upcoming generation. Delivery of primary education ranks highly for the UN cluster system and the SDGs; however, how do we efficiently educate the world in a standardised, measurable, and robust way?

During the summer of 2014, the author of this thesis spent two months in East Africa working with a global organisation that engages social enterprises, primary schools, orphanages, and special care homes to understand their needs and develop unique solutions to help meet them. It became clear that working with one organisation at a time resulted in greater local benefits (improved operations, sustainability, and efficiency metrics); however, scaling the education delivery problem could enable us to reap additional benefits, insights, and standardisation, which should be further studied to discover optimal delivery mechanisms.

Opportunity: Preventing Modern Slavery

The dark supply chain of human trafficking has proliferated over time and infected every corner of the globe (Alliance8.7, 2017). Despite the implementation of the Palermo Protocol, governments continuously grapple with the growing issue of vulnerable populations and their capturers who prey upon them. Private organisations, such as the Global Fund to End Modern Slavery, seek to dismantle trafficking supply chains by spreading awareness about how it operates and thereby decreasing vulnerability through education; however, can there be a more concerted effort to preventing the threat? The answer to this question has necessitated consultation with other non-profits, such as the Urban Institute and The Who, in order to create the practice-based research agenda that follows.

These discussions also fuelled the considerations behind this thesis and influence the questions that will answer.

In Chapter 4, we quantitatively explored this situation from a government's perspective to understand the key actions and levers which can be taken to effectively impact the supply chain of human trafficking. In Chapter 5, we further analysed illegal supply chains from an empirical perspective and outlined the key strategic manoeuvres which may hold promise in combatting their operation.

Re-think: Humanitarian Logistics

In relation to the opportunities mentioned above, many individuals outside the field believe that infrastructure and physical distance from the issues are debilitating issues in humanitarian work. We must, however, challenge this notion and see that organisations are trying to maximise operations just as any major corporation, by utilising existing infrastructure despite the distance. The quintessential difference, of course, between corporations and humanitarian organisations is, in OR/MS terminology, an objective function prioritised on life in the latter.

Re-think: Existing Infrastructure

It is easy to think that locations that require aid are located in remote regions and that existing infrastructure does not allow us to efficiently access them. This thought process discounts the ingenuity and resourcefulness of local people to move knowledge, materials, and aid where infrastructure may be considered substandard or unavailable. Consider this: If Coca-Cola can make its way into relatively small remote villages, why can't the medications and aid that humanitarian organisations are trying to provide to their beneficiaries make it to the same villages? More importantly, can supply chain research help? We emphatically believe the answer is yes. We may consider the study of existing delivery systems (private or otherwise) in order to understand, replicate, or optimise them in areas of need. Interested readers are recommended to read Vachani and Smith (2007), who discuss methods of physically reaching populations without

developed infrastructure, as well as Sodhi and Tang (2013), who explain the use of micro-retailers for the delivery of post-flood aid.

Re-think: International vs. Local

We somehow presume that the problems of humanitarian logistics/aid are in far-away countries and thus, even the author of this thesis has traveled to find them. Despite the fact that humanitarian crises occur globally, it is important to realise that similar problems are faced within our own regions, cities, and neighbourhoods.

For example, the author of this thesis resided in the U.S. state of North Carolina during the writing of Chapter 1, a state which ranks amongst the bottom of U.S. states in standings of primary education and average income levels. In some counties (districts) of the state, 1 in 4 children live below the antiquated U.S. poverty line (NCCP, 2019), a line that because of its age now reflects abject poverty. These children may not regularly have access to the nutrition necessary to work or learn. How do we reach, feed, and teach students who are impoverished, who do not have enough food to sustain themselves, or are missing the basic disposition to be able to learn? Taking this further, how would this impact society at large, as those children grow and attempt to enter an ever-demanding workforce?

The purpose of the example above that we would like to drive home is that the problems we aim to solve, such as lack of quality education, are not far away in distant lands; they exist locally and should also be carefully considered. The underlying truth is that because of the global (and local) nature of need, opportunity is closer than we think. A local understanding and community engagement can help us stumble onto organisations near us who are trying to tackle some of society's most debilitating problems and could use the prowess of supply chain optimisation and analytical methodology to help them along their paths.

Re-think: Slavery

Though slavery is a topic mostly relegated of our history books, what most people do not realise is that there are more currently more humans in slavery to-

day than there has ever been in recorded history (Wheaton et al., 2010). The difference between the past and the present is that slavery has now ventured underground due to international laws that prohibit it.

If we consider slavery in a vacuum, aside from its criminality, we can see that it is a business like any other that involves the sale and purchase of people (their "products"). Such products are delivered to customers who desire them at a negotiated price. There are intermediaries involved, and it functions as any normal business would, except for the horrifying fact that it is void of any ethical intent. However, because it is a business, it can, therefore, be studied with business tools. That is what this thesis will begin to do.

The New Agenda

It should be noted that because there is a renewed effort on all fronts (from the UN, SDGs, etc.) to improve operational impacts in humanitarian causes. This, in turn, opens up the landscape for even more research because there is now additional attention on, funding for, and availability of large amounts of data for analytics that was previously inaccessible (Sanders, 2016). Understanding the context of problems (i.e. beneficiaries, stakeholders, environments, goals, infrastructure) is central to building models and assumptions that can be robust and relevant enough for use in practice (Starr et al., 2012).

Although we should rely heavily on our core OR/MS strengths of Theory and Modeling, we believe there must be a renewed effort towards fully understanding the problems at hand and developing solutions that can be applied in settings beyond those envisioned by the heritage tools that we are accustomed to.

The new agenda, therefore, requires us to further engage with organisations in the field and to work side-by-side to develop new tools and research that fit the needs in practice. This new face of research may appear daunting and difficult to surmount because of its complex nature; however, it also welcomes support and brings with it the satisfaction of improving living conditions for people around the globe.

By pursuing this agenda, we continue to carry the analytical spirit of previous

OR/MS developments and further expand our boundaries to become more applicable along our path. This boundary spanning, we believe, is a completely natural extension of our research and would provide considerable insights, expertise, and needed analysis to the humanitarian sector. We have created the following figure to provide a summary of potential research directions discussed in this section, as well as the first chapter of the thesis, in the areas of disaster response, capacity building, and human rights.

Recap and Key Takeaways

There are many local and global organisations working to improve humanitarian logistics in a variety of ways. Academic collaboration requires us to re-think our focus areas, holds the promise of greater efficiency for organisations, and allows for a natural expansion of supply chain research.
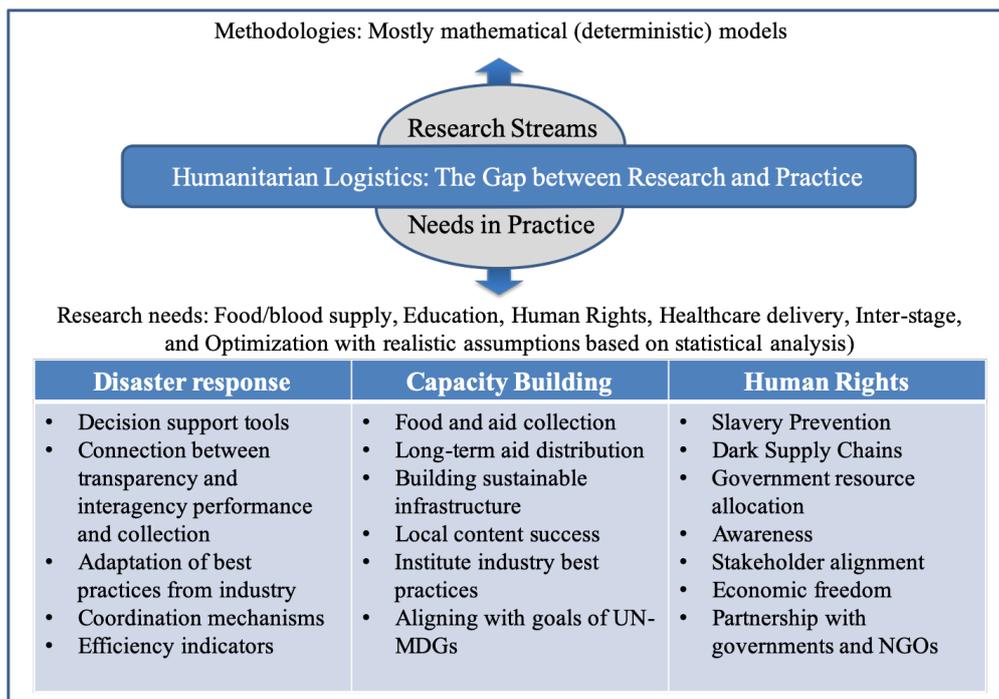

Figure 19: Summary of Gaps between Research and Practice

7.5.1   Dark Supply Chains

In addition to the work that is attempting to better the world, there is an ongoing threat to undermine such institutions. This threat emanates from *dark supply chains*, a term we use to refer to businesses that hide beneath detection and engage in business operations outside of the code of law. In doing so, dark supply chains harm human life and yet, as a business field, we have not engaged in the study of their operations.

The three largest illegal businesses in the world are engaged in the sale of drugs, weapons, and humans (ILO, 2014). Institutional responses to these types of supply chains have been fairly consistent around the world, with standardised legal frameworks instituted by governments and vulnerability assessments being carried about by NGOs, we seek to stop the bleeding from these crimes that attack at human life. As of 2016, it is estimated that over 170 people die each day from drug abuse in the United States (Hedegaard et al., 2017) and over 40 million people are enslaved worldwide (Alliance8.7, 2017).

