Experimentation with Procurement to Design and Model Supply Chains in Developing Economies

by

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ABSTRACT

This thesis proposes experimentation with procurement as a convenient tool to generate data, reveal supply chain phenomena, and garner access to stakeholders in developing economies. Based on experimentation with procurement, stylized analytical models of supply chains in developing economies can then be generated.

In particular this thesis explores experimentation with procurement in the context of food aid supply chains. In local and regional procurement, in which food is bought in a developing economy, and transoceanic procurement, in which food is bought in a developed economy and shipped to a developing economy, supply chain design is central to the humanitarian outcomes of food aid. Designing food aid supply chains involves weighing trade-offs between cost, quality, lead time, and the various interests that shape food aid policy. This thesis relies on two food aid supply chain case studies to build generalizable theory about experimentation with procurement.

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Contents

1. Introduction

Analytical modeling can be an effective tool to design supply chains. These models can have burdensome data requirements, require a deep understanding of a system's processes, and be difficult to validate. Accordingly, in developing economies these models are often not the most practical tools to design supply chains. Experimentation with procurement is a convenient tool to generate data, reveal supply chain phenomena, and garner access to stakeholders in developing economies. Based on experimentation with procurement, stylized analytical models of supply chains in developing economies can then be generated. In this thesis I propose research questions around experimentation with procurement, and use an inductive method to build theory around it as a tool for supply chain design.

This thesis explores experimentation with procurement in the context of food aid supply chains. Humanitarian, domestic, and geopolitical interests interact to determine the content, location, and quantity of food aid procurements and the destinations to which they are shipped. In local and regional procurement, in which food is bought in a developing economy, and transoceanic procurement, in which food is bought in a developed economy and shipped to a developing economy, supply chain design is central to the humanitarian outcomes of food aid. Designing food aid supply chains involves weighing trade-offs between cost, quality, lead time, and the various interests that shape food aid policy.

This thesis relies on two case studies to build theory about experimentation with procurement. These case studies focus on fungi growth and insect infestation in food aid supply chains. One case study addresses quality issues in the upstream portion of local and regional procurement supply chains in Uganda, which is dominated by smallholder farmers and middlemen. The other case study addresses quality issues in the portions of transoceanic procurement supply chains that pass through the ports of Djibouti and Durban.

In Uganda many farmers' crops are refused by local and regional procurement mechanisms due to quality issues. In Uganda in 2014-2015 the World Food Programme (WFP) ran a development project to provide about 16,000 farmers with airtight storage to improve on-farm stored crop quality: this storage was procured from three effectively independent supply chains at a cost of about $800,000. This procurement shed light on capacities and costs in the Ugandan post-harvest storage sector. In this case study I *ex post* evaluated the procurement.

Maintaining quality is a challenge for food aid shipments passing through many ports, including those of Djibouti and Durban. The two ports, in which USAID has moderate supply chain visibility and which have different handling and bagging capacities, present a compelling case for a procurement experiment. USAID is spending about $1 million to procure and ship 1,360 MT of food aid in new packaging options. This procurement is designed to reveal the capacities and costs of handling new food aid packaging options. In this case I helped design and *ex post* evaluate the procurement.

This thesis builds theory about how experimentation with procurement can provide data and reveal insight on supply chain processes in developing economies, and how this data and insight can lead to simple, stylized models. This thesis also explores the roles that donors, researchers, and implementing partners can play in *ex ante* designing experimentation and *ex post* evaluating a procurement. In particular, both case studies and in Section 8 both procurements are presented to illustrate the merits and challenges of different procurement designs—field based, or headquarters-based—and different procurement designs—organization-designed, researcher-designed

1.2 Research questions

Using the two case studies on supply chains in developing economies, this thesis answers one primary research question: how can experimentation with procurement reveal capacities and costs of supply chains in developing economies? An inductive argument is appropriate given both the context-specific findings (Section 2.3) and the gap in literature (Section 2.4). This thesis has significant implications for conducting supply chain due diligence and appropriately supporting—via subsidies or other mechanisms—supply chain actors. This thesis answers one secondary research question: how can food aid supply chains be designed using experimentation with procurement to maintain food quality? The primary research question is tested against one hypothesis: procurement can reveal manufacturing and material handling capacities of supply chains in developing economies. The secondary research question is tested against one hypothesis:

procurement must be large enough to stress the system to gain useful insights into capacities and costs in food aid supply chains.

1.2 Road-map

Section 2 documents the constraints of supply chain modeling, and proposes that experimentation with procurement can generate data, reveal processes, and validate models, which are all necessary steps to build stylized supply chain models. Section 3 details how the two case studies were selected and justifies the need for theory building around the idea of experimentation with procurement in developing economies. Section 4 and Section 5 give an introduction to food aid and quality issues in food aid, respectively. These are necessary to position the case studies on local and regional food aid procurement and transoceanic food aid procurement in Section 6 and Section 7, respectively. Finally, Section 8 presents an analysis of both case studies and discusses practical challenges to using procurement as a tool to design supply chains in developing economies.

2. Methods in Supply Chain Design and Modeling

2.1 Section Introduction

Several types of models have been proposed to evaluate the trade-offs inherent in supply chain design (Beamon 1998). Many of these models rely on thorough data requirements, a deep understanding of system processes, and relationships with supply chain stakeholders for validation. Access to this information in developing economies can be limited as compared to developed economies. Experimentation with procurement can test different chain designs (e.g. by revealing capacities and costs) and provide an alternative to conventional modeling tools when designing supply chains in developing economies. Procurement is one aspect of supply chain management: it is the coordination of the purchase of goods (or services). Experimentation with procurement is the systematic testing and deployment of supply chain designs. From data, insights, and validation garnered by experimentation, stylized models of supply chains in developing economies can be proposed and refined.

2.2 Supply Chain Design and Modeling

Modeling is a useful tool to design supply chains because it can help evaluate trade-offs inherent in supply chain design. Beamon (1998) separates supply chains into production planning and distribution, and Min and Zhou (2002) similarly separate supply chains into material management and physical distribution. Supply chain models, which apply to both inbound and outbound logistics, can be classified in at least three categories: (1) deterministic analytical models in which variables are known and which may have objective functions and constraints, (2) stochastic analytical models in which at least one variable is unknown but for which there is a probability distribution associated and which may have objective functions and constraints, and (3) simulation models which are designed to model systems often based on stochastic processes, feedback loops, and constraints (Beamon 1998, Min and Zhou 2002). These models can capture different trade-offs inherent in supply chain design.

Analytical models can be used to understand capacities, such as the rate at which a product can be produced, and costs, such as the cost of producing that product. Silver, Pyke, and Peterson (1998) give a range of analytical models to determine optimal order sizes and production schedules given forecasts across single and multiple periods.

Deterministic analytical models with objective functions that minimize cost or maximize profit can be used to optimize production rates and batch sizes (e.g. Williams 1983), base stock levels and lead times (e.g. Ishii *et al.* 1988), the location of finished products, subassemblies, and components (e.g. Cohen and Lee 1988), and facility locations (Nozick and Turnquist 2001). Stochastic analytical models can similarly be used to determine relationships between inventory level, lead time, service level policies, and costs. For example, Silver, Pyke, and Peterson (1998) extend deterministic analytical models of optimal order sizes to include stochastic parameters, such as stochastic demand variables. Stochastic models can be used to explore trade-offs under various inventory review systems (e.g. Svoronos and Zipkin 1991, Lee and Billington 1993).

Simulation models can also be effective in determining relationships between lead times, costs, and service quality (Persson 2002, Morrice et al. 2005, Hellstrom and Johnsson 2002). Simulation can be useful when supply chains' "complexity obstructs analytic evaluation" (e.g. van der Zee and van der Vorst. 2005, Ridall 2000). This thesis proposes experimentation as a tool to study supply chains in developing economies whose "complexity obstructs analytic evaluation," and as a mechanism to make stylized, analytical models.

2.3 The context: modeling in developing economies

The success of a supply chain model rests on at least three criteria: the strength of input data, a deep understanding of a system's processes, and the ability to validate findings (Persson 2002). In developing economies researchers building supply chain models often lack datasets, a complete understanding of a system's processes, and access to key supply chain stakeholders to validate findings. Social and management science research methods, such as observation and interviews, can give researchers some data and intuition about a system's processes.

Generally, the business environment in developing economies can impede the effectiveness of these social and management science research methods. In developed economies, firms' datasets are important tools to corroborate information gleaned from interviews, but firms' datasets are scarce in developing economies. Firms' datasets can also be useful to understand businesses over time. A researcher may be able to get a snapshot of a business's positions (e.g. inventory on hand) and policies (e.g. a re-order policy) in an interview, but it can be difficult and imprecise to elicit previous positions and policies in an interview.[1] In developing economies (as in developed economies) biases in responses to questions about capacities and costs can be difficult to overcome—yet unlike developed economies, datasets that may corroborate responses may not be available. Despite ample assurances about the academic nature of an interview, a firm may perceive it to be in their favor to overstate capacity or to understate costs in an interview. This unique business environment in part justifies building theory on experimentation with procurement as a tool to design supply chains in developing economies (Eisenhardt 2007).

Data can be a limiting factor in modeling supply chains (Persson 2002). Across a supply chain different organizations and firms may collect different data. Reconciling a model with real world data requirements can be burdensome even in developed economies (e.g. Chang and Makatsoris 2006). In most developing economies, computer-based systems that help plan procurements, track inventories, and tally sales are not used. Social science research methods can be used to elicit some data that a planning platform might readily offer in developed economies, but these methods can be limited in their ability to accurately elicit data such as historical order information or even recent but granular sales information.

A deep understanding of a system's processes can also be elusive to researchers modeling supply chains in developing economies. This deep understanding often requires a strong understanding of multiple firms' operations and interactions (Persson 2002). Even in developed economies there can be particular firms and situations where a deep understanding is limited because "industrial decisions take place rapidly" (Hellstrom and Johnsson 2002). In other words, decisions arise and are resolved in ad-hoc processes, and ad-hoc process can be difficult to articulate in a model. Again, social science research methods such as observation can be used to reveal systematic and even ad-hoc supply chain processes. However, these methods can be time-consuming, access to all supply chain stakeholders can be difficult, and it is impossible to observe the counterfactual that

[1] One time-consuming but feasible solution to this challenge is to hold many interviews over business cycles and seasons.

would be necessary to evaluate a supply chain design that requires a new process, material, or sales channel.

Finally, validation is a key step in modeling supply chains. Validation ensures that the data used to populate the model is robust, and that the processes used to build the model are interpreted correctly (Persson 2002, Berry and Naim 1996). Getting feedback from stakeholders up and down a supply chain in developing economies (as in developed economies) can be difficult for several reasons. Bhaskaran (1998) observes:

> "There are many incentives for a plant to try to optimize its individual operations. There are fewer incentives and/or opportunities for a supply chain to analyze interplant interactions and try to optimize the "whole system."

In both economies it may not be worth a firm's time to work with a researcher to validate a supply chain model. Even given a firm's willingness to validate model findings, communication can be constrained in developing economies: e-mail and computers with spreadsheet software are limited.

2.4 Literature gap: experimentation as complement to models

Experimentation with procurement complements supply chain models for developing economies. Experimentation with procurement can be thought of as the systematic deployment of various supply chains and the evaluation of these supply chains across relevant criteria. Sodhi and Tang (2014) propose stylized models for supply chains in developing economies, much like stylized models that have been proposed in operations literature (e.g. Arrow (1951) and the newsvendor problem) and economics literature (e.g. Ray (1998) and the nutritional poverty trap problem). In behavioral operations (mostly applied in developed economies) and behavioral economics literature (applied in developing and developed economies), experimentation has emerged as a tool to test and refine these stylized models. This thesis specifically proposes experimentation with procurement as a tool to test and refine stylized supply chain models for developing economies. Generally, there is limited literature on the use of experimentation to build and validate supply chain modeling in developing economies. This gap in literature also in part justifies a theory-building case study (Benbasast 2007). This thesis builds theory by showing that experimentation with procurement in developing economies can generate data to populate models, reveal supply chain processes in order to build stylized models, and garner access to stakeholders to validate these models. On the factory floor that Hellstrom and Johnsson (2002) allude to, on which "industrial decisions take place rapidly," experimentation with procurement can be used to explore those processes and their resultant data.

The use of experimentation to create stylized models and to design supply chains is not new to business environments in developed economies. Sterman (1989) reconciled the need to capture behavioral processes in supply chains by applying experimental methods to study individual behavior. More recently, the field of behavioral operations has begun to explore the role that biases play in business environments in developed economies. Decision-makers, often students in lab experiments, are shown to exhibit biases such as demand chasing, anchoring to the expected or mean demand, and aversion to the costs of excess inventory (e.g. Schweitzer and Cachon 2000; Kremer *et al.* 2010; Ho and Zhang 2008). Studies have also shown how different incentive mechanisms, such as contracts with prices adjusted to counter behavioral biases, can be built into conventional models (Becker-Peth *et al.* 2013; Elahi *et al.* 2013; Davis *et al.* 2014).

The use of experimentation to create stylized models and to design policy interventions in developing economies (as well as developed economies) is a well-developed field of inquiry. The field of economic development is using designed or natural experiments in many policy evaluations. These evaluations are typically deployed and studied to determine causality of development interventions (e.g. Imbens and Woolridge 2008). Many experimental studies (e.g. Duflo 2001, Miguel and Kremer 2004) used randomized trials to control for differences in income, geography, and other factors that determine the efficacy of a policy intervention.

This thesis sits at the intersection of developing economies, supply chain design, and experimentation. It is presented as a complement to Sodhi and Tang (2014), in which they propose stylized models that capture the unique business environment of developing economies. These stylized models can illuminate areas of uncertainty on which experimentation with procurement may shed further light, as well as emerge as experimentation generates data and reveals supply chain processes. The space that this thesis occupies among these three literature streams is illustrated in Table **1**.

Table 1: The gap in the literature

		Analytical	Experimental
Developed Commercial Context	Supply Chain Modeling	e.g. Arrow (1951) Example: Newsvendor modeling	e.g. Schweitzer and Cachon (2000)
Developing and Humanitarian Context	Economic Modeling	e.g. Ray (1988) Example: Nutrition trap modeling	e.g. Imbens and Woolridge (2008)
	Supply Chain Modeling	Sodhi and Tang (2014)	**The gap**

2.6 Supply chain design in developing economies

Supply chains in developing economies operate in fragmented markets and typically in the informal sector. Developing economies are often characterized by poor infrastructure, low supply chain visibility, limited environmental regulations, unique working capital requirements and risk aversion of firms, and informal contracting mechanisms. A conventional definition of supply chain management often includes three interrelated ideas: (1) the coordination of activities to maximize customer value and control costs, (2) the examination of goods, information, and finances, and (3) the engineering of that flow from raw materials (and even raw materials suppliers) to finished products (and even after-market support). Van der Zee and van der Vorst (2005) give a more "inclusive definition" of supply chain management that begins to approximate the complexity of some supply chains in developing economies,

> "The integrated planning, coordination, and control of all logistics business processes and activities in the supply chain to deliver superior consumer value at less cost to the supply chain as a whole while satisfying requirements of other stakeholders in the supply chain (e.g. the government or NGOs)."

The involvement of NGOs and governments might not even lead to least-cost or even profitable arrangements.

This thesis uses one case study of a procurement to provide 16,000 farmers airtight crop storage sector in Uganda, and one case study of an operation to provide food aid to individuals in the Horn of Africa and Southern Africa.

These case studies are written to illustrate the complexity and opacity of supply chains in developing economies. The supply chains that provide airtight storage to farmers in Uganda rely on a variety of small and large Ugandan firms. Even after hours of semi-structured interviews with supply chain actors, it is difficult to determine from where firms in the sector buy materials or hire laborers, and what factors like these may mean for their manufacturing or distribution capacities. It is similarly hard to estimate the costs at which they manufacture and distribute storage. Similarly, food aid supply chains and the quality of the food in them are dependent on contractors and sub- contractors for handling at foreign ports, such as in Djibouti and Durban. Given the modest supply chain visibility at these ports it is difficult to estimate the capacity of these actors to handle new packaging options, and the cost at which they may be handled.

These case studies are also written as examples in which experimentation with procurement generated data, revealed supply chain processes, allowed for validation, and set the scene for researchers to build stylized supply chain models. Data from the Uganda development project revealed the capacities and costs of firms involved in the Ugandan on-farm storage sector, and the ability to interview firms involved in the procurement was useful to understand the business environment. Similarly, a procurement in which food aid in new packaging is sent to Djibouti and Durban is a necessary tool to understand capacities and costs. The US Agency for International Development's (USAID) commitment to exploring new packaging is demonstrated with the procurement, and supply chain actors have been forthcoming in interviews about their processes.

3. Case study selection and design

3.1 Theory building

This section uses an inductive argument to build theory around experimentation with procurement. Primary empirical findings are central to each case (Meredith 1998, Fisher 2007, Eisenhardt 1989, Ketokivi 2014). First, an empirical approach to theory generation is justified "when context and experiences of actors are critical" (Benbasat 1987, Bonoma 1985). This is documented in Section 2.4. In developing economies, experiences of actors can differ from those in developed economies. Sodhi and Tang (2014) validate this notion, proposing stylized models that capture the unique business environment of developing economies. Second, building theory is justified because of the lack of literature at the intersection of supply chains, experimentation, and developing economies (Eisenhardt 2007). This is documented in Section 2.3. This thesis studies similarities and differences across the two case studies in Section 8 to "proceed toward theoretical generalizations" using inductive reasoning (Ketokivi 2014, Barratt *et al.* 2011). I duly note that case studies that build theory "far out strip" those that validate theory, but believe that theory building is justified in this thesis based on criteria set forth in literature (Ketokivi 2014, Barratt *et al.* 2011). This theory building has significant implications for how donors and implementing partners conduct supply chain due diligence and even offer support, via subsidies or other mechanisms, to supply chain actors.

3.3 Case Selection

This thesis uses theoretical sampling instead of biased sampling or statistical sampling to build theory. Theoretical sampling is useful in theory building case studies: with theoretical sampling it is easier to select case studies that include the nuance and context that are often key to building theory. Benbasat *et al.* (1987) goes further than just calling for researchers to disclose their sampling method by calling for case studies to be "thought out" as opposed to "opportunistically derived" (Barratt *et al.* 2011).

This thesis presents two case studies based on research projects that were thoughtfully sought out. The process by which the two research projects—that lead to the two case studies—were selected involved stakeholders working on a grant at the Massachusetts Institute of Technology (MIT) and from the US Agency for International Development

(USAID). The overarching goal of the grant is to develop a comprehensive methodology to evaluate technologies used in developing economies and in development interventions. Stakeholders from development organizations and technology firms proposed research projects usually centered around a product or family of products. MIT and USAID stakeholders considered a portfolio of the proposed project proposals, eventually selecting each research project based on a mix of criteria that included the level of 'buy-in' from the development and technology stakeholders, the degree of support from certain USAID missions, and the relevance of each research project to the overall goal of the grant. The Pugh method was used to compare and contrast the different project proposals.

While the research projects were "thought out" on the basis of being projects with interesting questions about supply chain design in developing economies, they are perhaps more "opportunistically" presented as case studies to answer the research questions of this thesis. Neither of the two projects, from which the two case studies were derived, were scoped to explicitly answer research questions on using experimentation with procurement to design supply chains. At the same time, I argue that because neither project was selected on that basis, the fact that the interaction between contracts, capacity, costs, and supply chain design produced similar phenomena in both projects suggests that this is a genuine research question. In other words, I argue that having *ex-post* identified this research question across two projects focused on supply chains in developing economies helps mitigate the somewhat opportunistic selection of the two case studies. The two projects were not selected on the basis of deriving two case studies to build theory, but rather theory was built based on case studies that emerged from two projects. Alternatively, Eisenhardt and Grabener (2007) write that selecting "particularly illuminating" case studies with theoretical sampling is a reasonable case-selection logic; I believe that these two case studies are "particularly illuminating."

This thesis presents two case studies. In creating theory, it can be useful to have four to ten case studies. With less than four case studies it can be difficult to illustrate a phenomenon and thus generate theory; with more than four a phenomenon clearly begins to emerge from among the case studies (Barratt *et al.* 2011). Eisenhardt and Grabener (2007) call this the "rich multicase story." Alternatively, it can be useful to have just one case study, which addresses context and supply chain actors in tremendous detail (Barratt *et al.* 2011). As I aim to build theory based on nuanced contextual findings I err toward presenting two very detailed case studies in lieu of four less detailed case studies, and in erring toward readability I avoid presenting four highly detailed case studies lest "the text balloon" (Eisenhardt and Grabener 2007). Two case studies, instead of one, help me meet Ketokivi and Choi's (2014) duality criterion for theory building from case studies: being "situationally grounded" and "empirically disciplined" while examining "theoretical implications."

3.4 Data collection

This section outlines the data collection and processing methods used in each case study. These case studies are based on multiple data sources, which is recommended by Eisenhardt and Grabener (2007) and Yin (1994). We had access to many knowledgeable actors involved in the supply chains of interest and the supply chain design process (Eisenhardt and Grabener 2007). The case with the World Food Programme (WFP) is based on semi-structured interviews, structured interviews, observation, and two datasets (logs from a long-haul transporter and WFP). The case with Food for Peace (FFP) is based on semi-structured interviews, observation, and various datasets furnished by USAID and available in academic literature. In many instances, these case studies use multiple methods to triangulate data (Eisenhardt and Grabener 2007). For example, in determining manufacturing capacity of Ugandan metal silo manufacturers we found differences between self-reported production rates and production rates inferred from data from the long-haul transporter that regularly picked up finished silos from the manufacturers. Interviews and experiments were administrated by one of four interviewers involved with the grant between August 2014 and May 2016.[2]

The WFP case study relies on data from a long-haul transportation firm and WFP, and dozens of semi-structured, structured, and unstructured interviews for an understanding of the supply chain processes. Responses in semi-structured interviews

[2] *Mark Brennan*. WFP case study: 2014-2015 academic year, field visits January and summer 2015; FFP case study, 2015-2016 academic year, field visits January 2016.
Jaime Castaneda. WFP case study: field visit summer 2015.
Emily Gooding. WFP case study: 2014-2015 academic year, field visits January and summer 2015.
Prithvi Sundar. FFP case study: 2015-2016 academic year, field visit January 2016.

were noted on pre-printed forms and typically recorded. The average semi-structured interview with a firm in a supply chain lasted one to two hours. Semi-structured interviews were given to try to limit researcher bias (Eisenhardt and Grabener 2007). Structured interview responses were noted on forms; these interviews tended to be much quicker and were not recorded. Some unstructured encounters, such as meetings with WFP or USAID, were not recorded, while others, such as interviews with development organizations, were recorded. Many stakeholders were interviewed twice, some three times: typically once in January 2015 on a pilot visit and once or twice in the summer of 2015 on a six-week-long field visit. Within that summer visit we revisited several stakeholders. This in effect acted as a validating step: we would review data and processes elicited in the previous interview for correctness, and then typically proceed in further detail. In the days after each interview we transcribed the recorded interviews and re-wrote notes from interviews that were not recorded into a narrative.

