Barter Financing in Agriculture: A Nash Bargaining Framework*

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March 22, 2026

ABSTRACT

In Brazil, barter has emerged as an alternative financing mechanism amid tightening credit constraints and reduced government support for agriculture. Under this arrangement, farmers receive inputs before planting and repay with a portion of their future harvest, creating a bargaining environment between producers and input suppliers. Despite its importance, there is limited theoretical analysis from the farmer's perspective. This paper develops a model based on Nash bargaining to examine how exchange terms are determined. The results indicate that barter outcomes depend on farmers' risk preferences, bargaining power, and macro-financial conditions. More risk-averse farmers accept less favorable terms to reduce uncertainty, while weaker bargaining positions further diminish their share of the surplus. Additionally, higher interest rates increase the relative attractiveness of barter compared to traditional credit, reinforcing its role in imperfect rural financial markets.

Keywords: Agricultural Markets; Nash Bargaining Equilibrium; Credit Constraints

JEL Codes: G32, Q14, D86

*This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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1 Introduction

Agricultural production is highly capital intensive at the beginning of the crop cycle. Before any revenue is realized, farmers must finance a significant fraction of their total production costs in order to acquire essential inputs such as seeds, fertilizers, and pesticides. To finance these pre-harvest costs, Brazilian farmers rely on a combination of own capital, bank credit, government programs, and alternative contractual arrangements such as barter, which

Empirical evidence suggests that farmers perceive several advantages in using barter. Arakawa (2014) document that farmers in Mato Grosso associate barter with improved risk management, just-in-time delivery of inputs, lower bureaucratic requirements, greater liquidity, and enhanced cash flow. Johann et al. (2017) show that large agribusiness companies not only extensively utilize barter as a commercial strategy but also actively encourage its adoption: 61.54% of firms in their sample frequently promoted barter contracts. Among farmers, especially those aged between 40 and 60, the primary motivation reported for using barter is risk minimization.

However, alongside its perceived advantages, barter also presents important economic drawbacks. Cançado et al. (2019) show that farmers, especially those with smaller farms and lower access to information, often have limited knowledge about the mechanisms of contract negotiation, which may weaken their position in the negotiation process. Furthermore, barter transactions involve hidden costs, such as embedded interest rates, default risk premiums, and manufacturers' and resellers' profit margins Porto (2016). These elements are not always transparent to farmers and may imply a higher implicit cost of financing relative to conventional financial alternatives.

These characteristics highlight a crucial and still underexplored dimension of barter financing: the problem of bargaining power. Barter contracts are not purely technological or financial arrangements; they are the outcome of a strategic negotiation process between heterogeneous agents with asymmetric information, different outside options, and unequal market power. On one side, input-supply firms and trading companies seek to secure future grain supply and to transfer price and credit risks through margins and standardized input packages. On the other side, farmers aim to reduce liquidity constraints and price uncertainty while preserving as much surplus as possible from their future production.

Hence, the effective conditions of a barter contract, including the grain-input exchange ratio, the implicit interest rate, the embedded risk premium, and package composition, are the result of a bargaining process whose outcome depends on the relative bargaining power of farmers and firms. Larger and more experienced farmers, with greater purchasing scale and more access to market information, tend to have stronger negotiating positions. In contrast, smaller and less informed farmers may accept less favorable terms due to restricted outside options and credit constraints.

Despite the importance of this negotiation process, most of the existing literature on barter in Brazil has focused either on descriptive institutional aspects or on empirical correlations, leaving the strategic dimension of contract formation largely unexplored. This paper addresses this gap by explicitly modeling barter as a bargaining problem between farmers and input-supply firms.

In this paper we develop a theoretical model of barter financing in which the contract terms emerge endogenously from a Nash bargaining equilibrium. In the model, the farmer and the input-supply firm negotiate over the surplus generated by the barter contract, taking into account their disagreement payoffs, risk preferences, production technology, and alternative financing opportunities. By embedding the barter contract within a Nash bargaining framework, the model allows for a formal analysis of how relative bargaining power, risk aversion, and outside options shape the allocation of surplus and the final terms of the contract.

This paper contributes to the literature by developing a theoretical framework in which barter contracts are determined through a Nash bargaining process under uncertainty. To the best of our knowledge, this is the first paper that models barter financing as a bargaining problem between farmers and input-supply firms, explicitly incorporating risk preferences, bargaining power, and macro-financial conditions.

2 Barter history

Barter as an agricultural financing instrument emerged in Brazil in early 90's, given the country fiscal crises throughout 80's decade that shrink government financial support, summing up with high interest rates imposed by the stabilization economic plan, *Plano Real*, and high debt farmers that were constrained to acquire financing in the private sector.

Therefore, Barter emerged in Brazil as an alternative financing mechanism when farmers faced increasing credit constraints from private institutions and a gradual reduction of government support to agriculture. In response to these difficulties, major agribusiness firms developed this new financing strategy, offering production inputs in exchange for an amount of future harvests.

In a barter operation there is no monetary transaction, the farmer acquire inputs from a seller in the pre-harvest period and pay this debt after harvest with production. In this financing structure the input seller finances the farmer. Silva (2012)

The operation begins with negotiations between the farmer and trading companies or cooperatives regarding the type and price of inputs. Once the deal is concluded and prices are set, the farmer issues a Cédula de Produto Rural (CPR) to the trading company or cooperative. The CPR, established under Law No. 8.929 of 1994, is a contract that formalizes the agreement between the farmer and the company. It includes clauses the farmer is obligated to fulfill, such as commodity specifications, quality standards, and post-harvest delivery dates Presidência (2025).[1] [2]

The CPR goals are i) to finance production through the early selling of the product of the rural producer, ii) to guarantee the supply of raw materials through early selling of agro-industrial production; iii) to sell inputs through the exchange of inputs for farm production by companies dealing in inputs; iv) to provide alternative investments for funds. Souza and Pimentel (2005)

The main risk associated with barter for a farmer is price risk. This risk arises from uncertainty in commodity prices between the time of contracting and delivery. For instance, if the commodity price increases, the farmer may face an opportunity loss, as part of the production has already been committed at a lower price than the prevailing market value. Conversely, if the price decreases, the farmer may benefit, since the contract price was fixed at a higher level. It is also important to note that production fluctuations affect the farmer's profit. Assume prices are given, in the case of a poor harvest, the fixed quantity of grain owed under the barter agreement represents a larger share of total output, thereby reducing the farmer's retained income.

Farmers advantages perception toward the use of barter are: i) risk management; ii) just-in-time input delivery (eliminating the need for on-farm storage); iii) time savings in input negotiations; iv) high availability of barter contracts; v) fewer prerequisites for approval; vi) market opportunities; vii) improved cash flow; viii) and greater liquidity. Arakawa (2014).

