Warehouse Receipt Financing for Smallholders in Developing Countries: Short on Logic, Long on Imagination

Mario J. Miranda
Francis M. Mulangu
Francis H. Kemeze*

November 21, 2017

Abstract

A warehouse receipt is a financial instrument that confers security interest in a commodity stored in a warehouse, allowing the commodity to serve as collateral for a loan. Warehouse receipt financing has been promoted by many development economists and practitioners as a common-sense solution to one of the more fundamental marketing problems faced by poor agricultural producers in the developing world. The primary argument is that smallholders, lacking access to affordable credit and dependable storage facilities, are unfairly forced to sell their surplus at harvest when prices are generally at their lowest. Warehouse receipt financing, in theory, permits smallholders to store their surplus safely in a modern warehouse, to sell at a later date when prices are higher, while allowing them to use the stored commodity as collateral to secure a loan to finance household consumption and investment needs in the interim. However, in practice, warehouse receipt financing generally has not been embraced by smallholders in developing countries in which it is available. Here, we develop and analyze a formal stochastic dynamic model of seasonal commodity marketing that exposes the transaction cost and risk reallocation problems that undermine the benefits of warehouse receipt financing to smallholders.

*The authors are, respectively: Professor, The Ohio State University, Columbus, OH; Senior Economist, Millennium Challenge Corporation, Washington, DC; and Post-Doctoral Fellow, International Food Policy Research Institute, Accra, Ghana. We gratefully acknowledge financial support for this research from the International Food Policy Research Institute.

1 Introduction

In its most elementary form, a warehouse receipt is simply a document issued by a warehouse operator as evidence that a specified commodity of stated quantity and quality has been deposited at a particular warehouse location by a named depositor. When backed by an appropriate legal and regulatory framework, a warehouse receipt becomes a formal financial instrument that allows the depositor to confer a security interest in the stored commodity to another party without requiring physical delivery. This enables the warehouse receipt to serve as possessory collateral for a loan.

Warehouse receipt financing has been promoted by many development economists and practitioners as a solution to one of the more fundamental marketing problems faced by poor agricultural producers in the developing world (e.g., Weidemann, 2000; IFAD, 2008; USAID, 2013b; IFC 2015). The primary argument is that smallholders, lacking access to affordable credit and dependable storage facilities, are unfairly forced to sell their surplus at harvest when prices are generally at their lowest. Warehouse receipt financing, in theory, permits smallholders to store their surplus safely in a modern warehouse, to sell at a later date when prices are higher, while allowing them to use the commodity as collateral to secure a loan to finance household consumption and investment needs in the interim.

The following excerpt from an International Fund for Agricultural Development (IFAD) Brief, which acclaims the impacts of a warehouse receipt pilot project it initiated in Tanzania in 2002, conveys the optimism shared by many in the development community regarding the benefits of warehouse receipt financing for smallholders:

> "In Tanzania, ... traders who can afford adequate storage sites often take advantage of smallholders' constraints: they collect agricultural products at very low prices and sell them during the most profitable market conditions. [As a consequence of the IFAD project,] small-scale farmers were able to store their produce in warehouses during harvest, when prices are relatively low, and release them to the market at better prices during periods of low supply. After the warehouse receipt system was introduced, farm gate prices increased up to 300 percent."

However, warehouse receipt financing has generally failed to deliver the benefits to smallholders promised by many of its proponents. The benefits of the IFAD pilot project, for example, have yet to prove sustainable or scalable. Today, in Tanzania, warehouse receipts are used almost exclusively

by large traders, processors, and exporters, at best indirectly benefiting only a small number of smallholders who are contractually integrated into the industrial value chain for highly processed and/or export commodities, and who, under contract, continue to sell their grain at harvest (William and Kaserwa, 2015).

In practice, warehouse receipt financing involves significant transaction costs and complex risk transfers that undermine its value to the smallholder. Rising prices during the marketing season alone will not guarantee that a smallholder will benefit from warehouse receipt financing. Prices must rise sufficiently to cover the costs of storing and maintaining the commodity in the warehouse, including the costs of security, insurance, quality control, utilities, and rental of warehouse space. Prices must also rise sufficiently to cover a host of transaction costs incurred upon depositing the commodity in, and withdrawing it from, the warehouse, including the costs of grading, cleaning, drying and bagging the commodity to meet legislated quality standards required for the issue of a warehouse receipt.

In addition, storing a commodity in a warehouse places the smallholder in the role of a speculator, potentially allowing him to benefit from commodity price increases during the marketing season, but also exposing him to the risk of commodity price declines, a risk that he is ill-equipped to bear due to his limited wealth and lack of access to efficient credit and risk markets. Pledging the stored commodity as collateral to a lender via a warehouse receipt affords some price risk protection to the smallholder in the form of an option to default on his loan, should the market value of the pledged commodity, net of storage and transaction costs, fall below the smallholder's debt obligation. However, the lender accounts for the possibility of default by raising the interest rate charged on the loan and/or offering a loan amount that is only a fraction of the market value of the commodity stored in the warehouse. As such, the smallholder inevitably is forced to retain much of the risk of price declines, or otherwise compensate the lender for assuming a share of it by paying higher interest rates.

Many informative monographs and technical reports on warehouse receipt financing in developing and transition economies have been published by international organizations in recent years. IFC (2013) and UNCTAD (1996) provide thorough expositions of how warehouse receipt financing operate in developing countries. ACE (2013) and FAO (2015) examine the legal and regulatory challenges that arise in the establishment of functional warehouse receipt systems in developing countries. Coulter (2014a) discusses the importance of effective warehouse collateral management. Onumah (2010) and USAID (2010) survey recent efforts to establish warehouse

receipt systems in Africa, and Höllinger, Rutten, and Kiriakov (2009) survey recent efforts to establish warehouse receipt systems in transition economies. However, few articles on warehouse receipt financing have appeared in the peer-reviewed economics literature (Coulter and Onumah, 2002; Larson, Anderson, and Varangis, 2004; Williams, 1984). And none of them provide a rigorous theoretical framework for the analysis of warehouse receipt financing, commodity storage, and smallholder marketing dynamics.

This paper, to our knowledge, is the first to formally model the inherently dynamic decisions that must be undertaken both by smallholders, in employing warehouse receipts in their marketing strategies, and by lenders, in setting their credit policies for smallholder loans secured by warehouse receipts. We employ dynamic programming to solve and simulate the model for a representative smallholder, with parameters calibrated to reflect the stylized facts of a typical northern Ghanaian maize farmer who consumes a portion of the grain that he harvests, but in a typical year also produces a modest surplus that he can sell to finance household non-grain consumption and investment needs. Despite being applied to a representative smallholder, our analysis yields clear insights into how warehouse receipt financing is undermined by transaction cost and risk reallocation problems, aggravating factors that are often ignored by its proponents. Our findings provide a compelling explanation for why poor smallholders in developing countries generally have been excluded from warehouse receipt financing, despite the many claims made regarding its apparent benefits.

In the following section, Section 2, we provide a general background discussion on warehouse receipt financing in developing countries. In Section 3, in order to render our discussion more concrete, we examine the warehouse receipt system in Ghana. In Section 4, we present a stochastic dynamic model of smallholder seasonal marketing decisions that explicitly captures the transaction costs associated with warehouse receipt financing and the smallholder's option to default on loan repayment. In Section 5, we commit to specific functional forms and calibrate the model parameters to reflect the stylized facts of a representative poor Ghanaian maize grower. In Section 6, we analyze how smallholder optimal marketing decisions depend on prevailing market conditions, expected appreciation in and the volatility of the market price over the marketing season, the smallholder's aversion to risk, storage and transaction costs, and the interest rates charged and collateral discounts imposed by lenders on warehouse receipt collateralized loans. In Section 7, we turn to the lender's problem and ask how the lender must set interest rates and discount the value of the grain offered as collateral to ensure an acceptable return on a loan secured by a warehouse receipt. In

Section 8, we summarize our findings, provide recommendations for promoting warehouse receipt financing among smallholders in developing countries, and offer suggestions for further research.

2 Background

Warehouse receipt financing is not new. Surviving Mesopotamian clay tablets document the use of warehouse receipts issued against stored grain as money in as far back as 2000 BCE (Geva, 2011). In the USA, warehouse receipts were issued by the Chicago Board of Trade as early as 1856 and continued to be used in unregulated form until they were formally organized under the Federal Warehouse Act of 1916.[1] Many countries in Latin America and Western Europe have long-established warehouse receipt financing systems based on legislation dating back to the start of the 20th century (Wehling and Garthwaite, 2015).