These businesses are not commonly seen as issues that warrant humanitarian attention or business analysis. They are labelled as "criminal" and thereby relegated as a separate area of consideration altogether, thereby creating a void in the business academic research that could help prevent them. However, we would contend that these supply chains, as much as any other major issue discussed in Chapter 1, are severe threats to human life and need further research. Furthermore, they must be included with other humanitarian topics because of their impact on human life. Finally, they deserve highlighting, rigorous analysis, and solutions, and that is what this thesis provides as a starting point by analysing them for what they are, supply chains that need to be stopped.

The structural exposition of dark supply chains in Chapter 3 highlighted a new area of opportunity for business research consideration. Though the analysis herein provided a general understanding of dark supply chains, there are potentially numerous applications of business tools that can be made to this area of study. For example, the application of analytical tools (e.g. optimisation rou-

tines and simulations) can test prior business assumptions in this field to generate new insights. The type of cases considered can be expanded beyond drugs and human slavery to other types of dark supply chains (e.g. weapons) which also require thorough analysis. Additionally, the exposition of these chains can be deepened through further qualitative studies. We must make it clear that the underlying businesses behind dark supply chains are nothing new; however, they have now been given a name in the hopes that they may be better known, studied, and understood.

Chapter 4 answered the question of a government's effort through the optimal budget allocation between prevention and prosecution towards inhibiting modern slavery in corporate supply chains. This opens a path for studying the specific activities that are most impactful for limiting the occurrence of modern slavery. Potential research on this may be pursued by analysing current government programmes and assessing their impact. Alternatively, future research may seek to consider how a company can respond to the danger of unintentionally using forced labour in their supply chains. For example, this can include assessing the engagement of external auditors, drafting enhanced supply contracts, or vertical integration. Finally, comparing the actual government actions and potential firm actions in a global context can provide insight into the current status of the relationship between governments, business, and modern slavery.

The study of how supply chains break (Chapter 5) was as an extension on the existing literature on disruption and risk management. The specific focus on catastrophic disruptions (i.e. failures) had a significant depth which has, as of yet, not been captured in the literature. Going forward, future research may consider a similar econometric analysis to understand the potential business impact of supply chain failures on corporate profit. Though some work has been done from a similar perspective on natural disasters, there is a gap in understanding of the impact of catastrophic disruptions from other causes, such as those detailed in the Supply Chain Failure Framework (SCFF). The business implications of this are rife. By providing such insights, businesses can better protect themselves through a more robust understanding of supply chain risk management (SCRM).

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Using the analytical foundations built in this thesis through the SCFF, Principles of War, and methods of analysing government intervention, additional research must be pursued in specific cases of illicit business activity. Chapter 6 considered the case of gold mining in Peru, but it is only example of the unbounded areas where research can dig deep into contextual understanding and analysis.

Finally, from an educational standpoint, it is critical that we develop teaching materials that enlighten business students on topics such as dark supply chains. In this way, our future business leaders will know what exists and how to protect their own supply chains from inadvertently encouraging such illegality. Creating such a more complete understanding of the full gamet of supply chain operations globally may also inspire them to take action to improve the current state of affairs, and we need the help. If we do not teach this material, or if there is a purposeful avoidance of these topics, it would be a diservice to academia and our students because we would, in effect, paint an incomplete picture of the real world we all share and seek to contribute to.

7.6 Concluding Remarks

This thesis is only the beginning of the work to apply quantitative supply chain tools to the dark supply chain of modern slavery. It is inescapable that the business world has dark corners where information scantly makes itself available, yet it is critical that we shine a light upon those corners. In doing so, we illuminate the worst parts of business while also understanding what enables that darkness to perpetuate.

Through these chapters, we have given dark supply chains a name, analysed their impact, and shown their potential vulnerabilities. In doing so, we have sought to make their business operations visible for further supply chain investigation. Over 40 million human slaves, their families, communities, societies, representatives, and governments seek to abolish modern slavery once and for all. In solidarity with them, this thesis was first submitted on 19 June, 2019, also referred to as "Juneteenth," a day that symbolises the legal abolishment of slavery in the United States 154 years ago.

The atrocity of modern slavery can be eroded with time, effort, and most importantly through concerted action. Academics and practitioners have contributed heavily toward mitigating this critical humanitarian problem. It is the continued will to act together that is, perhaps, the most critical tool at our disposal. Now, the door for supply chain research of this kind is open to enable further action through enhanced dialogue, analysis, and collaboration.

We will end where we began. The findings herein must be used for good, not evil. Peace, not war. Freedom, through the breaking of chains.

8   Appendix

This appendix provides an overview of past failures in war and business. The summaries herein are concise and are not meant to be comprehensive. Rather, each highlights the failure found and catalogued as part of the dataset analysed in Chapter 5. In our Methodology (Chapter 2), we include a sample evaluation that shows how the failure-type and failure-cause categorisations were determined, thereby highlighting the potential areas for bias and enhancing replicability.

8.1   Appendix A - Summary of War Failure Data

In this section, we provide an overview of the Inter-State wars from the CoW dataset in which our analysis found the existence of supply chain failure(s). For each, we provide a brief context of the war and detail of the impact of the failure.

Though an exhaustive review of literature could result in a limitless number of disruptions that have impacted supply chains over the course of history, that is not our intent. Our interest rests on the specific disruptions which were catastrophic and therefore met our definition to be considered a supply chain failure.

Therefore, utilising the definition of supply chain failure introduced earlier in this chapter and in our Methodology (Chapter 2), we now outline those failures that occurred across global militaries during Inter-State wars between 1816 and 2007. We repeat that this is not meant to be an in-depth summary of each relevant war, but rather concise information on the specific occurrence(s) of supply chain failure within the larger context of each war. It is provided for the purpose of academic rigor, replicability, and reader interest.

Depending on the source, each war entry may be known by slightly varied dates and names. Unless otherwise noted our data is aligned with those used by Sarkees and Wayman (2010) to maintain consistency with the CoW dataset. The following war summaries are ordered chronologically and follow a standard-

ised format.

Sample format used for Inter-State War Failures:
Name of War (Years fought in parenthesis)
Failure Type: From the FailureType Table
Failure Cause: From the Failure Cause Table (Country name in parenthesis)
Summary of war and description of failure

The Mexican-American War (1846-1847); Failure Type: Supply; Failure Cause: Trade (Mexico); U.S. President Polk sought to purchase New Mexico and California from Mexico as well as to settle the border dispute between Texas and Mexico. Mexico was reluctant to sell its land and stated that the Texas border was along the Nueces River, though the U.S. believed it should be along the Rio Grande River. Polk sent troops to hold the area between the two rivers and, whilst there, Mexico attacked them. The war was fought on multiple fronts (Mexico, Texas, California), but a key U.S. strategy was the blockading of Pacific Ocean ports to prevent intra-country shipments and delivery of foreign materials to Mexico. This blockade not only enabled the U.S. to lay siege to (and seize) cities along the Pacific Ocean but it logistically limited war material shipments to Mexico and similarly prevented Mexico from supplying material or troops along the Pacific Ocean (Bennett, 1897).

The Crimean War (1846-1848); Failure Type: Infrastructure; Failure Cause: Trade (Russia); When Russia invaded the Ottoman Empire, Britain and France joined forces for the first time in history to help prevent the empire's collapse. Britain had the largest navy in the world and France supplied the most trained and militarily advanced land army. Together, the odds were in their favour to counter Russian expansionary interests. One of Russia's key weaknesses was its navy, and therefore the British fleet was stationed in the Baltic Sea and the Gulf of Finland to form a blockade, thereby preventing the Russian fleet from sailing. Additionally, Britain's blockade of Russia prohibited its home (domestic) ports, and those of neighbouring coastal nations, from sending war materials to Russia. At first, the blockade did little damage because imports could continue to

reach Russia overland from Prussia (Germany). However, over time the blockade made Russian exports crash by 80%, causing economic turmoil through inflation and rebellions in the country. This, in addition to the lack of weapons and ammunition accessible by the army, hastened Russia's acquiescence to peace in the Treaty of Paris (Ponting, 2011).

The Lopez War (1864-1870); Failure Type: Demand; Failure Cause: Delivery (Paraguay); The ambitions of Paraguay's President Francisco Solano Lopez led him to war with the Triple Alliance of Brazil, Argentina and Uruguay. Although Paraguay had the most skilled army in South America, Lopez's manpower was quickly depleted whilst fighting a war with battle fronts of on all sides. Eventually, Lopez's army made a stand at Humaitá, a fortress which could be resupplied by river routes. Lopez was able to temporarily hold off the Triple Alliance there; however, Brazil managed to encircle the fortress to cut off the re-supply routes. In time, this led to starvation in the stronghold and an eventual surrender of the Humaitá fort to Brazil. This opened the path to the fall of the Paraguayan capital city and to Paraguay's eventual defeat (Taracido, 2016).

The Naval War (1865-1866); Failure Type: Environment; Failure Cause: Trade (Spain); During the time of the Paraguay war, there was another war brewing in western Latin America. Spain was trying to exert influence against Peru by blockading ports and capturing the island of the Chinchas, which were rich in the fertiliser Guano. Peru's leaders tried to find a diplomatic agreement with Spain but the Congress would not allow it because the will of the people was offended. Thus, Peru's leaders were deposed. The nationalist party gained control and vowed to retaliate against Spain. They allied with Chile, Ecuador, and Bolivia to declare war on Spain. Spain's war response was reliant on their navy, which sailed to Peru. The Spanish navy implemented multiple blockades along the coast; however, these blockades failed due to the long coastline involved and their naval attacks caused negligible military damage because of wise placement by the allies. In time, Spain ran low on supplies (especially oil) and had nowhere to refuel or resupply due to an embargo against them from all countries along the western coast. Therefore, in retaliation, the Spanish navy laid siege to the

unguarded town of Valparaiso before accepting defeat and sailing back to Spain (Collier and Sater, 2004).