Paes Leme and Zylbersztajn (2008) state that farmers know the exchange terms before the harvest, making the trade independent of soybean prices after harvest and thereby reducing risk and uncertainty for the farmer. Santos (2021) points out that the Barter system is an economically viable option, mainly due to the predictability of results and the low financial

[1]There are additional institutional arrangements and organizational structures involving farmers, input suppliers, and trading companies beyond those described here; see Silva (2012), Laing et al. (2013), and Cançado et al. (2019). For instance, Silva (2012) and Shimizu (2022) describes a commonly used structure in which farmers seeking production financing first issue a CPR, specifying the quantity, quality, delivery date, and place of delivery of soybeans. The CPR is then registered and with the registered CPR, farmers negotiate with local input suppliers to obtain production inputs. Subsequently, these suppliers endorse or transfer the CPR to grain trading companies interested in securing future soybean supply. In exchange, traders provide financial resources to the suppliers, who then deliver the input packages, including seeds, fertilizers, and agrochemicals, to farmers. Finally, at harvest, farmers fulfill the contract by delivering the agreed soybean volume to the trading companies, according to the terms established in the CPR. This structure is known as triangular barter.

[2]Porto (2016) describes the agricultural pesticide pricing of a barter operation as: a) Manufacturer's profit margin + financial cost associated with the "crop-season credit term" (the interest component embedded in the deferred payment period between sowing and harvest) + the percentage of default risk; b) Re-seller's profit margin + financial cost set by the manufacturer, which incorporates the default-risk percentage + possibly additional charges.

risks it entails. Porto (2016) also highlights that, for small farmers with limited education, exchanging input packages for bags of corn or soybeans delivered after harvest provides predictability and a clearer understanding of the transaction.

However, there are hidden costs that may be higher than those associated with other financing alternatives available in the market Porto (2016). Santos (2021) describes the hidden costs, such as high interest rates, default fees, manufacturers' and retailers' profit margins, among others.

Shimizu (2022) state that despite of barter had helped farmers to increase production it is difficult to increase their profit and expand production scale, this clain comes from the fact that farmers that use barter have fewer options of input acquisition and grain sales compared with farmers that do not use barter.

Moreover entering a barter contract also brings several drawbacks for farmers. For instance, input prices tend to be higher because producers negotiate individually and, the standard packages offered by suppliers often include generic agrochemicals that do not always match the specific needs of each farm. Shimizu (2022). Cançado et al. (2019) also show that farmers express concerns about penalty fees arising from non-compliance with contract terms, particularly in cases of failure to deliver the agreed quantity of the product.

For companies, Johann et al. (2017) show that large companies in Mato Grosso and Goiás are the ones that most frequently use and are most knowledgeable about barter operations. Around 40% of the companies in their study commercialized 31% or more of their revenue through barter, and 61.54% frequently encouraged farmers to use barter operations. Farmers that engage in this type of financing are typically 40 to 60 years old, education is not a determining factor, and for 66.67% of farmers the main motive to use barter is risk minimization.

The structure of barter contracts naturally opens room for bargaining between farmers and input-supply firms. On one hand, input companies seek to secure future grain delivery and guarantee raw material supply, aligning with one of the primary objectives of the Cédula de Produto Rural (CPR) mechanism, to finance agricultural production through the early sale of farmers' output Souza and Pimentel (2005). On the other hand, farmers enter barter contracts to mitigate price and liquidity risks, obtain just-in-time delivery of inputs, and reduce transaction costs in input acquisition Arakawa (2014).

This financial arrangement embeds several components that can be negotiated, such as the manufacturer's and reseller's profit margins, the financial cost of the crop-season credit term, and the premium associated with default risk Porto (2016). Paes Leme and Zylbersztajn (2008) corroborate the bargaining dynamics between farmers and input-supply firms by emphasizing that the greater use of barter among high-production farmers is driven by the supply side, as input suppliers strategically offer benefits and incentives to attract these producers and for input-supply firms, targeting high-production farmers is justified by lower acquisition costs due to volume purchasing and the prospect of higher overall sales volumes. Cançado et al. (2019) indicate that farmers view long-term relationships with trading companies as a way to enhance their bargaining power and obtain more favorable economic terms in contract negotiations.

These elements affect the final implicit price of inputs and the effective exchange ratio of grain-for-input. Therefore, the possibility of bargaining arises from the asymmetry of objectives and information between the parties: while firms aim to transfer financial and market risks through higher margins and standardized packages, farmers, particularly large-scale producers with substantial purchasing power, as well as those with greater experience and better access to information, may negotiate more favorable terms by comparing contract conditions, delivery timing, or even customizing input packages to match their specific production needs. In this sense, barter negotiations reflect not only market power relations but also the degree of financial literacy and information access among farmers, making the bargaining process a central element in determining the effective cost and efficiency of barter financing.

3 Brazilian Evidence on Barter in Agribusiness

The empirical literature on barter financing in Brazilian agribusiness is largely based on survey evidence from the states of Mato Grosso, Minas Gerais, and Rio Grande do Sul. These regions are highly representative of the country's agricultural structure: Mato Grosso leads national production of soybeans, corn, cotton, and cattle; Minas Gerais is the main producer of coffee and milk; and Rio Grande do Sul specializes in rice production.

Paes Leme and Zylbersztajn (2008) investigate the determinants that lead farmers to choose a particular financing strategy for purchasing fertilizer. The study interviewed soybean producers in the states of Goiás and Mato Grosso in 2004. The results indicate that 31% purchase fertilizer totally or partially through barter, 24.5% rely on their own capital, and 25% use credit from banks or private institutions.[3]

Farmers who rely on barter perceive that this arrangement optimizes time, reduces costs, and provides greater convenience and predictability in the process. The study also shows that as farmers' risk perception increases, i.e., as risk aversion rises, it increases the use of barter. Another result indicates that higher levels of trust in the company that supplies the inputs are associated with a greater use of barter. Finally, the evidence suggests that farmers with larger production volumes tend to use barter more frequently.

Arakawa (2014) investigate the perception of farmers in Lucas do Rio Verde, in the state

[3]Own capital: 24.5%; financing: 25%; barter: 11%; own capital/financing: 19%; own capital/barter: 6.5%; financing/barter: 10.5%; own capital/financing/barter: 3%.

of Mato Grosso, using interviews conducted during ENTECS (Crop Technology Exhibition) in 2013. The results show that barter contracts are offered by most traders in the region, and trade terms vary among farmers and traders. Some traders offer benefits such as allowing farmers to use storage space, providing discounts on storage costs, and enabling price negotiation at a time desired by the farmer.

Farmers associate barter with several advantages, such as managing price risk on both the sale of grains and the purchase of inputs; just-in-time input delivery (eliminating the need for on-farm storage); time savings due to bundled input packages; high availability of barter contracts; fewer prerequisites for approval; market opportunities for production surpluses; improved cash flow, since it becomes clearer for the farmer to visualize costs and revenues using the same unit of measure; and greater liquidity due to additional commercialization opportunities. Arakawa (2014)

Cançado et al. (2019) investigate the factors that lead soybean farmers in the State of Minas Gerais to use barter as a tool for risk management and input financing. The research was conducted in 2018 using a structured questionnaire. The results show that farming experience increases the probability of adopting barter, whereas age and farm size reduce this likelihood. The study also indicates a low level of knowledge about barter negotiations among farmers. However, there is a perception that the larger the planted area, the greater the benefits of using barter. The authors emphasize that this result is associated with the preference of farmers who cultivate large areas to rely on barter operations. The research further reveals that farmers who use barter are more likely to be landowners. Additionally, farmers believe that maintaining long-term relationships with trading companies can generate commercial advantages. Overall, there is a perception that barter is a low-risk financing and commercialization tool.