A warehouse receipt may be negotiable or nonnegotiable.[2] A negotiable receipt permits the holder to convey full ownership of the underlying commodity to others, effectively allowing the commodity to be traded impersonally and sight-unseen, without requiring physical delivery. A well-regulated negotiable warehouse receipt system is essential for the functioning of a centralized commodity exchange, a goal of many developing countries seeking to modernize their agricultural value chains and promote export of their agricultural products (USAID, 2010; USAID, 2013a). Negotiable warehouse receipts, however, effectively are for the exclusive use of larger traders, processors, and exporters who are fully integrated into the industrial value chain. High transaction costs, minimum volume requirements, and stringent quality provisions render negotiable warehouse receipts of little use to average smallholders or smallholder groups, who typically market their lower-quality grain in relatively small quantities, sometimes via a middleman, in regional markets that do not confer compensatory price premiums for higher quality grain.

In contrast, a nonnegotiable receipt conveys limited ownership rights only to a named registered holder. With a nonnegotiable warehouse re-

[1] A US National Bureau of Economic Research monograph, Jacoby and Saulnier (1944), provides an interesting historical account of warehouse receipt financing in the USA prior to World War II. Junior members of the research staff that produced the report included future Nobel laureates Simon Kuznets and Milton Friedman.

[2] Coulter and Shepherd (1995), Annex 2, provides a lucid explanation of the Common Law principles governing the commercial uses of warehouse receipts, including their use as collateral.

ceipt, the depositor may pledge the commodity as possessory collateral to a lender, while retaining title to (i.e., ownership of) the commodity. Under this arrangement, the lender assumes "constructive possession" of the grain stored in the warehouse. Although the lender does not physically possess the grain, and does not bear title to it, the grain cannot be released from the warehouse without his explicit consent. The receipt entitles the lender to assume ownership of the pledged commodity only if the depositor fails to repay his loan in full by the maturity date, while, at the same time, prohibiting the depositor from withdrawing the commodity from the warehouse until the loan has been fully repaid. Virtually all warehouse receipts currently issued to smallholders in developing countries either are nonnegotiable by matter of law, or are effectively nonnegotiable due to the absence of an adequate commercial infrastructure for the trade of warehouse receipts. The remainder of this paper is devoted exclusively to warehouse receipts issued to smallholders for the purpose of collateralizing marketing season loans.

When a lender grants a loan secured by a warehouse receipt, he must perform due diligence to guard his security interests in the underlying commodity serving as collateral. This is typically accomplished by introducing a third party to the financing arrangement, the collateral manager (UNCTAD, 2003). The collateral manager serves the interests of the lender by assuming "continuous, exclusive, and notorious possession" of the commodity deposited in the warehouse until such time that the lender authorizes its release. The manager's initial duties include confirming that the receipt has been legally registered, to ensure the commodity has not been pledged to another lender, and verifying that the commodity documented on the receipt exists, is of the stated quantity and quality, and is safely deposited in the warehouse.

During the life of the loan, the collateral manager is further responsible for monitoring the commodity deposited in the warehouse to ensure that it is: properly maintained to prevent loss from pests and fungus; insured against damage due to negligence or common perils such as fire, flood, and windstorm; and secure from theft, pilfering and fraudulent selling, or withdrawal of the commodity from the warehouse by the depositor without the consent of the lender. The collateral manager may be an independent inspection/surveillance company, though in many cases the warehouse operator serves this role. Under a typical collateral management agreement, the collateral manager is financially liable if the grain is stolen, damaged, or destroyed while under his possession, and thus must be commercially reliable, financially stable and properly bonded.

By way of illustration, consider a grain producer who wishes to store

his surplus in a commercial warehouse whose operator has been authorized to issue warehouse receipts and perform collateral management. A typical sequence of warehouse receipt financing transactions are as follows: 1) the smallholder transports and delivers his grain to the warehouse; 2) the warehouse operator inspects the grain, confirms that it meets basic quality standards, and off-loads the grain; 3) the warehouse operator cleans, dries, and sorts the grain to ensure it meets the standards required for the legal issue of a warehouse receipt, bags the grain, and stores it in the warehouse; 4) the warehouse operator issues a warehouse receipt to the smallholder, documenting the quantity and quality of the grain deposited in the warehouse, the fees due to the warehouse operator upon withdrawal, the date of deposit, and the date by which the grain must be withdrawn without incurring late penalties; 5) the smallholder approaches a lender and applies for a loan, offering the grain documented on the warehouse receipt as collateral; 6) the lender accepts the receipt, assuming constructive possession of the underlying grain, and grants a cash loan with prescribed interest rate and maturity to the smallholder for a specified fraction of the current market value of the grain; 7) on or before the maturity date of the loan, the smallholder finds a buyer for his grain and settles on a sales price; 8) the smallholder and buyer approach the lender and the buyer pays the lender the agreed sales price; 9) the lender deducts the amounts owed by the smallholder to him and to the warehouse operator and pays the remainder to the smallholder; and 10) the lender pays the outstanding charges to the warehouse operator and authorizes him to cancel the smallholder's warehouse receipt and either release the grain to the buyer or issue a new warehouse receipt in the buyer's name.

Transaction costs arise at various stages throughout the warehouse receipt financing sequence. Upon deposit, the depositor must pay for services rendered by: 1) transporters, for onloading and transporting the commodity to the warehouse; 2) the warehouse operator, for offloading, sampling, grading, cleaning, drying, and bagging the commodity and stacking it in the warehouse; and 3) the collateral manager, for certifying the grain and issuing and registering the warehouse receipt. Upon withdrawal, the depositor must pay for services rendered during the storage period by: 1) the warehouse operator, for storage services, including charges for pest control, fumigation, utilities, and use of warehouse space; 2) the collateral manager, for management services, including security, insurance, and quality and moisture monitoring; and 3) a broker, if one is used, to cover the sales commission and delivery to the buyer. The timing of actual cash outlays by the depositor vary. Payment for services rendered upon deposit are often deferred

until the commodity is withdrawn.

3 Warehouse Receipt Financing in Ghana

Warehouse receipt financing can assume varied forms, depending on the regulatory and legal system established for the issue and transfer of warehouse receipts. By way of example, consider Ghana.[3] In 2008, backed by the Government of Ghana and supported by two US Agency for International Development (USAID) projects, a body of Ghanaian producer groups, traders, processors and financial institutions involved in the grain trade formed the Ghana Grains Council (GGC).[4] One of the GGC's articulated missions is to facilitate the integration of smallholders into more competitive markets by establishing a regulated warehouse receipt system in Ghana, with the GGC itself acting as the certification and regulatory agency (Aning, 2015; Coulter, 2014b). The GGC oversees two types of warehouses: larger, "certified" commercial warehouses, which are authorized to issue warehouse receipts, and smaller, "approved" community warehouses, which are not.

For a warehouse receipt to be issued by a GGC certified commercial warehouse, the underlying grain must meet prescribed moisture and purity standards (GGC, 2017). For example, its moisture content must not exceed 12%, it must be free of agrochemical contamination, and its aflatoxin content must not exceed 15 parts per billion.[5] Each certified commercial warehouse must have facilities for drying and cleaning of grain to ensure these standards are met before the commodity is stored and a legal warehouse receipt is issued. Once the grain has been processed to meet the prescribed standards, the certified commercial warehouse may issue a warehouse receipt, valid for up to five months from deposit, which may be accepted as collateral by GGC-participating financial institutions.[6]

[3] In 2015, agriculture in Ghana accounted for 21% of the Gross Domestic Product and 54% of the national labor force. Agriculture in Ghana continues to be dominated by smallholder farmers practicing rainfed agriculture (FAO, 2015)

[4] Supporting USAID projects include the Agrobusiness and Trade Promotion (ATP) and Agricultural Development and Value Chain Enhancement (ADVANCE) projects.

[5] Other conditions apply. For example, the quantity of grain named on a receipt must be at least 2,500 kilograms.

[6] The GGC initially contracted two independent inspection companies, DMT Collateral Management Co. Ltd. and Ecosafe Ghana Ltd., to perform collateral management for all GGC certified warehouses. However, in 2017, the GGC dispensed with their services due to the high cost. At present, essential collateral management functions are carried out by the warehouse operators, with the GGC providing oversight via regular unannounced inspections.

As of April 2017, the GGC had certified twelve commercial warehouses, with a combined storage capacity of 54,600 metric tons, to issue warehouse receipts (GGC, 2017).[7] Weinco Ltd., the largest input supplier in Ghana, accounts for the majority of deposits and borrowing under the GGC certified warehouse receipt system. Through its outgrower scheme, Weinco coordinates more than 12,000 smallholder farmers organized in small groups through its Masara N'Arziki Farmers Association (MAFA). However, MAFA outgrowers do not directly participate in the GGC warehouse receipt system. Participating outgrowers are required to deliver all their grain, save that required for household consumption, to MAFA at harvest, and face tough sanctions that range from expulsion from the outgrower group to court proceedings if they fail to do so. Weinco offers MAFA outgrowers a minimum price guarantee based on cost of production and pays them a market-related price at harvest (Coulter, 2014a). Weinco takes ownership of the stocks delivered by its outgrowers at harvest and stores them in company warehouses for future delivery to contracted processors or sales to institutional buyers.