Franco Prussian War (1870-1871); Failure Type: Demand; Failure Cause: Encirclement (France); France declared war on Prussia due to a variety of ongoing issues between both countries; however, the former was unprepared for battle and the latter gained from alliances in southern Germany. France, fighting on multiple fronts, experienced the early capture of their emperor (Napoleon III) and a siege on Paris. The capital city of France would go into sustained starvation and lack of re-supply until the government accepted the terms of the Paris Commune in which Prussia gained the lands of Alsace and Lorraine. This obstruction of supplies into Paris led to a fall in the prestige of France, the hitherto dominant power in Europe, and a rise in Prussian standing which would help pave the way towards World War I (Sarkees and Wayman, 2010).

First Central American War (1876); Failure Type: Infrastructure; Failure Cause: Trade (El Salvador); Central America had many disputes over the course of the 1800's, some of which were caused by an opposition between rival political parties. In 1876, Guatemala invaded El Salvador to overthrow the latter's conservative government and install a liberal pro-Guatemalan government. Guatemala succeeded by prevailing against El Salvador in battle and also by instituting a naval blockade along the coast (Cardenal 1980).

War of the Pacific (1879-1883); Failure Type: Infrastructure; Failure Cause: Trade (Peru); In 1874, Chile and Bolivia had made an arrangement regarding land rights and Bolivian tax on Guano (a nitrate-rich fertiliser). Bolivia reneged on the agreement and raised the tax rates. This action, in addition to other brewing regional factors, led Chile to go to war with Bolivia and Peru (due to an alliance between Peru and Bolivia). Bolivia did not have a navy; however, Peru's navy was on par with Chile and, due to the regional topography, control of the seas was understood as essential. Chile acted first, neutralising Peruvian warships and eventually dominating control of the seas for the remainder of the war. This advantage helped Chile to move troops freely but, more importantly, enabled the blockade of Peruvian ports which had a devastating impact on Peru's econ-

omy and war ability. In time and after key losses, most importantly the battle of Huamachucho, Peru sued for peace (Collier and Sater, 2004).

Sino-French War (1884-1885); Failure Type: Infrastructure; Failure Cause: Information Security (China); After being forcibly withdrawn from Tonkin in 1874, France invaded China again in April 1883 to capture Hanoi. In the ensuing land and ocean battles, France was able to exploit a weakness in China's naval chain: China's north fleet and south fleet did not coordinate with each other. On 23 August 1884, the French decimated China's south fleet whilst the north fleet did not attend the battle. This lack of coordination by China gave France control of the waterways between China and Taiwan, allowing them to effectively implement a blockade to inflict harm on China's economy and force the country to make peace. Through this peace, France gained its protectorate over Annam whilst giving back the previously acquired areas of Formosa and the Pescadores Islands to China (Elleman, 2005).

Russo-Japanese War (1904-1905); Failure Type: Infrastructure; Failure Cause: Logistics (Russia); Russia had attempted to maintain its power in the Manchurian region for some time whilst limiting Japanese influence in the region. This ultimately led to a war on land and sea between the two countries that would claim more than 150,000 lives. One of the strategic areas of the war was Port Arthur which, although occupied by a Russian fleet, was successfully blockaded by Japan at the beginning of the war. With significant manpower Japan was also able to overcome Russian land opposition and take control of the hills around Port Arthur, allowing for the hill-side bombardment of Russia's fleet which could not leave, manoeuvre or receive reinforcements because of Japan's blockade. Russia called their Baltic fleet for support; however, by the time it arrived Port Arthur had been taken by the Japanese. Ultimately, Russia's Baltic fleet was also destroyed at the Tsushima Strait, giving Japan uncontested naval power against Russia for the remainder of the war (Sarkees and Wayman, 2010).

Italian-Turkish War (1911-1912); Failure Type: Demand; Failure Cause: Delivery (Turkey); Italy sought to expand its presence in Northern Africa by capturing Tripoli from the Ottoman empire. This began with a surprise attack by Italy and

a blocking of the seaports around Libya. Italy hoped to make it a quick war but fierce Ottoman resistance carried the fighting on for a year. In time, with the goal of hurting the Ottoman supply lines, Italy enacted a plan to place expeditionary corps near caravan routes to intercept shipments of war materials including ammunition, food and personnel. A little over a year after the initial invasion occurred, the Ottoman Empire agreed to cede Tripoli to Italy (Herrmann, 1989)

First Balkan War (1912-1913); Failure Type: Demand; Failure Cause: Delivery (Turkey); Inspired by Italy's capture of Tripoli during the Italian-Turkish war, Greece, Serbia and Bulgaria allied together to gain territory from a failing Ottoman empire. This war began a day before the Italian-Turkish War ended, though the stakes were much higher for the Ottoman empire which garnered hundreds of thousands of men to battle. Due to a series of Ottoman logistical failures, in addition to from key military defeats, the allied states were able to claim victory and the lands they sought. An example of the Ottoman logistical failures was the failure to supply transport (e.g. horses) or weapons (e.g. artillery shells) to the line of battle at Buni Hisar (on 30 October 1912) which allowed the Bulgarian army to break through the Ottoman lines. Holistically, the Ottoman loss of communication (via railway) between Adrianople and Constantinople, the loss of their supply lines to the fields of battle, and having their navy blockaded at Dardanelles all showed an unpreparedness for war and contributed to their eventual defeat (Hall, 2002).

World War I (1914-1918); Failure Type and Cause: Supply; Failure Cause: Trade (Germany);

Failure Type: Infrastructure; Failure Cause: Assets (Turkey); There are volumes of analysis on the causes (and subsequent events) of the first World War. Europe's regional territorial ambitions were rife prior to that the war; however, the final push was the assignation of the Archduke Franz Ferdinand of Austria-Hungary. The country used this as its casus belli to declare war, which due to alliances pulled the neighbouring countries into war as well.

When the Central Powers (Germany, Austria-Hungary, Romania, Bulgaria, and Turkey) joined forces with an eye for expansion, their war machines took on mul-

tiple fronts and, over time, made their way towards Paris and across Belgium. However, the Allies (Great Britain, France, the United States, Italy, Japan, Serbia, and to some extent Russia) were able to hold them off with a concert of land battles and naval victories (Phillips and Axelrod, 2005).

Although it can be said that there were multiple supply chain failures which occurred during the course of the war, one of the key contributing failures to success for the Allies was the obstruction of oil shipments (among other war materials) to the Central Powers through trade embargoes and naval blockades. The failure to obtain oil, a resource integral for modern warfare, severely diminished the Central Power's ability to use force. Similarly, Germany and Austria-Hungary faced extensive population strife due to a lack of food (a direct result of the blockade). These ongoing shortages created a persistent crisis which continued even after the signing of the peace accord (the Treaty of Versailles) and led to a revolution in Germany (Howard, 1993).

The major supply chain failure for Turkey was the persistent disruption of the Hejaz railroad line through Britain's collaboration with Arab troops. These disruptions constantly led to supply issues and a diversion of men to fix the railroads (infrastructure). The Arab nations performed these acts expecting valuable land to be given to them in the event of an Allied victory. This indeed did happen (though the size of the area was not to their expectation), and the land would be discovered as one of the largest oil reserves in the world (Smith 2005).

The eventual collapse of the German military machine would ensure Allied victory. However, it would pave the way to World War II when, incidentally, Hitler confidently marched on Russia backed by oil supply commitments he obtained in the Caucasus (Painter, 2012).

Manchurian War (1929); Failure Type: Infrastructure; Failure Cause: Information Security (China); This short war was spurred by the tension of future ownership of Manchuria, an area coveted by the USSR, China, and Japan, though in this specific war only the former two would battle for their interests. Battles began when China seized control of the jointly-operated Soviet-Chinese railway and simultaneously employed diplomatic aggression. The USSR retaliated by cut-

ting off diplomatic ties and placing troops along the Sino-Soviet border. Shortly after diplomatic resolutions failed, the USSR invaded China, utilising a combination of false radio-broadcast messages and leaflets to confuse the Chinese army about the USSR army's location. The false-communication worked and the Chinese army was ill-prepared for actual Soviet movements. China capitulated quickly and within three months, the two countries agreed to an end of hostilities with a return to the pre-war status quo (Patrikeeff, 2002).

Chaco War (1932-1935); Failure Type: Supply; Failure Cause: Trade (Bolivia); Bolivia and Paraguay were both land-locked countries with one coastal area under dispute: the Chaco. In 1932, Bolivia chose war to claim the Chaco and its access to the Atlantic for itself. In preparation for this, Bolivia ordered significant artillery from Vickers (a British munitions company) in the years leading up to the war, though much of the supplies would not reach Bolivia because the arrival to Argentine and Chilean ports was blocked by the host countries who took Paraguay's side in the war. Vickers also reported internal problems with product quality and its ability to ship on time to Bolivia. Conversely, Paraguay enjoyed the freedom of foreign shipments during the war from support with its neighbouring countries. Additionally, Paraguay anticipated the war and diversified their war material supplies from an estimated thirty-three countries, in that way if one order failed to arrive then a majority of others would continue (a strategy referred to as supply base diversification). Bolivia, despite its impressive war purchases, mistakenly single-sourced its war materials and deliveries did not arrive as needed. Due to this, Bolivian soldiers often had guns without cross-compatible ammunition and weapons which had limited performance capabilities, leading to disastrous consequences on the battlefield. Though both sides had logistics difficulties due to the remote terrain (Sarkees 2005), Bolivia's issues were significantly more pronounced and contributed to their loss in the war (Hughes, 2005).