In the FFP case study interviews are essential to both designing the procurement and the analysis. In field visits across the American Midwest and South interview responses in semi-structured interviews were noted on forms and not recorded. Like with the World Food Programme case study, unstructured encounters such as those with USAID were not recorded. The average semi-structured interview with a firm in the supply chain lasted one to two hours. Semi-structured interviews were given to try to limit researcher bias (Eisenhardt and Grabener 2007). There is a standing invitation to clarify any data or process descriptions with all of the firms that participated in the interviews, not unlike the follow-up, validating step in the Ugandan fieldwork. In the days after the interview a researcher wrote interview notes into a narrative.

Data processing and interview transcription related to both case studies happened usually 1-2 days after an interview or observation; our process was roughly consistent with the 24-hour rule given in some case building literature (Glaser and Strauss 1967). However, in both case studies, analysis happened months after data collection. In hindsight, transcription, processing, and analysis should have all occurred simultaneously with data collection (Glaser and Strauss 1967).

The interviews used to generate both case studies were not transcribed word-for-word and coded. This is because I am not looking to characterize qualitative themes and trends within and across the case studies. Coding may have been a necessary tool had I wanted to provide case studies of, perhaps, challenges of using procurement as a tool to reveal capacities and costs in supply chains in developing economies. That is certainly a fertile area for future work. In Section 8 I do foray into a qualitative discussion of experimentation with procurement in developing economies. That discussion is only a side commentary and not a rigorously structured analysis of, say, challenges in experimentation with procurement or the role of researchers in designing procurements.

Rather, the interviews used to generate the case studies were held to elicit (a) data, process descriptions, and validation, and (b) in the case of the FFP project in order to design the procurement. The analysis of these interviews focuses on triangulating data and process descriptions primarily by comparing responses to the same questions, and data that answers those questions, among supply chain actors.

3.5 Unit of analysis

The units of measurement of interest across these two case studies are the capacity of firms to abide by a contractual obligation—whether that be a manufacturing schedule or handling requirement—and the price or cost per kilogram of meeting that obligation. Having roughly consistent units of measurement across both case studies allows for the unit of analysis—the design of the procurement and the supply chain design insights from it—to be grounded in common empirical terms (Yin 2003). Across both case studies and in Section 8 both procurements are presented to illustrate the challenges of different procurement methods — field-based, headquarter-based — and designs — organization-designed, researcher-designed.

4. Famine and food aid

4.1 Introduction

Famine relief and food aid is a millennia-old issue, and yet still today 800 million people do not have enough food to lead an "active and healthy lifestyle," and famines continue to break out every few years (FAO 2015). Food aid has become a solution to food insecurity and famine. Food aid is a multibillion-dollar endeavor, led principally by rich donor countries and motivated by a mix of humanitarian, domestic, and geopolitical interests (Barrett and Maxwell 2005). Barrett and Maxwell (2005) break food aid into two areas: targeting and procurement. This thesis uses one case study of local and regional procurement and one case study of transoceanic procurement. The section on local and regional procurement uses a case study of on-farm crop quality from Uganda, and the section on transoceanic procurement uses a case study of food aid quality in supply chains that pass through the Horn of Africa and Southern Africa.

4.2 History of famine and food insecurity

The issue of famine and starvation has biblical roots. In the Book of Genesis (Genesis 41), the Pharaoh of Egypt has a dream in which he was standing by the Nile when seven fat cows emerged from the river, after which seven lean, ugly, and gaunt cows emerged from the river and ate the fat ones. He dreams the same thing about seven heads of good and bad grain. Pharaoh sends for Joseph who interpreted the dream: the seven good cows and heads of grain were to represent seven good years of harvests, and the seven bad cows and heads of grain were to represent seven years of famine. Joseph recommends Pharaoh appoint commissioners over the land to take a fifth of the harvest in every good year, and hold it in reserve for the bad years.[3] When the famine spread over the country, after having stored crops for seven years, all of the grain storehouses are opened and grain is sold grain to the Egyptians. Eventually, people came from all over the world to buy grain.

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[3] See, *The Daily Show*, Comedy Central. 9 November 2015. Television.
http://www.cc.com/full-episodes/fd06ks/the-daily-show-with-trevor-noah-november-9--2015---pras-season-21-ep-21021 at 5:30.
A presidential contender discusses the use of pyramids to store crop—and in particular, to store crop in an airtight fashion.

Famine persists from the story of Joseph, to the Romans (c.a. 436 BC), Kashmir (c.a. 918 AD), China (c.a. 1333 AD), Indian (c.a. 1770 AD), and Ireland (c.a. 1845-51) (Sen 1981). The Irish potato famine is often cited, having killed close to one-fifth of the total Irish population and having lead to the emigration of about one-fifth as well (Sen 1981).

In recent history, the Horn of Africa and the Sahel have been vulnerable to famine. In the Horn of Africa, Ethiopia experienced famines in 1958, 1966, 1973, and 1984, the latter of which spurred the song "We are the World" and 'the CNN effect', after correspondents gave reports from Western Ethiopia that were broadcast on network evening news shows (Philo 1993). Somalia, which is adjacent to Ethiopia, also experienced famine in 1991-1992 and more recently in 2011. In 1991-1992 in Somalia, Operation Provide Relief, the humanitarian counterpart to the militarized Operation Restore Hope, began delivering food aid for a famine that had already developed. In the Sahel, famine emerged 1968-1972 and again more recently in 2010. By the 1970s, Africa had become the primary destination of global food aid (Barrett and Maxwell 2005). Other famines have occurred in Bangladesh (1974), Cambodia (1975-1976), and intermittently in North Korea.

Today, just short of 800 million people or about one in nine of the world's population do not have enough food to lead an "active and healthy lifestyle" (FAO 2015). As a percentage of population, Sub-Saharan Africa has the highest prevalence of hunger – about one in four people in Sub-Saharan Africa are undernourished (FAO 2015). Globally there are 66 million hungry school-age children, who could be fed with about $3.2 billion per year (FAO 2015). Food insecurity is also closely linked with conflict and displacement: globally 59.9 million people are displaced, the largest number since international organizations have begun keeping track, making one in every 122 people a refugee, internally displaced, or seeking asylum (UNHCR 2015). The conflicts in the Democratic Republic of Congo, Central African Republic, Iraq, Syria, Afghanistan, Yemen, and Libya have contributed to the number of people in need of food aid.

4.3 Frameworks of famine and starvation

How academics and practitioners continue to conceptualize this hunger varies, but the work of Amartya Sen has anchored conceptions of hunger for more than three decades.

Amartya Sen's landmark book *Poverty and Famines* (1981) outlines a framework of starvation and famine that applies to today's instances of food insecurity and famine.

Published in the wake of the famine-dominated 1970s, Sen frames the issue of famine in terms of "the ability of people to command food," and, specifically, starvation as the *in*ability to command food. Sen envisions each individual in society as having (1) an endowment or "ownership bundle" and (2) an ability to command food or "an exchange entitlement mapping." An ownership bundle might include hours of labor, land, and some assets; an exchange entitlement mapping might be the amount of a certain commodity bundle an individual can get in exchange for those hours of labor. Thus in some cases, an individual will be forced to starve if and only if their endowment and exchange entitlement mapping do not entitle them to a minimum food requirement.[4] Sen writes this is an "entitlement failure." Sen's analysis still serves as a paradigm with which to view starvation and famine, and current famine relief efforts—both food or cash transfers—continue to fit into his framework.[5]

Figure 1: Food Aid Stocked at Texas Warehouse

4.4 Targeting and procurement in famine response

Barrett and Maxwell (2005) divide the food aid process into two components: targeting and procurement. Targeting refers to providing appropriate food aid to appropriate populations over appropriate time-frames, while

[4] This can be thought of as about 1,400 calories, though the WFP estimates a person needs on the order of 2,400 to live active and healthy lifestyles.
[5] It is worth contrasting Sen's framework of famine and starvation to that of Malthus. Malthus in an *Essay on the Principle of Population* (1798) focused on the human population's capacity to grow geometrically, and that with that population growth the marginal individual would have ever diminishing resources on which to live.

procurement refers to the sourcing, transportation, and distribution processes required to move food aid 'from the farm to the village'. In the past two decades procurement has been reexamined, as the 'farm' is increasingly in Africa or Southeast Asia instead of places like West Texas, Kansas, or Sweden (Lentz *et al.* 2013, Garg *et al.* 2013, Lentz *et al.* 2013b).

Barrett and Maxwell (2005) write there are three principle reasons to deliver well-targeted food aid to a population: short-term humanitarian assistance if and only if there is a problem of food availability; provision of a longer-term safety net to protect productive assets; and asset rebuilding among poor, food-insecure populations where other resources are scarce. Within food aid programming, there are three genres of aid: program food aid, which is foreign aid in the form of food; project food aid, such as school feeding or food for work programs; and emergency food aid, which is to provide short-term relief. From 1992 to about 2001 Food for Peace allocations were about evenly split between emergency food aid project or program food aid, with project food aid accounting for few allocations; since 2001 emergency programming has increase to be about 75% of allocations (CRS 2014). Barrett and Maxwell (2005) summarize this emergency food aid, "The humanitarian objective of food aid is to make a big difference at the margin in brief periods in localized situations." This thesis focuses predominantly on the procurement of emergency food aid, but insights apply to program and project food aid as well.

Barrett and Maxwell (2005) effectively divide food aid procurement into two supply chains: local and regional procurement (e.g. triangular transactions) and transoceanic procurement. Local and regional procurement (LRP) is the process by which a multilateral organization (e.g. the United Nations World Food Programme (WFP)) or non-governmental organization (NGO) (e.g. Catholic Relief Services, Save the Children) procures food aid from within the country being targeted to receive food aid or from a country in the region. One LRP mechanism is a triangular transaction, in which one country reimburses another country in excess (i.e. compensates plus a margin) for sending food aid to a third country. Transoceanic procurement is the process by which the same organizations rely on food aid from rich donor countries, typically across an ocean from the country being targeted to receive food aid. When local food markets are assessed to be functioning in an area targeted to receive food aid, cash programming—in which organizations transfer cash to recipients—is used. This thesis focuses on local and regional procurement and transoceanic procurement supply chains.

Figure 2: Notional TP and LRP Supply Chains

(to Ethiopia via Djibouti, with LRP sourcing in Uganda and TP sourcing in the US)

4.5 Transoceanic procurement

In response to famines and domestic harvest surpluses, the United States and—later—the European Union, European Union member states, Canada, and Japan began famine relief programs. In the United States, the Food for Peace Act of 1954 (i.e. Public Law 480 or P.L. 480) was enacted to create a secondary market for crop surpluses, and eventually led to the creation of the Office of Food for Peace (FFP). Commodity prices had fallen in the years after the Korean War (Barrett and Maxwell 2005). By the early 1960s, P.L. 480 accounted for more than half of US food exports and most of the US total overseas aid budget (Barrett and Maxwell 2005).

The humanitarian focus of FFP expanded with Public Law 89-808 in 1966 so that the "US might lead the world on the war against hunger" (Johnson 1966). In other words, the Food for Peace Act was recast as development assistance instead of surplus control (Barrett and Maxwell 2005). By 1971 food aid was about 14% of overseas development assistance (Barrett and Maxwell 2005). Until the 1980s, most food aid came from government surplus stocks that were filled with commodities purchased in order to provide a market floor (Barrett and Maxwell 2005). The 1990 farm bill reorganized FFP, changing the purpose of P.L. 480 to be the reduction of food insecurity worldwide instead of surplus support; Barrett and Maxwell (2005) observe that there is no evidence that food aid has had any impact on domestic farm prices in the 25 years preceding 2005 (Barrett and Maxwell 2005). Similar in-kind donation programs emerged out of the EU, Canada, and Japan, and various states have wrestled with the triple-bottom-line of an in-kind food aid program: supporting domestic farming, advancing geopolitical interests, and providing humanitarian relief.

4.6 Transoceanic procurement: the American case

Beginning with P.L. 480 and continuing with P.L. 89-808, transoceanic procurement has long been a staple of American humanitarian relief. FFP is currently implemented by the United States Agency for International Development (USAID), and the United States Department of Agriculture (USDA) is responsible for commodity procurement (CRS 2014). Annual spending on international food aid programs was about \$2.5 billion over the FY 2006 - FY 2013 period (CRS 2014). Of the four main American food aid programs, Food for Peace (e.g. "Title II food aid") receives about 80% of the annual funding. Between 2000 and 2010 the Title II program became the primary source of US food aid shipments. In FY 2010, 2.1 million metric tons of FFP aid reached over 55 million people in 46 countries (USAID 2013). In the FY 2016 budget proposal, USAID requested about \$1.4 billion for FFP's Title II emergency

Figure 3: Food Aid is Often Procured from Suppliers with Plants in Small Midwestern Towns

and non-emergency food aid, asking for 75% (i.e. $1.05 billion) for traditional transoceanic food aid (USAID 2016). This thesis focuses on the transoceanic supply chains of FFP's Title II program.

FFP primarily sends commodities like sorghum and wheat in bulk via transoceanic procurement. In FY 2014 sorghum and wheat were the two largest Title II commodities by volume shipped, by an order of magnitude. Sorghum accounted for 51% of all shipments and wheat accounted for 23% of all shipments in Q1 2016 according to USAID data. Non-cereal commodities have increase "modestly" since the Food Aid Convention of 1999; in 2002 coarse grains were about 50-60% of commodities sent, with blended foods, rice, wheat and wheat flour making "modest upticks" since the 1970s (Barrett and Maxwell 2005).

In some industries, between 1980 and 2000, US food aid exports became quite large relative to commercial exports. For example, in some years 15% of rice exports or 12.1% of wheat exports have been food aid; the nonfat dry milk powder aid has commanded similar market shares (Barrett and Maxwell 2005). Firms like Cargill, Louis Dreyfus, ConAgra, and ADM dominate bidding for bulk commodity contracts (Barrett and Maxwell 2005). Cargill and ADM were responsible for more than one third of all food aid shipped in FY 2013: these are firms that have economies of scale, and can provide bulk grains relatively cheaply (Barrett and Maxwell 2005). Some other agricultural sectors, such as the yellow split pea industry, have many qualified bidders and the sector as a whole is a bit more fragmented than the coarse grain and wheat industries. Overall, Barrett and Maxwell (2005) estimate an 11% premium on market prices for procurement of food aid.

Table 2: Commodities Sent (USAID Data)

Commodity (FY 2014)	**Type and Size**	**Bagged**	**Bulk**	**% of total**
Bulgur	50-KG WP	Y		<1%
Soy Fortified Bulgur	50-KG WP	Y		<1%
Wheat Flour	50-KG WP	Y		<10%
Wheat Soya Blend	25-KG MWPB	Y		<1%
Wheat*	50-KG WP	Y	Y	23%
Corn Soya Blend	25-KG MWPB	Y		<1%
Corn Soya Blend Plus	25-KG MWPB	Y		<10%
Cornmeal	25-KG MWPB	Y		<10%

Corn	50-KG WP	Y	Y	<1%
Sorghum**	50-KG WP	Y	Y	51%
Soy Fortified Cornmeal	25-KG MWPB	Y		<1%
Beans	50-KG WP	Y		<1%
Peas	50-KG WP	Y		<10%
Lentils	50-KG WP	Y		<10%
Rice**	50-KG WP	Y	Y	<10%

50-KG WP: Woven Polypropylene *: All varieties/shipment methods
25-KG MWPB: Multiwall paper bag **: All shipment methods

A greater variety of commodities are shipped in packages than in bulk: the commodities shipped in bulk are those for which American ports and industry have capital-intensive bulk handling infrastructure, such as rice, sorghum, and wheat. Bagged commodities include beans, bulgur, cornmeal, corn-soy blends, flours, lentils and peas, oil, as well as the commodities sent in bulk: rice, sorghum, and wheat. For comparison, Table **3** lists prices of shipping commodities in bulk and in packages. The large-scale food processors have "consistently pressed for increased levels of procurement of [bagged], processed, or fortified commodities in US food aid programs" – in contrast to large agricultural interests, which have favored bulk commodity purchases, which more directly benefit farmers (Barrett and Maxwell 2005).

Table 3: Cost of Bulk and Bagged Shipping (USAID Data)

Commodity	**Shipping Type (Q1 2016)**	**Commodity Price Estimates USD/MT**
Soft white wheat	Bulk	221
	Bagged	375
Sorghum	Bulk	196
	Bagged	300

The cost of bulk or bagged shipping food aid varies by destination. West Africa is consistently the most expensive destination for both bagged and bulk ocean shipping. Wheat, sorghum, and corn are always cheaper to send in bulk. It can be cheaper to send bagged than bulk aid to destinations like Southeast Africa and Southeast Asia; this is primarily a function of the common nature of the trade route and the infrastructure in place at the receiving port.

Table 4: Cost of Various Shipping Routes (USAID Data)

Trade Route (Q1 2016)	Bagged Shipping Price Estimate USD/MT	Bulk Shipping Price Estimate USD/MT
Central America & Caribbean	164	150
West Africa	320	225
South East Africa	182	200
Red Sea	230	155
South East Asia	146	165

Bagged food aid can actually be further bifurcated into containerized or break-bulk ocean shipping: while most ocean cargo is now containerized, some food aid still goes by way of break-bulk carriers. Cargo preference laws determine how food aid is shipped, and at what price it is shipped. For example, for about thirty years after establishing P.L. 480, cargo preference restrictions required that at least half of the gross tonnage be on privately owned US-flagged commercial vessels (Barrett and Maxwell 2005). The US-flagged, privately owned break-bulk fleet enjoys these preference laws. Barrett and Maxwell (2005) estimate that it costs an extra $200 million a year to ship on US-flagged, privately owned vessels – and that in between 1991-1993 a weighted average premium of 68% was observed for shipping services. Today, cargo preference laws account for only about 5-15% in total of US-flagged ships' cargo by volume (Barrett and Maxwell 2005).

4.7 Local and regional procurement

In 1984, the European Community procured 10,000 MT of white maize from Malawi for distribution in Tanzania. The first shipment did not arrive in Tanzania until March of 1986, well after it should have. The year-long was the first hint of the complexity of local and regional procurement. Barrett and Maxwell (2005) note that contractual enforcement issues, processing and transport capacity, and substandard quality and sanitary regulations can all impede local and regional procurement. The World Food Programme's local and regional smallholder procurement mechanism, Purchase for Progress, began out of early procurement experiments in the 1990s, and was formally begun in 2008 (WFP 2011).

As markets continued to develop, a 1996 regulation by the European Commission heralded the growth of local and regional procurement as an overall share of food aid procurement (Lentz *et al.* 2013, European Community 1996). A study of the impact of the regulation found that local purchases could reduce transportation costs and delivery times (European Community 1996). Almost a decade later, in the United States, the 2008 farm bill authorized a $60 million pilot project to explore local and regional procurement, specifically authorizing funding for two years of $25 million procurements (see 7 United States Code 1726c). By 2010, the World Food Programme procured over 2.6 million MT of food valued over $975 million dollars – the United States, as a point of comparison, procures roughly 1-2 million MT per year (WFP 2010, Lentz *et al.* 2013). As of 2010, only 3% or 92,000 MT of all World Food Programme local and regional procurements, which totaled 2.7 million MTs, were from smallholder farmers through their Purchase for Progress mechanism (WFP 2011). The vast remainder of procurements were local and regional purchases from institutional sellers (e.g. national grain reserves). As of 2016, almost all of the food aid donated by Sweden, Netherlands, and Germany, and about three quarters of the food aid donated by Switzerland, the UK, and Norway, comes in the form of local purchases or triangular transactions (Barrett and Maxwell 2005). In the FY 2016 budget proposal, Food for Peace requested that 25% of the requested $1.4 billion be available for flexible interventions such as LRP (USAID 2016).

Initial cost-effectiveness studies validated the European Commission finding. In particular, Tschirley and del Castillo (2007) compared World Food Programme LRP costs in Zambia, Kenya, and Uganda to American transoceanic procurement costs for 2001-2005 (Tschirley and del Castillo 2007). They found that LRP costs were 57% of transoceanic procurement costs. A comprehensive cost-effectiveness and time-savings study had not been completed until Lentz *et al.* (2013). Using data from nine countries, they found time-savings of about 14 weeks, and cost-effectiveness savings of LRP over 50% compared to transoceanic procurement. However, they did find that processed commodities—which are among the most expensive commodities sourced from the United States—were sometimes more expensive in developing countries (e.g. LRP of corn soy blend costs 26% more compared to transoceanic procurement). Lentz *et al.* (2013) summarize the cost trade-offs between LRP and transoceanic procurement showing weighted average ton per commodity type, combining internal transport, shipment and handling (ITSH), and commodity costs.

Table 5: Procurement Costs taken ***directly*** from Lentz *et al.* (2013)

	Ocean USD/MT	ITSH USD/MT	Commodity USD/MT	Total USD/MT
Transoceanic				
Processed products	212.66	151.28	1145.90	1509.84
Pulses	221.61	141.32	705.93	1068.85
Cereals	227.68	182.96	384.34	794.97
LRP				
Processed products	NA			1636.14
Pulses	NA			809.78
Cereals	NA			362.56

5. Quality issues in food aid

5.1 Section Introduction

One family of toxins produced by fungi and a few prolific insects motivate the policy component and the secondary research question of this thesis. Fungi growth in stored products is an issue with tremendous, direct human health implications; Western and African countries both set standards for maximum allowable concentrations for one particularly damaging family of toxins that are a byproduct of fungi growth. Insect infestation also impacts human health by degrading the nutrient quality of stored products; Western and African countries similarly set standards for insect-damaged commodities. Local and regional procurement and transoceanic procurement share the issue of fungi growth and insect infestation in food aid. In transoceanic supply chains, fumigation occurs to control fungi growth and insect infestation. However, when fumigants are applied incorrectly—as often happens in developing countries—or insufficiently applied, loss as well as impacts on human health can occur (USAID 2013). Even with fumigation, losses occur. There is a need for new food aid packaging and storage options to prevent fungi growth and insect infestation, to decrease the amount of food loss, and thus to increase the total volume of food in food aid supply chains.

5.2 Fungi and toxins, and fungi and toxin regulation

Just as famine has a long history of impacting the human condition, the effect of fungi has a long-documented impact on human and crop health. In 600s and 700s BC, the annual late-April festival of "Robigalia" was held to curry favor with the god Robigus and protect grain from "rust" and "mildew" (Peraica *et al.* 1999, Van Dongen and De

Groot 1995). In the 1970's outbreaks of fungi-related toxin contamination of grain affected 140 and 78 people in Ethiopia and India, respectively (Peraica *et al.* 1999). Some fungi, like Ergot, have been effectively mitigated by grain cleaning procedures.