According to the GGC, through April 2017, certified commercial warehouse operators have issued receipts for 46,942 metric tons of maize, of which 12,555 metric tons have been financed for GH¢ 4.9 million (approximately $1.2 million). However, GGC partner financial institutions have generally refused to accept warehouse receipts as collateral on smallholder loans. The overwhelming majority of warehouse receipts have been issued by the certified warehouse operators to themselves to enable them to use company-owned grain stored in company warehouses as collateral to secure loans to finance their operations and manage their cashflow (Mulangu, Kemeze, and Miranda, 2017).

4 A Model of Seasonal Smallholder Marketing

Consider a typical smallholder who on an annual cycle produces, stores, consumes, and sells "grain".[8] Each year, the smallholder produces enough grain to generate a modest surplus beyond what he needs for his annual household consumption. The smallholder's objective is to market his surplus

[7] Although the legal and regulatory foundations have been laid for GGC-issued warehouse receipts to serve as negotiable instruments of trade, the necessary commercial infrastructure remains non-existent. The GGC plans to establish a centralized exchange for the impersonal trade of grain via negotiable warehouse receipts. However, this goal has yet to be achieved. Until it is, GGC warehouse receipts, in practice, are best said to be nonnegotiable.

[8] Our model could also reasonably be applied to a small farmer group or cooperative.

grain so as to maximize the present value of current and expected future utility derived from purchasing and consuming non-grain goods and services over an infinite horizon.[9] Time is marked in years, with each year divided into two seasons: a "marketing" season $i = 1$, followed by a "lean" season $i = 2$. The marketing season begins with the harvest and ends with the start of the lean season; the lean season ends with the following year's harvest.

The smallholder begins the marketing season with a stock of freshly harvested surplus grain. He must decide how much of this grain to sell at the prevailing market price, how much to store on his farm, and how much to deposit in a commercial warehouse.[10] The smallholder also begins the marketing season with a stock of cash, which he may draw from, supplementing proceeds from grain sales, to purchase non-grain goods to be consumed during the marketing season; alternatively, he may augment his cash holdings with sales proceeds in excess of what he spends on non-grain goods. Cash held for the duration of the marketing season is kept on the farm and earns no interest.

Grain may be stored at no cost on the farm, but suffers post-harvest losses at a given rate over the marketing season. Grain stored in the warehouse does not suffer post-harvest losses. However, the smallholder incurs costs upon depositing the grain in and withdrawing it from the warehouse. If the smallholder deposits grain in the warehouse, he receives a warehouse receipt, which he presents to a lender as collateral to obtain a cash loan equal to a fraction, called the "advance rate", of the market value of the grain. The loan is to be repaid with interest at the end of the marketing season.

The smallholder begins the lean season with a stock of surplus grain stored on his farm, a stock of surplus grain deposited in the warehouse, and a stock of cash. He sells the grain stored on the farm at the prevailing market price. He must then decide whether to repay his loan and sell the grain he has deposited in the warehouse, at a price that may, or may not earn a premium over the prevailing market price for common grain. He does so if the value of the grain, net of outstanding storage and handling

[9] Smallholder cash outlays might include purchase of non-grain foodstuffs and non-food consumer goods; payment of schooling, health care, wedding, and funerals expenses; purchase of fertilizer and seed for the following growing season; and perhaps financing a separate non-farming household enterprise or small business.

[10] "On-farm" generally refers to anywhere on the farmer's property. Stocks stored on the farm could include stocks stored in the farmer's house (very common), in a separate enclosed facility (e.g., a silo), or outside in the open air and covered by a tarp or thatched roof.

charges, exceeds his loan obligation. Otherwise, he strategically defaults on his loan and surrenders the grain to the lender, who assumes ownership of the grain and liquidates it to cover the unpaid loan, at least in part.[11] The smallholder draws from his initial stock of cash and proceeds from grain sales to purchase non-grain goods to be consumed during the lean season, saving the remainder. Cash held for the duration of the lean season is kept on the farm and earns no interest. Grain cannot be carried over from one marketing year to the next.

To fully develop the smallholder's formal dynamic optimization problem, we introduce the following exogenous parameters: u_i, the smallholder's season i utility of function, which expresses utility in terms of the amount of cash spent on non-grain goods during the season; δ_i, the smallholder's subjective discount factor over the duration of season i; θ, the proportion of grain stored on the farm at harvest that is lost by the end of the marketing season; R, the gross interest rate charged on the marketing season loan; γ, the loan advance rate; τ_1, the unit cost of depositing grain in the warehouse at the beginning of the marketing season; τ_2, the unit cost of withdrawing grain from the warehouse at the end of the marketing season; and π, the percent price premium earned on the open market by warehouse-stored grain over farm-stored grain at the end of the marketing season, if any. We also introduce the following exogenous random variables: $\tilde{q}_1$, the surplus output at harvest; $\tilde{p}_1$, the price of grain at harvest; and $\tilde{\epsilon}$, the gross appreciation in the grain price over the marketing season.

Let $V_1(s_1, p_1, q_1)$ denote the smallholder's maximum attainable present value of current and expected future utility of consumption at the beginning of the marketing season, given his stock of cash s_1, the prevailing market price of grain p_1, and his stock of freshly harvested surplus grain q_1. Also, let $V_2(s_2, p_2, q_2, p_1, w_1)$ denote the smallholder's maximum attainable present value of current and expected future utility of consumption at the beginning of the lean season, given his stock of cash s_2, the prevailing market price of grain p_2, his stock of surplus grain stored on the farm q_2, his stock of surplus grain deposited in the warehouse w_1, and the harvest price p_1. By Bellman's Principle of Optimality (Bellman, 1957), the value functions V_1 and V_2 must satisfy the following pair of functional equations:

[11] If the smallholder defaults on his loan, he remains eligible for warehouse receipt financing the following year. The possibility of default is anticipated by the lender, who considers it a cost of business and sets his advance and interest rates accordingly; the lender's expected profit from a warehouse receipt loan is independent of whether the borrower defaulted the preceding year.

At the beginning of the marketing season, the smallholder solves

$$\begin{aligned} V_1(s_1, p_1, q_1) = \max_{e_1, f_1, w_1} \quad & u_1(e_1) + \delta_1 E_1 V_2(s_2, \tilde{p}_2, q_2, p_1, w_1) \\ \text{s.t.} \quad & e_1, f_1, w_1 \geq 0 \\ & f_1 + w_1 \leq q_1 \\ & L = \gamma p_1 w_1 \\ & s_2 = s_1 + L - \tau_1 w_1 + \\ & \qquad p_1(q_1 - f_1 - w_1) - e_1 \geq 0 \\ & q_2 = (1-\theta) f_1 \\ & \tilde{p}_2 = p_1 \tilde{\epsilon}. \end{aligned} \tag{1}$$

Here, the smallholder observes his stock of cash s_1, the prevailing market price p_1, and his stock of surplus grain q_1, and chooses how much cash to spend on non-grain goods during the marketing season e_1, how much grain to store on his farm for the duration of the marketing season f_1, and how much grain to deposit in the warehouse for the duration of the marketing season w_1. Upon depositing grain in the warehouse, the smallholder incurs transaction costs $\tau_1 w_1$. The warehouse then issues the warehouse receipt to the smallholder, which the smallholder presents to the lender as collateral on a cash loan in the amount $L = \gamma p_1 w_1$, equal to a specified proportion γ of the current value of the grain deposited in the warehouse $p_1 w_1$. We denote by s_2, $\tilde{p}_2$, and q_2, respectively, the smallholder's stock of cash, the market price of grain, and the smallholder's on-farm stock of surplus grain at the start of the following lean season. The constraint $s_2 \geq 0$ indicates that the smallholder is unable to borrow cash, apart from what he may obtain by presenting his warehouse receipt as collateral.

At the beginning of the lean season, the smallholder solves

$$\begin{aligned} V_2(s_2, p_2, q_2, p_1.w_1) = \max_{e_2} \quad & u_2(e_2) + \delta_2 E_2 V_1(s_1, \tilde{p}_1, \tilde{q}_1) \\ \text{s.t.} \quad & e_2 \geq 0 \\ & g_2 = \max\{0, (1+\pi)p_2 - \tau_2 - R\gamma p_1\} \\ & s_1 = s_2 + p_2 q_2 + g_2 w_1 - e_2 \geq 0. \end{aligned} \tag{2}$$

Here, the smallholder observes his stock of cash s_2, the prevailing market price p_2, his stock of surplus grain stored on the farm q_2, the harvest price p_1, and his stock of surplus grain deposited in the warehouse w_1. The smallholder repays his loan, withdraws his grain from the warehouse and sells it at the prevailing premium market price if, and only if, the market value of one unit of deposited grain $(1+\pi)p_2$, less the cost of withdrawal τ_2, exceeds the amount due on the loan $R\gamma p_1$; otherwise, he defaults on his loan and

surrenders the grain in the warehouse to the lender. The smallholder augments his cash holdings s_2 with proceeds of sales of grain stored on the farm $p_2 q_2$ and net proceeds from his terminal warehouse transaction $g_2 w_1$, and decides how much cash to spend on non-grain goods during the lean season e_2, saving the remainder. We denote by s_1, $\tilde{p}_1$, and $\tilde{q}_1$, respectively, the smallholder's stock of cash, the market price of grain, and the smallholder's stock of surplus grain at the start of the following year's marketing season. The constraint $s_1 \geq 0$ indicates that the smallholder cannot borrow cash.