Shimizu (2022) compare, using survey data, farm management practices between farms with and without barter contracts in Lucas do Rio Verde and Tangará da Serra, in the State of Mato Grosso. Barter is the predominant financing method among farmers with arable land below 1,000 hectares. The results show that farmers who rely on barter have fewer options for both input procurement and grain sales compared to those who do not use barter. These farmers also face higher implicit interest rates. In contrast, farmers that access bank credit tend to have a wider range of suppliers and trading partners, which allows them to reduce costs, increase profitability, and expand their scale of production. The authors also stress that input prices may be higher in barter operations, since farmers often purchase individually and therefore do not benefit from volume discounts.

Using a simulation based on a representative grain-producing farm in Mato Grosso, Lorenzon and Dalchiavon (2019) show that barter reduces variable costs and significantly increases profitability, with total profits rising by approximately 38% compared to cash purchases, alongside a notable improvement in profit margins. Complementing this evidence, Scremin et al. (2020), analyzing soybean farms in Rio Grande do Sul, find that barter entails the lowest input cost burden among competing financing options and serves as an effective hedge against input price volatility, as well as fluctuations in interest and exchange rates. Furthermore, Henschel et al. (2025), using Monte Carlo simulations for farms in Mato Grosso do Sul, demonstrate that barter consistently delivers higher expected profitability combined with lower volatility when compared to bank credit and own capital, even under adverse scenarios. Taken together, these studies suggest that barter financing not only enhances profitability but also improves risk management, making it a robust and efficient financial strategy for agricultural producers.

Johann et al. (2017) show that large companies in Mato Grosso and Goiás are the ones that most frequently use and are most knowledgeable about barter operations. Around 40% of the companies in their study commercialized 31% or more of their revenue through barter, and 61.54% frequently encouraged farmers to use barter operations. Farmers that engage in this type of financing are typically 40 to 60 years old, education is not a determining factor, and for 66.67% of farmers the main motive to use barter is risk minimization.

4 The Model

To analyze the main determinants of barter transactions, we model the decision problem faced by a farmer who must finance agricultural inputs before harvest. The farmer's production process involves a time lag between the input decision and the realization of output, represented by:

$$Y^i_{t+1} = A^i_{t+1} F(X_t) \tag{1}$$

where A^i_{t+1} denotes an idiosyncratic shock to total factor productivity, and X_t is the amount of agricultural inputs chosen at time t for the harvest at time $t+1$. The commodity price is assumed to be stochastic. Thus, the farmer faces two sources of uncertainty: an idiosyncratic productivity shock and an aggregate price shock.

Both shocks are assumed to be mutually independent. This assumption reflects the institutional environment of agricultural production: output prices are determined in international commodity markets, where farmers act as price takers, whereas productivity shocks are idiosyncratic and farm-specific.

4.1 Nash Bargaining Process

The farmer's utility function is strictly increasing and strictly concave in profits, implying risk aversion. Let r_{t-1}denote the predetermined interest rate on input financing, agreed upon at time $t-1$ and due at time t, i.e it is known. Furthermore, it is assumed that financing entails an additional cost, $\theta \in [0,1]$, reflecting storage costs incurred during the production cycle.

Alternatively, the farmer may choose to pay for part of the input costs through barter. Let $n_t^b \in [0,1]$ denote the fraction of total input costs, $Z_t X_t$, where Z_t is the input price, covered via barter. The remaining fraction, $(1-n_t^b)$, is financed through conventional credit.

By choosing to cover part of the input costs through barter, the farmer avoids the storage cost θ, under the assumption of just-in-time input delivery. However, this option requires the farmer to commit to delivering B_t units of future output as payment.

The terms B_t and n_t^b are determined through a bargaining process between the farmer and the agricultural input supplier. We assume a weighted (generalized) Nash bargaining framework Nash et al. (1950). Let $\phi \in (0,1)$ denote the bargaining power of the farmer, and let ExA and ExF represent the expected surpluses of the farmer and the input supplier, respectively. The bargaining solution jointly determines B_t and n_t^b by solving:

$$\mathcal{H} = \max_{\{B_t, n_t^b\}} (ExA)^{\phi}(ExF)^{(1-\phi)} \tag{2}$$

The timing of events within each period is summarized as follows:

1. The states A_t^i and P_t are revealed.
2. The farmer chooses the input quantity X_t for the next production period.
3. The farmer and the input supplier negotiate the cost and quantity of barter through the bargaining process.

The expected surplus for the farmer is defined as the difference in utility between the barter scenario, π_{t+1}^b, and the scenario where all inputs are financed via credit, π_{t+1}^f:

$$ExA = \beta E_t \left[u(\pi_{t+1}^b) - u(\pi_{t+1}^f) \right] \tag{3}$$

The input supplier's expected surplus is the difference between the present value of revenues under barter, $P_{t+1}B/(1+r_{t-1}) + (1-n_t^b)Z_t X_t$, and the value of selling all inputs at the market price, $Z_t X_t$:

$$ExF = E_t \left(\frac{P_{t+1}B}{1+r} \right) + (1-n_t^b) Z_t X_t - Z_t X_t \tag{4}$$

$$ExF = E_t\left(\frac{P_{t+1}B}{1+r}\right) - n_t^b Z_t X_t \tag{5}$$

4.2 The Farmer's Problem

The farmer's objective is to choose the level of agricultural inputs X_t in each period in order to maximize the expected lifetime utility derived from profits. This decision is made under uncertainty and subject to the constraints imposed by the production technology and the financing mechanism (either via credit or barter). Formally, the farmer solves the following dynamic optimization problem:

$$\max_{\{X_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t u(\pi_t) \tag{6}$$

subject to:

i) Profit equations under each financing regime:

$$\pi_t^b = P_t\left[A_t^i Y_t(X_{t-1}) - B_{t-1}\right] - (1 - n_{t-1}^b)(1 + r_{t-1} + \theta)Z_{t-1}X_{t-1} \tag{7}$$

$$\pi_t^f = P_t\left[A_t^i Y_t(X_{t-1})\right] - (1 + r_{t-1} + \theta)Z_{t-1}X_{t-1} \tag{8}$$

ii) Non-negativity and barter constraints:

$$X_t \geq 0; \quad (B_{t-1}, n_{t-1}^b) = \arg\max\{\mathcal{H}\} \tag{9}$$

Equations 7 and 8 represent the realized profit in period t under two alternative financing strategies:

Equation 7 corresponds to the case where the farmer chose to barter a positive share of input costs in period $t-1$, i.e., $n_{t-1}^b > 0$. In this case, the farmer receives the market value of output net of the amount B_{t-1} committed to the input supplier. Additionally, the remaining fraction of input costs that was not bartered is paid back with interest and storage cost.