Fungi lead primarily to quality losses in commodities. Quality losses are typically measured in terms of the byproducts of fungi. Of particular concern are mycotoxicoses, a class of toxins produced by some fungi. These toxins appear—in developed and developing countries, Peraica *et al.* (1999) emphasize—when temperature and humidity support the growth of certain fungi. Like Ergot, some mycotoxicoses have disappeared from the food supply after better food hygiene measures (e.g. throwing out fungus-contaminated rice) (Peraica *et al.* 1999). Aflatoxins, a type of mycotoxicoses, however are still prevalent in nuts, cereals, and rice under conditions of high humidity and temperature and are acutely toxic, immunosuppressant, mutagenic, teratogenic, and carcinogenic compounds (Peraica *et al.* 1999). Connections between aflatoxin presence and kwashiorkor syndrome have been explored (de Vires *et al.* 1990, Hendrickse *et al.* 1982). Shepard (2003) notes that research in various West African countries including Ghana, Nigeria, and the Gambia has focused on aflatoxin contamination in staple foods such as maize and groundnuts. Another type of mycotoxicoses called fumonisins appear under similar conditions to aflatoxins, and also have human health implications (Dutton 1996). It has also been shown that fungi can even lead to quantity losses (Lazzari 1998).

The regulations that determine acceptable levels of mycotoxicoses contamination vary from country to country. As of 2003 global limits for aflatoxin B_1 contamination varied: 21 countries permitted 5 micrograms per kilogram and 29 countries permitted 2 micrograms per kilogram. At the extremes, 10 countries permitted more than 5 micrograms per kilogram and one country permitted 1 microgram per kilogram (FAO 2003). There are also collective limits for aflatoxin variants B_1, B_2, G_1, and G_2: of the 76 countries that propose collective limits for aflatoxin, 17 countries propose 20 micrograms per kilogram and 29 countries propose 4 micrograms per kilogram (FAO 2003). The European Union set their total limit at 4 micrograms per kilogram, while the United States set its limit at 20 micrograms per kilogram (FAO 2003). In Africa, the range for mycotoxicoses limits was 10 micrograms per kilogram at the lowest and 20 micrograms per kilogram at the largest, though the median was about 10 micrograms per kilogram (i.e. a few outliers were at 20 micrograms per kilogram) (FAO 2003). In Africa, a total of fifteen countries (covering about 59% of the continent's population) had aflatoxin regulations (FAO 2003).

5.3 Insects and insect damage regulation

While fungi lead primarily to quality losses in commodities, insects (and other pests) also degrade grain leading to quality and quantity losses. These losses also have human health implications, by way of the consumption of less and less nutritious crop. Quantity losses can be thought of as dry weight losses, which can result from prolonged exposure to insects as well as birds, rodents, or bag leakage (FAO 1994). For example, a sample that has experienced quantity loss due to insects will produce less meal if ground than a sample that has not. Of course leakage of products, in the case of a perforated bag, can lead to insect, bird, and rodent losses as well as quantity losses during transportation (FAO 1994). Quality losses can be defined as nutritional losses—reductions in fiber, protein, and fat content (FAO 1994). Affognon *et al.* (2015), in a meta-analysis published in World Development, failed to find conclusive empirical evidence on the nutritional degradation of crops that experience infestation in the six countries that they analyzed. Other studies looking at the relationship between infestation and nutritional quality have found evidence that nutritional content of crop degrades with insect infestation (Ojimelukwe *et al.* 1999). Crude protein, fiber, lipid and vitamin counts can decrease (Reddy and Pushpamma 1986, Cook 1990). For example, one study by a Ugandan university found that crude protein, fiber, and lipid counts decreased severely with weevil infestation and less severely with fungus infestation (Matovu and Okello 2010). Of note, the crude protein content of the control sample was about 11% and that of the weevil treated sample was about 8%, which was a significant difference. Of even more significance, the percentages of crude fiber was about 22% in the control sample, 4% in the weevil treatment sample, and 6% in the fungi treatment sample; the percentages of crude lipid was again 22% in the control sample, 2% in the weevil treatment sample, and 3% in the fungi treatment sample.

The insects that infect crops in the United States vary somewhat from those that infect crops in Africa, though some insects are ubiquitous. The US Department of Agriculture identifies five primary insects that cause the most damage to crop in storage and shipment in the United States: the granary weevil, the rice weevil, the maize weevil, the lesser grain borer, and the Angoumois grain moth (USDA 1986). With the exception of the lesser grain borer, the larva of the insects live entirely within the kernel. In Africa insects like the larger grain borer, lesser grain borer, maize weevil, cowpea weevil, and the Indian meal moth pose challenges (FAO 1996).

The regulations on insect damage and presence in crop vary country by country, like regulations surrounding fungi contamination. In the United States, 22 Code of Federal Regulations 110 allows the Food and Drug Administration (FDA) to set defect action levels, or acceptable levels of contaminants in food (USDA 1995). Exceeding a defect action level makes a food "adulterated and unfit for human consumption" (see Food, Drug, and Cosmetics Act Section 402(a)(3)). For example, in cornmeal the FDA allows for an average of 1 or more whole insects per 50 grams, an average of 25 or more insect fragments per 25 grams, and 1 or more rodent hairs per 25 grams or 1 or more rodent excreta fragment per 50 grams. Similarly, the handbook sets maximum defect action levels for wheat (e.g. an average of 32 or more insect-damaged kernels per 100 grams) and wheat flour. Food aid leaving the United States must adhere to these defect action levels. In Uganda, for example, where much of the crop is traded on informal markets, regulation can have little impact on what is actually traded, but there are insect damage and presence regulations: grades 1, 2 and 3, may have 1%, 3%, and 5% respectively of insect damage (UBOS 2015). (Damage is generally defined as a certain percentage of insects or broken kernels per lot.)

5.4 Food aid and quality challenges

Barrett and Maxwell (2005) observe that quality control can be a significant issue in both local and regional procurement as well as transoceanic procurement.

> "[We were] unable to find any systematic statistics on food aid spoilage. But few practitioners doubt that spoilage rates of food procured in donor countries and shipped internationally are less than the equivalent rates for food procured in recipient countries."

The issues of fungi growth and insect infestation apply across both local and regional procurement and transoceanic procurement.

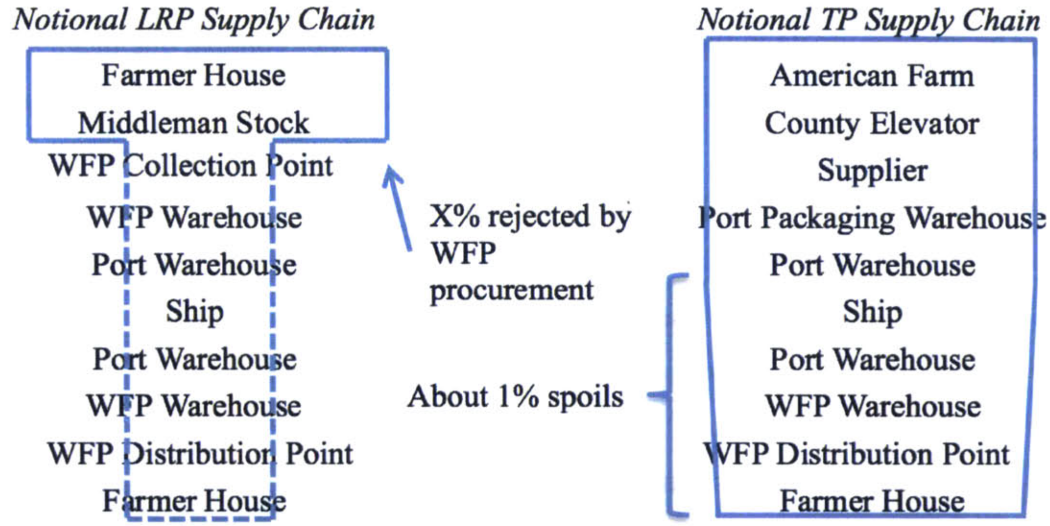
In the instance of local and regional procurement, quality control can be thought of as a two-stage challenge: controlling quality on the farm, and then controlling quality while in the procurer's network of warehouses and distribution centers. If on-farm quality dips below given criteria (i.e. those set by a procurement protocol, often based on national quality standards), the local and regional procurement process is moot: the procurer cannot buy crop and even begin to attempt to manage it through its network of warehouses and distribution centers. For example, in Uganda, interviews with the World Food Programe Country Office estimated that they reject about 60% of the crop brought to their local procurement mechanism—Purchase for Progress (P4P)—because it fails quality standards. In Uganda, these quality standards are the East African Community Standards, to which Uganda, the other member states of the East African Community, and international organizations and non-governmental organizations operating in-country adhere. This thesis focuses on the challenge of controlling and improving on-farm quality.

In the instance of transoceanic food aid, quality control can also be thought of as a two-stage challenge: there is the upstream challenge of controlling the quality of the food aid while in the care and custody of USAID ocean shipping contract awardees (e.g. freight forwarders and ocean shipping lines) or USDA commodity supplier contract awardees (e.g. commodity suppliers, American inland handling contractors), and the downstream challenge of controlling the quality of the food aid once in the custody of a PVO. As Barrett and Maxwell (2005) note, there are not readily available statistics on upstream or downstream loss in transoceanic food aid supply chains. This thesis focuses on the challenge of controlling and improving upstream quality, noting that processes that apply to upstream quality control certainly apply to downstream quality control.

In both food aid supply chains, certain handling practices as well as fumigation are used to control fungi growth and insect infestation. Phosphine-based fumigants, which are used in both supply chains primarily to control insect infestation, have also been shown to slow the growth of the primary mycotoxicoses strain of concern (i.e. aflatoxin) (Leitao *et al.* 1987). The application of phosphine-based fumigant has been shown to successfully control aflatoxin growth over longer fumigation periods if commodity is of lower water activities, and in higher concentrations if commodity is of higher moisture content (de Castro *et al.* 2001). In addition to phosphine-based fumigation, appropriate drying, storage, and transport methods can also be used to prophylactically prevent some fungi growth (i.e. maize should be kept at a moisture content below 13.5%).

Figure 4: Notional Supply Chains with Quality Issues

100% enters pipeline: in LRP about (100-X)% emerges while in TP 99% emerges



5.5 Quality issues in transoceanic food aid

The issue of loss in transoceanic supply chains can be framed in terms of MT procured under the commodity contract and shipped under the ocean shipping contract, but discarded before arriving at a beneficiary community. As Barrett and Maxwell (2005) noted, reliable estimates of loss in transoceanic procurement (or regional procurement, for that matter) are scant. Many insights into loss are anecdotal: a shipment (e.g. 1000 MT) of grain docked off the Port of Sudan gets infested; commodity in containers (c.a. 18.5 MT/container) waiting to be unloaded in Djibouti is damaged by water; "a shipment" (e.g. 100 MT) of wheat flour gets infested. Additionally, loss can be defined differently: there might be some estimates due to infestation, others from exceeding fungi criteria, and some that consider both.

This thesis estimates annual loss in transoceanic supply chains based on USAID's recent Programmatic Environmental Assessment (PEA) of phosphine fumigation in food aid supply chains. The PEA summarizes, "Even with fumigation, USDA and FFP partners have had to destroy many hundreds of mega tons of commodity in recent times due to infestation, although these losses were estimated at 1% or less" (USAID 2013). This estimate acknowledges the contradictory nature of that statement, as if to say it is not possible that loss estimates could be that low given such high rates of destroying commodities. However, while the estimate of 1% or less might be problematic as it is intuitively somewhat low, the estimate of "many hundreds of mega tons" is equally problematic and far too high.

The upper estimate in the PEA verges on infeasible. For context, one mega ton equals on million MT, and a recent USDA document estimates that P.L. 480 and other food assistance instruments (e.g. Bill Emerson Trust Fund) have been responsible for the distribution of 375 million MT of commodities (USDA 2016).[6] Thus, by the estimate given in the PEA, USAID/USDA might have destroyed due to loss about as much as they have shipped since P.L. 480 was enacted. In other words, this could be a loss rate of up to even above 100%. For further context, a loss rate of 1%, when applied to an estimated, liberal FFP tonnage of about 2 million MT, would result in about 20,000 MT per year of loss. Scaling this annual loss amount by about 50 years, a rough approximate of the years for which FFP activities have been authorized, a total loss estimate would be about 1 million MT. Applying a 1% loss rate to all P.L. 480 activities, of which FFP is a subset, would result in an estimate of 3.75 million MT of loss.

Thus the PEA estimates total losses between a value on the order of "many hundreds" of million MT "in recent years" and a value on the order of 1-3.75 million MT based on an annual rate of 1% loss since P.L. 480 was enacted. This thesis errs towards using the lower estimate of the PEA as the foundation for further analysis, as the lower estimate is based on a loss rate—just in terms of order of magnitude—that is similar to loss rates found in literature (Affognon *et al.* 20150). A recent BBC report on public sector food supply chains in India observed a loss rate of 0.5%, which loosely lines up with USAID's lower estimate (BBC 2015).

To gain more intuition about the scale of issue, this lower estimate can be reframed in terms of individuals. For example, in 2010 in Uganda the volume of food supply quantity

[6] It is worth noting that in the past decade some of these MT are beginning to be procured locally under local and regional procurement arrangements, but that is a relatively recent phenomena.

(cereals excluding beer) was 64 kg per person and in Ethiopia was 149 kg per person (FAOSTAT). Taking Ethiopia as an illustrative and conservative example, had the 20,000 MT lost to spoilage been all cereal and Ethiopia been in a year-long state of famine requiring food assistance, it would have been possible to feed about 13,000 Ethiopians their annual cereal intake that year with commodity lost to spoilage.[7] To further give context to the scale of famine and food relief, between 2010 and 2012 nearly 260,000 people died in the Somalia famine (BBC 2013).

5.6 Health issues due to fumigation

An issue associated with loss is the impact of fumigation on human health. Repeated fumigation of commodities is key to minimizing losses. Fungi growth and insect infestation tend to be well controlled in the United States with appropriate handling and fumigation; fumigation is a common and often required practice in waypoint and beneficiary countries such as Djibouti and Ethiopia, respectively.

A series of domestic laws govern USAID's responsibilities in the case of fumigation. The National Environmental Policy Act (NEPA) of 1970 regulates the process by which fumigants are applied in program activities and their impacts weighed (USAID 2011, USAID 2013). All USAID project activities are assessed through an Initial Environmental Examination (IEE), and any activities requiring fumigants are assessed through a Pesticide Evaluation Report and Safe Use Action Plan (PERSUAP) (USAID 2013). Even so, there is concern whether the IEE and PERSUAP are "adequately rigorous" (USAID 2013). The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) regulates pesticides to protect applicators, consumers, and the environment, and gives the US Environmental Protection Agency (USEPA) authority to regulate the procurement and application of pesticides. An Environmental Assessment (EA) is required when an activity includes "procurement or use" of a fumigant like phosphine that is registered by the EPA as a Restricted Use Pesticide (RUP) (see 22 Code of Federal Regulations 216.3(b)(i)). Until the publication of a Programmatic EA (PEA) by USAID

[7] The population of Uganda was about 34 million people in 2010 and Ethiopia was about 87 million people in 2010; FAOSTAT estimated that about 2.17 million MT were consumed as non-beer cereals in 2010 in Uganda, and 12.96 million MT in 2010 in Ethiopia.

in 2013, the EAs submitted by PVOs may have neither fully captured the environmental effects of fumigation nor demonstrated adequate mitigation measures (USAID 2013).

Phosphine-based fumigation has human health as well as environmental impacts. Phosphine-based fumigation can impact the health of warehouse and port workers, residents near warehouses and ports, and animals native to air- and watersheds, and minimally impact local ambient air and water quality (USAID 2013). In particular, over-fumigation or improper fumigation can also expose beneficiaries to residual fumigants (USAID 2013). The 2013 PEA delivered several recommendations to ensure FFP activities and future EAs are compliant with existing USAID environmental guidelines including:

- Disposal of spent phosphine residues must be given careful consideration. Spent residues can still contain 3-5% phosphine. Partner Voluntary Organizations (PVOs) or PVO implementing partners must have the sophistication to handle and dispose of spent residues.
- Nearby residents must be notified by the PVO prior to conducting fumigation. International best practices and those used by the World Food Programme (WFP), such as locating fumigation areas 100m from human habitation, should be used (see FAO 1969).
- A PVO must ensure that spraying be done in accordance with USAID's Pesticide Procedures that require (1) a PERUSAP is approved and (2) fumigants are used in an "environmentally sound manner."

These recommendations address the human health and environmental challenges of fumigation. However, their effect is heavily dependent on the PVO's faithful implementation. The PEA even notes that recommendations like these are "not necessarily applicable for practical use in host countries because of logistically difficult conditions" (USAID 2013). In practice PVOs may not have the capacity to implement these recommendations. As such, it is possible that more rigorous USAID guidelines and EAs may not mitigate the environmental effects of fumigation. In the worst-case scenario, more onerous guidelines and reporting requirements will increase the cost of delivering food aid without decreasing the impact of fumigation on human health. Thus new food aid packaging options, which can avoid or reduce the need for fumigation, can impact human health.

5.7 Quality issues in local and regional procurement food aid

For local and regional procurement, this thesis studies quality issues in the upstream, pre-procurement portion of local and regional procurement supply chains, which is dominated by smallholder farmers and middlemen who face quality loss that *a priori* excludes them and their crops from local and regional procurement mechanisms. In other words, this section considers the many MTs that were never procured because of insufficient quality.[8] As there is only little research on this issue, this section summarizes research on quality issues in downstream, post-procurement supply chains to gain context.

Through 2013 the quality of food aid in downstream local and regional procurement supply chains had not been thoroughly assessed. Barrett and Maxwell (2005) generally note that quality and sanitary standards can prove to be "substandard" in LRP source countries. A 2009 Government Accountability Office (GAO) report notes, "Evidence has yet to be systematically collected on LRP's adherence to quality standards and product specifications, which ensure food safety and nutritional content" (GAO 2009).

Harou *et al.* (2013) provide a first study of quality in downstream local and regional procurement supply chains, focusing on Burkina Faso and Guatemala (Harou *et al.* 2013). In Burkina Faso quality of local and regional procurement commodities matched or surpassed the transoceanic commodities.[9] They also found no significant difference between commodities from local and regional procurement and transoceanic procurement in Gautama.[10] This indicates that the commodities that enter and pass through the local and regional procurement supply chain remain of good quality (or that local and regional procurement supply chains have very efficient mechanisms to dispose of commodities that spoil in the pipeline).

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[8] To be clear, maintaining quality along any food aid supply chain is a challenge. However, both the challenges of and solutions to maintaining quality along a local and regional procurement supply chain will be indirectly addressed by way of discussing the challenges and solutions to maintaining quality along a transoceanic supply chain.

[9] There were a few unexceptional instances of quality issues; there was one live insect in a millet sample, and some cowpea samples had dirt and broken beans, which were not hazardous to human health.

[10] They tested for aflatoxin contamination in a lab; 1% of the 11.8 MT of maize failed a humidity test.

The impact of quality standards on from whom local and regional procurement mechanisms buy is less studied. An analysis of commodity suppliers—both prospective and actual—to local and regional procurement mechanisms has not been undertaken, likely because of a lack of data about prospective suppliers and thus an inability to rigorously comment on the counter-factual. Understanding the counter-factual case would include studying to whom commodity suppliers sell in lieu of local and regional procurement mechanisms, perhaps anticipating not meeting quality standards or not wanting to or being unable to invest in meeting quality standards. As noted above, the suppliers of WFP—which has an extensive local and regional procurement mechanism—can be differentiated into institutional and large suppliers and smallholder farmers. Only about 3% of WFP local and regional procurements are from smallholder Purchase for Progress suppliers; the other 97% are from local and regional institutional and large suppliers. This thesis focuses on local and regional procurements from smallholder Purchase for Progress farmers, noting that improves storage methods for smallholder farmers can also apply to institutional and large suppliers.

6. World Food Programme Uganda Crop Storage Provision Case

6.1 Case introduction

Local and regional procurement, challenged by non-airtight on-farm storage, poor post-harvest handling practices, and thus poor crop quality, provides an opportunity for procurement experimentation. In Uganda in 2014-2015 the World Food Programme (WFP) ran a $1.35 million development project to provide about 16,000 farmers with airtight storage: this storage was procured from three, effectively independent, supply chain designs. Using two data sets, semi-structured and unstructured interviews, and a risk profiling method, this case study examines how analysis of procurement options reveals manufacturing and distribution capacity, and the present value price of storage to a farmer. The units of measurement are manufacturing or distribution capacity (products available according to schedule) and present value price of storage to the farmer ($/kg stored). This procurement case study illustrates the trade-offs and relationships between the reliable availability of products, the size of the firm supplying those products, and the price of those products to the farmer, and demonstrates insights to design better supply chains. In designing two new supply chain models and using one existing supply chain model, WFP gained insights into the capacities and costs intrinsic to the provision of airtight storage in Uganda. This case study is written as an *ex post* analysis of WFP's operation.

6.2 History: United Nations World Food Programme in Uganda

WFP has been operating in Uganda for decades. Uganda has a population of 38 million people, with an annual per capita GDP of $715 (WFP 2016). Uganda is a low-income developing country according to the World Bank. In Uganda, refugees and some populations in the North require food assistance. Since 2013, Uganda has absorbed nearly 180,000 South Sudanese refugees (WFP 2016). Recent refugees from Burundi and Democratic Republic of Congo have pushed the number of refugees in Uganda to about 500,000 (WFP 2016). Many of these refugees require food assistance, and WFP supports 70% of them (WFP 2016). In Uganda's northern Karamoja region, Ugandan households struggle to meet their basic nutritional needs. WFP estimates that "more than 100,000 people in Karamoja will require treatment for moderate acute malnutrition annually over the next few years" (WFP 2016). WFP operates a school-feeding program in Karamoja in 284 schools (WFP 2016). Overall, WFP aims to assist about 1.2 million people in 2016 in Uganda, the vast majority of which will benefit from food assistance programs (WFP 2016). Of note, WFP also has other substantial relief operations in the region. Between December 2015 and March 2016, they have airdropped at least 900 MT of commodities into South Sudan via the Entebbe airport (WFP 2016). WFP also has feeding operations in the Central African Republic, Democratic Republic of the Congo, and South Sudan.