Under fairly standard and noncontroversial regularity assumptions, Blackwell's Theorem guarantees that the value functions exist, are unique, and are continuous (Stokey and Lucas, 1989; Blackwell, 1965). The key assumptions are that the utility functions u_i are twice continuously differentiable, strictly increasing and strictly concave; the per period discount factors δ_i are less than unity; and the exogenous random variables have bounded supports.

The Euler conditions governing the smallholder's optimal consumption, stockholding and marketing decisions at harvest are informative. Let λ_i denote the marginal utility of cash at the beginning of season i; let μ_i denote the marginal utility of grain at the beginning of season i; and let ξ denote the shadow price on the savings nonnegativity constraint, that is, the shadow price of "illiquidity", at harvest.[12] Then the Euler conditions imply that $\delta_1 E_1 \tilde{\lambda}_2 = \lambda_1 - \xi$, that is, the present-valued marginal utility of cash expected at the beginning of the lean season equals the marginal utility of cash at harvest, less the shadow price of illiquidity; in particular, if the smallholder's borrowing constraint is not binding, the present-valued marginal utility of cash is equated across seasons in expectation.

The Euler conditions also yield conventional intertemporal arbitrage complementarity conditions governing the storing of stocks on the farm and depositing them in the warehouse:[13]

$$f_1 \geq 0 \perp \delta_1 (1-\theta) E_1[\tilde{\lambda}_2 \tilde{p}_2] \leq \mu_1 \tag{3}$$

$$w_1 \geq 0 \perp \delta_1 E_1[\tilde{\lambda}_2 \tilde{g}_2] + \lambda_1(\gamma p_1 - \tau_1) \leq \mu_1. \tag{4}$$

In equilibrium, the discounted expected value at the beginning of the lean season of what survives of one unit of grain stored on the farm at harvest, $\delta_1(1-\theta)E_1[\tilde{\lambda}_2 \tilde{p}_2]$, cannot exceed the value of the grain at harvest, μ_1, for otherwise the smallholder would have an incentive to store more on the farm;

[12] λ_i and μ_i are the derivatives of the value function V_i with respect to s_i and q_i, respectively.

[13] The symbol $\perp$ between two weak inequalities indicates a complementarity condition: both inequalities must be satisfied, and at least one must be satisfied with strict equality.

and if the value of grain at harvest exceeds the discounted expected value at the beginning of the lean season, the smallholder will not store grain on the farm. Similarly, the discounted expected value at the beginning of the lean season of one unit of grain deposited in the warehouse at harvest, $\delta_1 E_1[\tilde{\lambda}_2 \tilde{g}_2]$, plus the value of the cash raised from the warehouse receipt loan at harvest, $\lambda_1(\gamma p_1 - \tau_1)$, cannot exceed the value of the grain at harvest, μ_1, for otherwise the smallholder would have an incentive to deposit more in the warehouse; and if the value of grain at harvest exceeds its discounted expected value at the beginning of the lean season, plus the value of the cash raised from the warehouse receipt loan, the smallholder will not deposit grain in the warehouse. Given that the opportunity cost of one unit of grain at harvest μ_1 is the same regardless of the mode of storage chosen, the smallholder will choose the mode that offers the greatest expected net benefit.

5 Model Parameterization

The value functions lack known closed-form expressions. However, if the functional forms are explicitly specified and the model is fully parameterized, it is possible to compute arbitrarily accurate numerical approximations for the value functions and the smallholder's optimal storage and marketing policies using collocation and Gaussian quadrature methods (Miranda and Fackler, 2002; Judd, 1998). To posit a model that may be solved and simulated numerically, let $t_i > 0$ denote the duration of season i in years, so that $t_1 + t_2 = 1$, and assume the following:

The smallholder's season i utility of consumption function, which expresses utility in terms of the amount of cash spent on non-grain goods e during the season, takes the form

$$u_i(e) \equiv \frac{\alpha_i}{1-\psi} e^{1-\psi}, \tag{5}$$

where α_i is a seasonal weighting factor and $\psi > 0$ is his constant relative risk aversion. More specifically, we set $\alpha_i = t_i^{\psi}$ to ensure consistency of the utility functions across seasons, accounting for the differences in the lengths of the seasons.

The exogenous random variables take the following forms: 1) $\tilde{\epsilon}$, the gross appreciation in the grain price over the marketing season, is lognormal distributed with expectation $\bar{\epsilon} > 1$ and volatility $\sigma_\epsilon > 0$;[14] 2) $\tilde{p}_1$, the price of

[14] In other words, the price expected at the end of the marketing season, conditional on the harvest price p_1, is $p_1\bar{\epsilon}$.

grain at harvest, is lognormal distributed with expectation 1 and volatility $\sigma_p > 0$; and 3) $\tilde{q}_1$, surplus production at harvest, is lognormal distributed with expectation 1 and volatility $\sigma_q > 0$. The random variables are assumed to be serially and mutually independent and identically distributed over time.[15] Note that for ease of interpretation, and without loss of generality, we normalize prices and quantities so that the price and surplus output expected at harvest both equal 1.

The seasonal subjective discount factors are given by $\delta_i \equiv \exp(-\rho t_i)$, where $\rho > 0$ is the smallholder's annualized continuous subjective discount rate; the gross interest rate on the loan is given by $R \equiv \exp(rt_1)$, where $r > 0$ is annualized continuous rate of interest charged on the loan.

We calibrate the model parameters to fit the stylized facts of a "representative" smallholder. Our representative smallholder is a maize grower in northern Ghana, where the typical "marketing season" lasts 5 months, from mid-November to mid-April. He cultivates 2 hectares of land and, using traditional seed and production technology, on average produces 7.5 100 kg bags of maize per hectare. Annual output per hectare fluctuates from year to year primarily due to weather, historically exhibiting a coefficient of variation of 70%. The smallholder on average consumes 50% of what he produces, selling the remainder on the market. Thus, our smallholder is not a "subsistence" farmer, but rather a "near-subsistence" farmer who in a typical year produces a marketable surplus of 7.5 100 kg bags. The increase in the market price over the marketing season has historically averaged 40%, exhibiting a coefficient of variation of 40% from year to year.

If the smallholder stores maize on his farm at harvest, he expects to lose 10% of it before the end of the marketing season.[16] The smallholder may also safely store his grain in a certified commercial warehouse and obtain a warehouse receipt to use as collateral for a loan. To deposit his maize in the warehouse at harvest, the smallholder must pay \$5 per bag to cover transportation to the warehouse and the cleaning and drying performed by the warehouse to ensure the stored grain meets the legal standards required for the issue of a warehouse receipt. To withdraw his maize from the warehouse at the end of the marketing season, the smallholder must pay \$2.5 per bag to cover the cost of storage and collateral management fees. If the smallholder presents his warehouse receipt to a lender as collateral, he receives a loan maturing at the end of the marketing season carrying an annualized interest

[15] The volatility of a positive random variable is the standard deviation of its logarithm.

[16] Many published estimates of grain post-harvest losses in Africa are higher, sometimes much higher, but typically refer to post-harvest losses as the grain passes through the entire marketing chain, and thus include losses after the grain has been sold by the smallholder.

rate of 20%, for an amount equal to 75% (the advance rate) of the current market value of the maize stored in the warehouse. Unless the smallholder defaults on his loan, he markets the grain deposited in the warehouse at the end of the marketing season at the price prevailing on the local market, receiving no price premium for the grain, despite it having been processed to ensure it meets the quality standards prescribed for the issue of a warehouse receipt.