Equation 8 corresponds to the case where the farmer relied entirely on conventional credit, i.e., $n_{t-1}^b = 0$, and thus repays the full cost of inputs with interest and storage fees, but retains the entire output.

The term $(1 + r_{t-1} + \theta)$ captures the full cost of financing through credit, combining the nominal interest rate r_{t-1} with the storage cost θ. In contrast, the barter mechanism allows the farmer to avoid θ, but at the expense of giving up future output, B_{t-1}.

The values of B_{t-1} and n^b_{t-1} are endogenously determined by the Nash bargaining process described in Section 4.1, and are thus treated as predetermined from the farmer's perspective when choosing X_t.

This setup highlights a key trade-off: credit imposes higher monetary costs due to interest and storage, whereas barter reduces upfront financial burden but entails giving up a portion of future production. The farmer's optimal input choice will depend on the relative risks and expected returns under each financing strategy, shaped by productivity shocks, price volatility, and bargaining outcomes.

4.3 Barter and Volatility

This section presents the analytical results of the model. We assume that the aggregate price shock has unconditional mean and variance given by $E(P_t) = \bar{P}$ and $Var(P_t) = \sigma^2_P > 0$. The idiosyncratic productivity shock has unconditional mean equals to one and positive variance given by $E(A^i_t) = 1$ and $Var(A^i_t) = \sigma^2_A > 0$.

[Local effect of barter under small risk] Let P_t and A^i_t be mutually independent. For σ^2_P and σ^2_A sufficiently small and $n^b_{t-1} > 0$, barter decreases the volatility of farmers profit by reducing only price risk.

From equation 7, the variance of farmers profit under barter in period t is:

$$Var(\pi^b_t) = Var(P_t \left[A^i_t F(X_{t-1}) - B_{t-1}\right] - (1 - n^b_{t-1})(1 + r_{t-1} + \theta)Z_{t-1}X_{t-1}) \tag{10}$$

Since the second (negative) term in the right hand side of 10 is constant at t, then:

$$Var(\pi^b_t) = Var(P_t \left[A^i_t F(X_{t-1}) - B_{t-1}\right]) \tag{11}$$

Assume $X_t = P_t(A^i_t F(X_{t-1}) - B_{t-1})$. Moreover, note that, in t: $E(A^i_t F(X_{t-1}) = F(X_{t-1}) = \bar{Y}$, therefore:

$$\mu = E(X_t) = E[P_t A^i_t F(X_{t-1}) - P_t B_{t-1}] = \bar{P}(F(X_{t-1}) - B_{t-1}) = \bar{P}(\bar{Y} - B_{t-1}) \tag{12}$$

$$\sigma^2_X = Var(X_t) = Var(\pi^b_t) = Var(P_t A^i_t F(X_{t-1}) - P_t B_{t-1}) \tag{13}$$

Using the properties of variance under mutually independent shocks:

$$\sigma_X^2 = [F(X_{t-1})]^2 Var(P_t A_t^i) + B_{t-1}^2 Var(P_t) - 2F(X_{t-1})B_{t-1}Cov(P_t A_t^i, P_t) \tag{14}$$

By the properties of variance and covariance and substituting $Var(P_t) = \sigma_P^2$ and $Var(A_t^i) = \sigma_A^2$:

$$Var(P_t A_t^i) = \sigma_P^2\sigma_A^2 + \sigma_P^2 + \bar{P}^2\sigma_A^2 \tag{15}$$

Moreover:

$$Cov(P_t A_t^i, P_t) = E(A_t^i)Var(P_t) = \sigma_P^2 \tag{16}$$

Substituting equations 15 and 16 into equation 14:

$$\sigma_X^2 = \bar{Y}^2(\sigma_P^2\sigma_A^2 + \sigma_P^2 + \bar{P}^2\sigma_A^2) + B_{t-1}^2\sigma_P^2 - 2\bar{Y}B_{t-1}\sigma_P^2 \tag{17}$$

Assuming $\sigma_P^2\sigma_A^2 \approx 0$:

$$\sigma_X^2 = \bar{Y}^2\bar{P}^2\sigma_A^2 + \bar{Y}^2\sigma_P^2 + B_{t-1}^2\sigma_P^2 - 2\bar{Y}B_{t-1}\sigma_P^2 \tag{18}$$

$$\sigma_X^2 = \bar{Y}^2\bar{P}^2\sigma_A^2 + \sigma_P^2[\bar{Y}^2 + B_{t-1}^2 - 2\bar{Y}B_{t-1}] \tag{19}$$

$$\sigma_X^2 = [\bar{Y}\bar{P}]^2\sigma_A^2 + \sigma_P^2[\bar{Y} - B_{t-1}]^2 \tag{20}$$

Equation 20 shows the variance of farmer profits under barter and locally shocks.

It is straightforward to show that the farmers profit without barter is:

$$Var(\pi_t^f) = Var(P_t A_t^i F(X_{t-1})) = [\bar{Y}\bar{P}]^2\sigma_A^2 + \sigma_P^2[\bar{Y}]^2 > \sigma_X^2 = Var(X_t) = Var(\pi_t^b) \tag{21}$$

Furthermore, note in equation 20 barter decreases total volatility and its effect depends only on price variance σ_P^2:

$$\frac{\partial \sigma_X^2}{\partial B_{t-1}} = -2\sigma_P^2[\bar{Y} - B_{t-1}] < 0. \tag{22}$$

Equation 20 shows the variance of farmer profits under barter as the sum of two components. The first one is driven by the volatility of productivity shocks and the second one is driven by prices shock. The first term, the productivity risk, is independent of B_{t-1} while the second term, the price risk, is partially reduced by B_{t-1}.

4.4 Definition of Equilibrium

The model is formulated as a dynamic game between the farmer and the agricultural input supplier, which we refer to as the agricultural firm. The interaction is characterized by a pure-strategy Markov Perfect Equilibrium (MPE), where each agent's strategy depends solely on the current state of the economy and not on the entire history of past actions.

Formally, the state space at time t is defined as:

$$S_t = (P_t, A_t^i)$$

where P_t is the aggregate commodity price and A_t^i is the idiosyncratic productivity shock affecting the farmer.