Figure 5: Conventional Crop Storage Options, Taken at World Food Programme Crop Collection Point

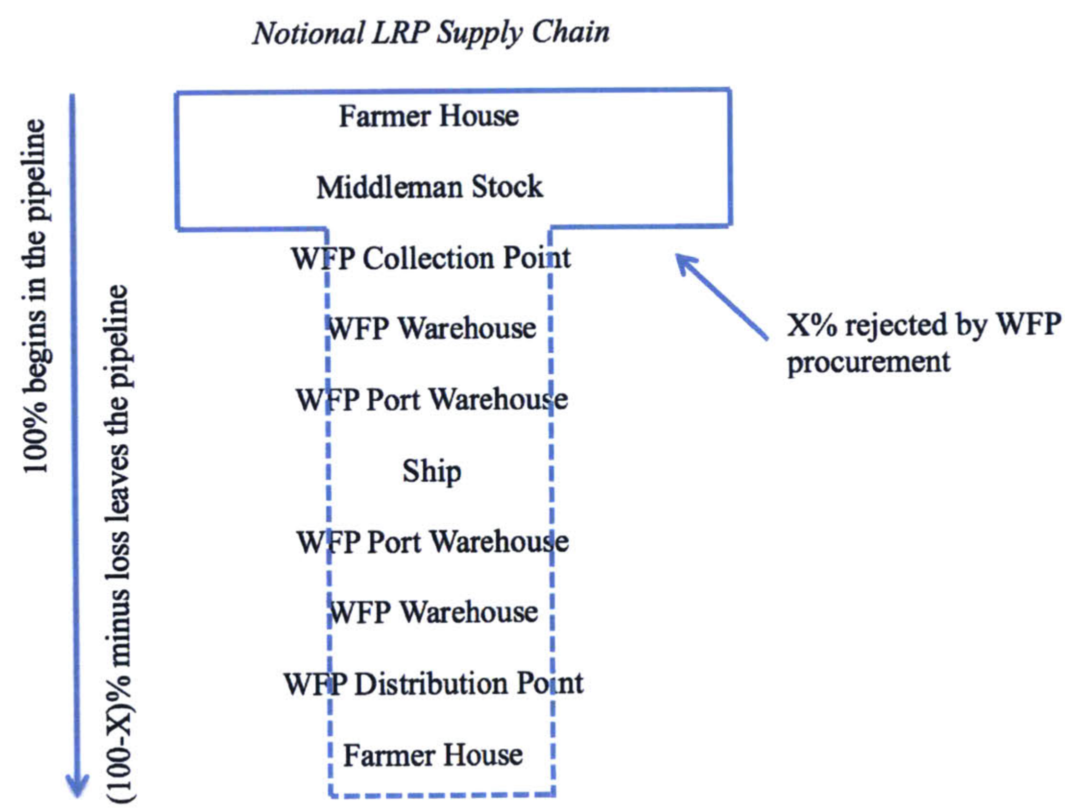
Local and regional procurement has a long history in Uganda. WFP procured over 1.2 million MT of food in Uganda between 1994 and 2007 (just under 100,000 MT each year), and launched the Agriculture and Marketing Supporting component of their Uganda Country Office in 2002 (WFP 2011). This is in part because Uganda, on the whole, tends to be an agriculturally bountiful country. In much of the country farmers enjoy two harvests instead of just one harvest because of rainfall and climatic patterns. Uganda also has a strong agricultural sector that exports raw commodities to regional markets (e.g. maize) and international markets (e.g. coffee) (WFP 2016). In 2015, WFP purchased over 55,600 MT of local food worth $20 million to support both Ugandan and regional food assistance operations (WFP 2016). Small-scale farmer groups supplied over 14% of those commodities; WFP had set a programmatic goal of sourcing at least 10% of commodities from small-scale farmer groups in 2015 (WFP 2016).

Both cost and lead time has been shown to be lower for local and regional procurement (LRP) in Uganda. Tschirley and del Castillo (2007) found that in Uganda LRP costs were 55% of transoceanic procurement costs. Both procurement costs can be thought of as the cost of purchasing the commodity and the cost of transporting the commodity. The follow data presents LRP as being cheaper and quicker than transoceanic procurement. I do not explore whether cost savings are from cheaper commodities, cheaper transportation, or both; similarly, I do not explore whether time savings are from quicker procurement processes, shorter transportation distances, or both. Lentz *et al.* (2013) found that beans/yellow peas LRP (n=1) cost $662.95 per MT while transoceanic procurement (n=1) cost $731.68 per MT. With such small sample sizes it was not possible to determine significance. Maize flour/corn meal LRP cost $457.52 per MT (n=1, with vouchers converted to beans and maize at prevailing distribution zone's market price) while transoceanic procurement cost $833.34 per MT (n=8). This was a statistically significant difference at the 1% level. Lentz *et al.* (2013) also found that LRP shipments (n=2) had lead times of five weeks while transoceanic procurement (n=14) had lead times of 20 weeks. This was a statistically significant difference at the 1% level. Additionally, they observed that in neighboring Kenya corn-soy blend LRP (n=7) cost

$800 per MT while transoceanic procurement (n=2) cost $985.02 per MT; this is likely because of relatively well-developed local manufacturing infrastructure. All of the procurements in Lentz *et al*. (2013) were for emergency programming. LRP in and around Uganda has the potential to reduce the cost and lead time of food aid.

Many studies focus on quality of crop that has been procured. Quality of crop pre-procurement (i.e. at the household or middleman level) is a separate issue. While there is scant data on it, it is not unreasonable to assume that loss in the post-procurement local and regional procurement pipeline may only be a couple percent: on par with the transoceanic food aid supply chains discussed in Section 5 and 7, or government run local and regional procurement programs in countries like India (BBC 2015). This is based on the observation from Harou *et al.* (2013) that quality issues in local and regional procurement are about the same magnitude as transoceanic procurement. However, the

Figure 6: Volume in Local and Regional Procurement Supply Chain



percent loss of crop when considering the entire local and regional procurement pipeline—from prospective or actual farmer to beneficiary—is higher than percent loss of crop in the post-procurement portion of the pipeline.

6.3 Quality and Regulation in Local and Regional Procurement in Uganda

Food quality in Uganda has posed a problem for local and regional procurement. In an interview WFP with the Uganda Country Office, respondents estimated that they reject about 60% of commodities brought to their local and regional procurement mechanism because of quality issues; this is illustrated in the notional local and regional procurement supply chain in Figure **6**. This is unsurprising as WFP notes that "post-harvest losses have been estimated to reach 40% in some [agricultural] sectors" (WFP 2016). Food loss, in terms of quality and quantity losses, is an issue in Uganda.

The frequency of local and regional procurement contract default can be seen as a proxy for supplier quality issues, and there are some default rates available for Uganda. Harou *et al.* (2013) confirms there are in fact local and regional suppliers who do not or cannot supply commodities due to issues meeting quality standards. Across countries surveyed in a WFP report on local and regional procurement, 36% of defaults from contracted suppliers were due to quality issues in Purchase for Progress pilot countries (WFP 2011).[11] The other options for default included too low a price, bulking capacity, WFP delays, side-selling, and financial weakness of FOs; quality was the largest reason for contractual default. Studying contract default rates shows a difference between large and institutional suppliers and smallholder suppliers. The WFP report found an overall *Purchase for Progress* default rate of 29% in Uganda, which was high compared to *standard* default rates of large and institutional suppliers in neighboring Kenya (2%), Mali (0%), and Guatemala (1%). There was no *standard* local and regional procurement default rate given for Uganda. However, Uganda is not an anomaly in terms of Purchase for Progress defaults: Purchase for Progress default rates in neighboring Kenya (13%), Mali (27%), and Guatemala (36%) were similar to that of Uganda. Thus I might estimate that 10% (i.e. 36% of all WFP defaults due to quality issues*29% default rate in Uganda) of all Ugandan Purchase for Progress farmers default due to quality issues in Uganda. I have a lower estimate of 10%, estimated from default data, and an upper estimate of about 60%, from an unstructured interview, for crops rejected due to quality in Uganda.

[11] Time-frame for this data was not given.

Regulation is the basis for crop rejection and is one plausible reason for the contractual defaults in Uganda: it is possible smallholder farmers default because they can not meet quality standards, or because they do not bring crop for fear of not meeting quality standards or to avoid the transaction cost of meeting quality standards. For commodity grades 1, 2 and 3, 1%, 3%, and 5% (respectively) of a lot may have insect damage according to East African Community Standards (UBOS 2016); losses can be up to 40% of a lot in Uganda according to WFP (WFP 2016). In Uganda as well as across the East African Community, the East African Community Standards set the threshold at 10 micrograms per kilogram of aflatoxin, and at 5 micrograms per kilogram of aflatoxin B_1 (UBOS 2016). Organizations like WFP adhere to local standards when doing local and regional procurement; these standards, at least for aflatoxins, are stricter than those of the United States.

Table 6: List of World Food Programme Case Interviews

R: Recorded, F: Form, N: Notes

	#/total in sector	Method	Location	Visit 1	Visit 2
Metal Silo Supply Chain Actors					
Long-Haul Transporter		Semi-structured interview	Kampala	R/F	R
		Observation		N	N
Metal Silo Manufacturer	1/6	Semi-structured interview	Gulu	R/F	R/F
		Observation		N	N
		Risk experiment		-	F
Metal Silo Manufacturer	2/6	Semi-structured interview	Jinja	R/F	R/F
		observation		N	N
		Risk experiment		-	F
Metal Silo Manufacturer	3/6	Semi-structured interview	Kampala	R/F	R/F
		Observation		N	N
		Risk experiment		-	F
Metal Silo Manufacturer	4/6	Semi-structured interview	Kampala	R/F	R/F
		Observation		N	N
		Risk experiment		-	F
Metal Silo Manufacturer	5/6	Semi-structured interview	Soroti	-	F
		Observation		-	F
		Risk experiment		-	F
Metal Silo Manufacturer	6/6	Semi-structured interview	Mbarara	-	F
		Observation		-	F
		Risk experiment		-	F
Sheet Metal Wholesaler	1/2	Semi-structured interview	Kampala	R/F	R/F
		Observation		N	N
Sheet Metal Wholesaler	2/2	Semi-structured interview	Kampala	R/F	R/F
		Observation		N	N

Program Stakeholders					
WFP Uganda		Unstructured interviews	Kampala	N	N
		Archival Data	-		-
USAID Uganda		Unstructured interviews	Kampala	N	N
Other Crop Storage Supply Chain Actors					
Implementing Partner	1/9	Unstructured interview	Agago	N	-
		Observation		N	-
Implementing Partner	2/9	Unstructured interview	Jinja	N	-
		Observation		N	-
Plastic Silo Manufacturer	1/1	Semi-structured interview	Kampala	R/F	R/F
		Observation		N	N
Airtight Bag Distributor	1/2	Semi-structured interview	Kampala	R/F	R/F
Airtight Bag Manufacturer	1/2	Unstructured interview	Cambridge	-	N
Airtight Bag Manufacturer	2/2	Semi-structured interview	Kampala	-	R/F
Prospective Local Distributor	-	Semi-structured interview	Jinja	-	N
Prospective Local Distributor	-	Semi-structured interview	Soroti	-	N
Prospective Local Distributor	-	Semi-structured interview	Soroti	-	N
Prospective Local Distributor	-	Semi-structured interview	Lira	-	N

6.4 Supply chain design to address quality issues

Working with a cohort of 16,000 farmers, of which 12,000 were Purchase for Progress farmers, WFP began a development project designed to kindle an airtight crop storage sector in 2014-2105. The physical motivation of the intervention was that airtight storage maintains a stored crop's moisture content and avoids insect infestation during storage, if used correctly. Before placing a crop in storage, certain drying and cleaning routines are important to bring down moisture content and to try to preempt insect infestation. Airtight storage, ideally, prevents insects from entering the stored crop, and—as insects continue to multiply and consume oxygen—eventually kills of insects that were in the crop either as larva or adults. The economic and social motivations of this intervention is that storage, perhaps in conjunction with credit, might allow smallholder farmers to hold crops for months after harvest and then sell crops to markets; that storage might improve the quantity and quality of the crop available on the market (and implicitly available for WFP procurement); and that storage might improve the quantity and quality of the crop consumed in the household. Thus reduced quantity and quality losses can bring several economic and health benefits to smallholder farmers, households, and communities participating in markets.

WFP provided subsidies to farmers, working capital to airtight crop storage manufacturers, and coordinated orders, advertising, and training. After a round of fundraising, Special Operation 200617 began in 2014. This project was run primarily from the Uganda country office, which allowed for operational flexibility and entrepreneurship when supply chain issues arose. In the first year of the project, WFP worked with about 16,000 farmers in 28 districts. The airtight storage options consisted of an airtight crop bag, a plastic silo, and two sizes of metal silos (WFP 2015). In the fall of 2015, WFP launched the second iteration of its project (SO2). This project aimed to reach 34,000-40,000 farmers in Uganda (WFP 2015).

The link between airtight (i.e. hermetic) on-farm storage for farmers, and in particular improved storage for Purchase for Progress farmers, and local and regional procurement is clear. Better on-farm storage could lead to better crop quality, and thus lower defaults as well as improve quality of procurements. To WFP this is formally a "Logistics Capacity Development Operation," or in effect a development project that has humanitarian implications. In the second year of the project, for example, farmers were selected *not* necessarily on the basis of Purchase for Progress participation. WFP's post-harvest loss initiative, headquartered in Uganda, now works with many countries to address this issue. Of course there are direct implications of this project for WFP's local and regional procurement mechanism, and hence why this case is framed in terms of local and regional procurement, but the impetus of this project is developmental. WFP is an organization that excels at logistics and is bringing to bear expertise in logistics to what is in part a complicated logistics problem.

In the first year of the project, WFP contracted with ten firms to provide the 16,000 farmers airtight storage as well as crop processing equipment (i.e. tarps). The revenue from WFP to these firms (and to project partners) is presented in Table 7. In total, the project involved 12 Uganda-based firms: this count includes the two raw-material suppliers of the six metal silo manufacturers, and excludes upstream firms and business units like the lid and plastic pellet suppliers of the plastic silo manufacturer, the metal suppliers' upstream suppliers, and the supplier for the crop bag distributor.

Figure 7: Order Sheet Presented to Farmers

Procurement from

- **6 metal silo manufacturers of 7,437 metal silos for $505,500**
- **1 plastic silo manufacturer of 6,362 plastic silos for $241,756**
- **1 crop bag distributor of 27,064 bags for $75,779**

6.4.1 Flow of Finances and Information

Across the three product supply chains, the flow of goods and information was relatively similar.[12] The project can be broken into three activities: farmer training, storage manufacturing and long-haul transport, and farmer mobilization for storage collection. These activities temporally overlapped: training and manufacturing happened concurrently, as did manufacturing, long-haul transport and collection.

[12] There were actually four product supply chains in the operation: for simplicity, this analysis for the most part excludes the supply chain of the 24,000 tarps provided by a UK-based company. The tarps were treated very similarly to the bags during shipment, so we do not learn many insights from them. Tarps are fundamental to effective airtight storage: clean and dry crop going into airtight storage is the absolute precursor to clean and dry crop coming out of airtight storage. Tarps all to often get eclipsed in the discussion of airtight storage; this thesis is guilty of doing exactly that.

To train farmers and garner orders, WFP worked with nine project partners—Uganda-registered non-governmental organizations—throughout the pre-manufacturing period to interface with the farmers. These nine project partners worked across 21 rural locations in 16 governmental districts to collect orders from farmers. (These 21 rural areas, each with a warehouse or 'collection point, would then become the points to which farmers traveled to collect their storage.) In the early months of the project, partners conducted trainings with farmers to introduce them to the products. After the training, they were presented with Figure 7 and asked to place orders. Farmers were not required to pay upon placing an order, though WFP reported that some tried to pay upfront.

WFP was central to setting manufacturing schedules, quantities, and transport schedules. Orders were relayed to WFP from project partners, which passed them on to manufacturers in the case of silos or distributors in the case of bags. For the small metal silo manufacturers, WFP provided some payment upfront because the manufacturers did not have sufficient cash reserves to pay for the costs of production: procuring supplies, hiring and accommodating labor, etc. The amount that WFP paid manufacturers and the distributor was a contracted amount for the production of the silo or sale of the bag. All contractual remuneration (net any payment upfront) happened after WFP trucks picked up the products. The six metal silo manufacturers were collectively paid \$505,500 for 3,475 medium and large silos, while the plastic silo manufacturer was paid \$241,756 for 6,362 silos. The bag distributor was paid \$75,779 for 27,064 bags. WFP contracted with a long-haul transportation firm to move products to the 21 rural locations. WFP paid this firm for the transport of silos and bags.

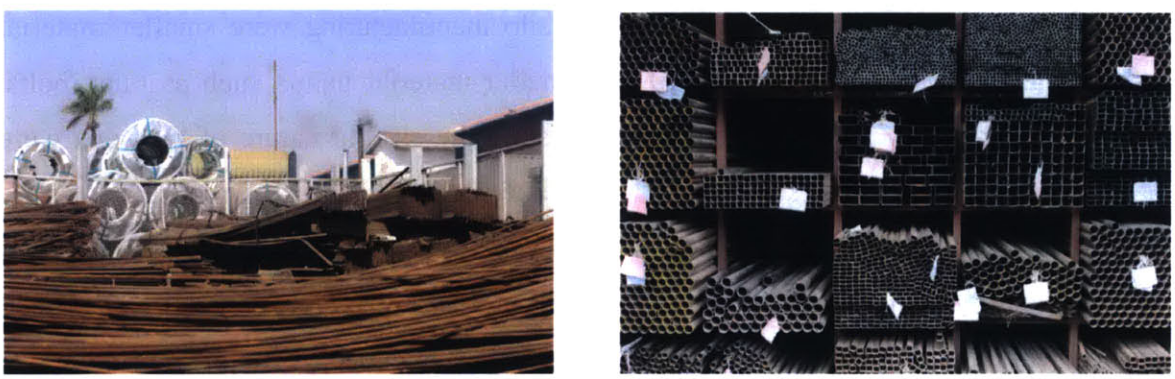
The project partners were response for follow-up trainings and for mobilizing farmers to collect products. Project partners took the lull between collecting orders and distribution to re-engage farmers with follow-up trainings. When products eventually arrived at the 21 rural locations, brought by the long-haul transportation firm, project partners mobilized farmers to come pick up and pay for their products. WFP subsidized an estimated retail price that was approximately the landed cost of the silo after manufacturing and transport plus margins for each firm, though it did not include sales channel costs (e.g. training). From data provided by WFP, it is possible to estimate that this total training cost—including initial, follow-up, distribution—was at minimum \$16 per farmer and at maximum $27 per farmer, with an average of $20 per farmer; the initial training included a meal. Initially the project partners worked on a rule of no-payment-no-product, though as the harvest got nearer and farmers began to default on their pick-ups, they moved to a system in which farmers were given the product in exchange for future payment. In some cases this meant project partners were responsible for extracting payment from farmers, and in other cases this meant that farmer collectives paid project partners upfront and the burden of collecting payments was passed on to the farmer collectives.

Table 7: Summary of costs or total remuneration to project partners and suppliers

	Total revenue to partners
Training costs	\$374,825
Metal silo costs	\$505,500
Plastic silo costs	\$241,756
Crop bag costs	\$75,779

6.4.2 Flow of Goods: Metal Silos

Figure 8: The stock-out of sheet metal, in the two major sheet metal providers in Uganda, was a challenge for small metal silo manufacturers



There were six firms involved in the manufacturing of metal silos. The inputs for silos consist of (1) sheet metal, (2) rivets and bolts, (3) several items of machinery, and (4) labor. Sheet metal (about one half to three fourths of the cost of goods sold depending on the manufacturer) for silos flowed from sheet metal wholesalers to the six contracted manufacturing firms. Four of the firms used one of the wholesalers (or one of their outlets) as a primary or secondary supplier, while three of the firms used the other wholesaler as a primary or secondary supplier. One interviewee reported that the quality of one of the wholesalers was better than another.

Sheet metal stock-outs were an issue for the wholesaler-manufacturer relationship. One firm manager reported traveling all the way to Kenya to procure sheet metal because the two Ugandan sheet metal wholesalers stocked out.[13] She bought the sheets at about the same price per sheet in Kenya as she would have from one of the two wholesalers in Uganda, but after accounting for inland transportation—a bus (2,400,000 UGX) and pickup trucks (200,000 UGX)—the landed cost per sheet became higher than that of domestic procurement. Traveling to Kenya in order to meet the contracted production schedule was an extreme measure. She made this trip with the specific intent of adhering to the WFP production schedule.

Several of the other manufacturers reported needing to check whether the sheets needed for manufacturing (0.08mm galvanized iron) were in stock before placing an order: it was not a guarantee that wholesalers would have the necessary sheets in stock. From the perspective of the wholesalers, the 0.08 mm galvanized iron sheets are a slow-moving stock keeping unit (SKU) in businesses that have lucrative and large structural steel and roofing business units. In the words of one sheet metal wholesaler,
"This project is peanuts for us."

The other three components in metal silo manufacturing were smaller material inputs, machinery, and labor. Most of the smaller material inputs such as nuts, bolts, cartridges for silicon guns, and candles for testing the airtight nature of the silos were bought locally. Most of the smaller machinery like cutting shears and wrenches that were bought for the project were also bought locally. A tool like a cutting shear might last several months. Some machinery, which can be considered a capital expenditure instead of a project expense, was bought internationally and had expected lifetimes of over five years. Labor payment schemes, and labor cost per silo, differed by firm: some firms paid laborers per silo while others paid per silo and subsidized housing and eating. Some had complex arrangements with foremen and quality inspection teams getting a payment per silo in addition to laborers getting a fixed rate per silo. However, piece rate (i.e. payment per silo) payment schemes—at least with laborers—were consistent across the firms.

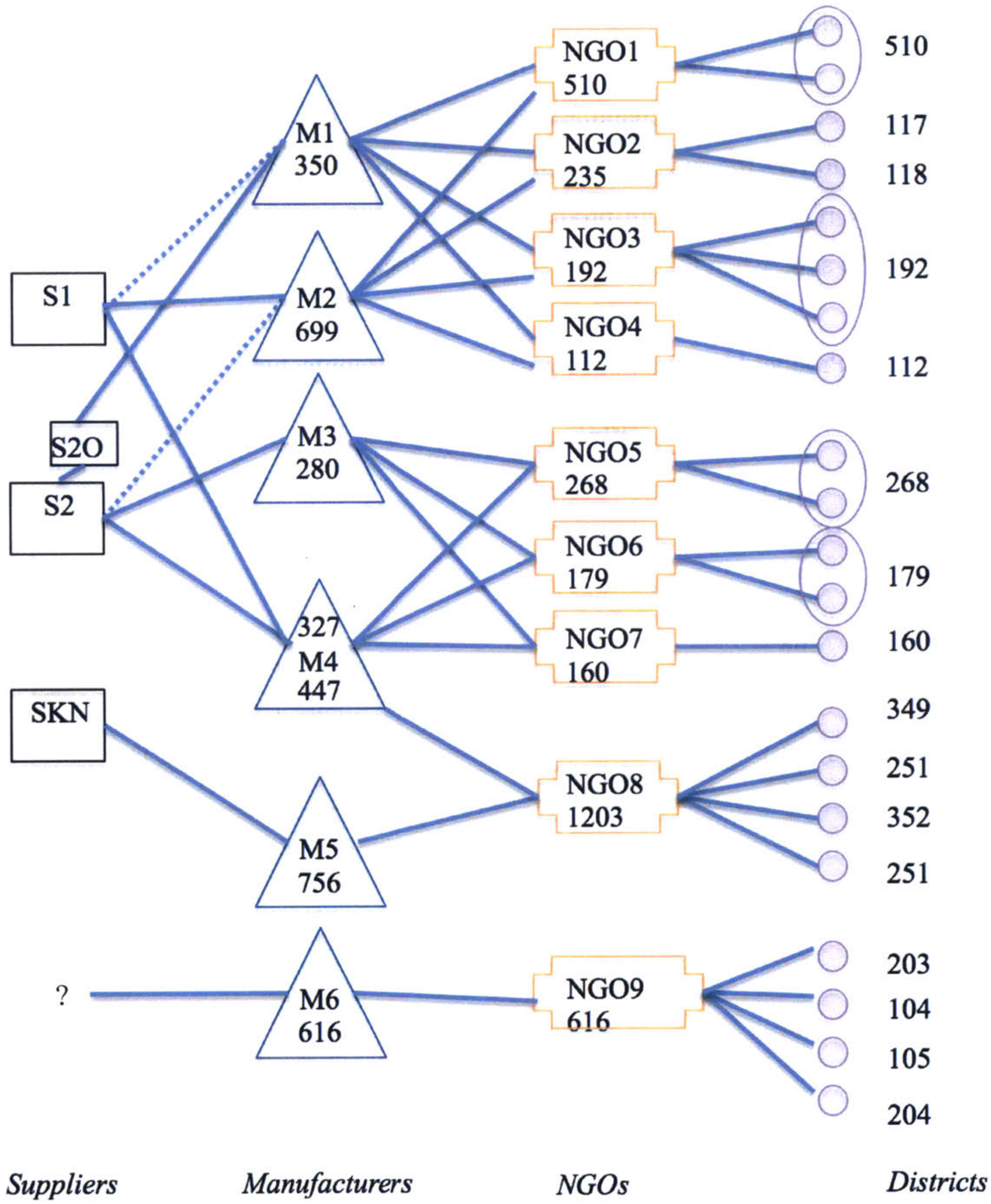
[13] We did not elicit procurement data from one sheet metal wholesaler.