Based on the available data, we set our base-case model parameters to the values in Table 1. Sources of data used to calibrate our model include: Maize yields, season time spans, and smallholder farm size and consumption patterns were obtained from the Ghana Ministry of Food and Agriculture. Price data was kindly supplied by Esoko, an African agricultural marketing information technology service provider with a regional office in Accra. Production data was drawn from the World Bank Ghana Living Standard Survey 6 (Ghana Statistical Service, 2014) and the International Food Policy Research Institute Medium and Large-Scale Farmers and Agricultural Mechanization in Ghana Survey (IFPRI, 2016). Post-harvest loss data were obtained from The African Postharvest Loss Information System (APHLIS). Data for warehouse storage charges and other warehouse and warehouse receipt financing transaction costs were obtained through personal interviews with 10 warehouse operators in northern Ghana (Mulangu, Kemeze, and Miranda, 2017). Data for interest rates and advance rates on warehouse receipt financed loans were obtained through personal interviews with 14 rural banks in northern Ghana (Mulangu, Kemeze, and Miranda, 2017).

6 Smallholder's Optimal Policy

We now analyze our representative northern Ghanaian smallholder's optimal marketing and storage policy, and begin by solving the model under the base case parameterization. We find that, under this parameterization, the smallholder will sell 52% of his surplus grain on the open market and store the remaining 48% on his farm. He will spend 80% of his market proceeds on marketing season consumption and save the remaining 20% in cash for the duration of the marketing season. The smallholder will not store any of his surplus grain in the warehouse and will not assume a warehouse receipt loan.

Next, we perform sensitivity analysis, individually varying the values of the marketing season state variables and key model parameters around their base case values, ceteris paribus. The most salient result of these

Table 1: Base Case Parameter Values

Symbol	Value	Description
t_1	5/12	duration of marketing season in years
t_2	7/12	duration of lean season in years
ρ	0.05	annualized subjective discount rate
ψ	4.00	smallholder relative risk aversion
θ	0.10	percent on-farm storage losses over marketing season
τ_1	0.20	unit cost of depositing grain in the warehouse
τ_2	0.10	unit cost of withdrawing grain from the warehouse
π	0.00	price premium received by warehouse stored grain
r	0.20	annualized rate of interest on loan
γ	0.75	loan advance rate
$\bar{\epsilon}$	1.40	expected gross price appreciation over marketing season
σ_ϵ	0.40	marketing season price appreciation volatility
σ_q	0.70	annual surplus production volatility
σ_p	0.40	annual harvest price volatility

simulations is that the smallholder will not store in the warehouse, and thus will not access warehouse receipt financing, under a very wide range of market conditions and variations in certain model parameters. In particular, the smallholder will not store in the warehouse: 1) provided the quantity harvested is less than 500% of its historical mean; 2) provided the harvest price is less than 300% of its historical mean; 3) provided cash stocks held at harvest are less than 5 times the historical mean value of annual production; 4) provided the smallholder's coefficient of relative risk aversion is less than 20; and 5) even if the price where expected to rise five-fold during the marketing season or the marketing season price volatility were to double. Moreover, the smallholder will not take out a warehouse receipt loan even if the interest rate on the loan were reduced to 0% or the advance rate were raised to 100%. These robust findings are not particularly surprising, and are consistent with observation: under existing regulations governing warehouse receipt financing and historically observed market conditions, smallholders in Ghana do not avail themselves of warehouse receipt financing, and express little interest in doing so.

Our simulations reveal that the key drivers of smallholder demand for warehouse storage and warehouse receipt financing are the relative expected

benefits of on-farm versus warehouse storage. The former depend primarily on the post-harvest loss rate of on-farm storage. The latter depend primarily on the spread between the price premium afforded grain whose quality has been enhanced by storing in the warehouse and the costs associated with warehouse storage and warehouse receipt financing.

Figure 1 shows how the optimal quantities of grain sold on the market, stored on the farm, and deposited in the warehouse by the smallholder vary with the on-farm storage loss rate. As seen in this figure, on-farm storage remains the most economical way for the smallholder to store his surplus grain as long as the loss rate remains below 23%, a figure that is well above reported rates below 10%.

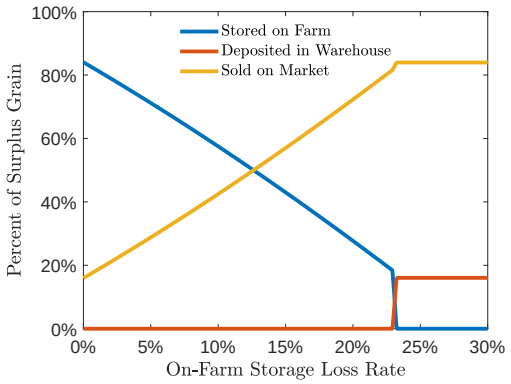

Figure 1: Disposition of Surplus Grain vs. On-Farm Storage Loss Rate.

The left panel of Figure 2 gives the percent of surplus grain deposited in the warehouse by the smallholder as a function of both the price premium (expressed as a percent of the lean season market price for common grain) and the unit transaction costs (expressed as a percent of the harvest price). Clearly, the amount deposited in the warehouse is a nondecreasing function of the price premium and a nonincreasing function of the transaction costs. No surplus grain will stored in warehouse if the price premium is sufficiently low or the transaction costs are sufficiently high; conversely, all surplus grain will be stored in warehouse if the price premium is sufficiently high or the transaction costs are sufficiently low.

The right panel of Figure 2 provides a contour plot for ease of interpretation. The dotted line indicates the locus of price premiums and transaction costs at which warehouse receipt financing becomes marginally economical for the smallholder, that is, the minimum price premium that must be earned by grain stored in the warehouse relative to common grain stored on

the farm in order to just compensate the smallholder for the higher transaction costs incurred from warehouse storage. The other contour lines indicate loci of price premiums and transaction costs at which the smallholder will deposit specified percentages of his surplus grain in the warehouse.

As seen in right panel of Figure 2, with the price premium fixed at its base-case value of 0%, warehouse receipt transaction costs per unit of grain would have to fall from their base-case value of 30% to 11% of market price in order for the smallholder to store in the warehouse; moreover, the smallholder would not store all of his surplus grain in the warehouse, even in the absence of transaction costs. Also, with transaction costs fixed at their base-case value of 30%, the price premium earned by grain stored in the warehouse would have to rise from its base-case value of 0% to above 17% of market price for the smallholder to store in the warehouse; moreover, the smallholder would still store less than 80% of his surplus grain in the warehouse if warehouse grain enjoyed a price premium of 30% over common grain. Given the essentially linear upward sloping form of the contour lines, a very regular tradeoff between transaction costs and price premiums is evident. Specifically, for warehouse storage to remain economical (i.e., along the dotted line), the price premium earned by warehouse grain would need to rise 0.9% to compensate for a 1% rise in transaction costs.

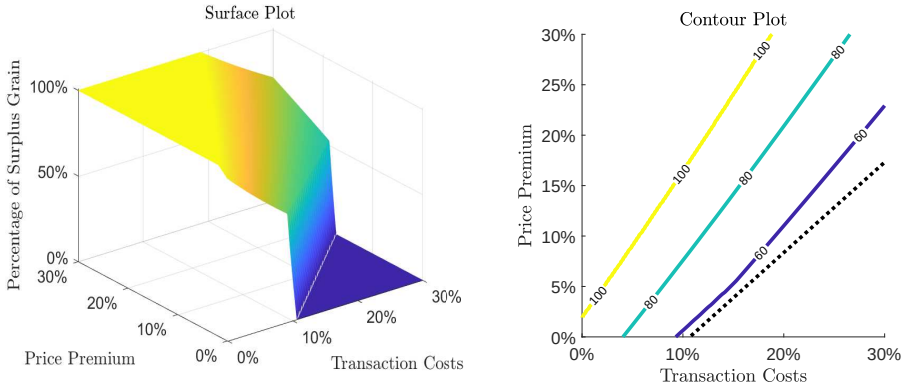

Figure 2: Percentage of Surplus Grain Deposited in Warehouse vs Transaction Costs and Price Premium.

In order to better understand the effects of key model parameters on warehouse receipt financing, assume now that warehouse transaction costs are equal to 22.5%, as compared to the base case value of 30%, and warehouse stored grain earns a modest premium of 7.5%, as compared to the base case value of 0%, so as to make warehouse storage more competitive

with on-farm storage.

Figure 3 illustrates how expected appreciation in the market price over the marketing season $\bar{\epsilon} - 1$ affects the smallholder's harvest time marketing and storage decisions. As seen in this figure, the smallholder will sell his entire surplus on the market if the price is expected to rise less than 11% over the marketing season, a figure that is very close to the on farm loss rate. As the expected appreciation rises above this level, the smallholder will begin to store on his farm, and sell less on the market. Once the expected appreciation just reaches approximately 66%, the smallholder will no longer sell any of his surplus grain on the market, choosing instead to store it all on his farm. However, if the expected appreciation exceeds this critical level, the smallholder will again sell some of his surplus grain on the market, selling more and storing less as the expected appreciation rises. This is due entirely to an intertemporal consumption substitution effect that is driven by the smallholder's inability to borrow cash by means other than a warehouse receipt loan, which remains uneconomical. Increased expected appreciation of the market price over the marketing season increases the value of smallholder's grain, but that value cannot be realized until the end of the marketing season. In order to balance marginal utility between the marketing and lean seasons, the smallholder's only option is to sell more of his surplus grain at harvest, forgoing some of the benefits of storing arising from price appreciation, in order to consume more during the marketing season.