In each period, agents make decisions recursively based on the current state. The Markov equilibrium is defined by a set of policy functions for the farmer and the agricultural firm that jointly satisfy optimality and consistency conditions. The recursive algorithm for solving the equilibrium is as follows:

1. **Bargaining Stage:** For each possible input level X_t, the farmer and the agricultural firm engage in a Nash bargaining process to determine the barter contract. This involves jointly choosing the fraction of inputs to be bartered, n_t^b, and the quantity of future output pledged in exchange, B_t. These values are determined by solving the bargaining problem defined in Equation 2, taking the current state S_t as given:

$$(B_t, n_t^b) = \arg\max \left\{(ExA)^{\phi}(ExF)^{1-\phi}\right\}$$

2. **Input Decision Stage:** Given the bargaining outcome from step 1, the farmer chooses the optimal input level X_t that maximizes the expected discounted utility of profits over time, as defined in Equation 6. The farmer incorporates the financing conditions, whether via credit or barter, which are summarized by (B_{t-1}, n_{t-1}^b) from the previous period's negotiation:

$$X_t = \arg\max \; E_0 \sum_{t=0}^{\infty} \beta^t u(\pi_t)$$

   subject to the profit constraints under either credit or barter arrangements.

This recursive structure ensures that strategies are dynamically consistent and optimal given the current information. The Markov property implies that, despite the dynamic nature of the problem, the complexity is reduced by focusing only on current observable states, rather than the full history of shocks or decisions.

The resulting equilibrium reflects how farmers adjust their input decisions in response to price and productivity shocks, considering the trade-offs between credit and barter financing. Likewise, the agricultural firm adapts its bargaining strategy based on the expected surplus from future deliveries versus immediate monetary payments.

4.5 Model Calibration and Parameterization

To solve for the theoretical model presented in the previous section, this part provides the empirical and quantitative foundations necessary for its computational implementation. The model will be solved quantitatively through iterative numerical methods applied to the theoretical framework already discussed. For this purpose, it is essential to calibrate all structural parameters so that they reflect plausible economic behavior and remain consistent with empirical evidence on farmers' risk preferences, production technology, and market conditions. By grounding the model in realistic data and behavioral assumptions, the subsequent simulations can reproduce the dynamic interactions that characterize agricultural decision, in particular, the barter contracts, making under uncertainty.

Table 1: Transition matrices for price and productivity shocks

Shock	**Transition Matrix**	**Reference**
Price	$\begin{bmatrix} 0.60 & 0.40 \\ 0.30 & 0.70 \end{bmatrix}$	Agbodjan (2022)
Productivity	$\begin{bmatrix} 0.90 & 0.10 \\ 0.12 & 0.88 \end{bmatrix}$	Matis (1985)

The transition matrices presented in Table 1 highlight a notable difference in the persistence of states between productivity and commodity prices. The productivity matrix exhibits high persistence, with probabilities of remaining in the same state of 0.90 for low productivity and 0.88 for high productivity, indicating that productivity shocks are highly dependent on the current state. In contrast, the price matrix shows lower persistence, with probabilities of 0.60 and 0.70 for remaining in low and high price states, respectively, suggesting that commodity prices are more volatile and less dependent on their previous state. This distinction reflects the greater inertia in crop yields compared to the more fluctuating nature of agricultural market prices.

Table 2: Calibrated parameters of the benchmark model with justification

Parameter	Value	Description	Justification / Source
θ	0.1	Storage cost when financing	Assumed moderate cost based on typical storage and credit expenses
ϕ	0.5	Farmer's bargaining weight	Assumed equal bargaining power between farmer and firm
β	0.96	Subjective discount factor	Standard value used in agricultural dynamic models to represent intertemporal preferences
α	0.8	Production function exponent: $Y_{t+1} = A_{t+1}X_t^\alpha$	Typical diminishing returns assumption for crop production ($0 < \alpha < 1$)
r	0.05	Given interest rate for the production cycle	Approximates market interest rates for short-term agricultural loans
z	1	Given price of agricultural inputs	Normalization for input prices in model simulations

Table 2 presents the calibrated parameters of the benchmark model used in this study. It includes the storage cost when financing (θ), the coefficient of relative risk aversion (γ), the subjective discount factor (β), the production function parameter (α), and the deterministic prices: interest rates (r) and input prices (z). The justification column provides the rationale or source for each parameter, including references from the literature for risk aversion.

4.5.1 Simulation Scenarios and Sensitivity Analysis

The calibrated parameters form the backbone of the simulation exercises that follow. Each parameter value was chosen to balance empirical plausibility and analytical tractability, ensuring that the model reproduces realistic patterns of agricultural decision making under uncertainty.

The simulation scenario considered stronger risk aversion ($\gamma = 1.5$), capturing a more conservative behavioral pattern typical of smallholders facing liquidity constraints and higher exposure to production and market risks.[4]

[4]The empirical literature on farmers' risk preferences shows substantial heterogeneity in estimates of the coefficient of relative risk aversion (CRRA), reflecting differences in farm size, farmer type, methodological approach, and institutional context. Smallholders and subsistence farmers typically display higher levels of risk aversion, with CRRA values often above 2 or even exceeding 3 Lien et al. (2023), whereas commercial farmers generally present moderate values between 0.5 and 1.0 Rommel et al. (2023). Experimental methods frequently produce lower estimates, usually between 0.1 and 0.7, such as the average CRRA of 0.13 reported in an experimental study in China Liu et al. (2016). In contrast, structural estimations based on observed production, credit, or insurance decisions tend to generate higher values, often between 1 and 3 Bougherara et al. (2011). Programming models used in agricultural economics commonly assume CRRA values around 2 to replicate observed behavior Liu (2018). Institutional context also matters, as farmers in developing countries

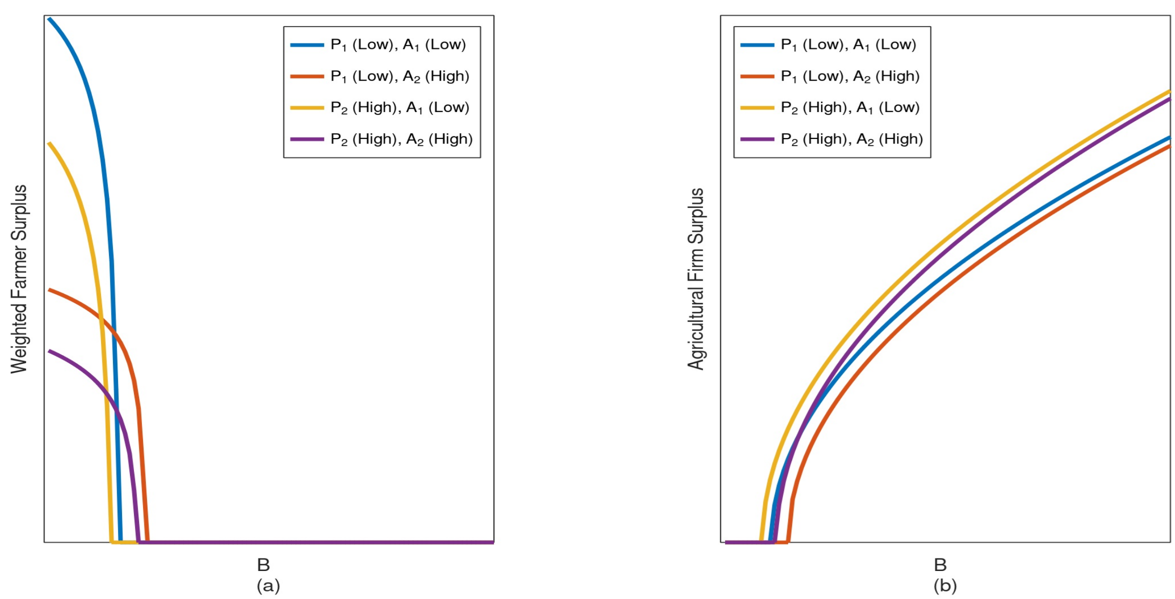
By comparing outcomes across these two risk aversion levels, the analysis explores how behavioral heterogeneity affects optimal input use, barter contracts, and income volatility. Additionally, sensitivity checks will be conducted by varying key parameters, such as the interest rate (r) and the farmer's bargaining weight (ϕ), to assess the robustness of the results. This strategy allows identifying which dimensions of the model exert the greatest influence on the economic outcomes simulated, offering insights into how credit conditions, bargaining power, and risk preferences jointly shape farmers' welfare and production efficiency.