Nomonhan War (1939); Failure Type: Demand; Failure Cause: Delivery (Japan); In a continuation of hostilities between Japan and the USSR, in 1939 Japan sought to obtain additional land along the Mongolian border with Manchuria (an area referred they referred to as Manchukuo). Mongolia had an alliance with the

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USSR and therefore, after preliminary Japanese attacks, both Mongolia and the USSR counter-attacked. This short war was fought in land and air battles. In the end, Japanese troops were repelled back to the pre-invasion border. During one of the key battles, the USSR was able to out-flank Japan on two land fronts, completely encircling Japan's 23rd division and effectively cutting them off from any support or resupply. After refusing to surrender and being unable to receive reinforcements due to the encirclement, the entire division was decimated during repeated attempts to escape. Soon after this, Japan sued for peace (Coox, 1990).

World War II (1939-1945);
Failure Type and Cause: Infrastructure, Blockade (United Kingdom)
Failure Type and Cause: Supply, Blockade (Bulgaria)
Failure Type and Cause: Infrastructure, Capture (China)
Failure Type and Cause: Infrastructure, Capture (Vichy France)
Failure Type and Cause: Infrastructure, Communication (Germany)
Failure Type and Cause: Demand, Logistics (Hungary)
Failure Type and Cause: Demand, Logistics (Italy)
Failure Type and Cause: Environment, Embargo (Japan)
Failure Type and Cause: Demand, Logistics (Romania)
Failure Type and Cause: Demand, Encirclement (USSR)

Source for World War II summaries: Phillips and Axelrod (2005)

Twenty-one years after the 'War to End All Wars' (as World War 1 was known), World War II saw the longest and most advanced use of weapons and strategy in the modern age. As such, there is a dense literature on almost every angle of the war; however, for brevity, we provide a brief summary below prior to detailing the related supply chain failures.

The main belligerents of World War II were known as the allied and axis powers. The allied powers principally consisted of Britain, the United States, Colonial French forces (the 'Free French'), and the USSR. The principal Axis powers consisted of Germany, Italy, and Japan (by virtue of the Rome-Berlin-Tokyo pact between them). The first movement into the war was made by Germany's inva-

sion of Poland on 1 September 1939, causing Britain and France to declare war on Germany. Germany used its blitzkrieg ("lightning") tactic to quickly overwhelm Poland by land, sea, and air. France fell to Germany next, and a puppet government was put in its place (known as 'Vichy France'). The German army used the blitzkrieg tactic to quickly move west, capturing every area up to the point of the English channel where Britain held them at bay. During Hitler's conquests of Western Europe, Italy invaded North Africa and Japan invaded the Orient. Until the end of 1941, the axis momentum was ferocious.

During this time, the United States only took part in the war to supply Britain and the Free French. However, on 7 December 1941, the Japanese attack on Pearl Harbour brought the United States into the war, and together with the other allied powers (at this point including the USSR, who had also been invaded by Germany), were able to retake the captured lands of North Africa, Europe, and the Orient. Italy was taken by the allies with costly force, Germany surrendered only when defeat was clear and Japan, though attempting to continue warfare, capitulated after the dropping of the only two atomic bombs to ever be used in any war. The war also contained horrible violations of human rights, which led to global agreement on anti-genocide laws. Finally, the end of the war saw the creation of the United Nations, the World Bank, and GATT, all of which marked a large shift towards globalisation.

As World War II engaged every major country, each countries military supply chains were thus spread across the world as well. Though supply chain issues may have occurred on a repeated and small scale, we focus only on the failures as part of our analysis. Therefore, as discussed in our statistical coding protocol, we maintain our definition of failure to mark the critical issues that occurred, though every country involved may have experienced supply chain disruptions throughout the war.

Summary of major supply chain failures experienced (by country) during World War II:

Britain. German patrol of the English channel greatly impaired British sea-going vessels. This lasted until America's entry into the war, and their subsequent im-

plementation and fine-tuning of the hunter-killer campaign (specifically tasked to remedy the blockade) by using squadrons for finding and destroying any German naval presence.

Bulgaria. Bulgaria relied on German reinforcements in their support of the Axis war effort; however, when the USSR joined the allied powers and invaded Bulgaria, it cut off the latter from German troop reinforcement.

China. Also on the allied side, China lost many of its resource capabilities when Japan captured its supply routes in the Indochina region.

Germany. The British naval blockade campaign significantly impacted Germany, much as it had in the first World War. However, in this war, the blockade did not impact Germany in the beginning of their operations, as Germany had secured access to food stores and oil. The effect came later in the war as Germany was no longer able to sail at will (especially after the sinking of its key battleship, the Bismark). However, communication issues for Germany were much more impactful than this.

A disinformation campaign by the allies led Hitler to believe that the allied invasion (Operation Overlord) would most likely land at Pas de Calais, not Normandy. By 25 August 1945 (after D-day, invasion day at Normandy) German troops in west France were isolated as Allied troops pushed through Normandy. Furthermore, the Allied forces managed to break Enigma, the encoded communications system used by Germany. On land, this allowed for knowledge of army locations, strength and planned routes. On the seas, this enabled successful targeting (or avoidance, as needed) of German u-boats.

One of the major accomplishments of the USSR army was the external defence of Stalingrad, and then once the Germans had fought their way into the city, being able to encircle them, effectively trapping them. This encircling manoeuvre worked and helped the USSR cut off supplies Germany's ability to supply its army. By doing so, the USSR captured "five corps headquarters, 14 German infantry divisions, three motorised and three panzer divisions, two Romanian divisions, and a Croat infantry regiment, in all some 250,000 men." Furthermore,

Near the end of the war, Berlin was encircled by two Soviet fronts, (led by a race between commanders Konev and Zhukov) just as the German capital city fell to the Allies.

Hungary. Though there was a loss of access to resources in Stalingrad, in addition to the loss of access to oil after the invasion of Russia, the biggest failure came when Hungary was finally pinned down by the USSR in December of 1944. In this case, Budapest was unable to be relieved by German forces and was forced to capitulate.

Italy. Italy suffered multiple losses during the war, especially in its main theatre: North Africa. Many of these losses were spurred by a loss of resources due to attacks on the Italian logistics corridor.

Japan. The U.S. instituted a blockade of Japan during the U.S. invasion in May 1945. During the war, there were numerous attempts to cut off supplies from both sides, in addition to those made by the blockades. For example, in the Pacific theatre the U.S., heading north, used their 'island hopping strategy' to leave Japanese units stranded by skipping past their islands to fight on islands further north. The Allied forces also cracked the coding systems used by Japan (magic). The ability to decode messages provided the allies knowledge of a transport of Japan's naval commander who they subsequently shot down, striking a critical blow to Japan. The biggest failure for Japan was an embargo on oil which limited its fighting strength and forced it to shift its strategy.

Romania. Although Romania initially progressed well on the side of the Axis powers, after operation Barbarossa (when the Axis powers turn on their ally, the USSR, by invading them), the red (USSR) army switched allegiance to the allied powers and declared war on Germany and her allies, including Romania. During the battles fought, the Red army was able to effectively cut off the country of Romania from German supply, thereby negating her main source reinforcements.

USSR. Germany blockaded Leningrad and the lead Soviet tank corp was encircled (and subsequently defeated) in Poland. This was a trick the red army would

reverse on Germany at another battle in the war in the USSR's defence of Stalingrad. Additionally, when Hitler decided to turn the German army towards the USSR, one of the main strategies used was to attempt to cut oil supply to reduce the strength of the Red (USSR) army. This was not devastating, though Russia took major losses during the war because of it.

Vichy France. After the initial fall of France to Germany, the Free French government operated in exile (from London) on the side of the Allies. Germany installed a puppet regime in the city of Vichy, France to govern the country. Thus, this puppet French regime was known as 'Vichy France' and operated on the side of the axis powers. However, the Vichy government lost many ships to the Royal Navy when they made port and the ships were repurposed for the Allies. Furthermore, the remainder of the fleet was then scuttled when the French navy turned on itself.

The Berlin Airlift A point of interest as an example of avoiding a potential supply chain failure: After World War II was over, administration of Berlin was split between East Berlin (administered by the USSR) and West Berlin (administered by the United States). The USSR attempted to blockade West Berlin in opposition to it being the capital of a proposed Western German state. This blockade would have lead to starvation of the city and no option for resupply of the defending army. In response, U.S. President Truman implemented the Berlin Airlift, a 321-day airdrop of supplies which eventually led to an end of the blockade. Eventually, West Germany was created and the Berlin Wall took form.

Korean War (1950-1953); Failure Type and Cause: Demand, Delivery (China); Failure Type and Cause: Demand, Delivery (North Korea); Korea was split into trustee administration along the 38th parallel at the end of World War II. The USSR was made responsible for Korea north of that line and the United States made responsible for Korea south of that line. Each separate parts of Korea considered their government to represent the entire Korean peninsula which led to ongoing conflict. Five years after the partition, North Korea invaded South Korea. War broke out with China and the USSR supporting North Korea, while the newly created United Nations (UN) sided with South Korea. The United States

represented the majority of the fighting force in South Korea on behalf of the UN. North Korea pushed as far south as the Pusan Perimeter, where the UN forces were running out of retreat space.