Another salient result revealed by Figure 3 is that the price appreciation expected over the marketing season has no discernable impact on the demand for warehouse storage and warehouse receipt financing. In particular, the smallholder will not seek warehouse receipt financing even if the price is expected to rise ten-fold during the marketing season (not pictured). This result is notable, given that proponents of smallholder warehouse receipt financing typically stress that its benefits derive primarily from the smallholder's ability to exploit price rises during the marketing season. The result, however, should not be surprising. Increased price expectations over the marketing season raises the expected net benefits of both on-farm and warehouse storage nearly equally. A smallholder will use warehouse receipt financing only if the warehouse transaction costs, adjusted for the premium earned by warehouse stored grain and the option value of default, are less the costs of storing on the farm.

Figure 4 illustrates how marketing season price volatility σ_ϵ affects the smallholder's harvest-time marketing and storage decisions. As seen in this figure, the smallholder will store on the farm if the price volatility is rela-

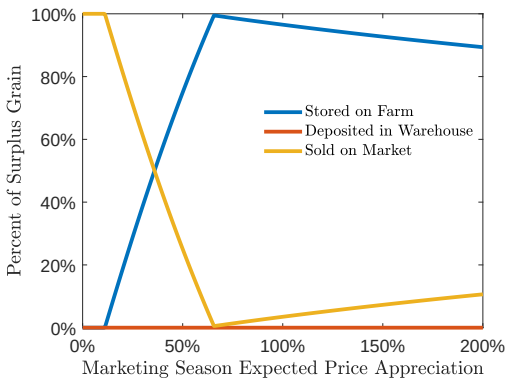

Figure 3: Disposition of Surplus Grain vs. Expected Price Appreciation over the Marketing Season.

tively low and in the warehouse if the price volatility is relatively high, with the total amount stored falling steadily with the price volatility. However, increased volatility raises the option value of default, making the warehouse storage and warehouse receipt financing more attractive. Just the same, it must be noted that the lender would naturally respond to any increase in the likelihood of default by reducing the loan advance rate or raising the interest rate on the loan. If the lender's response were factored into our simulation, it is unclear whether increased price volatility would lead to increased use of warehouse receipt financing by the smallholder.

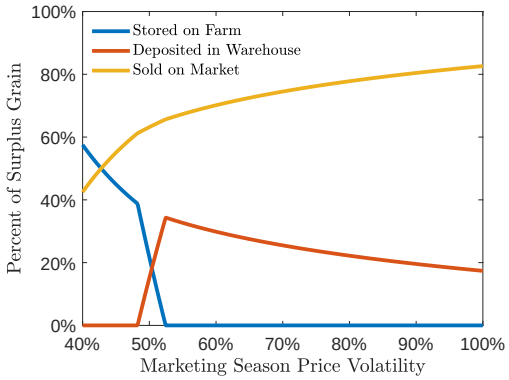

Figure 4: Disposition of Surplus Grain vs. Marketing Season Price Volatility.

Figure 5 illustrates how the advance rate on the warehouse receipt loan γ affects the smallholder's harvest-time marketing and storage decisions. As seen in this figure, the smallholder will store exclusively on the farm if the

advance is rate is less than 82% and exclusively in the warehouse if the advance rate is greater than 89%. Over the range of advance rates for which warehouse storage is economical, the amount stored in the warehouse, and thus the size of the warehouse receipt loan, rises at an increasing rate as the advance rate approaches 100%, ultimately reaching the point (approximately 94%) where it is economical for the smallholder to store all of his surplus grain in the warehouse. The reasons for this are straightforward. The unit cost of on-farm storage is independent of the advance rate. However, the option value of defaulting rises with the advance rate, and dramatically so as the advance rate approaches 100%, making the warehouse receipt loan, and thus warehouse storage, more attractive to the smallholder.

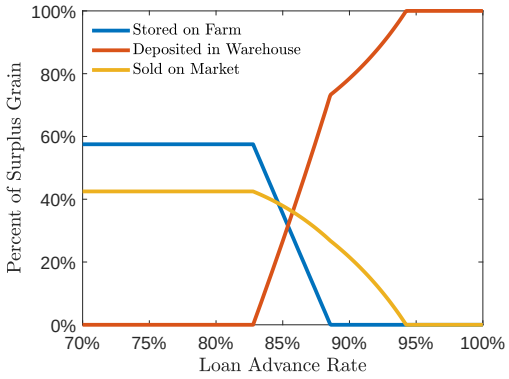

Figure 5: Disposition of Surplus Grain vs. Loan Advance Rate.

Figure 6 illustrates how the annualized interest rate on the warehouse receipt loan r affects the smallholder's harvest-time marketing and storage decisions. As seen in this figure, the smallholder will store exclusively in the warehouse if the loan interest rate is less than 3% and exclusively on the farm if the loan interest rate is greater than 8%. Over the range of interest rates for which warehouse storage is economical, the amount stored in the warehouse, and thus the size of the warehouse receipt loan, rises as the interest rate is lowered to 0%; however, even with a 0% interest rate, the smallholder will still store less than 60% of his surplus grain in the warehouse.

7 Lender's Optimal Policy

The lender wishes to set the interest rate and the advance rate on the smallholder's marketing season loan so as to maximize total profit. His primary

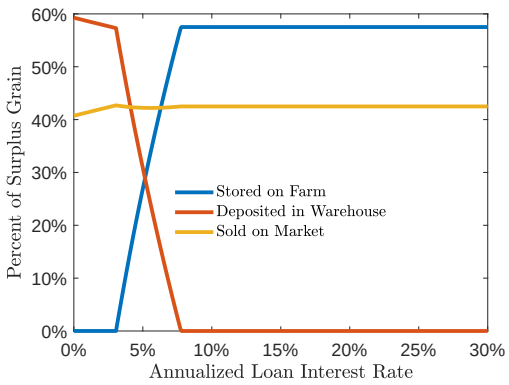

Figure 6: Disposition of Surplus Grain vs. Loan Interest Rate.

concern is the possibility that the smallholder will default on his loan repayment obligation if prices fail to appreciate sufficiently during the marketing season. Given our assumption that the appreciation in the market price over the marketing season is lognormal distributed, it is possible to derive explicit closed-form expressions for the smallholder's probability of default and the lender's expected rate of return on each unit of cash loaned. In particular, the probability of default is given by

$$P^d = \Phi(\log \epsilon^*/\sigma_\epsilon + \sigma_\epsilon/2) \tag{6}$$

where

$$\epsilon^* \equiv \frac{\tau_2 + R\gamma p_1}{(1+\pi)\bar{\epsilon} p_1} \tag{7}$$

and Φ is the standard normal cumulative distribution function. It is straightforward to show that the probability of default rises with the unit withdrawal transaction costs τ_2, the price volatility σ_ϵ, the gross interest rate charged on the loan R, and the advance rate γ, and falls with the harvest price p_1, expected appreciation $\bar{\epsilon}$, and the price premium afforded grain stored in the warehouse π.

The lender's expected rate of return per unit of cash loaned is given by

$$RoR = \delta_1 \bar{\epsilon}(\epsilon^*(1 - \Phi(\log \epsilon^*/\sigma_\epsilon + \sigma_\epsilon/2)) + \Phi(\log \epsilon^*/\sigma_\epsilon - \sigma_\epsilon/2)) - \gamma. \tag{8}$$

It is straightforward to show that the lender's expected rate of return per unit of cash loaned falls with the withdrawal unit transaction costs τ_2 and the gross interest rate charged on the loan R, and rises with the harvest price

p_1, expected appreciation $\bar{\epsilon}$, and the price premium afforded grain stored in the warehouse π. The sign of the derivative of the lenders expected rate of return with respect to the advance rate γ, however, is ambiguous.

However, focusing on how the lender's expected rate of return per unit of cash loaned can be misleading, since lender efforts to vary the terms of the loan to increase the rate of return would also reduce the size of the loan demanded by the smallholder. Given the lender wishes to maximize profit per loan, he must account for how the terms of the loan will simultaneously affect both the rate of return and the size of the loan.

Figure 7 illustrates how the loan advance rate and loan interest rate affect the lender's profit per loan, given the revised warehouse transaction costs of 22% and price premium of 7.5%. The left panel gives the lender's profit, expressed as a percentage of the unit market value of grain, as a function of both the loan advance rate and the loan interest rate. Clearly, if the advance rate is set too low or the interest rate is set too high, the smallholder will not store in the warehouse and thus will not take out a warehouse receipt loan, implying the lender will earn no profit. For any given interest rate, the lender can raise profit per loan by modestly increasing the advance rate. This has the effect of increasing the demand for the loan, but raising the probability of default, albeit with a positive net effect. However, once the advance rate reaches a critical level, further increases in the advance rate will reduce the lender's profit per loan. Beyond the critical level, the smallholder will store his entire surplus in the warehouse, implying that further increases in the advance rate will not increase the size of the loan demanded by the smallholder, and only increase the probability of default.