5 Bargaining Structure and Barter Contract Design

This section first defines the bargaining region as the set of (B, n) pairs that yield strictly positive surpluses for both the farmer and the input supplier, conditional on the current state (P, A). Finally, it evaluates how key behavioral parameters, risk aversion (γ), bargaining power (ϕ) and interest rate (r), shape equilibrium barter costs across states. Understanding how bargaining power shapes the cost of barter contracts provides insights into how contractual asymmetries can affect farmers' access to financing and overall market efficiency.

Figure 1 reports the weighted surpluses for both parties: panel (a) presents farmers' surpluses, while panel (b) shows firms' surpluses.

Figure 1: Surpluses Under Bargaining as a Function of Barter Output per unit of input.



Source: Author's own elaboration. Benchmark economy with $\gamma = 1.5$.

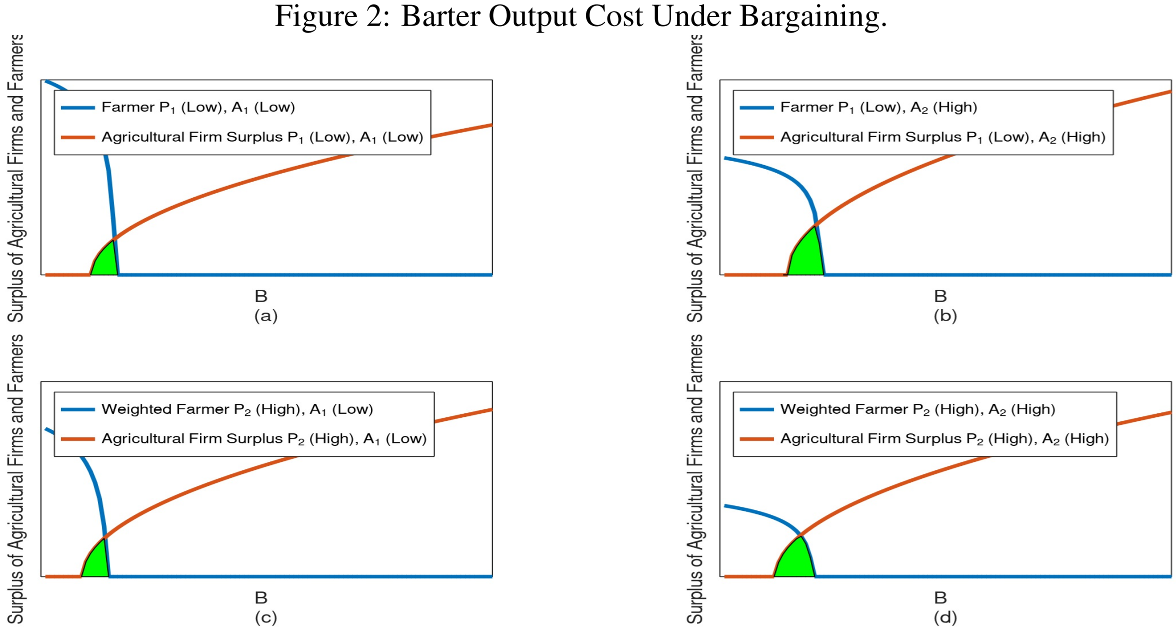
tend to be more risk averse due to limited access to credit, insurance, and other risk management instruments Dillon (1978); Leblanc and et al. (2021); Gómez-Limón and Sanchez-Fernandez (2003). Given the lack of consensus regarding the precise level of risk aversion among Brazilian farmers, this study adopts alternative CRRA parameters in the simulations, including a conservative value of $\gamma = 1.5$.

Figure 1 Panel (a) demonstrates that, as the Barter output per unit of input (B) increases, the farmer's surplus diminishes at a faster rate for low-productivity farmers, particularly under assumption of high persistence of the productivity shock. This result is consistent with Nash bargaining theory, in which the threat point of a less productive farmer is weaker, reducing the agricultural input supplier's ability to extract surplus in equilibrium. Consequently, increases in (B) disproportionately erode the surplus of less productive farmers when productivity shocks are highly persistent.

Figure 1, panel (b), shows that for firms, as the Barter output per unit of input (B) increases, the resulting gain in surplus is larger in high-price states. This occurs because higher output prices amplify the revenue generated from the quantity of production committed under Barter contracts, thereby increasing the firm's share of the negotiated surplus. Consequently, the positive effect of an increase in (B) on firms' surplus is more pronounced when market prices are elevated. It is also important to note that price variations exert a stronger impact on surpluses than productivity shocks, for firms.

Figure 2 illustrates the surpluses of the farmer and the firm for each level of output per unit of input committed to Barter, B. The figure contains four panels: panel (a) corresponds to the low-price, low-productivity state; panel (b) to the low-price, high-productivity state; panel (c) to the high-price, low-productivity state; and panel (d) to the high-price, high-productivity state.

Figure 2: Barter Output Cost Under Bargaining.