In a bold manoeuvre, the UN forces successfully invaded by sea at Incheon, effectively cutting off all supplies, communication, and support to North Korean troops located south of the Incheon area. Those troops who could not sneak back into North Korea were captured. The UN forces then pushed northward to take back Seoul from North Korean occupation followed by a siege of the North Korea capital until it fell. This caused China to enter the war on land, utilising a large land army to push through Manchuria and retake Seoul. UN forces retreated initially and then fought back, especially working to severely limit Chinese supply lines. This forced Chinese Commander Peng to ask his government "For what are they [Chinese soldiers] giving their lives? We have no aircraft. We have only a few guns. Transports are not protected. More and more soldiers are dying of starvation" (Barnouin 2006). This made China reliant on USSR assistance, who agreed to fly air protection over Chinese supply lines. Ultimately, UN forces recaptured Seoul and the 38th parallel was enforced (again) as the border. A demilitarised zone was created along this border which is still in effect (Haruki and Baldwin, 2013).

Sinai War (1956); Failure Type: Infrastructure; Failure Cause: Information Security (Egypt); Fear based on Egypt's prior actions regarding the maritime corridor caused Britain, France and Israel to ally together in a secret attempt to secure the future use of the Suez Canal. The attack began with a daring mission that required surprise. Israel flew four fighter planes close enough to the ground so that their blades could chop the telephone lines connecting Egypt to the Sinai. This infrastructure attack effectively delayed the mobilisation of Egypt's army. After the telephone lines were cut, Israel dropped paratroopers near the Canal while Britain and France worked together to mitigate the Egyptian air force. Due to the lack of communication systems, Egypt did not immediately realise that they were at war, though when it did learn of the situation it dispatched forces accordingly. By this time, however, significant damage had already been done and international pressure from the United States and the Soviet Union man-

dated a cease-fire of hostilities. Israel, in seeking to ensure its maritime route, attacked and successfully opened the Straits of Tiran before the cease-fire took effect. Although Israel obtained its goal of shipping access, international support for this war sided with Egypt. Britain and France faced harsh international criticism for their support (Herzog, 1982).

Assam War (1962); Failure Type: Infrastructure; Failure Cause: Information Security (India); The British rule of India left many questions as to the Indo-Sino border (separating India and China). In 1962, India decided to test the boundary and placed its troops forward of the disputed border area. China responded by organising an army to push the Indian troops back and thereby reclaim the territory, which it successfully did despite international pressure to limit force. One of the key reasons for success for the Chinese was the limitations on India's infrastructure. Mis-communication was rife (e.g. the debacle at Shen-La) wireless communication was poor due to the mountain passes prohibiting communication. Furthermore, India's forward posts were very scarcely populated and with insufficient ammunition. The war lasted less than a month and ended with a cease-fire, returning most of the borders to pre-war areas, with the exception of leaving China with control of Aksai Chin and India having access to northern areas of Assam (Palit 1991).

Six Day War (1967); Failure Type: Infrastructure
Failure Cause: Information Security (Egypt)
Failure Cause: Information Security (Jordan)
Failure Cause: Information Security (Syria)
Following the Suez Crisis, Israel was apprehensive about being restricted from access to the Straits of Tiran. Israel also had other regional issues which continued to linger with Egypt, Syria and Jordan. Due to these concerns, on 5 June 1967 Israel launched a series of pre-emptive strikes on Egyptian military installations with the main goal of eliminating Egyptian air capability. To accomplish this, Israel meticulously planned its covert missions to remain completely hidden and used spy information it had received on Egypt's (substantial) air force. The first and foremost risk Israel took was flying almost its entire air fleet to Egypt, thereby leaving Israeli airspace almost completely undefended. The planes flew

close to the ground to avoid radar detection, yet they were picked up by Jordanian installations (utilising British machinery) who saw the squadrons and sent an encrypted alarm to Egypt before the Israeli jets were able to make it to their target. However, in a communication error that laid the course for this short war, Egypt did not read the alarm. The reason for this was because Jordan was using message encoding that Egypt had changed the day prior without telling Jordan. Thus, Egypt did not open the message and when Israeli jets reached their air bases, Egyptian planes were on the ground while their pilots were having breakfast. Needless to say, it didn't fare well for the Egyptians. A majority of the Egyptian air force was destroyed and Israel dominated the skies for the remainder of the quick war.

Furthering the communication foul, Jordan and Syria were told by Egypt that the Egyptian forces had defeated the Israeli invasion, and thus both Jordan and Syria attempted to invade Israel based on poor information provided by their ally. The result was catastrophic for the invaders. Israel had uncontested air power against land armies and was successfully able to capture the Golan Heights (from Syria), the West Bank and East Jerusalem (from Jordan), in addition to the Sinai and the Gaza Strip (from Egypt), ending the war strongly in Israel's favour (Oren, 2003).

Football War (1969); Failure Type: Demand; Failure Cause: Assets (El Salvador); Citizens of El Salvador who had migrated to Honduras were facing ill-treatment in their host country. At the same time, both countries were competing in the preliminary matches of the World Cup. El Salvador won the matches, leading to riots and murders between civilians. This building of civil and political strife between El Salvador and Honduras led to a short war between the neighbouring South American countries. El Salvador invaded Honduras, pushing through defences and capturing a town before being stopped because of Honduran air attacks on El Salvador's oil facilities. These air strikes limited the ability of the army to move due to lack of oil. This supply chain attack bought time for neighbouring countries to help arrange a cease-fire. Begrudgingly, El Salvador accepted the cease-fire, one of the conditions of which was that peacekeepers protect citizens of El Salvador who were living in Honduras (Phillips and Axelrod,

2005).

Communist Coalition (1970-1975); Failure Type: Supply; Failure Cause: Trade (Cambodia); Although not directly involved in the Vietnam War, Cambodia's border was often used by the North Vietnamese army to supply the Viet Cong in the South. In 1970, the war spilt into Cambodia when its leader (Prince Norodom Sihanouk) was overthrown and replaced by his prime minister, Lon Nol. Sihanouk led a government in exile from China and, in alliance with North Vietnam and the Viet Cong, invaded Cambodia to overthrow the Lon Nol led government. Sihanouk's forces shut down major shipping lanes and sieged the capital city of Phnom Penh, which led to near starvation of the city. U.S. airlifts helped provide food to besieged victims, yet in time the U.S. Congress showed disinterest in continuing support and shortly thereafter, Lon Nol's government surrendered. We note that this entry contains additional years compared to that of the CoW inter-state dataset (which ends this conflict in 1971). These additional years were added in the interest of summarising the entirety of the conflict which led to the Cambodian Civil War (Phillips and Axelrod, 2005).

Bangladesh (1971); Failure Type: Supply; Failure Type: Trade (West Pakistan); After Pakistan obtained its independence, it was split into East and West Pakistan. However, the two areas did not come together harmoniously. Due to internal conflicts, Pakistan had a civil war between its East and West regions, a conflict that India got involved in to protect East Pakistan (the area that would thereafter become Bangladesh). This involvement caused West Pakistan to declare war and attack India. India responded with military action, dominating the skies with jets. Therefore, West Pakistan's only supply route was by sea. Knowing this, India's Operation Jackpot [The Daily Star, 2015] saw commandos destroy Pakistani ships in four major ports: Chittagong, Mongla, Chandler, and Narayanganj. Similarly, a key leverage point used by India was the naval blockade of East Pakistan's coast (Singh, 1980). These actions limited Pakistan's ability to resupply its troops, thereby degrading Pakistan's fighting position and helping contribute to the end of the war.

Yom Kippur War (1973); Failure Type and Cause: Demand, Delivery (Egypt); Fail-

ure Type and Cause: Demand, Delivery (Syria); Six years after the Six Day War, the Arab countries planned retaliation. Led by Egypt (with military and political backing from the Soviet Union), a surprise attack was arranged during the Israeli holiday of Yom Kippur. The Egyptian military forces (who heavily outnumbered the Israeli forces) were able to make significant progress into the East Bank. However, Israel scrambled its military and was able to recover. Israel pushed the majority of the fighting onto the West Bank whilst completely isolating the Egyptian third army on the East Bank. This encircled division, totalling an estimated 45,000 soldiers, was used as leverage in the cease-fire negotiations between the superpowers representing Egypt and Israel at the United Nations (the USSR and the United States, respectively). Without the cease-fire, it was predicted that Egypt's Third Army would have been decimated. Furthermore, Israel's counter-invasion of Syria severely damaged air delivery of munitions from the Soviet Union and naval attacks on Syrian ports impeded delivery of supplies via sea-freight (Herzog, 1982).

Falkland Islands (1982); Failure Type: Supply; Failure Cause: Trade (Argentina); Argentina invaded the Falkland Islands to re-establish its claim to them against the United Kingdom. This was based on old disputes over the islands, which were owned (at different times) by England and Spain, and whilst under Spain's dominion were managed by Argentina in the early 1800's. When Argentina took control of the islands in 1982, the British assembled a fleet to sail over eight-thousand miles to re-take the islands. In this war, Britain secured the assistance of major countries such as the United States, France, and locally in Chile, to provide resources and logistics links. One of the key fears of the British ships was Argentina's use of French Exocite missiles. These missiles were specifically designed to be dropped by aircraft to sink naval vessels. Argentina, however, had a limited supply of these missiles and, given the impending battles, heavily chased international procurement of more. In a covert effort, Britain managed a worldwide sabotage of Argentinian (and the allies of Argentina) supply chains from procuring the missiles. They even went so far as to buy all Exocite missiles for sale and destroy their abilities in order to prevent Argentina from having access to them (Note 2002). In the end, Argentina ran out of Exocite missiles

and of the few they had, some did not explode due to improper fuses. Britain won the war, yet Lord Craig, Marshal of the Royal Air Force, is quoted to have said regarding Argentina's difficulties sourcing the Exocite missiles and fuses: "Six better fuses and we [Britain] would have lost" (Keegan, 2002).