The right panel of Figure 7 provides a contour plot for ease of interpretation. The dotted line indicates the locus of loan advance and interest rates at which warehouse receipt loans become marginally profitable for the lender. The other contour lines indicate loci of loan advance and interest rates at which the lender will earn prescribed profits per loan. As seen in right panel of Figure 7, with the interest rate fixed at its base-case value of 20%, the lender would have to raise the advance rate from its base-case value of 75% to above 82%, thereby tolerating a higher rate of default, in order to turn a profit. Also, with the advance rate fixed at its base-case value of 75%, the interest rate would have to be lowered below its base-case value of 20% to 8% for the lender to begin turning a profit.

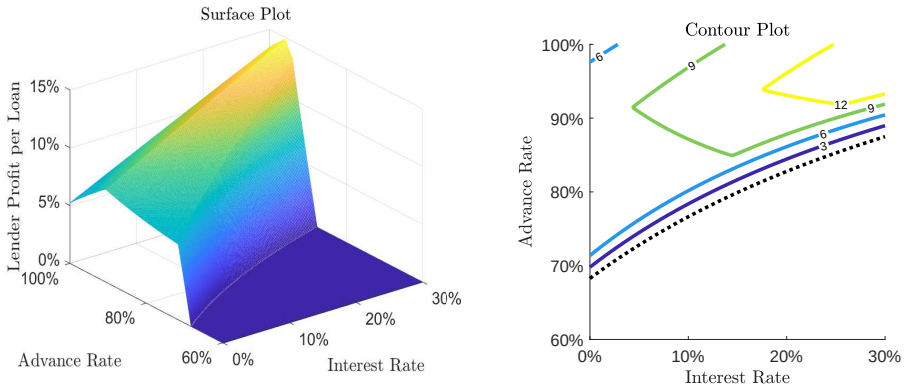

Figure 7: Lender Profit per Loan vs Loan Interest Rate and Advance Rate.

Lenders in Ghana report that they prefer to charge the same interest rate on warehouse receipt loans as they do on other commercial agricultural loans and, as such, vary only the advance rate to address default risk associated with warehouse receipt loans. In order to better understand the optimal choice of advance rate, let us fix the loan interest rate at 20%, which is approximately the rate of interest charged by lender's in Ghana for commercial agricultural loans. Figure 8 gives the percentage of surplus grain stored in the warehouse under two scenarios. In the first scenario, "Lower Transaction Costs", the price premium is held constant at its base case value of 0%, but transaction costs are reduced 10% below their base case value of 30%. In the second scenario, "Higher Price Premium", the transaction costs are held constant at their base case value of 30%, but the price premium is raised 10% above its base case value of 0%. Figure 9 gives the lender's profit per loan, expressed as a percentage of the market value of one unit of grain, under the same two scenarios. In both figures, the dotted lines indicate the advance rates that maximize the lender's profit per loan.

As seen in Figure 8, the smallholder will store in the warehouse and assume a warehouse receipt loan if offered a 60% advance rate, provided he earns greater price premium for doing so. Also, the smallholder will store in the warehouse and assume a warehouse receipt loan if offered a 73% advance rate, provided his transaction costs are reduced. Under both scenarios, lenders maximize profit by setting the advance rate exactly at the level that just induces the smallholder to store all of his surplus grain in the warehouse. However, increasing the advance rate beyond that level is unprofitable for the lender, as it would only raise the probability of default without raising the demand for warehouse loans. The most salient result

illustrated in Figure 9, however, is that the lender's profit is higher at all advance rates if the warehouse stored grain earns a higher premium of 10% compared to a reduction of 10% in transaction costs. This suggests that efforts to increase warehouse receipt financing among smallholders might be better served by increasing the price premium earned from warehouse storage, rather than reducing warehouse financing transaction costs.

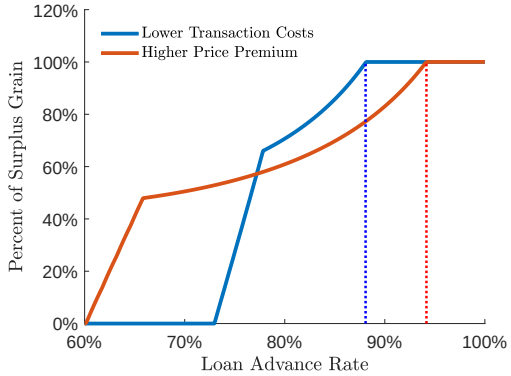

Figure 8: Percentage of Surplus Grain Deposited in Warehouse vs Loan Advance Rate.

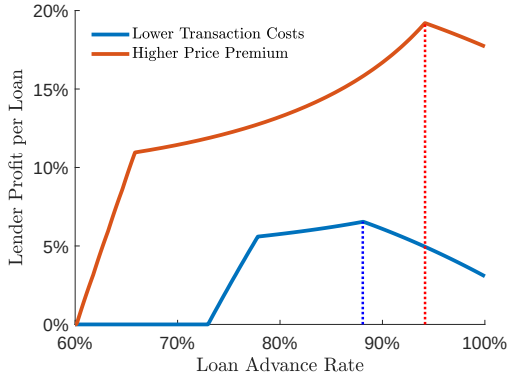

Figure 9: Lender Profit per Loan vs Loan Advance Rate.

8 Conclusions

In this paper, we have developed and analyzed a dynamic structural model of smallholder warehouse receipt financing that explicitly captures the transaction cost and risk reallocation associated with its use. We find that, although

an expectation of rising prices during the marketing season is necessary for warehouse receipt financing to benefit the smallholder, it is not sufficient. For warehouse receipt financing to benefit the smallholder, the price he receives for grain stored in the warehouse must earn a premium over grain stored on the farm in order to offset the higher costs of storage and the additional costs of processing the grain to meet the legislated high standards required for the issue of a warehouse receipt.

The costs of storing grain in a commercial warehouse and obtaining a warehouse receipt loan are significant, and can easily exceed the costs of storing on the farm. Warehouse storage and warehouse receipt financing costs include: charges for onloading and transporting the grain to the warehouse; charges for offloading, sampling, grading, cleaning, drying, and bagging the grain on delivery; charges for pest control, fumigation, utilities, and use of warehouse space while the grain is in the warehouse; and charges for collateral management, including charges for security, insurance, and quality and moisture monitoring. Storing grain in a warehouse will avoid the post-harvest losses suffered by grain stored on the farm under less favorable conditions and will raise its overall quality through the processing it must undergo to meet the higher standards required for the issue of a warehouse receipt. However, if the enhanced quality fails to command a price premium on the market, the costs will not be recovered, and the smallholder will be better served selling his grain at harvest or storing it on the farm and selling it at a later date.

If warehouse receipt financing is to be adopted by smallholders, either the cost of warehouse receipt financing must be reduced for smallholders or the price premium earned by enhanced grain stored in the warehouse must be raised. The demand for higher quality grain might be raised in a variety of ways. First, the state could institute standards for the grading and labeling of grain stored in a warehouse, so that its higher quality can be readily recognized at point of sale, particularly if it is sold in regional auction markets. Second, the state could promote expansion of the downstream high-value-added grain processing sector, which would demand higher quality grain to ensure efficient industrial processing and uniform quality output. Third, the state could promote increased exportation of raw grain, which would naturally require grain that meets high international quality standards. Fourth, the state, as a public health measure, could mandate that grain purchased by public schools, the armed forces, and other state institutional buyers meet higher standards. However, all these efforts combined may well prove inadequate. As long as the majority of grain produced by smallholders is destined for consumption by poor households, poultry and

livestock, the desired price premiums may fail to materialize.

The cost of warehouse receipt financing to smallholders might be reduced in a variety of ways. Electronic registration of warehouse receipts, modernization of warehouses, and improvements in commercial infrastructure could reduce costs to some degree. Yet another way to reduce the costs of warehouse receipt financing for smallholders would be to institute a dual or graduated warehouse receipt system that allows for the issue of warehouse receipts on grain of varying quality, to include grain that meets the high quality standards demanded by processors and exporters on the one hand, and grain that meets the lower quality standards accepted by non-industrial users, livestock producers, and households, on the other. Minimum quantity requirements could also be reduced for the lower quality grain. Under such a graduated warehouse receipt system, the lower quality grain typically produced by smallholders could still be used to secure warehouse receipt financing without being subjected to the costly processing needed to meet the high quality standards currently required for the issue of a legal warehouse receipt.