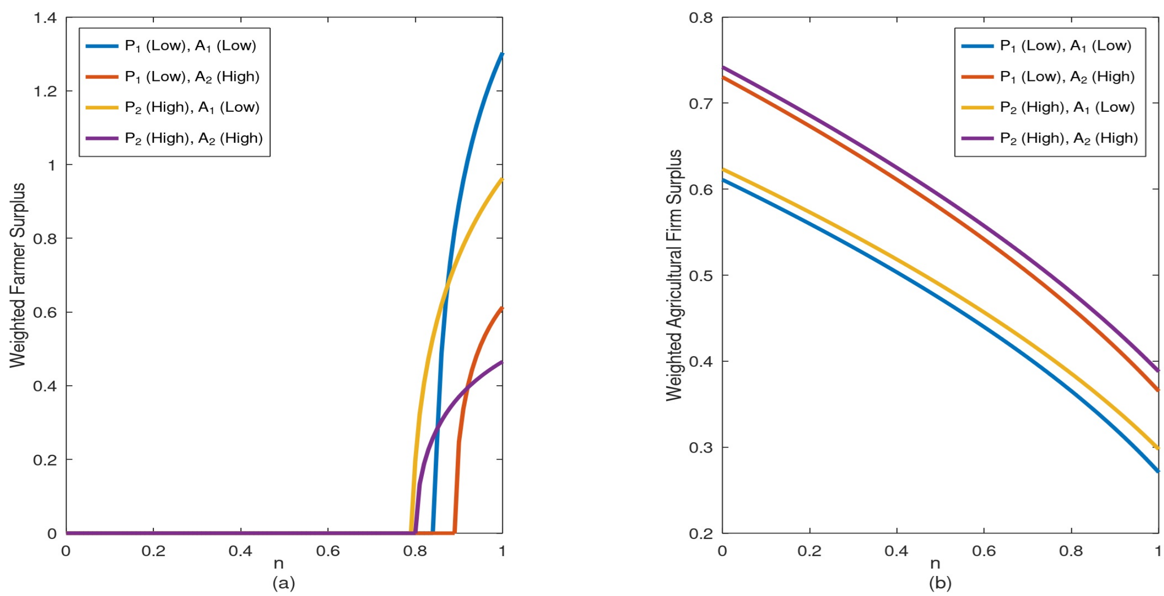


Source: Author's own elaboration. Benchmark economy with $\gamma = 1.5$.

The green area represents the bargaining region in which the Barter cost is determined. In the Nash bargaining framework, the negotiated outcome depends on the joint surplus generated by the farmer–firm relationship, which is influenced by productivity and output value. As shown in Figure 2, the bargaining region is smaller in low-productivity states and larger in high-productivity states. Lower productivity reduces output per unit of input, compressing the total surplus available for division, while higher productivity expands output and total revenue, increasing the surplus shared between the agents. This effect arises from shifts in the production frontier and therefore occurs independently of the price state, leading to larger equilibrium surpluses in both high- and low-price environments.

Figure 3 shows how the Barter share affects the distribution of surplus between farmers and firms, for farmers, panel (a) and form firms, panel (b) as a function of Barter percentage n.

Figure 3: Surpluses Under Bargaining as a Function of Barter Percentage.

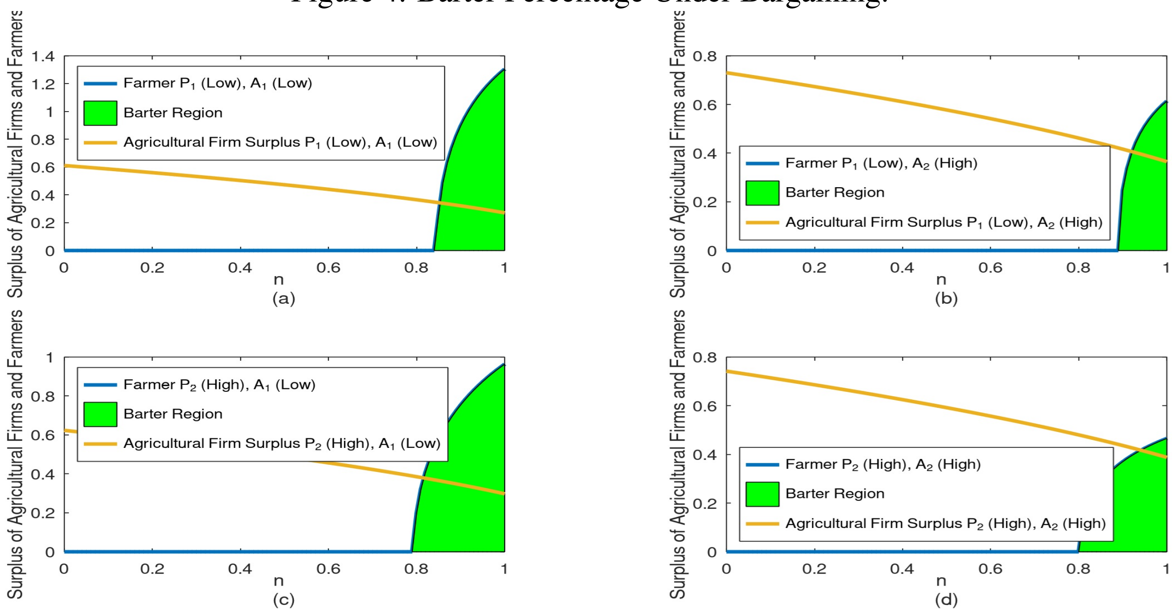


Source: Author's own elaboration. Benchmark economy with $\gamma = 1.5$.

Figure 3 panel (a) indicates that as the Barter share increases, low-productivity farmers obtain a larger surplus in both low- and high-price states, with the highest surplus occurring under low productivity and low prices. This occurs because Barter reduces income volatility and liquidity constraints by pre-committing part of the output, effectively providing financing and risk-sharing, which is particularly valuable for farmers with weaker outside options. Panel (b) shows that firms obtain higher surpluses in high-productivity states across both price environments. Higher productivity increases output and total revenue, expanding the joint surplus generated by the match. Since the Nash bargaining solution divides this larger surplus according to bargaining weights, firms capture a proportionally larger payoff when productivity is high.

Figure 4 illustrates the surpluses of the farmer and the firm for each level of Barter percentage, n. The figure contains four panels: panel (a) corresponds to the low-price, low-productivity state; panel (b) to the low-price, high-productivity state; panel (c) to the high-price, low-productivity state; and panel (d) to the high-price, high-productivity state.

Figure 4: Barter Percentage Under Bargaining.



Source: Author's own elaboration. Benchmark economy with $\gamma = 1.5$.

Figure 4 illustrates the bargaining region for the share of inputs financed through Barter, defined as the set of allocations where both agents obtain positive surpluses. The equilibrium Barter share is determined through Nash bargaining by jointly maximizing the agents' surpluses, which depends on parameters such as bargaining power, risk aversion, and the interest rate. Panels (a) and (c), corresponding to low-productivity states under low and high prices, exhibit the largest bargaining regions. This occurs because low productivity significantly weakens the farmer's outside option relative to the firm's, expanding the range of surplus allocations that satisfy individual rationality. Consequently, even though total surplus is smaller, the asymmetry in disagreement payoffs enlarges the bargaining set, a result that holds under both price regimes.