Gulf War (1990-1991); Failure Type: Supply; Failure Cause: Trade (Iraq); Disputes between Iraq and Kuwait, in addition to a poor political situation in Iraq, led to Iraq's invasion and complete take over of Kuwait (including the Kuwaiti government, towns, and oil fields). Middle-eastern countries called for protection and it was received from around the world. To begin, the United Nations (UN) implemented resolutions 660-662 which called for the immediate departure of Iraqi forces from Kuwait. A week later, a latter resolution (UN resolution 665) enabled the full blockade of supplies entering Iraq, which had a detrimental impact on its war posture and also impacted Iraq's already failing economy. The blockade used is said to be one of the most effective ever made, as it impacted not only food supply and the movement of arms, but more importantly to the Iraqi leadership, it completely prevented the ability for Iraq to sell oil, which was its main method of financing the war. This spurred Iraq to attempt negotiations; however, they were rejected. Following Iraq's refusal to leave after the final UN warning (resolution 678), the UN authorised force to drive the Iraqi forces out of Kuwait. It should be noted that the UN resolutions were pushed through with the strong support of the United States. The U.S. placed many protective troops in Saudi Arabia as part of Operation Desert Shield and helped bring together the coalition by rallying the international community. Coalition forces, mainly led by the U.S. took to force on 15 January 1991 in Operation Desert Storm. Though Iraqi troops lit fire to the Kuwaiti oil wells during their departure, Kuwait was successfully cleared or Iraq presence. Iraq was not invaded by coalition forces during this war (Freedman and Karsh, 1993).

Bosnian Independence (1992-1995); Failure Type: Demand; Failure Cause: Logistics (Yugoslavia); After the end of the Cold War, rumblings of independence came to the smaller states within Yugoslavia. Croatia and Slovenia declared independence with a comparatively limited response from the Yugoslav government. However, when Bosnia (which had a large Serbian population) attempted

to do the same, it led to war with Serbian-majority Yugoslavia. In time, Croatia backed Bosnia in this war against Yugoslavia, which turned the situation into a war between ethnicities. The United Nations immediately implemented an arms embargo on all belligerents, but this did not work well at first because the Yugoslav army was mostly Serbian and thus the Bosnian citizens found it difficult to buy weapons for their self-defence. Regardless of the embargo; however, both sides were still able to obtain weapons on the black market. The actual supply chain failures came into play when in 1995, years after the war started, U.S. bombing began taking out ammunition depots and supply corridors of Yugoslavia, while an air and naval blockade prevented movement of materials and troops. Unable to move or resupply, these international actions made the Serbian forces aware of the impending onslaught from international powers and severely limited their ability to use force (by ground, air, or sea). Together, this helped force the way to peace talks (Magaš and Žanić, 2001). We note that the years of battle in the CoW dataset are only 1992; however, we extend our analysis to 1995 when foreign intervention helped put an end to the war.

Azeri-Armenian Conflict (1993-1994); Failure Type: Infrastructure; Failure Cause: Workforce (Azerbaijan); In 1991, motivated by ethnic and political issues, in addition to a desire to become part of the country of Armenia, the region of Nagorno-Karabakh declared independence from Azerbaijan. Azerbaijan, however, sought to keep the area as part of its country and therefore conflict initially erupted between Karabakh fighters and the Azeri-army. Armenia came to the aid of the Nagorno-Karabakh, and this led to war between Armenia and Azerbaijan which grew until 1994. International pressure, including embargoes on trade, sought to stem the tide the war which dragged on into 1994 and led to the displacement of hundreds of thousands of civilians. In the end, Azerbaijan had lost thousands of soldiers and was forced to conscript children under 16 years of age to fight in the conflict. Due to significant losses in fighters, including the disaster of the Omar Pass, and international pressure, Azerbaijan was pushed towards a cease fire, which was agreed to by Armenia and Karabakh fighters (De Waal, 2013).

Badme Border (1998-2000); Failure Type: Demand; Failure Cause: Assets (Eritrea);

Eritrea seceded from Ethiopia in 1993, yet with ongoing borders contentions between the two countries. These border conflicts persisted and in 1998, when Eritrea's army marched into a disputed area held by Ethiopia, the two countries went to war. Although Eritrea was able to make some initial progress into the disputed territory, by the year 2000 Ethiopia was able to gain the majority of it back. One significant achievement of the Ethiopian army was to remove Eritrea's integral supply road between Barentu and Mandefera, preventing reinforcement of supplies to Eritrean troops on the Western front. This helped push momentum in Ethiopia's favour (BBC 2000) and led to the capture of Barentu, effectively ceding Eritrea's southwest region. Ethiopia (eventually) recovered a significant amount of the invaded territories after these strategic losses, Eritrea agreed to a cease-fire which returned the border to pre-war positions (Lorton, 2000).

War for Kosovo (1999); Failure Type: Infrastructure; Failure Cause: Logistics (Yugoslavia); After the succession of Bosnia from Yugoslavia, the latter went through new political elections and a restructuring with Serbia and Montenegro. One remaining area of international concern was Kosovo, which had a population that also sought independence from Yugoslavia and was willing to go to war for it. The KPA, a guerrilla army formed by those seeking independence, was formed to battle for against the Yugoslavian regime. Skirmishes led to battles, and these altercations led to all-out war which displaced almost a million people. Similar to the Bosnian War for independence, the War for Kosovo was watched by foreign powers who were concerned about the potential for further genocide in Yugoslavia as well as the migrant crisis the war was directly causing. Unlike the Bosnian War, NATO did not formally declare war or sanctions until much later in the process; however, that did not stop the UN forces (led by US command) from disabling Yugoslavian infrastructure. During the spring of 1999, UN forces used their air force to destroy Yugoslavian army bunkers, ammunition plants, oil refineries, communication towers (including television broadcasting capability), and even the bunker below the house of the Yugoslavian leader. In addition to this, UN forces dominated the skies with approximately 600 planes, making it almost impossible for the Yugoslavian

army to receive supplies by air or move without risk of detection leading to further infrastructure losses. These air strikes against the Yugoslavian logistics infrastructure, essentially disabling the army from operating, helped lead to peace talks. Shortly thereafter, NATO formally declared war. The cessation of war (due to the use of international force) came on 11 June 1999 (Clark, 2001).

Invasion of Afghanistan (2001); Failure Type: Infrastructure; Failure Cause: Assets (Afghanistan); One month after attacks on the U.S., the United States and coalition forces went to war against radical groups which took control of Afghanistan after the departure of the Soviet Union and the subsequent fall of communism in the country. The United Nations helped by imposing an arms embargo on Afghanistan, but this did not lead to a failure in their supply chain. The actual failures came as part of U.S. Operation Enduring Freedom, a strategic attack of defences, supply lines, troops, and airports. It was essentially an onslaught on the entirety of the radical group's infrastructure. One of the major supply chain blows was levied by the fall of Mazar-i-Shariff, the main northern outpost for rebel forces. In a successful capture mission (which was similarly repeated in the Invasion of Iraq), coalition forces were able to re-purpose Mazar-i-Shariff as a supply centre for themselves, allowing them to conduct forward operations from the previous opponent stronghold. Ultimately, they secured the majority of the country and helped the Northern Alliance (a collaboration of mujahideen groups) come into power and trained their militaries to hold the country from radical groups (Neville, 2015).

Invasion of Iraq (2003); Failure Type: Infrastructure; Failure Type: Assets (Iraq); In an effort to thwart the future use of weapons of mass destruction and in order to facilitate regime change in Iraq, the United States and coalition countries invaded the country in a similar method to those used during the Invasion of Afghanistan (see the previous summary). The invasion began with air strikes on key military targets, supply lines, and the capture (and subsequent exploitation) of Iraqi air bases. These actions caused (and precipitated) a quick collapse of the Iraqi government, its armed forces, and caused its dictator to go into hiding before being captured. A major impetus to shift in the war was the capture of the H2 and H3 Iraqi airbases. These air base facilities were major supply hubs for

the Iraqi army (especially of large weapons). Therefore, when captured, these served the coalition forces in two ways: it would directly disrupt supply lines for the enemy whilst also enabling the use of forward bases for the invading forces (Cornish, 2004).

8.2   Appendix B - Summary of Business Failure Data

In this section, we compile supply chain failures sourced from industry reports, corporate announcements, databases, and examples from prior literature. Each entry was verified using scholarly or authoritative news sources.

It is important to note that, to the best of the author's knowledge, this list of supply chain failures in business (N = 24) has never existed before. Typically, this knowledge has been collated a handful at a time or is used anecdotally. However, in addition to learning from this history, a further contribution of this thesis is in the fact that it is providing these failures which were hitherto uncompiled.

Sample format used for Business Failures:
Name of Company
Failure Type: From the FailureType Table
Failure Cause: From the FailureCause Table
Year; Summary of event; Description of failure

Summaries are ordered chronologically.