After manufacturing and quality inspection the silos were ready for loading onto a long-haul transport truck hired by WFP. The manufacturers were responsible for loading, and often paid a piece-rate for laborers to load silos onto trucks. Long-haul transporters typically moved silos from manufacturers directly to the 21 rural locations at which farmers were to pay for and pick up silos, sometimes stopping by two manufacturers in the same day if they were both producing in the same town. The project partners took custody of the silos when they arrived at the rural locations.

Table 8: Product Flow Matrix From Metal Silo Manufacturers to Project Partner

		M1	M2	M3	M4(1)	M4(2)	M5	M6
		350	699	280	327	447	756	616
NGO1	510							
NGO2	235		1049					
NGO3	192							
NGO4	112							
NGO5	268				607			
NGO6	179							
NGO7	160							
NGO8	1203						1203	
NGO9	616							616

Figure 9: Notional Flows of Goods (Metal Silos)



Metal Silo Supply Chain Year One of Special Operation
(Number of Silos)
Notional Network
Dotted line is secondary source for raw materials

6.4.3. Flow of Goods: Plastic Silos and Airtight Bags

The flow of plastic silos and airtight bags is a good contrast to the flow of metal silos because the supply chains almost exclusively involve large firms and organizations.

In the plastic silo supply chain, the Ugandan manufacturer uses a Middle Eastern supplier for plastic pellets and a South African supplier for lids. There was a well-established relationship between the manufacturer and its plastic pellet supplier, which competes on the international plastic pellet market. This is because the manufacturer's primary business is water tank production. Water tanks require identical material inputs as silos with the exception of lids; the manufacturer hopes to begin to produce lids themselves. The manufacturing process is very capital intensive, though no incremental capital expenditures besides silo molds were a direct result of the project. The molds were bought from Kenya at a cost of about $1,000 per mold; the initial cost of other capital required for water tank and silo manufacturing well exceeds $1 million, and most of the assets that comprise that $1 million have lifetimes of 5-10 years. After production, the manufacturer uses a dedicated fleet to deliver silos to the WFP warehouse in Kampala in batches of about 100-150 silos. From that warehouse, WFP would transport the silos to the 21 rural destinations. With water tank sales, they use that dedicated fleet to move water tanks to retailers and wholesalers in rural areas. The manufacturer estimated that the WFP project would account for about 3% of their annual revenue.

In the airtight bag supply chain, the Ugandan distributor—the sole licensed distributor in Uganda for this type of airtight bag—relies on a Kenyan supplier (which also has a formal relationship with the manufacturer of the airtight bag) and the manufacturer itself. The bags are manufactured in the Philippines. They are either shipped to the Kenyan subsidiary that then fulfills the Ugandan distributor's orders or they are shipped directly to the Ugandan distributor. As bags are low-value and small, and lead times from Kenya or the Philippines can be long, the Ugandan distributor stocks bags in advance of receiving orders. Their primary costs are purchase costs, which when coming from the Philippines often include freight up to the port of Mombasa, Mombasa-Kampala corridor logistics costs, and Ugandan labor costs. In their regular sales to customers like farmers groups they use the public bus system to ship bags to rural areas.

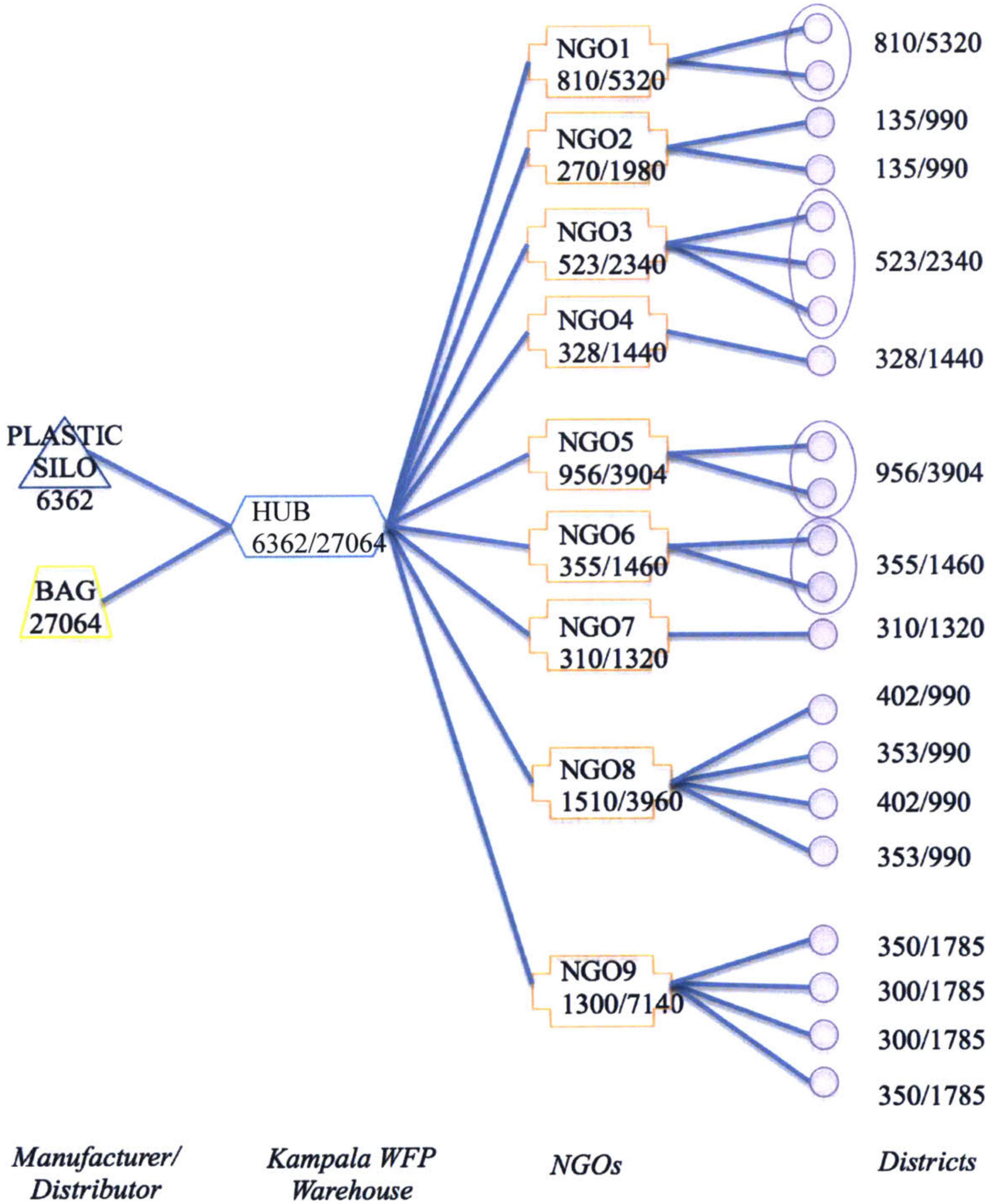
They did not report having much visibility into their inventory, costs, and profits other than the observation,

"My dear, this is Uganda. The margins are very small."

Table 9: Product Flow Matrix from Manufacturer / Distributor to Project Partner

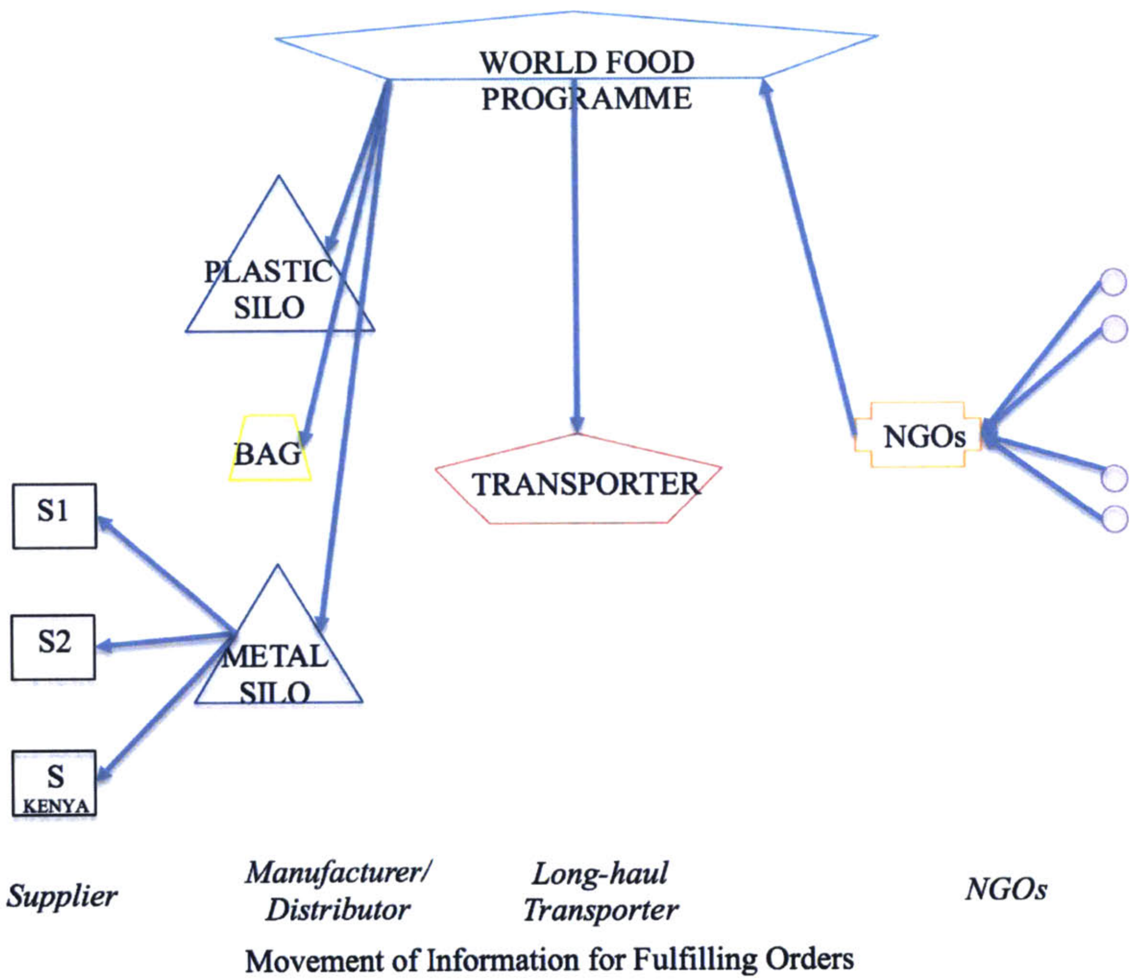
	Plastic Silo	Bag
	6362	27064
NGO1	810	5320
NGO2	270	1980
NGO3	523	2340
NGO4	328	1440
NGO5	956	3904
NGO6	355	1460
NGO7	310	1320
NGO8	1510	3960
NGO9	1300	7140

Figure 10: Notional Flow of Goods (Plastic Silo/Airtight Crop Bag)



Plastic Silos/Airtight Crop Bag Supply Chain Year One of Special Operation
(Number of Plastic Silos / Numbers of Bags)
Notional Network

Figure 11: Flow of Information



6.5 Contracting, capacity, and behavioral mechanics of supply chain

In this section I consider how procurement reveals insights for supply chain design. An activity based costing (ABC) approach was used to estimate the manufacturers' costs, and a similar approach to estimate their capacities. Key to this approach was the semi-structured interview. In each interview we completed a "process map" with each manufacturer: this map listed all the activities required to produce a silo or distribute a crop bag as well as times and costs for each activity. The findings from this ABC approach were checked against data from WFP and the long-haul transportation firm. Many of the qualitative insights from the interviews were corroborated with WFP and the long-haul transportation firm data; the quantitative insights were more difficult to interpret. This section, for simplicity, only presents data from WFP and the long-haul transportation firm, which is qualitatively supported by the ABC-style interviews.

6.5.1 Testing Capacity

The contracting mechanisms between WFP and their suppliers of crop storage—the six metal silo manufacturers, the plastic silo manufacturer, and the airtight bag distributor—were similar. WFP contracted for quantities of crop storage items at given intervals, which were set to match the schedule of the long-haul transporter. In advance of production, WFP offered working capital and training to metal silo manufacturers, and research and design support to the plastic silo manufacturer.

WFP contracting did not include clauses that penalized delayed production or distribution. However, there were indirect incentives to maintain production schedules. Working well with WFP might lead to future contracts; at the time of production, revenue from the project was up to 100% for some of the metal silo manufacturers and 7% for the plastic silo manufacturer. However, even with these indirect incentives, adhering to the schedule was difficult, primarily for the metal silo manufacturers but also for the plastic silo manufacturer. Table 10 shows the number of products late at the time of a pick-up, and is based on data from the long-haul transporter. Nearly one third of all silos eventually produced were produced behind schedule.

There are at least two phenomena that can explain this effect and they are hard to separate: metal silo manufacturers may have been limited in a physical sense (i.e. capacity constrained) to produce silos according to the production schedule, or manufacturers may have been unwilling, perhaps because of other more profitable projects, to produce silos according to the production schedule. (Table 10 could alternatively present total number of shipments that were short at least one unit at time of a scheduled pickup.)

Table 10: Number of Silos and Bags Short at Time of Scheduled Pickup

	Large Metal Silos	Medium Metal Silos	Total Metal Silos	Plastic Silos	Bags
Total Produced/Distributed	863	2,175	3,038	6,326	27,064

Total No. Short Off Contracted Quantity at All Times of Pickup	463	530	993	356	989
Percent Short	53%	24%	32%	6%	4%

For metal silo manufacturers, given the percentage of the revenues attributable to this project, it is more likely that they were capacity constrained. However, one could argue that, given the percentage of revenues that this project took, it is surprising that they did not add more capacity. Surely they would want to curry favor with WFP in the hopes of winning contracts in the coming years? However, silo production was very labor-intensive: all laborers went through a WFP training and several managers reported a learning effect in terms of both the rates of production and the quality of production. Thus there may have been a perceived barrier to quickly adding more labor, and they may have truly been capacity constrained. One could also argue that they should have anticipated that capacity constraint, given the managers and equity owners of the six manufacturing shops were experienced artisans and produced some silos in advance of receiving orders to generate a buffer during the peak of the project.

However, through a behavioral experiment we found five of the six silo manufacturers to be highly risk adverse as defined by Holt and Laurry (2002). They develop a simple empirical way to test risk aversion. In completing a risk lottery, we found that manufacturers almost consistently selected the "safe" choice in the experiment. Manufacturers were asked to select option A or option B for each of the ten decisions displayed in Table **11**. A risk-neutral subject would have selected five safe choices.

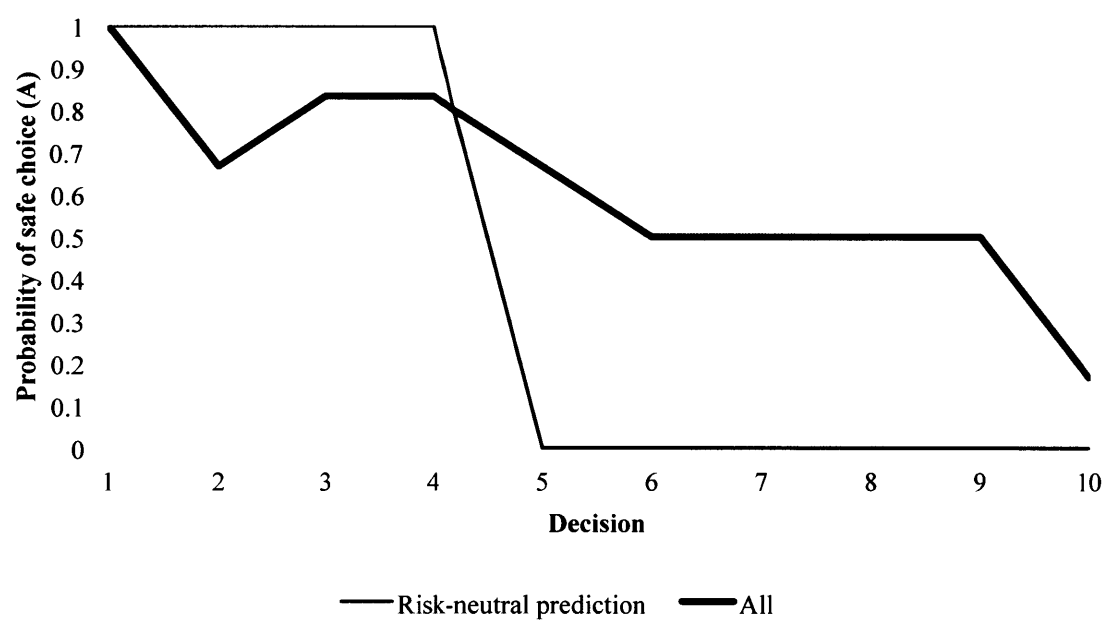
Table 11: Risk Lottery

Decision	OPTION A	OPTION B	Your choice A or B
1	1/10 chance of winning Sh 6,100 9/10 chance of winning Sh 4,900	1/10 chance of winning Sh 11,700 9/10 chance of winning Sh 300	
2	2/10 chance of winning Sh 6,100 8/10 chance of winning Sh 4,900	2/10 chance of winning Sh 11,700 8/10 chance of winning Sh 300	
3	3/10 chance of winning Sh 6,100 7/10 chance of winning Sh 4,900	3/10 chance of winning Sh 11,700 7/10 chance of winning Sh 300	
4	4/10 chance of winning Sh 6,100	4/10 chance of winning Sh 11,700	

	6/10 chance of winning Sh 4,900	6/10 chance of winning Sh 300	
5	5/10 chance of winning Sh 6,100 5/10 chance of winning Sh 4,900	5/10 chance of winning Sh 11,700 5/10 chance of winning Sh 300	
6	6/10 chance of winning Sh 6,100 4/10 chance of winning Sh 4,900	6/10 chance of winning Sh 11,700 4/10 chance of winning Sh 300	
7	7/10 chance of winning Sh 6,100 3/10 chance of winning Sh 4,900	7/10 chance of winning Sh 11,700 3/10 chance of winning Sh 300	
8	8/10 chance of winning Sh 6,100 2/10 chance of winning Sh 4,900	8/10 chance of winning Sh 11,700 2/10 chance of winning Sh 300	
9	9/10 chance of winning Sh 6,100 1/10 chance of winning Sh 4,900	9/10 chance of winning Sh 11,700 1/10 chance of winning Sh 300	
10	10/10 chance of winning Sh 6,100 0/10 chance of winning Sh 4,900	10/10 chance of winning Sh 11,700 0/10 chance of winning Sh 300	

Had the manufacturers produced some silos in advance of receiving orders and produced in excess of the eventual orders received, they would have been left with large, high-value inventory. Capital for 25 unsold silos would be about a quarter of the average of the six manufacturing firms' monthly revenues for all products.

Figure 12: Proportion of safe choice decisions in risk lottery



The plastic silo manufacturer reported constantly running their manufacturing line to produce plastic silos over several periods of the project. As there is a changeover cost to switch from water tanks to silos (i.e. changing the molds), and the WFP orders were set in advance of production and adjusted through the production period, it is possible they batched production across weeks to minimize the changeover cost of switching molds. This changeover cost is magnified by the fact that the high-quality water tank sector in Uganda appears to be competitive: there are four or five major high-quality water tank manufacturers, all of which have market penetration in rural areas and in Kampala, and this manufacturer reported running their plant continuously. One respondent involved with the project observed that the manufacturer did have a tendency to over promise.

Overall, storage products from large firms were available more consistently than storage products produced by smaller firms.

6.5.1 Understanding costs

For this case study, the cost analysis is much simpler than the capacity analysis. As the silos were new to the Ugandan market and the bags had relatively small market penetration in the post-harvest sector, WFP used a combination of estimated landed costs and supply chain actor margins, inferred from procurement bids, to determine an unsubsidized price of storage to a farmer. This is shown in Table **12**. This analysis considers the lifetime of the storage, a 5% discount rate, the WFP estimated price of storage to a farmer, and the capacity of the different storage options. The price to the farmer (unsubsidized) is taken from Figure **7**; the years of life column was ad-hoc elicited from manufacturers, project partners, and program stakeholders, and is the weakest parameter in this analysis. While WFP may have been able to elicit costs by issuing a request for proposals, this cost was validated by the procurement of the thousands of units of each product.

Overall, the price to the farmer over a 20 year time horizon did not substantially differ by manufacturer size (a 20 year time horizon was selected because the plastic silo is estimated to last about 20 years). This finding is sensitive to any of the assumptions, and ex-post evidence of the actual re-purchase rates of these products is needed.

Table 12: Discounted price per kg stored to farmer over 20 year horizon with replacement

	Price to the Farmer	**kg capacity**	**Cost/kg capacity**	**Years of Life**	**Ugandan Seasons**
Large metal silo	$180.00	1,300	$0.14	10	20
Medium metal silo	$130.00	530	$0.25	10	20

Plastic silo	$38.00	250	$0.15	20	40
Airtight bag	$2.80	80	$0.04	2	4

Discount Rate	5%

Table Continued: Discounted price per kg stored to farmer over 20 year horizon with replacement

	Present Price to the Farmer/ kg capacity	**0 years**	**2 years**	**…**	**10 years**	**12 years**	**…**	**20 years**
Large metal silo	$0.22	$0.14			$0.09			
Medium metal silo	$0.40	$0.25			$0.15			
Plastic silo	$0.15	$0.15						
Crop bag	$0.25	$0.04	$0.03		$0.02	$0.02	…	$0.01

Using the same method, I perform a sensitivity analysis of two of the more critical assumptions in the analysis: the time horizon and the crop bag re-purchase rates. This is presented in Table **13**. As plastic silos in this model are purchased every 20 years, years 15 and 25 might be "fair" time horizons to consider. In both cases the plastic silo remains cheaper than the metal silos. Years 29, 19, 9 are presented to show the sensitivity of the analysis to the re-purchase of a silo.