Governments and international development organizations committed to promoting warehouse receipt financing for smallholders should choose the sectors they target for pilot programs so as to best meet the conditions needed for success. For example, warehouse receipt financing has failed to attract direct participation among smallholders in Ghana because it has been targeted to maize, which, as a common staple, is primarily destined for sale to livestock producers and poor rural households who place little value on higher quality grain and will refuse to pay a premium for it. Premium rice in Ghana may have a better success at attracting warehouse receipt financing among smallholders. Consumption of premium long grain perfumed Thailand rice has been growing in Ghana at 40% per year in recent years, especially among wealthier urban consumers, and commands a price premium in excess of 100% over local rice varieties. As such, the potential exists for smallholders to obtain the price premiums needed to cover the high costs of commercial warehouse storage and warehouse receipt financing.

In drawing our conclusions, we do not mean to suggest that a well-regulated warehouse receipt system for the trade of high quality grain would not benefit smallholders, only that it generally will not benefit them directly as often claimed by the development community. The establishment of a centralized commodity exchange based on the trade of negotiable receipts issued on high quality grain could promote the modernization of the agricultural value chain, making it more efficient, stimulating investment in processing capacity, and promoting commodity exports. Such advance-

ments would benefit all growers of grain, including smallholders. However, negotiable warehouse receipts traded on exchanges, due to stringent quality standards and minimum volume requirements, would at best benefit smallholders indirectly, and only the limited few that are formally integrated into the agricultural value chain via contract farming. In short, promoting value chain development by establishing centralized exchanges based on the trade of warehouse receipts and promoting smallholder access to warehouse receipt financing are not entirely compatible goals, and cannot both be met by a single, undiscriminating set of regulations governing the issue of warehouse receipts.

A potential extension to the research reported here would be to examine the use of warehouse receipt financing by warehouse operators, rather than smallholders, given that the former are currently the primary users of warehouse receipts in developing countries. Such an analysis would have to faithfully capture the contractual relationships between the warehouse operator and the processor at one end, and between the warehouse operator and contracted nucleus farmers and outgrowers at the other end. Another potential area ripe for research is the use of less formal inventory financing schemes by farmer groups currently storing in smaller and technically less sophisticated community warehouses. Such research would have to address the special role played by intermediating microfinance institutions and the subsidies and credit guarantees that they typically provide, as well as the apparent lack of trust smallholders place in storing their grain in more loosely supervised community warehouses. Finally, the development of centralized commodity exchanges presents a host of challenging questions that largely remain unanswered, and which merit further study, given the push in many African countries to establish exchanges to modernize their agricultural marketing chains and promote exports of their agricultural products.

We should be skeptical of unsubstantiated claims made regarding the benefits of warehouse receipt financing for smallholders. The problems associated with smallholder warehouse receipt financing are complex, and require a deeper understanding of the transaction and risks costs that undermine its value to smallholders. Rising prices during the marketing season alone are not sufficient to ensure the smallholder will benefit from warehouse receipt financing, contrary to the claims made by its many proponents.

Ultimately, development economists, practitioners and policymakers must seriously consider the possibility that separation of production, storage, and marketing functions may well be the most efficient way to organize the agricultural value chain in some developing countries. If so, warehouse receipt financing not be the panacea for smallholder marketing problems claimed

by many. Having smallholders sell their entire surplus grain at harvest, rather than storing it, even if prices are generally at their lowest, may well be economically sensible for the smallholder.

References

ACE Global Depository. 2013. "Warehouse Receipt Financing." Technical Report, Dubai, United Arab Emirates.

Aning, Alexis. 2015. "The Role of Warehouse Receipt Systems in Agricultural Modernization in Africa." Technical Report, African Center for Economic Transformation, Accra, Ghana.

Bellman, Richard E. 1957. *Dynamic Programming*. Princeton, NJ: Princeton University Press.

Blackwell, David. 1965. "Discounted Dynamic Programming." *Annals of Mathematical Statistics* 36 (1):226–235.

Coulter, Jonathan and Gidgeon E. Onumah. 2002. "The Role of Warehouse Receipt Systems in Enhanced Commodity Marketing and Rural Livelihoods in Africa." *Food Policy* 27 (4):319–337.

Coulter, Jonathan and Andrew W. Shepherd. 1995. "Inventory Credit: An Approach to Developing Agricultural Markets." FAO Agricultural Services Bulletin 120, Food and Agriculture Organization of the United Nations, Rome, Italy.

Coulter Consulting Ltd. and Sullivan & Worcester UK LLP. 2014a. "Study on Appropriate Warehousing and Collateral Management Systems - Volume I - Key Findings." Technical Report, Technical Centre for Agricultural and Rural Cooperation, Wageningen, The Netherlands.

———. 2014b. "Study on Appropriate Warehousing and Collateral Management Systems - Volume II - Technical Country Reports." Technical Report, Technical Centre for Agricultural and Rural Cooperation, Wageningen, The Netherlands.

Food and Agriculture Organization of the United Nations. 2015. "Ghana Food and Agriculture Policy Trends." Country fact sheet, Food and Agriculture Organization of the United Nations, Rome, Italy.

Geva, Bejamin. 2011. *The Payment Order of Antiquity and the Middle Ages: A Legal History*. Oxford, United Kingdom: Hart Publishing.

Ghana Grains Council. 2017. `http://www.ghanagrainscouncil.org/en/`. Accessed: April 15, 2017.

Höllinger, Frank, Lamon Rutten, and Krassimir Kiriakov. 2009. "The Use of Warehouse Receipt Finance in Agriculture in Transition Countries." Technical Report, The World Bank, Washington, DC.

International Finance Corporation. 2013. "Warehouse Finance and Warehouse Receipt Systems: A Guide for Financial Institutions in Emerging Economies." Technical Report, The World Bank, Washington, DC.

———. 2015. "Money in the Barn: How Warehouse Receipts Can Improve the Life of Farmers." Retrieved from `http://www.ifc.org/wps/wcm/connect/region__ext_content/regions/sub-saharan+africa/news/za_ifc_warehouse_receipts_kenya`.

International Fund for Agricultural Development. 2008. "Empowering Farmers in Tanzania through the Warehouse Receipt System." Brief, September, Rome, Italy.

Jacoby, Neil H. and Raymond J. Saulnier. 1944. *Financing Inventory on Field Warehouse Receipts*. New York, NY: National Bureau of Economic Research.

Judd, Kenneth L. 1998. *Numerical Methods in Economics*. Cambridge, MA: MIT Press.

Larson, Donald F., Jock R. Anderson, and Panos Varangis. 2004. "Policies on Managing Risk in Agricultural Markets." *The World Bank Research Observer* 19 (2):199–230.

Miranda, Mario J. and Paul L. Fackler. 2002. *Applied Computational Economics and Finance*. Cambridge, MA: MIT Press.

Mulangu, Francis M., Francis H. Kemeze, and Mario J. Miranda. 2017. "Warehouse Receipts and Financial Practices: The Case of Ghana." Technical Report, African Center for Economic Transformation, Accra, Ghana.

Onumah, Gideon E. 2010. "Implementing Warehouse Receipt Systems in Africa: Potential and Challenges." Working Paper, Paper presented at Fourth African Agricultural Markets Program Policy Symposium, September 6-7, Lilongwe, Malawi.

Stokey, N.L. and Robert E. Lucas, Jr. 1989. *Recursive Methods in Economic Dynamics*. Cambridge, MA: Harvard University Press.

United Nations Conference on Trade and Development. 1996. "Collateralized Commodity Financing, with Special Reference to the Use of Warehouse Receipts." Technical Report, Geneva, Switzerland.

———. 2003. "A Primer on New Techniques Used by the Sophisticated Financial Fraudster." Technical Report, Geneva, Switzerland.

U.S. Agency for International Development. 2010. "ICT to Enhance Warehouse Receipt Systems and Commodity Exchanges in Africa." Briefing Paper, Washington, DC.

———. 2013a. "Ethiopia Warehouse Receipt System and Regulation: A Case for Expansion." Technical Report, U.S. Agency for International Development, Washington, DC.

———. 2013b. "Improving Food Security with Warehouse Receipts." Brief, Washington, DC.

Wehling, Philine and Bill Garthwaite. 2015. "Designing Warehouse Receipt Legislation: Regulatory Options and Recent Trends." Technical Report, Food and Agriculture Organization of the United Nations, Rome, Italy.

Weidemann Associates, Inc. 2000. "Warehouse Receipts: Financing Agricultural Producers." Technical Note No. 5, Washington, DC.

William, J.G. and N. Kaserwa. 2015. "Improving Smallholder Farmers Access to Finance Through Warehouse Receipt System in Tanzania." *International Journal of Economics and Financial Research* 1 (92):41–49.

Williams, Jeffrey C. 1984. "Fractional Reserve Banking in Grain." *Journal of Money, Credit and Banking* 16 (4, Part 1):488–496.