Edison Records; Failure Type: Supply; Failure Cause: Trade; In 1877, Thomas Edison, based on his experiments and attempts to improve the telegraph, inadvertently devised a recording device. This was the first time that humans were able to record audio and the first words ever recorded were the ever-popular "Mary had a little lamb." Though it would not become common until decades later, the ability to record audio launched Edison's company (Edison Records) into a household name and consumers across North America wanted the ability to play back pre-recorded audio, especially music. Replaying music meant that

customers could listen to various types of instruments without having to actually have them in their home, and Edison was eager to provide the highest fidelity music possible; however, material shortages came in the way. World War I meant that wax, metal, and their production facilities needed to be repurposed for the war effort. Due to this, Edison Records was unable to use its wax recipe in record making. In light of this, competitors launched their own variations and 'recipes' of records which were not reliant upon wax. Edison Records was unable to compete due to their lack of supply and lost its market share. Although it was the first audio recording company, its name has long been forgotten due to this failure (Gronow and Saunio, 1999).

General Motors; Failure Type: Infrastructure; Failure Cause: Assets; In the 1980's General Motors (GM) dominated the automobile market. The company's CEO (Roger Smith) attempted to invest in the future by partnering with a Japanese company to install robots in its factories. In time, Roger Smith would end up spending $40 billion in upgrades to its production facilities and yet, when compared to simpler plants of competing companies, throughput was equal or less. Many anecdotes were given to the early adoption of technology, a humorous one being that the robots actually ended up painting each other instead of the cars they were meant to. However, this failure of infrastructure led to a decline of GM's status as a producer and allowed rival companies (especially from Japan such as Toyota, Honda, and Nissan) to eat away at its market share. Interestingly, at the time General Motors attempted to leapfrog the competition, the company could instead have purchased Honda and Nissan at a lower combined cost than it invested in its failed production robots (Pfeffer, 1996).

Isotoners; Failure Type: Supply; Failure Cause: Workforce; In 1994, new management initiatives pushed Isotoners to move its stable manufacturing centre from the Philippines to other east Asian production areas in search of lower cost labour. However, this did not take into account that their Philippines labour was well trained (many employees had been there for over 15 years) and had provided high-quality production for the company and its customers. Rather than slowly transitioning, the employees were let go and the production was moved. The shutting of the Philippines factory led to a fiasco of procurement

issues, ultimately reducing product quality and cutting consumer sales in half. Worst of all, the production move increased costs above those of operating the original plant was no longer viable. The parent company of Isotoners (the Sara Lee Company) decided to sell off the failing line and did so in 1997 to the investment firm Bain Capital (SCDigest, 2006).

Foxmeyer; Failure Type: Infrastructure; Failure Cause: Assets; In 1995, Foxmeyer Drug Co. was one of the biggest drug distribution companies in the U.S., rivalled only by McKesson Corp. At the time, Foxmeyer used a mainframe system called Unisys Corp to manage its invoices and inventories. The Unisys system was becoming antiquated. Instead of slowly upgrading, Foxmeyer decided to completely refresh the computing infrastructure across the entire company by installing SAP. There were multiple issues with this strategy, most of which were that the company was not ready for the switch and key processes were not put in place to ease the transition. Furthermore, the transition had to be expedited because of what the senior management deemed as urgent business needs, thus shortcuts were taken in setting up the enterprise system. The issues began swiftly. Foxmeyer found that SAP could not interface well with the legacy system (Unisys), the connected automation warehouse they built was sending out the wrong medicine (when it was not turning off randomly), and the software itself wasn't offering the cost savings the company thought it would. Ultimately, the version of SAP that Foxmeyer was using (version R/3 in 1995) could only handle a few thousand items per day, whereas Foxmeyer actually needed it to process approximately 500,000 per day. The situation went from bad to worse when the company could not meet its deliveries, experienced personnel began to leave and, less than a year later, the company's stock price had dropped from $25/share to approximately $3 per share before it was bought out by McKesson (Bulkeley, 1996).

Apple; Failure Type: Demand; Failure Cause: Delivery; In 1995, Apple was scheduled to launch the brand new line of its personal computer, the Power Mac. Two years prior, Apple had seen a drop in earnings of 84% and in 1994, Apple over-produced its Power Book (laptops). Due to this, Apple played it safe and ordered a conservative number of Power Mac's (desktops) for

production. The demand for desktops, however, was explosive and the lack of inventory contributed to a substantial loss of market share not only in 1995, but in the following years for their position in the personal computing market (McCune 1996). By 1996, Apple's incorrect demand estimation, on top of strong industry competition for its operating system, cut the stock price almost in half and it was not until 1998 that it would begin to recover. During the peak of orders without sufficient supply, it is estimated that Apple's backlog was over $1 billion USD. Due to missed deliveries, customer dissatisfaction was rife. In time, Steve Jobs would retake the helm of the company to launch innovative products such as the iPod and iPhone, though these would not recover the market dominance it previously lost in personal computing (SCDigest, 2006).

Denver Airport; Failure Type: Infrastructure; Failure Cause: Assets; In 1995, the city of Denver planned to open its brand new airport with a price tag of $3.2 billion USD. Due to the distance from the air terminal to baggage handling, the city agreed to install an underground automated baggage handling system from BAE Systems. However, the automated system had repeated issues in which the automated luggage carts would collide with each other and come off the tracks. The opening for the new airport was pushed back four times before the Mayor of the city decided to spend $50 million to have a backup luggage system provided by a secondary company. The backup system would allow the airport to open using traditional baggage systems utilising trains and manual carts; however, even this system took time to develop and install. Ultimately, Denver had to wait until the following year (after the holiday rush) before moving routes from the old airport, a delay cost that was estimated at $33 million per month, in addition to the costs of the additional infrastructure itself (NYT, 1994).

Adidas; Failure Type: Infrastructure; Failure Cause: Assets; In 1996, Adidas attempted to update the warehouse management system (WMS) at a U.S. distribution facility in Spartanburg, South Carolina. The first WMS attempt failed, and then a second attempt failed as well. Though the facility was meant to be highly automated and promised significant gains in material handling, the benefits did not materialise. The key problem with the first WMS attempt was that Adidas was trying to force two separate systems (UNIX and Stratus) to interchange with

each other. Unfortunately, this produced many issues and the company who was first responsible for the UNIX side of the interchange (Integrated Software Logistics Engineering) went out of business. Despite the data interchange not working correctly, Adidas allowed operations from the warehouse to continue. This resulted in an inability to meet approximately 80% of North American demand. Following this, Adidas experienced a significant loss of market share as customers went to competitors, a loss which took significant time and effort for Adidas to recover from (SCDigest, 2006).

Airbus; Failure Type: Infrastructure; Failure Cause: Information; In 1996, Airbus, a global manufacturer of airplanes, was expected to release its new competitor against the Boeing Dreamliner: the Airbus A380. The supply chain; however, was attempting to balance its multiple production sites as well as its split European management between Germany and France. Due to a lapse of communication, parts from different production facilities were incompatible with each other, only to be discovered when the plane was in build phase (Airmic 2011). Airbus announced to its shareholders that the A380 would be delayed by six to seven months at a reduction of operating profit by approximately \$2.5B. The airlines stock plummeted over 26% after the announcement and multiple airlines switched suppliers by ordering through Boeing instead of Airbus (Clark, 2006).

General Motors; Failure Type: Supply; Failure Cause: Workforce; In 1996, following its robots debacle, General Motors (GM) faced another major supply chain issue when trying to diversify its supply base of components for anti-lock brakes. GM's key component supplier for this area was Delphi, a company responsible for providing 90% of brakes used by GM. When Delphi found out that GM was attempting to increase its number of suppliers, thousands of Delphi's employees went on strike for almost three weeks before GM could source their brakes from other suppliers. The resulting supply shortage caused General Motors to lose \$900 million due to underproduction, shut down 26 plants, and fire over 170,000 workers. These numbers do not include the further impact the halt in production had on GM's other suppliers. This failure exemplifies the dangers of attempting to improve procurement practices yet inadvertently making them much worse (Franklin, 1998).

Dole; Failure Type: Supply; Failure Cause: Trade; In 1998, the agricultural industry suffered the consequences of Hurricane Mitch in Central America. The hurricane dropped almost three feet of rain onto multiple countries, including those critical in the supply chain of banana growth. The two dominant manufacturers, Dole and Chiquita, had very different reactions to the hurricane. Whereas Chiquita was able to shift its production to nearby countries not as harshly affected (such as Panama), Dole relied upon the heavily impacted countries of Nicaragua, Honduras, and Guatemala. This resulted in a loss in market share which Chiquita was ready to pick up, as well as a loss of about $100 million due to the hurricane floods that year. Though Chiquita also had financial impacts from crop loss, they were substantially less than Dole's due to their ability to procure from other areas (Hittle and Moustafa 2011).

Chiquita; Failure Type: Environment; Failure Cause: Trade; In 1998, similar to its competitor Dole, Chiquita sourced its primary supply of bananas from Central American countries that were hit by Hurricane Mitch. Chiquita, unlike Dole, had planned to multi-source from other suppliers and was in a better position to meet consumer demand, especially based on alternative supply arrangements from Panama. However, the company still lost $50 million due to the impact of the hurricane on regional crops (Hittle and Leonard, 2011).