Table 13: Sensitivity analysis of present value price to the farmer per kg stored

Bag life	2 yr	2 yr	2 yr	2 yr	2 yr	2 yr	2 yr	2 yr	2 yr
Time-horizon	30	29	25	20	19	15	10	9	5
LMS	$0.31	$0.28	$0.28	$0.28	$0.22	$0.22	$0.22	$0.14	$0.14
MMS	$0.55	$0.49	$0.49	$0.49	$0.40	$0.40	$0.40	$0.25	$0.25
PS	$0.21	$0.21	$0.21	$0.21	$0.15	$0.15	$0.15	$0.15	$0.15
CB	$0.30	$0.29	$0.27	$0.25	$0.23	$0.20	$0.17	$0.15	$0.10
Bag life	1 yr	1 yr	1 yr	1 yr	1 yr	1 yr	1 yr	1 yr	1 yr
Time-	30	29	25	20	19	15	10	9	5

horizon									
LMS	$0.31	$0.28	$0.28	$0.28	$0.22	$0.22	$0.22	$0.14	$0.14
MMS	$0.55	$0.49	$0.49	$0.49	$0.40	$0.40	$0.40	$0.25	$0.25
PS	$0.21	$0.21	$0.21	$0.21	$0.15	$0.15	$0.15	$0.15	$0.15
CB	$0.57	$0.56	$0.53	$0.47	$0.46	$0.40	$0.31	$0.28	$0.19

LMS: large metal silo; MMS: medium metal silo; PS: plastic silo; AB: airtight bag.

All of these values presented in Table **13** are the present value price per kg stored to the farmer of constantly deploying storage. To comment on the sustainability and appropriateness of the intervention I would need to estimate the expected increase in revenue from using storage, and could combine the cost of storage and revenue from storage to present the net cost (or benefit) of storage. I do not offer those calculations. This analysis—in the context of this thesis—assumes that all four storage options are equally effective in a technical sense, and focuses exclusively on the present value price per kg stored to the farmer of the different storage options. From this analysis I show how procurement can reveal costs in a supply chain.

6.6 Case conclusion

Food quality in Uganda has posed a problem for local and regional procurement, and an estimated 10%-60% of Purchase for Progress farmers' products is refused due to quality issues in Uganda. In Uganda in 2014-2015 WFP ran a development project to provide about 16,000 farmers with airtight storage to improve on-farm crop quality: this storage was procured from three effectively independent supply chains. WFP found that some smaller vendors were unable to maintain a production schedule. Larger, well-established firms providing airtight bags and plastic silos tended to produce storage more consistently. Offering a training program for metal silo manufacturer's labor was necessary but not sufficient for consistent production. The program also found that the immediate price to the farmer varied, and that per kilogram stored, airtight bags were the cheapest option. When that cost was discounted and adjusted for lifetime of product and storage capacity, the present value price to the farmer changed: per kilogram, stored plastic silos became the cheapest product by a wide margin. By designing two product supply chain models and using an existing supply chain model, and spending $823,038 for a procurement, WFP gained insights into the provision of airtight storage in Uganda.

7. Food for Peace material handling case

7.1 Case introduction

Transoceanic food aid shipments that pass through the ports of Djibouti and Durban face challenges similar to other food aid shipments: insect infestation and toxin contamination emerge as a function of planned lead times, delays, climatic conditions, packaging, treatments (e.g. fumigation) and initial quality states. These two ports, with different material handling and bagging capacities, are part of a procurement experiment in which food aid in various packaging options is procured, shipped to the port, and monitored. Spending about $1 million on procurement and shipment of food aid (that will be programmable), the US Agency for International Development (USAID) is shipping 1360 MT of food aid to the ports of Djibouti and Durban. That the food aid is programmable means that the food aid used in this procurement can be given to beneficiaries. The unit of measurement in this case is handling capacity (number of successfully filled and handled bags) and cost ($/kg sent). This procurement case study illustrates the trade-offs between packaging options that require additional labor, capital, or time for filling, sealing, or port handling. In experimenting with ten packaging options for three commodities, USAID is working to understand how foreign and domestic handling capacities and costs determine supply chain design. This case study was written as an analysis of an on-going operation.

7.2 History: Food for Peace in Durban and Djibouti

The United States has shipped many million metric tons of food aid since Public Law 480's inception through the ports of Djibouti and Durban, intended for Horn of Africa and Southern Africa destinations, respectively. Djibouti hosts a port and USAID pre-positioning warehouse, and serves countries like Ethiopia and Somalia. In FY 2016, Somalia received $127 million of Food for Peace (FFP) funding (USAID 2015); in FY 2016, Ethiopia received $416 million of FFP funding (USAID 2016b). The Port of Durban similarly functions as a waypoint and pre-positioning warehouse for food aid, serving countries such as Zambia and Zimbabwe.

The Horn of Africa often experiences food insecurity. In one report the UN Food and Agriculture Organization (FAO) calls the Horn of Africa "one of the most food-insecure regions in the world" (FAO 2000). The seven countries in the region have a combined population of 160 million people, of which 70 million "live in areas prone to extreme food shortages" (FAO 2000). In the three decades prior to the FAO report's publication in 2000, these countries have been threatened by famine once a decade. This fact holds since the report was published: in 2011-2012 a drought brought famine to southern Somalia that killed an estimated 260,000 people (AP 2013). Comparatively, Southern Africa experiences bouts of food insecurity but neither of the chronic level nor magnitude of the Horn of Africa.

Food procured for the Horn of Africa and Southern Africa can come from local and regional mechanisms or transoceanic mechanisms. Data on the percentage of food aid that is locally and regionally procured and sent to these regions compared to the percentage that is procured from the United States and sent to these regions are not readily, publically available. This section focuses on procurements from the United States.

The transoceanic supply chain, and the responsibility for handling within the supply chain, is similar for commodities en route to Djibouti and Durban. In the United States, the US Department of Agriculture (USDA) procures food aid under a "commodity contract," which entails a competitive bidding process. This contract typically includes the procurement of the commodity itself, as well as inland transportation to an American port of departure.

Figure 13: A small commodity supplier in North Dakota and a large commodity supplier in Texas

Often around the port of departure the food is transferred to the care and custody of an ocean shipping contract awardee, selected by USAID in a competitive bidding process.

The food aid remains under the care and custody of the ocean shipping contract awardee for handling in portions of the port of origin, all of ocean shipping period, and some portions of the port of destination. Awardees are often large ocean liners like Maersk, but awards also go to smaller break-bulk carriers. In practice a subsidiary or sub-contractor of the ocean shipping contract awardee does some of the port handling on both the domestic and international sides of the supply chain. It remains up to USDA and USAID to set the contractual language for handling on commodity and ocean shipping awards. The handling processes typically diverge when commodities arrive at a port: the port of Durban has more mechanization and infrastructure than that of Djibouti.

Table 14: List of Food for Peace Interviews

R: Recorded, F: Form, N: Notes

	No in Sector		Method	Location	Visit	Call
			Commodity Supply Chain Actors			
Pulse Supplier	X	1 of X	Structured Interview Observation	North Dakota	F N	-
Simple Milled Product Supplier	2	1 of 2	Structured Interview Observation	Midwest	F N	-
Complex Milled Product Supplier	2	1 of 2	Structured Interview Observation	Midwest	F N	-
Bulk Grain Supplier	Y	1 of Y	Structured Interview Observation	Gulf	F N	-
			Domestic Port Supply Chain Actors			
Port Warehouse	19	1 of 19*	Structured Interview Observation	Gulf	N N	-
Port Warehouse	19	2 of 19*	Structured Interview Observation	Gulf	N N	-
			Bag Supply Chain Actors			
Multiwall Paper Bag Manufacturer	10	1 of ~10 1 of ~10	Unstructured Interview Observation	Southern US	N N	-
Poly. Bag / FIBC Manufacturer	10	1 of ~10 1 of ~10	Unstructured Interview Observation	Southern US	N N	-
Airtight Bag /Liner Manufacturer	1	1 of 1	Unstructured Interview	-	N	>10
Insect Growth Regulator Supplier	1	1 of 1	Unstructured Interview	-	N	>10
			Program Stakeholders			
USAID Food for Peace (Procurement)				-	-	>10
USAID Food for Peace (Transport)				-	-	>5

USDA Kansas City Commodity Office				-	-	>10
WFP Ethiopia				-	-	-
WFP Djibouti				-	-	-
Kansas State University				-	-	1
Commodity Stakeholders						
US Dry Pea and Lentil Council	6	1 of 6**	Unstructured Interview	-	-	>5
North American Millers Assn.	6	2 of 6	Unstructured Interview	-	-	>5
US Wheat	6	3 of 6	Unstructured Interview	-	-	1
US Grain Council	6	4 of 6	Unstructured Interview	-	-	1

*There are 19 certified domestic port warehouses for Title II Food Aid.
**There are six principle American interest groups that involved in Title II food aid.

7.3 Quality and Regulation in Transoceanic Procurement for Durban and Djibouti

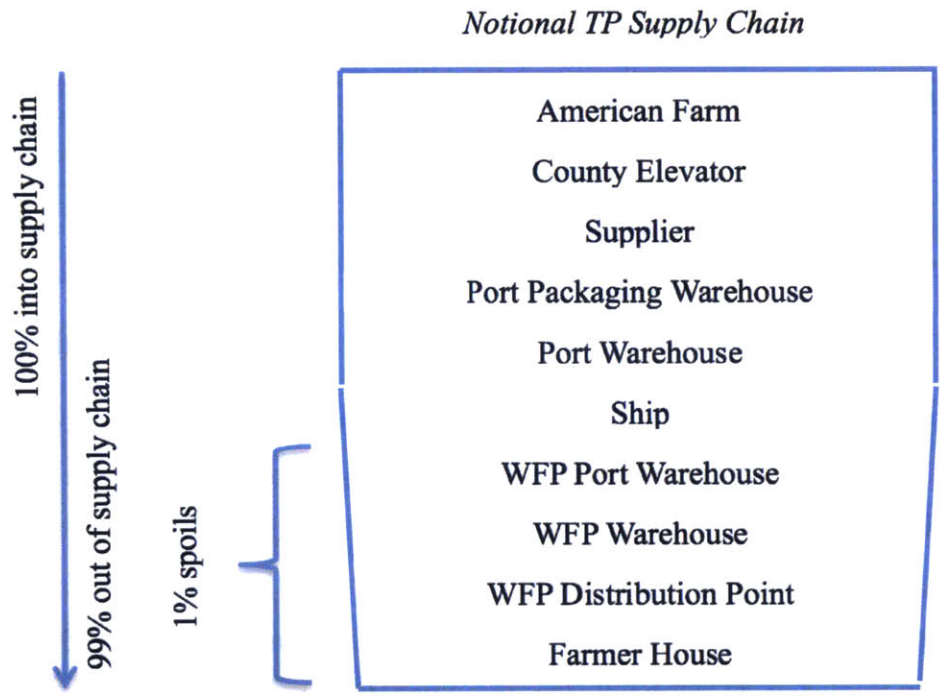
Maintaining food quality of shipments to and through Djibouti and Durban has posed a challenge for transoceanic food aid, though not necessarily a greater challenge than shipments to and through other receiving ports. In part this is due to the lead times involved in shipping products to these ports, and in part it is due to the climatic conditions of the ports. Shipping by ocean, from Houston to Durban takes about 25 days and shipping from Houston to Djibouti via the Suez Canal takes about 24 days (Searates.com). The climatic conditions at the ports, and along the route, are different: Table 10 shows the average relative humidity and average monthly temperature.

Table 15: Climate of and distance to ports considered

Foreign PREPO Location	Distance from Port of Houston (km)	Average Annual Temperature (C)	Average Monthly Temperature Variation (C)	Average Relative Humidity (%)	Average Monthly Relative Humidity Variation (%)
Djibouti	14824	29.9	11.3	63.3	31
Durban	15306	20.5	8	79.1	10

Climate determines which insects and fungi exist in which areas. In particular, high humidity and/or large temperature variations may lead to ‘precipitation’ and/or high moisture contents of commodities in both airtight and non-airtight bags.

Figure 14: Notional Loss in Transoceanic Procurement Supply Chain



There are at least four other aspects relevant to maintaining food aid quality: (1) ensuring domestically-bagged shipments are appropriately sealed in the United States, (2) ensuring bulk shipments that are bagged or bagged shipments that are re-bagged to smaller bags at a foreign port do not introduce contaminants to the product, (3) mitigating the impact of port congestion on lead times and consequently quality loss, and (4) regulating how delicately bags are handled at both domestic and foreign ports, as perforations in both airtight and non-airtight bags can lead to quality issues. USDA and USAID have moderate visibility of the processes that might lead to quality losses along the transoceanic supply chain into Djibouti and Durban. Figure 14 illustrates losses in the supply chain: as noted above, this thesis estimates that they are about 1%, and tend to occur during ocean and inland shipping in a foreign country.

Maintaining quality in these food aid supply chains currently requires fumigation. This fumigation occurs both domestically and abroad. FFP, the US Department of Agriculture Kansas City Commodity Office (KCCO), one interviewee at a major commodity shipping company, and two interviewees at port warehouses note that domestically, fumigation can happen at several points along the supply chain: on the farm, in a processing facility, in a warehouse, or at the domestic port. Internationally, fumigation occurs at similar waypoints: port warehouses, primary warehouses, secondary warehouses, or tertiary warehouses. A UN World Food Programme (WFP) Logistics Cluster Logistics Capacity Assessment in Ethiopia, for example, specifically notes the ability of Ethiopian third party logistics providers to provide or outsource fumigation services. Fumigation in Ethiopia can cost about \$3/MT (WFP 2010b), which is about six times larger than the USAID Programmatic Environmental Assessment's global estimate of \$0.59/MT (USAID 2013). WFP does not offer Logistics Capacity Assessments for most Southern African states, beyond an abbreviated assessment in Lesotho, and region-specific details of fumigation practices in Southern Africa are sparse. The quality of application of fumigation across regions in Africa may be different; improper fumigation practices can lead to spoiled commodities.

Mitigating quality losses is important to preserve a product's nutritional content, to avoid the health-damaging effects of some toxins (e.g. Leiato *et al.* 1987), and to reduce 'spoiled' and thus discarded commodity. Regulation is the formal basis for determining when shipments have spoiled. Shipments become infested and contaminated with toxins as an unexplored function of lead times, climatic conditions, packaging, and initial quality states. Aflatoxin contamination specifically is more of a function of the environment and initial quality—specifically, of humidity and crop moisture content. There are some models that explain aflatoxin contamination, but they explicitly focus on climatic conditions and implicitly on lead times (i.e. fungi growth leading to aflatoxin contamination over time) (e.g. Wael *et al.* 2013). South Africa has maximum allowable limits for aflatoxin B_1 of 5 micrograms per kilogram, with a total aflatoxin limit not to exceed 10 micrograms per kilogram in 2004 (see South Africa Act No. 54 of 1972 as amended by Government Notice No. R. 1145 on 8 October 2004). Djibouti, as a member for the Common Market for Eastern and Southern Africa (COMESA), has been the subject of several studies but an up-to-date presentation of aflatoxin regulation is not readily available (PACA 2014). Insect infestation can come from extreme events like country-wide insect infestation (like the 2004 Horn of Africa locust infestation) (e.g.

WFP 2010b), improper fumigation practices (USAID 2013), and delayed fumigation due to events like port bottlenecks.

7.4 Supply chain design to address quality issues

Working with two new packaging providers, one offering an airtight bag in 25 kg, 50 kg, and 1000 kg sizes and the other offering an insect growth regulator to apply to otherwise generic, commercial 25 kg, 50 kg, and 1000 kg bags, FFP and MIT began a pilot project to determine how improved food aid packaging might reduce loss. The project will use about $1 million to procure and ship yellow split peas, sorghum, and corn soy blend plus (CSB+) to the ports of Djibouti and Durban each in ten different new packaging options.

This project was run primarily from the FFP Washington DC office, with concurrence from the regional FFP offices and USAID missions that cover the ports of Djibouti and Durban. This, combined with the fact that this was a procurement driven by the United States government and not an implementing organization, meant that we experienced somewhat less operational latitude than WFP may have experienced in Uganda. For example, it took about a month to put the right approval and systems in place to be able to procure commodities in 1000 kg bags. At the same time, the centralized nature of the procurement and strong support from USAID and USDA allowed for a very complex experimental design to be operationalized, which will ultimately clearly document the cost-effectiveness of various new packaging options.

Procurement of 68 lots of 20 MT each

- 3 commodities
- 2 destination ports
- 9 packaging options to be mixed and matched (for a total of 10/commodity for domestic-bagged shipments and 4/commodity for foreign-bagged shipments)
  - 6 distribution and shipment-sized
  - 3 shipment-sized
- 2 ocean shipping methods: domestic-bagged and foreign-bagged

The goal of the project is to determine which improved food aid packaging is the most cost-effective. While the focus of the operation (and major area of quality loss) is ocean transport and inland handling, studying the domestic portion of the supply chain is relevant because domestic suppliers must have the capacity to incorporate new packaging into their bagging, loading, and unloading processes. This section details bagging and material handling processes across three distinct supply chains: (1) a bagged milled product, (2) bagged pulses and grains, and (3) bulk grains (i.e. ocean shipping occurs in bulk). The three product supply chains are presented to illustrate the uniqueness of each procurement, and thus the many variables that remain uncertain in supply chain design. The following section presents procurement experimentation as an effective method to explore supply chain design given these uncertainties.

7.4.1 Products considered

USAID and MIT are working with new packaging providers to explore new packaging options in the supply chain. Currently food aid bagged in the United States is shipped in 25 kg multiwall paper bags or 50 kg woven polypropylene bags, and food aid shipped in bulk and bagged at a foreign port is only bagged in 50 kg woven polypropylene bags. First, we are working with the provider of an insect growth regulator (methoprene), which can be applied, to 25 kg multiwall paper bags and 50 kg woven polypropylene bags currently used in food aid as well as 1000 kg bags currently used in commercial food supply chains. The firm sells the insect growth regulator, which is incorporated in the manufacturing process typically at a large, commercial bag manufacturing firm. Second, we are working with the provider of brand of airtight bags: these can also come in 25 kg, 50 kg, and 1000 kg sizes. The 25 kg and 50 kg bags are made of a polyethylene liner inside a woven polypropylene bag, or are a stand-alone thick polyethylene bag.

Their 1000 kg size has the outside appearance of a generic commercial 1000 kg bag but has an airtight liner. Finally, we are working to introduce generic 1000 kg bags, with no insect treatment or airtight liner to the supply chain. All of the 1000 kg bags—insect growth regulator treated, airtight, or generic—will need to be re-bagged at the foreign port into either 25 kg multiwall paper bags or 50 kg woven polypropylene bags. A complete list of products being considered for the pilot is in Table 18.

7.4.2 Flow of Finances and Information

The coordination and movement of finances and information was determined through multiple conversations with FFP and KCCO. The typical food aid procurement begins with FFP putting in a sales order for a destination: this sales order designates how much of each commodity FFP requires for a country.[14] These sales orders determine where and how commodities should be bagged, and provides details on both commodity and domestic land shipping requirements, as well as ocean and foreign land shipping requirements.

KCCO takes a sales order and issues invitations to bid on commodity contracts. These invitations cover the procurement of the commodity and domestic transportation to various points: to a domestic trans-load facility, a ship in a domestic port, or a domestic warehouse. The process between issuing invitations and awarding contracts typically takes a few weeks. Once the bidding period is closed, KCCO awards bids within 24 hours. USDA directly pays the awardee of a commodity contract.

A division of FFP is responsible for issuing invitations to bid on ocean shipping contracts in response to sales orders. These can be issued a week or so after the commodity invitation is issued, and are awarded at about the same time. FFP solicits bids for ocean shipping about one time per month. A series of laws must be considered in awarding the ocean shipping contracts (i.e. preference for US flagged carriers, certain US ports, and break-bulk carriers). In general USAID cannot require that bagged commodities go via containerized or break-bulk ocean shipping, but can require that

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[14] In the case of an actual procurement, the process begins with a query from a country office. However, in the case of the operation, the procurement originated with FFP-DC. In the case of our procurement, FFP actually issues a purchase requisition, because technically our purchase was destined for a USAID prepositioning facility instead of a PVO.

some commodities going to certain ports be shipped in containers as a theft prevention measure. USAID indirectly pays for the ocean shipping contract: PVOs pay for the ocean shipping with funding that USAID provides through transfer authorizations.

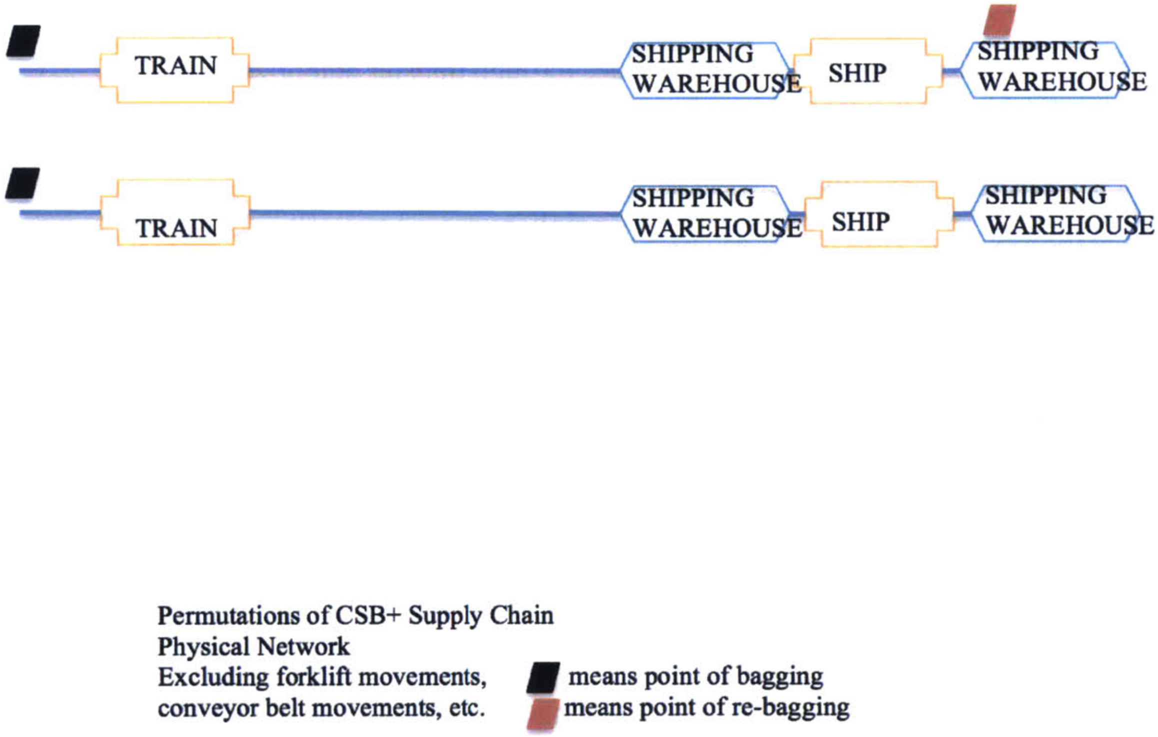
7.4.3 Flow of Goods

7.4.3.1 Bagged supply chain overview

Commodities originate with commodity suppliers spread typically across the American Midwest and Pacific Northwest. The average size of these suppliers varies by commodity. Coarse grains and wheat tend to come from large firms (e.g. ADM, Cargill) and milled products and pulses tend to come from small businesses. USDA prioritizes procurement from small businesses where possible. According to USAID data, in FY 2014 no bulk whole grains were purchased from small businesses, but 86% of cornmeal, 40% of corn soy blend, 98% of beans, and 97% of lentils came from small businesses.