Hershey's; Failure Type: Infrastructure; Failure Cause: Information; In 1998, Hershey's invested over $100 million USD in upgrades its technology systems. Unfortunately, it decided to upgrade multiple systems (e.g. customer relationship management, demand planning, ordering) at the same time and the ability for the systems to interact took much longer than expected. Not only that, but on multiple occasions, the system did not work at all and product's were waiting to be shipped without the company knowing where they was destined for, leading to aggravated consumers and chaos within the company's supply chain. Hershey's later disclosed that the mishaps cost the company over $150 million USD in lost orders and their profits took a severe hit as well. To recover, Hershey's launched an Electronic Data Interchange (EDI) platform that could parse communications between their multiple systems. It then had to go to Wall Street and convince analysts that their supply chain processes were robust and that

this failure was a one-time mistake (SCDigest, 2006).

Nike; Failure Type: Infrastructure; Failure Cause: Assets; Beginning in 1999, Nike attempted a global telecommunications upgrade to bring its systems onto the German software SAP. However, the installation did not go as smoothly as they hoped and the company drastically overproduced some products while underproducing other products due to software glitches that made planning very difficult. Nike's stock took a 20% hit because of its issues and the software manufacturer it was working with (i2) blamed Nike for not following expert advice. Years later, Nike would fully roll out a software package suited for its business that led to competitive growth, decreasing inventory and alignment with actual demand (Cnet, 2002).

Cisco; Failure Type: Demand; Failure Cause: Delivery; In 1999, during the internet bubble, telecommunications companies could not keep pace with the rate at which clients were upgrading equipment and installing new networking hardware. Cisco, a major manufacturer of connectivity hardware, incorrectly assumed that the market would continue to grow yet was hit hard when the internet bubble burst. Ultimately, Cisco had to write off approximately $2.2 billion in excess equipment, an action which cut their stock price in half. To mitigate future issues, the CEO of Cisco (John Chambers) installed a new method of work which forced senior managers to work on multi-division teams, to discuss limitations, and areas of future growth. This led the company into new ventures, product lines, and countries, though Cisco's stock price is still approximately still half of what it once was in 1999 (Kimes, 2008).

Toys 'R' Us; Failure Type: Demand; Failure Cause: Delivery; In 1999, toy sellers were attempting to shift demand online due to the advent of technology and home orders. Toys 'R' Us had not been a major player in the online market; however, in November 1999 it embarked on a massive marketing campaign which offered free shipping for online orders and guaranteed delivery by Christmas for any order placed by 10 December. This did not go as planned. Toys 'R' Us experienced immense demand and its supply chain was unable to cope, thereby failing to deliver on its guarantee. Two days before Christmas, the company

e-mailed every customer who would be receiving their products late and apologised for the delay. In a public relations effort, the retailer gave each customer who would not receive their packages by Christmas a gift voucher for $100 to its stores (Hansell 1999). However, this was not enough. The damage had been done, as irate customers complained profusely via national news outlets and a tarnished reputation resulted due to its debacle. Eventually, Toys 'R' Us would outsource its supply chain fulfilment services (SCDigest, 2006).

Ericsson; Failure Type: Supply; Failure Cause: Trade; In 2000, Ericsson and Nokia were two of the global phone manufacturers vying for market share. Both used a plant owned by Philips to source processing chips for their phones. However, in March of 2000, when a lightning strike hit the Philips plant and caused a fire, Ericsson's reaction was delayed compared that of Nokia. Nokia, to its credit, worked with Philips to understand the actual impact and the extended timeline that would be required for repairs. Ericsson, however, operated under the impression that it was a minor setback and that it would be fine. It would not. The fire disabled the plant for months. Nokia quickly went to the global supply market to secure external chip and manufacturing options. When Ericsson realised the full picture it was too late and the global chip capacity was already reserved. This procurement mistake caused Ericsson an estimated $400 million USD in lost sales. This event led Ericsson to no longer producing its own phones (Sheffi and Rice Jr, 2005).

Land Rover; Failure Type: Supply; Failure Cause: Trade; In 2001, Land Rover employees came into work on a Friday morning and realised that no chassis shipments had arrived for their Discovery vehicle model. Upon calling their sole supplier for chassis, they found out that the supplier, UPF Thompson, was going bankrupt and would not be sending any more materials. The supply set back shut down the Land Rover assembly line. In order to temporarily restart the supplier, Jaguar was asked to invest $35 million to prop up UPF (Hittle and Leonard, 2011). The dispute went to British court where Land Rover and UPF Thompson decided to settle for an undisclosed amount. Thereafter, Land Rover's supply chain partners bought UPF in order to secure future supply of parts (SCDigest, 2006).

WebVan; Failure Type: Demand; Failure Cause: Delivery; In 2001, WebVan was a pioneer in the internet market area of grocery shopping. The company was one of the first to tout the ability to take online orders for groceries and deliver them to a customers door within a specified time window. This capability helped WebVan achieve a valuation of over $800 million USD, a poster-child for the dot-com era. Utilising the cash received from venture capabilities funding based on their valuation, WebVan built massive high-tech facilities with thousands of employees supporting its multi-state operations. However, the company incorrectly estimated large demand and built a warehouse infrastructure capable of handling a much larger customer base than actually materialised. At the time, the trend was too new to consumers and thus much of the facility infrastructure went unused. This, in addition to a low-margin pricing strategy, led the company to be unable to continue operations. The company which was worth billions in market cap fell rapidly and its stock trading was frozen on the Nasdaq as it was forced into bankruptcy (Delgado, 2001).

Toyota and GM; Failure Type: Supply; Failure Cause: Workforce; In 2002, the U.S. Longshoremen's strike rattled American imports. A failure to reach consensus between the docks and the labour unions led to a 10-day labour strike which blocked the import of materials for major supply chains across the United States. Although some industries were able to mitigate the supply chain repercussions of the strike by heeding warnings and importing buffer stock in advance, others, such as the automotive industry, were severely impacted. For example, the NUMMI plant (owned by Toyota and GM) in California was shut down within the first few days of the strike, despite having spare supplies on hand in case a strike materialised (Sheffi and Rice Jr, 2005).

Boeing; Failure Type: Supply; Failure Cause: Trade; In 2004, Boeing announced the sale program for its newest plane, the 787 Dreamliner. Designed using the newest technologies (including lower cabin compression, lower fuel consumption and therefore a lighter carbon footprint with further flight capabilities), the plane stirred global appeal and Boeing cashed in over $100 billion in sales for the Dreamliner before the planes were even built. As part of Boeing's plan to build the planes, the company created a global supply chain strategy where it

would rely upon a network of companies to source the parts and production in a piecemeal fashion. By doing so, Boeing expected to source the best parts from all over the world whilst also saving cost due to the outsourcing of major technical work, such as the building of the fuselage. Unfortunately, the company tasked to build the fuselage was unable to meet Boeing's requirements and the timeline for the release of the plane slipped as a result. Customers who ordered the plane asked for penalty payments whilst Boeing attempted to perform damage mitigation. Ultimately, Boeing ended up paying at least $2 billion in additional costs due to this failure in its supply chain. The Dreamliner was eventually released; however, it was two years behind schedule due to delays caused by supply procurement issues (Greising and Johnsson, 2007).

Bosche; Failure Type: Supply; Failure Cause: Assets; In 2005, customers of the automotive part manufacturer Bosch were hit by a supply chain issue regarding quality. The company, known for distributing high-quality components, sold defective high-pressure pumps and unknowingly passed these along to their consumers. Ultimately, it was an upstream supplier who had made the mistake in the supply chain, yet the quality-gap slipped through and it cost Bosch millions to remedy (Thun and Hoenig, 2011).

Mattel; Failure Type: Supply; Failure Cause: Trade; In 2007, the global toy-maker Mattel came under scrutiny for the dangerous procurement and sale of toys which could poison children (due to lead in the paint), or in the case of Mattel toys with small magnets, become dislodged and lead to death if accidentally swallowed. The major lead scandal had to do with suppliers in China (the country where Mattel was sourcing 65% of its toys). The lead contamination was rooted in the paint production process of the suppliers. This paint was applied onto small race car toys, mostly sold to children in North America. A separate Chinese supplier was responsible for making the toys where small magnets could be dislodged and this had led the death of children, again in North America. The scandal gripped news headlines and led to a loss of sales and stock price for Mattel. The company reacted by recalling all potentially affected products and working with its suppliers to improve supply chain practices (Barboza and Story, 2007).

Zavvi; Failure Type: Supply; Failure Cause: Trade; In 2008, the crash of Woolworth's affected many other companies due to their connections to the U.K. conglomerate. One such company was Zavvi, an entertainment retailer which competed with stores such as HMV. A year prior to the crash, Zavvi was a part of the Virgin Megastores group. The brand was sold to Woolworth's and was also financially indebted to them based on the structure of the sale contract. One integral issue barred Zavvi from being able to continue operations (or paying its debt to Woolworth's). Zavvi only purchased its supply from Woolworth's, a company which had just stopped operating. This meant Zavvi was unable to receive products, make sales, and thereby unable make a profit at all. Despite efforts to save the company by Ernest & Young and Virgin Megastores, Zavvi quickly disintegrated. The resulting financial issues and lack of supply led Zavvi to file for bankruptcy the day before Christmas that year (Power, 2008).

Target; Failure Type: Demand; Failure Cause: Logistics; In 2013, Target attempted to expand its stores into Canada. The roll-out strategy was designed to be big, with 124 stores opening at the same time across the country. However, Target was unable to deliver products to its stores and therefore customers were disappointed with a lacklustre offering due to empty shelves. After the debacle, the company decided to rescind their northern expansion plan and focused efforts on their U.S. operations instead (Wahba, 2015).

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