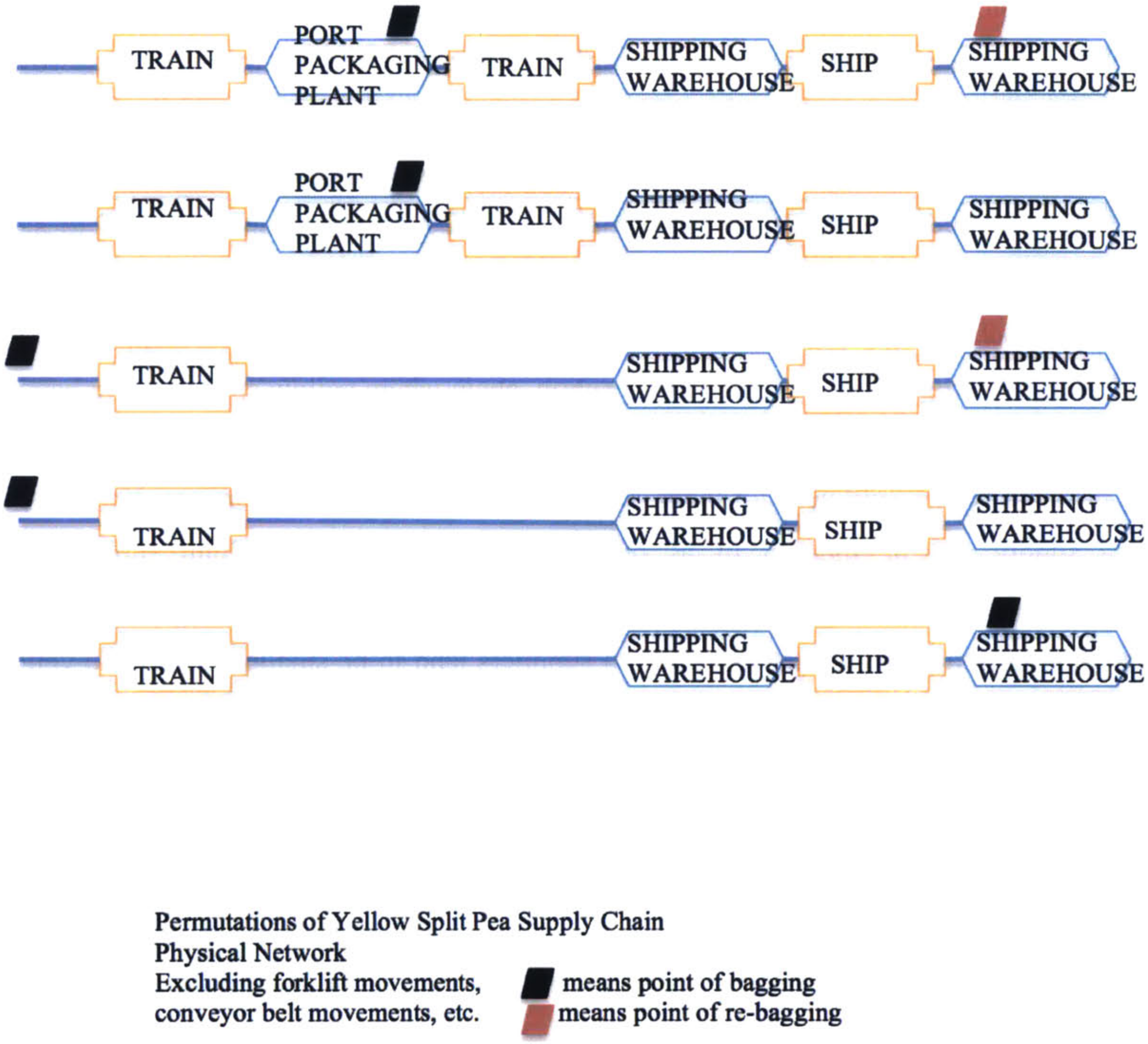
If the commodity was procured under a commodity contract that specified that it be bagged before ocean shipping, it is either bagged at the supplier or placed in a hopper rail car at the supplier and sent to a port where bagging takes places at a warehouse. Milled products must be bagged at the supplier, while pulses and grains can be bagged at a port or the supplier. In the case of bagged ocean shipping, at the port the commodity will be taken out of a rail car, bagged if it is not already bagged, placed in a transit shed, and moved to a dockside shed. Bagged food aid is either sent on a container or break-bulk carrier. In the case of containerized ocean shipping, it is loaded into a 20ft or 40ft container that is then loaded onto the ship. In the case of break-bulk ocean shipping, it is loaded onto the ship directly.

Figure 15: Permutations of CSB+ Supply Chain (Physical Flows)



CSB+ production looks similar to commercial milled product processing and shipment. CSB+ is currently bagged at the supplier in a 25 kg multiwall paper bag that requires a heat sealer. CSB+ could also be shipped in 1000kg bags, though currently the supplier only uses 1000kg bags for commercial orders. Changing to airtight bags with an inner liner would require a new heat sealer; any bag that requires an outer polypropylene bag would require a new sewing machine, as well as extra labor if added in conjunction with an inner liner that requires heat sealing. There were concerns about non-perforated bags pillowing with milled product. Conventionally, once CSB+ is bagged it is not re-bagged; using 1000kg bags would require CSB+ be re-bagged at a foreign port. The permutations of the CSB+ supply chain considered in this study are outlined in Figure 15.

Figure 16: Permutations of Yellow Split Pea Supply Chain (Physical Flows)



Yellow split pea food aid processing and shipment looks similar to commercial yellow split pea processing and shipment. Using a bagging machine for woven polypropylene 50 kg bags, peas are dropped into the bag. For commercial orders that use 1000 kg bags, peas are dropped from a clean bin into the bags. The yellow split pea supplier we interviewed anticipated having to add a heat-sealing machine and to slow down the line by one-third for any airtight liner inside a polypropylene bag, to add a heat-sealing machine for any airtight liner, and they were apprehensive of the slippery nature of the thick airtight bags. In an alternate supply chain where yellow split peas are bagged just before ocean shipping, yellow split pea suppliers will contract with port warehouses to package yellow split peas for them, and ship the peas in bulk hopper cars. Yellow split pea supply can be thought of as representative of bagged sorghum supply: both commodities require 50 kg woven polypropylene bags, both suppliers can postpone bagging until a port warehouse, and both suppliers tend to be smaller firms. The yellow split pea supply chain is outlined in Figure 16.

In the instance where a commodity supplier postpones bagging until a port warehouse, effectively sub-contracting the function, the bagging process looks similar. Both FFP and KCCO explained and confirmed the port packaging process; we interviewed two port warehouses that serve as trans-shipment bagging and containerization points, as well as one that serves as a break-bulk loading point. The commodity supplier or ocean freight carrier coordinates the port and foreign warehousing, but typically the ocean freight carrier coordinates all activity at the port (e.g. Maersk has contracts with warehouse providers at ports across the world). Some ports, like the port of Houston, have multiple warehouses that are approved, while others only have one approved warehouse (USDA 2015).[15]

The first warehouse that we interviewed offers bagging services, containerization services, and break-bulk loading. It can receive shipments by rail and truck, and bulk or bagged shipments from each modality.

[15] Cities with approved port facilities for handling cargo include Beaumont, TX; Chicago, IL; Chickasaw, AL; Houston, TX; Jackson, FL; Lake Charles, LA; Longview, WA; Milwaukee, WI; Mobile, AL; Norfolk, VA; Savannah, GA; Tacoma, WA.

When commodities arrive at the firm in bulk, it is moved by conveyor to a hopper and then bagged. The firm runs the bagging machine for 25 kg multiwall paper or 50 kg woven polypropylene bags somewhat infrequently for food aid (e.g. every 2 months). They also fill commercial orders in 1000 kg bags. They anticipated having to add one extra laborer and a heat sealing machine for any airtight liner inside a polypropylene bag, and having to slow the line down. Assuming a thick airtight bag could be fed through a heat-sealer rapidly, it should not slow down their line, though it would likely require a new heat sealer.

When commodities arrive at the firm in bags, if they are bagged in airtight bags, the firm would have to unload the cars and take care to not puncture the bag. They do not have the infrastructure to drive forklifts into boxcars, thus would not be able to unload 1000 kg bags from boxcars, though they have the infrastructure to drive forklifts them into trucks, thus 1000 kg bags could be sent in trucks. The warehouse sends much of its food aid in containers, though a portion goes via a break-bulk loader (a "spiralveyor") into a ship's hull. They load two containers at a time. While loading commodities in airtight bags in containers, the firm's workers would have to be careful not to puncture any bags. Rigging a container liner would take extra time and labor. They currently do not have the infrastructure to load 1000 kg bags into break-bulk holds.

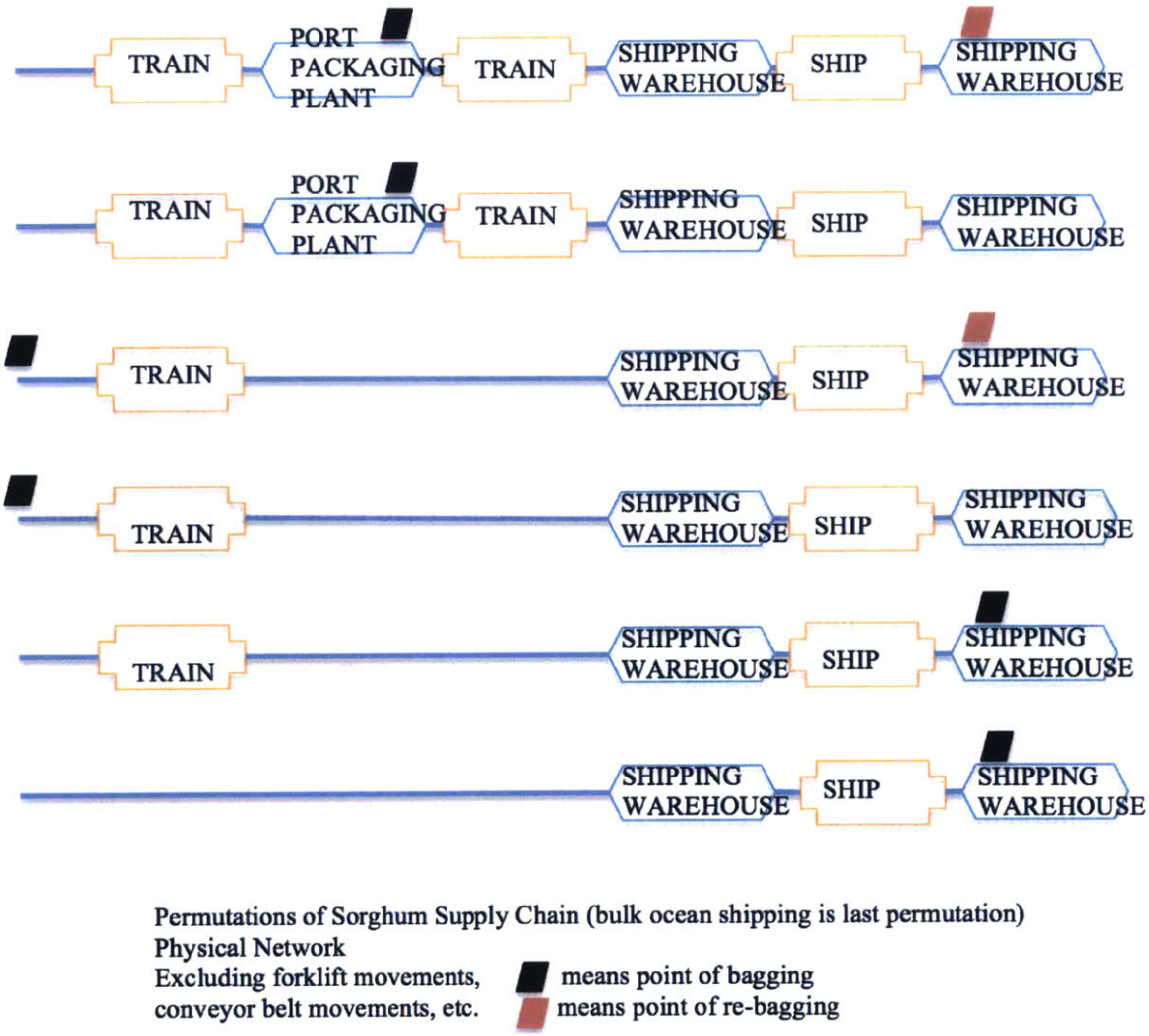
The second warehouse that we interviewed has similar process and anticipated similar adjustments to its lines given new packaging options.

7.4.3.2 Bulk grain supplier overview

FFP, through data and several conversations, illustrated the bulk ocean shipping process. In the case of bulk ocean shipping, a supplier typically has bulk stock at a port. Loose commodity is loaded onto the ship using a conveyor and hose alongside empty bags. USAID only ships a few commodities in bulk, though bulk ocean shipping constitutes the vast majority of the shipping by volume. In FY 2014, bulk ocean shipping accounted for 842,270 MT, which is 72% of all aid shipped. This 72% represents commodities like wheat, corn, sorghum, and rice (of which there are six varieties shipped).

The commercial bulk grain market depends on firms with large economies of scale. We interviewed one large bulk grain company based in the South. They can process about 300 trucks per day and about 21 rail cars per hour, which is about 36,000 bushels per hour.[16] About 80% of what they receive by volume is via rail, and about 20% of what they receive by volume is by truck. The grain is loaded into one of about fifty silos. They have a capacity to load 1,200 MT per hour with two spouts onto a bulk ship. Any new packaging would not affect their operations. Permutations of bagged and bulk sorghum are shown in Figure **17**.

Figure 17: Permutations of Sorghum Supply Chain (Physical Flows)



[16] Bushels are commodity-specific units. A bushel of wheat, for example, is 27 kg. Thus the plant can process about 972,000 kg of wheat or 972 MT of wheat per hour.

7.4.3.3 Unloading at a foreign port

Over several conversations, FFP illustrated the unloading and customs process for bagged commodities at a foreign port. It is just after unloading a ship and clearing customs that the bagged and bulk supply chains converge.

When the bagged commodities are shipped in containers, the container is off-loaded. This off-loading occurs at a container yard, in which the customs process is observed. When a break-bulk ship arrives at a discharge port, bags are off-loaded and typically pass through a customs warehouse. As the supply chain currently exists, there is no re-bagging step in which a 1000 kg bag is re-bagged into a 25 kg or 50 kg bag.

FFP also provided insight into the bulk grain discharge process. When a ship arrives at a foreign port with a bulk shipment, bagging machines are dropped or moved alongside the ship and the grain comes off on a conveyer belt. Grain is bagged right alongside the ship. In the case of bulk shipments, the customs inspection occurs on the ship. Bulk shipments account for much of the FFP tonnage. At this point, the two supply chains—bulk and bagged—effectively converge.

Commodities designated for pre-positioning go to a port warehouse, which USAID contracts. In some instances, ocean freight carriers are made responsible for transport far inland, while in other instances the PVO takes custody of the shipment. Often upon arriving at a foreign warehouse the commodity will be fumigated. The fumigation risk of poorly applied fumigant is not primarily at the port of entry, but rather the risk is greater inland at the secondary and tertiary warehouses of those PVOs.

7.5 Contracting, capacity, and behavioral mechanics of supply chain

This procurement case study illustrates the trade-offs and relationships between packaging options that require additional labor, capital, or time for filling, sealing, or port handling.

7.5.1 Testing capacity

The contracting mechanics between USDA and USAID and, respectively, commodity contract and ocean shipping awardees, as well as USAID's pre-positioning warehouse operators, have room for nuance. Through a series of line items in sales orders it is possible to specify material handling requirements, such as processes for re-bagging 1000 kg bags or handling delicate, airtight 25 kg and 50 kg bags. These sales orders are then translated to invitations to bid on commodity and ocean shipping contracts. USDA also provides guidelines, though mostly focused on the make of the bags, in Commodity Requirements readily available on their website (USDA 2016). The way the procurement system currently exists, USAID can specify in what bags commodities are to be bagged and if they are to be ocean shipped.

While USAID and USDA can specify certain handling processes in contracts, for the average shipment USAID and USDA have little control over several dimensions of the supply chain:

1. Commodity supplier bagging line process
2. Commodity supplier loading process
3. Bag supplier
4. Trans-shipment warehouse bagging line process (if applicable)
5. Trans-shipment warehouse unloading process (if applicable)
6. Trans-shipment warehouse loading process (if applicable)
7. Ocean shipping mode if bagged: container or as break-bulk
8. Transport time to port from supplier
9. Transport time to packaging warehouse from supplier (if applicable)
10. Transport time on ocean
11. Domestic port of origin
12. Foreign port unloading process
13. Foreign port bagging process (if applicable)
14. Foreign port customs storage time

All of these aspects have a bearing on the success of the proposed new packaging. As noted above, some requirements may force contactors with bagging lines to adjust rates or introduce new machines like heat sealers, or port warehouses to use new material handling processes like more delicate handling for airtight bags or forklifts for 1000 kg bags.[17]

There is precedent for enforcing bagging, handling, and shipment requirements. Specifically, there are guidelines for which party is responsible if commodities are

[17] To be clear, the issue of new machinery, adjusting output rates, and new handling processes apply in the United States as well as abroad: we recognize this in our cost analysis, as it considers the costs of new bags both domestically and internationally. By focusing on the handling capacity of foreign ports, we are asking questions like does a foreign port have affordable forklifts to rent? Does a foreign port have the infrastructure to re-package an 1000 kg bag into 50 kg bags without contaminating the commodity with moisture? In other words, with moderate foreign supply chain visibility, we are unsure of the capacity of foreign ports, but this capacity has a significant bearing on the success of any new packaging option.

damaged or contractual agreements are not fulfilled, FFP has explained in conversations. If commodities are damaged under the commodity contract, USDA is responsible for working with the parties in the commodity contract to determine any remuneration. Under an ocean shipping contract, the commodities are shipped "under the care and custody" of an ocean carrier. With the exception of commodities designated for pre-positioning, USAID technically never takes custody of the commodity. If commodities were damaged under the shipping contract, USAID in the case of a pre-positioning shipment or the PVO in the case of a programmed shipment would be responsible for working with the parties in the ocean-shipping contract.

Some bagging and handling requirements with the new packaging will become more burdensome. Currently USAID's supply chains do not involve re-bagging 1000 kg bags into 25 kg multiwall paper bags or 50 kg woven polypropylene bags at foreign ports, and so the capacities to re-bag commodities are not known. Even in the United States some firms expressed apprehension with 1000 kg bags because of how their receiving and loading docks are configured. However, in the United States, in the worst case scenario, a firm ill-equipped to handle 1000 kg bags may bid for a contract, sub-contract the function to a port warehouse who has that capacity, and pass that cost back to USAID. In Djibouti and Durban the question is not at what cost may 1000 kg bags be handled, but instead is there the machinery, infrastructure, and processes to handle 1000 kg bags at all. Similarly, the food aid bags currently used are somewhat sturdy and can become perforated without loosing much of their resistance to insects: they are not particularly resistant to insects in the first place, and thus fumigation is a necessary step through the upstream and downstream portions of the supply chain. However, the capacities of ports like Djibouti and Durban to handle delicate bags that may provide greater resistance to insects—without fumigation, but only if they remain perfectly intact—are also unclear.

7.5.2 Understanding costs

In this case study, the cost analysis is actually more complex than the capacity analysis. In the capacity analysis the unit of measurement is the faithfulness of the implementation of the contract, whether that be contractual clauses about cleanly re-bagging or delicately unloading bags.

The cost analysis is more opaque. The procurement will give USAID intuition into the costs of using new packaging options in two ways. First, USAID can compare commodity and ocean shipping contract bids and awards ($/kg sent) under the current system and that of the pilot procurement. However, it is possible fixed costs may either be substantially passed onto USAID and USDA in the bids or not-at-all passed onto USAID and USDA in the bids for the contracts. As a simple example, if a contractor at the Port of Djibouti has to buy a forklift for the procurement, it is possible that she will charge USAID for the cost of that forklift in her bid to unload the small procurement. It is also possible that there will be a learning effect in which the rates of sealing, loading, unloading, etc. improve and costs decrease with the number of bags processed. As another simple example, as port workers in Durban get better at handling the slippery airtight bags, they will be able to unload bags at a quicker rate. In this case, the cost per bag would be expected to diminish over weeks or months.

Thus, the second way we can get intuition from the procurement is to visit supply chain actors and build up a cost analysis. The accounting principle of 'with or without' is the basis of this analysis: given a supplier's baseline output of kg per day, laborers required, and machinery required, each proposed packaging option can be evaluated in terms of its effect on the output rate, or labor or machinery required. Changes in output rates, labor, and machinery can all be converted into costs saved or incurred, and thus new packaging options can be compared across the same unit of measurement: $/kg sent. In Figure 18 and Figure 19 each point in the supply chain at which a touch happens is noted with an arrow. Field interviews with suppliers, baggers, unloading teams, trucking teams, and warehouse operators at this points are necessary to understand how new packaging would impact costs.

Figure 18: Domestic bagging supply chain starting at supplier and ending at ship

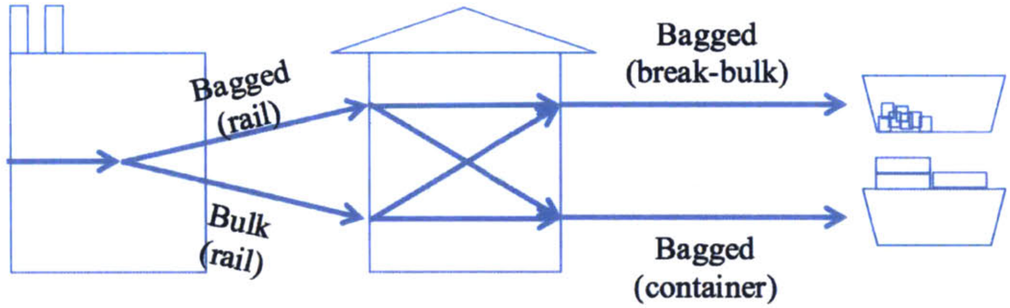
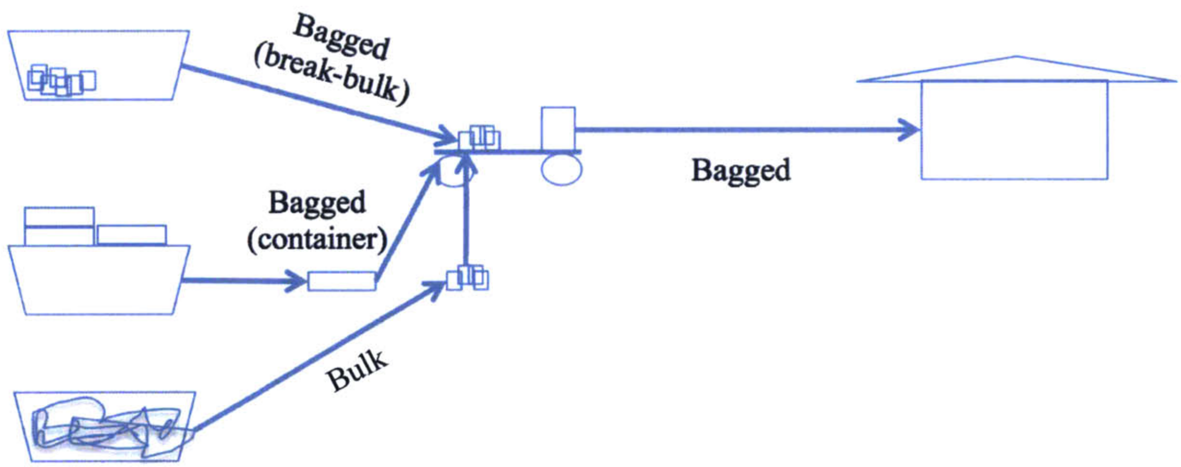


Figure 19: Foreign bagging supply chain beginning at ship and ending at warehouse (Excluding re-bagging 1000 kg bags)



7.6 Case conclusion

The ports of Djibouti and Durban are active stocking and waypoints for food aid to the Horn of Africa and Southern Africa, respectively. Shipments transiting these ports face quality challenges that resemble the challenges of other food aid shipments globally. The two ports, in which USAID has moderate supply chain visibility and which have different handling and bagging capacities, present a compelling case for a procurement experiment. About $1 million is being bought and shipped through the ports, illustrating the capacities and costs of contract awardees and their sub-contractors to handle improved food aid packaging.

8 Discussion

8.1 Section introduction

This section reviews the units of measurement and analysis common to both case studies, after which it explores how both case studies can be explicitly framed in experimental terms with research questions, hypotheses, experiments (i.e. procurements), and analysis. For illustrative purposes, this discussion proposes one simple stylized model derived from each case that is based on the insights from procurements. This discussion contrasts the two procurements, one designed by an organization and *ex post* analyzed by researchers through the lens of experimentation, and one that was designed by researchers in experimental terms and analyzed as it was implemented. Finally, this section revisits the initial research question of the thesis: how can experimentation with procurement reveal capacities and costs of supply chains in developing economies. Returning to Barratt's (2011) discussion of inductive case studies, this section reiterates the inductive reasoning used to build theory around the use of experimentation with procurement to design supply chains in developing economies.

8.2 Units of measurement and analysis

The units of measurement of interest across these two case studies are the capacity of firms to abide by a contractual obligation—whether that be a manufacturing schedule or handling requirement—and the price or cost per kilogram of meeting that obligation (Yin 2003). With the World Food Programme (WFP), this is a case of a supplier meeting a production or distribution schedule, with an exploration of the underlying behavior, incentives, and manufacturing capacities that may have contributed to their production rates. With Food for Peace (FFP), this is the case of a contractor or sub-contractor being able to handle large or delicate bags at ports, and the incremental cost that each type of bag might pose to the handler (Dube and Pare 2003). Having roughly consistent units of measurement across both case studies allows for the unit of analysis—the design of the procurement and the supply chain design insights from it —to be grounded in common empirical terms.

8.3 Framing the WFP procurement in terms of experimentation

In their 2014-2015.project, WFP tested the manufacturing capacity of three separate airtight storage supply chains models and gained information about prices and costs of products. Only the airtight bag supply chain existed before the project and so there were several unknowns about the metal and plastic silo supply chains' capacities and costs. WFP found that the plastic silos out performed the metal silos and that airtight bags out performed the plastic silos in terms of the immediate price to the farmer per kilogram of storage capacity and the supplier's reliability. When compared over some time horizons and re-purchase rates, plastic silos can be cheaper than airtight bags in terms of present value price to the farmer per kilogram of storage capacity. (These calculations do not speak to return on investment per kilogram of stored crop, though assuming they all work equally well the return on investment should be the same.)

WFP teases out three basic criteria about the products and sector using experimentation with procurement: (a) the immediate price to a farmer per kilogram of storage capacity of three different products, which is important given that Ugandan farmers are poor and have little access to affordable credit, (b) the present value price to a farmer of storage over a fixed time-horizon with re-purchases, which is important to determine the cost of the intervention from the farmer's perspective and (c) the capacity of the supply chain to reliably provide the product, which is important to satisfying future demand and adjust project planning. To some degree WFP conducted due diligence for farmers and prospective crop storage distributors, as its procurement revealed costs and capacities.

From this procurement one could argue that in fact WFP only found the price to the farmer per kilogram of storage capacity and the capacity of the supply chain to reliably provide that product in the highly artificial context in which WFP inundated manufacturers and the distributor with orders.[18] Thus an argument that might weaken the findings from experimentation with procurement—and other experimentations with

[18] There is a caveat here that further elevates this concern: midway through the project the World Food Programme began shifting some demand away from some metal silo manufacturers toward the more reliable manufacturers, so the independence assumption does not totally hold. However, what we did not observe was likely an even greater inundation of orders on the metal silo manufacturers thus even more delays. Thus while the magnitude of conclusions about the different supply chains may have changed had they not shifted demand—metal silo manufacturers may have further under performed—the absolute conclusions— airtight bags were more reliably produced than plastic silos which were more reliably produced than metal silos—stay the same.

procurement—are that if the project was completed over a longer timeline, or with more training and earlier notice of orders, the capacity of suppliers may not be a concern. One World Food Programme respondent noted,

"This is a development project on a humanitarian timeline"

To this critique I argue that a mature Ugandan airtight storage sector would exhibit brief, intense selling periods. Demand for airtight storage would quickly rise around harvests when farmers have money from some crop sales to buy storage and are focused on preserving the quality and quantity of unsold crop. Research on inputs like fertilizer show that attention to an agricultural input often occurs right when the input is needed, which in the case of fertilizers is right around the planting season (even though this is not always when money is available) (e.g. Duflo *et al.* 2010). In the case of airtight storage, this would be right around the harvest season. Coulibaly *et al.* (2012) also support the notion of an intense single sales period for storage, "Risk sharing strategies are needed for the manufacturers and distributors of [airtight] bags." Furthermore metal silo manufacturers are unlikely to address capacity constraints by producing such a high-value product on a make-to-stock basis given their levels of risk aversion and working capital requirements. Thus any capacity constraints experienced during the WFP project may be experienced during a storage season in a mature crop storage market.

More generally, I argue against this critique by suggesting that even in a market that does not experience brief, intense selling periods it is useful to understand manufacturing capacity and bottlenecks. By inundating manufacturers and the distributor with orders, WFP learned that sheet metal wholesalers do not keep substantial buffer stock of the sheet metal used for silo manufacturing, that even distributors who keep ample buffer stock appear to have minor challenges servicing all demand, and that changeover costs may be high for plastic silo manufacturing, thus mechanisms to batch order delivery and pick-ups may help reduce costs. These constraints are all useful in designing new crop storage supply chains.

It is also possible to argue that in fact WFP only found the price per kilogram of storage capacity of the product and the capacity of the supply chain to reliably provide the product given that this was a new product. The prices and the reliability of production or distribution of new products vary with time, often with prices decreasing and reliability improving over time. It is possible that these suppliers could experience learning effects that decrease manufacturing or distribution costs as well as increase reliability. To this critique I argue that my results based on available data may not capture the effect that learning may have on prices and reliability. In this way just one procurement is an imperfect tool to understand capacities and prices.

8.6.1 Phrasing in terms of experimentation

It is possible to phrase the WFP project in terms of experimentation. As each product supply chain was mostly independent of the others, the World Programme effectively ran an experiment with their procurement.

Table 16: WFP Project in Experimental Terms

	Wholesaler	Manufacturer	Distributor	Orders
Metal Silo	2 Inputs Wholesalers - Kampala	6 Manufacturers - Across Uganda	-	3,038
Airtight Bags	-	1 Manufacturer - Philippines	1 Distributor - Kampala	6,326
Plastic Silo	2 Input Wholesalers - Middle East, South Africa	1 Manufacturer - Kampala	-	27,064

This procurement could have been more explicitly written in terms of experimentation:

Research question: Which of the three airtight storage supply chain models in Uganda produces products with the lowest immediate and present value price to farmers and with the least capacity issues? How should future storage-sector facilitation, and in particular supply chain design, be conducted?

Hypotheses: (1) Products from large firms will be produced or distributed more consistently than products from small firms and (2) storage produced or distributed by large firms will be priced lower than storage produced by small firms ($/kg stored).

Experiment: On a schedule that resembles the quick airtight storage selling period, procure 27,064 airtight bags made in the Philippines and distributed by a Ugandan distributor, 7,437 metal silos made by six manufacturing firms supplied principally by two metal sheet suppliers, and 6,362 plastic silos made in Uganda by a manufacturer supplied by firms in the Middle East and South Africa.

Results: Using data from WFP and the long-haul transporter as well as interviews with various supply chain actors, it appears that inconsistent production with metal silo manufacturers exceeded that of the plastic silo manufacturer and the airtight bag distributor. It also appears that in terms of the immediate price per kilogram of storage to the farmer, airtight bags are cheaper than plastic silos, and plastic silos are cheaper than metal silos. Under some time-horizons and re-purchasing schedules, plastic silos have a lower present value price per kilogram of storage to the farmer.

Supply chain design questions for further research[19]: Can metal silo manufacturing be centralized like plastic silo manufacturing? Can agreements with metal sheet suppliers be negotiated in advance of production to ensure stock and reduce production delays? How do the three product supply chains compare when the cost aspect considered is not price at the manufacturer's or distributor's gate but price inclusive of transport to the first major town?

8.4 Framing the FFP procurement in terms of experimentation

In conjunction with USAID, we designed a partial-factorial experiment to determine the effectiveness of new packaging in food aid supply chains. The goal was to determine how handling capacities would impact the cost-effectiveness of new packaging options. To do so we designed a procurement of three commodities, selected as representative products for the three major product groups which USAID sends, and are sending the three commodities to two countries, selected on the basis of lead time, average temperature, and average and variance of humidity. Sorghum was sent as a bagged product as well as a bulk product; all bagged commodities were sent without dictating whether the shipments go on a break-bulk carrier or container carrier with the exception of a few shipments that were to be sent in a lined container.

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[19] Of note here, I am not independently proposing these ideas: well in advance of this thesis, WFP proposed and answered many of these follow-on supply chain design questions over the second iteration of the project. WFP experimented with supply chains that included centralized metal silo manufacturing, and working with manufacturers and distributors to provide their own long-haul transport to major towns near farmers. This is the epitome of iterative supply chain design, and WFP's organizational culture – characterized by flexibility and operational innovation – allowed for them to iterate on their supply chain design based on procurement insights.

Table 17: Commodities considered and as a percent of food aid

Commodity	Category	Total Quantity Shipped 2015 (MT)	Percentage of Total FFP Food Aid (%)
Corn Soy Blend Plus	Milled	45,000	4
Split Yellow Peas	Pulse	75,000	7
Sorghum	Grain	570,000	50

It is possible to argue that in fact FFP will only find ports' capacities to handle new packaging conditional on this packaging being a new material requiring new processes at ports: new processes are rarely rolled out in a smooth and low cost manner. In other words, it is also possible that there will be a learning effect in which the capacities, costs, and rates of sealing, loading, and unloading improve over time. This is not unlike the WFP procurement: that was introducing a new product in the Ugandan manufacturing sector and this is introducing a new product in the port handling space. To this critique, much like in the WFP case study, I argue that my results based on available data may not capture the effect that learning may have on costs and capacity. Again, I concede that in this dimension one procurement is an imperfect tool to understand capacities and prices.

In effect FFP is also conducting an exercise in supply chain due diligence with commodity contract awardees responsible for the procurement of the packaging and with ocean freight contract awardees as they are often responsible for moving commodities through foreign ports with contractors and sub-contractors.

8.6.1 Phrasing in terms of experimentation

We are implementing a partial-factorial design to determine how new packaging interacts with existing handing capacity, given contractual language and guidelines that are designed to maximize the awareness of appropriate handling processes. Table 3 summarizes the packaging and shipment options in the design. With ten domestic new packaging options, applied across three commodities and two foreign ports, we have 60 domestic new packaging permutations; with four bulk bagging options for sorghum applied across two foreign ports, we have 8 bulk shipment permutations. In total we have 68 shipments.

Table 18: Experimental Design

	Bag (Domestic)	Bag (Foreign)	Container Liner	Fumigate
Bagged	Untreated WPP or MWP	Same as Domestic	N/A	BAU
	Untreated FIBC	Untreated WPP or MWP	N/A	BAU
	CPES	Same as Domestic	N/A	No
	TCPES	Same as Domestic	N/A	No
	IGR Treated WPP or MWP	Same as Domestic	N/A	No
	FIBC with PE	CPES	N/A	No
	FIBC with PE	TCPES	N/A	No
	IGR Treated FIBC	IGR Treated WPP or MWP	N/A	No
	Untreated WPP or MWP	Untreated WPP or MWP	PET	No
	Untreated FIBC	Untreated WPP or MWP	PET	No
Bulk	N/A	Untreated WPP or MWP	N/A	BAU
	N/A	CPES	N/A	No
	N/A	TCPES	N/A	No
	N/A	IGR Treated WPP or MWP	N/A	No

WPP	Woven Polypropylene Bag	CPES	Continuous Polyethylene Bag
MWP	Multiwall Paper Bag	IGR	Insect Growth Regulator
FIBC	Flexible Intermediate Bulk Container	PE(TL)	Polyethylene (transit) liner
TCPES	Thick Continuous Polyethylene Sheet Bag	BAU	Business as Usual

This procurement can be written in terms of experimentation:

Research question: Are new packaging options cost-effective methods of reducing loss in the transoceanic supply chain?

Hypotheses: (1) Packaging options that require additional domestic labor will be more expensive than those that require additional domestic machines ($/kg sent), (2) supply chains that place product in distribution-sized bags earlier in the supply chain rather than later are more costly ($/kg sent), and (3) packaging options that do not require additional handling capacity due to new bag sizes or decreased bag sturdiness will perform better during foreign handling.

Experiment: Procure 1,360 MT of food aid comprised of three commodities going to two foreign ports that are bagged domestically in one of ten packaging options or at a foreign port in one of four packaging options.

As this is an ongoing procurement I cannot presents results; however, it is important to remember that the unit of analysis of this thesis is the procurement itself, which is underway.

8.4 Stylized models from procurement

From procurements it is possible to gain insights into capacities. These insights can be translated into analytical models that capture the nuance of supply chains in developing economies. This section gives suggests one model that can be designed from each procurement.

A stylized model can be written for the WFP case study. In a procurement with perfect contractual fulfillment one would observe,

$$y_t = x_t$$

where y_t is realized production at time t and x_t is the order during time t. The procurement revealed that about one third of production of all metal silos in the WFP procurement was delayed, but only a few percent of the plastic silos or crop bags. One might write an empirically grounded production function for metal silos in period t as,

$$y_t = (1-d_i)x_t$$

Where d_i is the average percent short off a contracted quantity at a pick-up time. This gives us some intuition into the manufactures constraints. To achieve fulfilled orders at the end of every period t one might observe that a production routine such as,

$$\hat{y}_t = (1-d_i)x_t + y_{0,t}$$

would achieve $\hat{y}_t$ where $\hat{y}_t = x_t$ and $y_{0,t}$ is made-to-stock silos produced in advance for period t such that $(d_i)x_t = y_{0,t}$. More generally, the $\hat{y}_t = (a)x_t + y_{0,t}$ can help us think through trade-offs that capacity constrained manufacturers in developing economies face, and mechanisms—such as placing early orders—that large organizations might use to help them overcome capacity constraints. In further procurements, large organizations might begin to experiment with different inputs with this model: extra training, early orders, incentives for on-time production, and penalties for delayed production could all be systematically applied to firms within the cohort of manufacturers. Design of experiments methods can help isolate the effect of different treatments despite small sample sizes.

A similar stylized model could be written for the FFP case study. In a procurement with perfect contractual fulfillment one would observe,

$$w_i = z_i$$

where w_i is the number of bag i leaving the port meeting contractual requirements (e.g. re-bagged, not punctured) and z_i is the number of bag i entering the port. Knowing that b_i of bag i in the FFP procurement were not successfully handled, one might write an empirically grounded handling function as,

$$\hat{w}_i = (1-b_i)\, z_i$$

where $\hat{w}_i$ is the number of bag i leaving the port that meets contractual requirements. Thus if FFP or even a commodity importer wants to observe w_i bags of bag i leaving the port meeting contractual handling requirements, they might send $z_i + b_i z_i + b_i^2 z_i + b_i^3 z_i \ldots$ If $b_i << 1$, $z_i + b_i z_i$ is a good estimate; if $b_i \sim 1$, $z_i + b_i z_i + b_i^2 z_i$ might be more appropriate estimates.

The parameters used in these models—d_i in the case of the WFP model and b_i in the case of the FFP model—would have been difficult if not impossible to elicit from interviews and observation alone. Rather, the method of combining procurement data with rich semi-structured and structured interviews as well as observation allows us to generate insights and build models that reflect phenomena in supply chains in developing economies.

8.5 Procedure, design, and collaboration

This discussion contrasts the two procurement designs. The first is a project designed by an organization's field office and *ex post* analyzed by researchers. The other is an operation that was designed by researchers using design of experiments methods while working with an organization's headquarters.

Table 19: Procurement Cases Presented in this Thesis

	Experimental by design	Not explicitly experimental by design
Designed by researchers	FFP case study	
Designed by practitioners		WFP case study

	Field-based procurement	Headquarters-based procurement
Designed by researchers		FFP case study
Designed by practitioners	WFP case study	

Working with WFP through the 2014-2015 academic year we drafted and refined research questions and hypotheses about their on-going procurement through the fall and spring. Through the fall, these questions and hypotheses were based on challenges and successes with the procurement that were referenced on semi-frequent Skype calls with WFP stakeholders. The first field visit to Uganda in January was to scope the research by administering preliminary interviews with supply chain actors, and the second field visit was entirely focused on data collection via interviews, experiments, and data sharing. We were working to serve as an "honest broker" and so pursued an interesting and unique research and evaluation agenda (Pielke 2007).

In working with FFP through the 2015-2016 academic year we developed a concrete research question in collaboration with FFP—what new packaging is cost-effective—and made our own hypotheses and procurement design. In the case of the FFP procurement, field visits were more focused on data collection and less focused on scoping, as that was more easily completed with frequent phone calls. However, some research scoping was a derivative of some of the domestic fieldwork.

The WFP project, which was run out of a field office, experienced significant operational latitude. When demand for metal silos appeared that it would (further) overwhelm the metal silo manufacturers capacities, WFP instructed its project partners to steer farmer orders toward the plastic silos and crop bags. When farmers began defaulting on their orders, WFP worked with its project partners to arrange creative financing and loan schemes. When it came time to design the second iteration of the project's supply chains, WFP worked with manufacturers to reconfigure the plastic silo so that it was stackable produce a metal silo at one centralized manufacturer. Decisions in the WFP project were quickly operationalized.

The FFP operation, which was run out of the FFP Washington DC office, had latitude in some ways the WFP project did not—but was also constrained in some ways the WFP project did not. The FFP operation was more focused on making USAID and Partner Voluntary Organizations (PVOs) processes better, and less focused on any one particular country or group of beneficiaries (though we selected the ports of Djibouti and South Africa). Eventually buy-in on new packaging options from national governments and food aid beneficiaries will be necessary, but for the procurement we only had to garner USAID mission and FFP regional office buy-in. At the same time regulations were prominent in the procurement process: we navigated environmental regulations, with USAID completing a PERSUAP (explained in Section 5.6) for the insect growth regulator-treated bags; procurement systems, with people across the USDA Kansas City Commodity Office (KCCO) working hard to make procurement in 1000 kg bags feasible; and made-in-America regulations, which involved visits to two firms in the American bagging industry as well as long discussions with the two new packaging providers with whom we are working.

8.6 Return to primary procurement research questions

This section revisits the initial research question of the thesis: how can experimentation with procurement reveal capacities and costs of supply chains in developing economies. Case studies from WFP and FFP show that experimentation with procurement can illustrate capacities and costs within supply chains. As a simple measure of a supply chain, procurements requires bids, and bids give a supply chain designer intuition into the estimated prices of a product in a developing economy. As a more complex measure of a supply chain, procurement can illuminate the capacity of supply chain actors in developing economies to oblige contracts on production or handling. Insights from procurements can be used to better design supply chains of products and interventions, and thus to better allocate budgets across products or within interventions. Donors and implementing partners can use procurements to develop mechanisms to support suppliers and other supply chain actors (e.g. Purchase for Progress farmers), not unlike commercial firms use procurement to conduct supplier due diligence. From the analysis of the case studies, we can "proceed toward theoretical generalizations" using inductive reasoning: experimentation with procurement is a tool that tests supply chain dynamics in developing economies (Ketokivi and Choi 2014, Barratt *et al.* 2011). In practice, there are benefits to *a priori* using experimental methods to design procurements, and costs and benefits to operationalizing that procurement from a field office rather than a centralized headquarters.

8.7 Return to secondary food aid research question

This section returns to the secondary research question of this thesis: how can food aid supply chains be designed using experimentation with procurement to maintain food quality? Supply chain management is central to purchasing and shipping food aid, and so procurement is a useful tool to test various supply chain designs that might improve efficiency or reduce costs. Experimentation with procurement should be used systemically as a tool in both local and regional as well as transoceanic procurement.

There are several supply chain design questions that experimentation with procurement might address:

- *Trial to increase availability of crop storage.* Provide some farmers vouchers for one type of crop bag to 'ensure demand.' Offer two echelons of supply chain actors—retailers and village agents—start-of-season in-kind working capital or end-of-season buyback options for that crop bag. Evaluate supply-side availability and demand-side uptake of crop storage at the end of a harvest season.
- *Partial factorial experiment to evaluate vegetable oil packaging.* Procure several containers worth of vegetable oil, all packaged in different ways, and send to two ports with different handling capacities.
- *Controlled contract experiment with Purchase for Progress Farmers*: vary terms of contracts with Purchase for Progress farmers (or large and institutional suppliers) in some districts (or countries) and hold contracts constant in other districts (or countries). The goal of varying terms of contracts is to reduce default rates. Hypothesizing that crop spoils while farmers are waiting for a pick-up, or opportunities to side sell emerge during delayed pick-ups, contracts could include

scheduled pick-ups, unannounced pick-ups, and an option where farmers can call and get a pick-up at their convenience within two days.

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