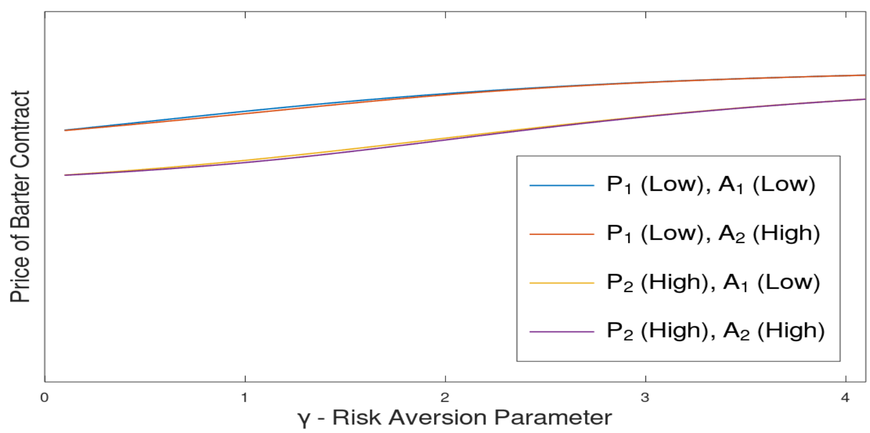
6 Quantitative Experiments on Barter Price and Cost Dynamics

This section conducts a series of experiments varying the key behavioral parameters of the model, the farmer's degree of risk aversion (γ), bargaining power (ϕ) and interest rate (r), in order to analyze their effects on the equilibrium cost of the barter contract. Unless otherwise stated, all other parameters remain at benchmark values. It is important to highlight that, in this section, the quantity of inputs is taken as given.

6.1 Risk Aversion Scenarios

Figure 6.1 illustrates how the contracted barter output per unit of input cost responds to increases in the farmer's risk aversion. As the farmer becomes more risk-averse, he is willing to accept a higher barter cost, since the barter arrangement effectively functions as insurance against adverse price shocks. Following the standard result in Nash-type bargaining problems, an increase in the farmer's risk aversion leads him to accept a less favorable barter price by agreeing to worse terms Roth and Rothblum (1982).

Figure 5: Effect of Risk Aversion on the Barter Cost.



Source: Author's own elaboration. Benchmark economy with $\gamma \in [0.1, 4.1]$.

Figure 6.1 shows that lower commodity spot prices are associated with higher Barter costs for farmers, since a decline in prices reduces the value of future output and increases the relative cost of obtaining inputs through Barter. Higher productivity, in contrast, lowers Barter costs by improving the farmer's repayment capacity. The results also indicate that Barter costs are more sensitive to price shocks than to productivity shocks, highlighting the importance of market price volatility in shaping contract conditions. Finally, as farmers become more risk averse, the sensitivity of Barter costs to price fluctuations declines, since risk-averse agents prefer more stable contractual terms even if they are less favorable.

Table 3: Farmer's Risk Aversion Elasticities

States	γ=0.1	γ=1	γ=2	γ=3	γ=4
$P_{\text{Low}},\ A_{\text{Low}}$	0.0196	0.1766	0.2281	0.1946	0.1257
$P_{\text{Low}},\ A_{\text{High}}$	0.0157	0.1781	0.2289	0.1947	0.1257
$P_{\text{High}},\ A_{\text{Low}}$	0.0143	0.2307	0.4294	0.4735	0.3637
$P_{\text{High}},\ A_{\text{High}}$	0.0112	0.2176	0.4593	0.5107	0.4093

Note: $\varepsilon = \dfrac{\partial \ln B}{\partial \ln \gamma}$ measures the elasticity of the contracted barter output with respect to the farmer's coefficient of relative risk aversion.

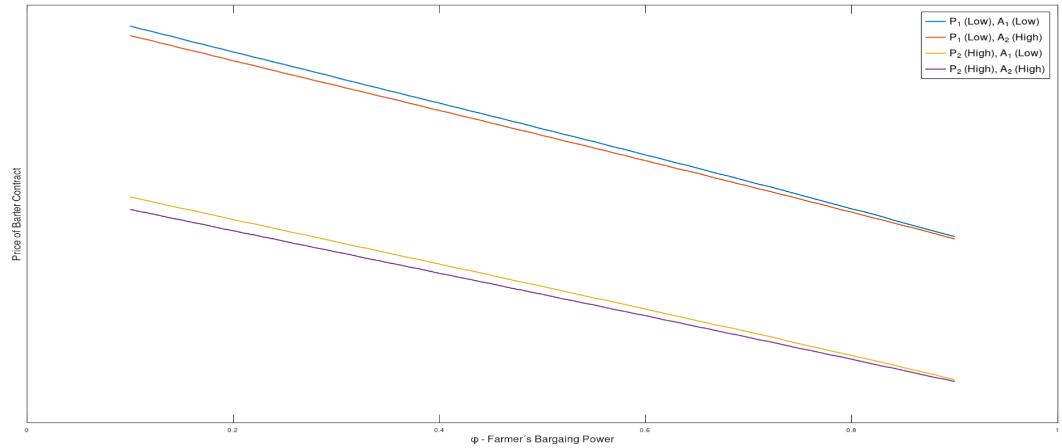
Table 3 presents the elasticities of the contracted barter output with respect to the farmer's coefficient of relative risk aversion, $\varepsilon = \frac{\partial \ln B}{\partial \ln \gamma}$. The results show positive elasticities, indicating that higher risk aversion increases the amount of output the farmer commits under the barter contract. This reflects the insurance role of barter: as the farmer becomes more risk-averse, he is willing to trade a larger share of future production to secure input financing and reduce exposure to market price uncertainty. As γ increases, the magnitude of the elasticity becomes larger in high-price and high-productivity states, reflecting the catching-up effect of barter costs as farmers in these states become more risk-averse.

6.2 Bargaining Power Scenarios

Having established the insurance channel via risk aversion, we now turn to bargaining power. Varying ϕ rotates the Nash product toward either party, altering how state-contingent surpluses are split and, in turn, how sensitive the negotiated terms are to productivity shocks.

Figure 6 shows that the cost of the barter contract for the farmer decreases as the farmer's bargaining power (ϕ) increases. For a given level of the spot price, productivity shocks exert a stronger influence on barter costs when the farmer's bargaining power is low than when it is high. This pattern reflects the structure of the Nash bargaining solution: when ϕ is small, the firm captures a larger share of the surplus, so variations in the farmer's productivity have a greater impact on the terms the farmer can negotiate. As ϕ increases, the Nash product shifts more weight toward the farmer's utility, allowing him to appropriate a larger portion of the joint surplus and thereby reducing the marginal effect of productivity shocks on the equilibrium barter cost.

Figure 6: Effect of Farmer's Bargain Power on the Barter Cost.



Source: Author's own elaboration. Benchmark economy with $\gamma = 1.5$, $\phi \in [0.1, 0.9]$.

Table 4: Farmer's Bargaining Power Elasticities

States	ϕ**=0.1**	ϕ**=0.3**	ϕ**=0.5**	ϕ**=0.7**	ϕ**=0.9**
$P_{\text{Low}},\ A_{\text{Low}}$	-0.0635	-0.1876	-0.2833	-0.5035	-0.6803
$P_{\text{Low}},\ A_{\text{High}}$	-0.0534	-0.1576	-0.2853	-0.5062	-0.6823
$P_{\text{High}},\ A_{\text{Low}}$	-0.0636	-0.1881	-0.3418	-0.5075	-0.6880
$P_{\text{High}},\ A_{\text{High}}$	-0.0645	-0.1905	-0.3454	-0.5115	-0.6899

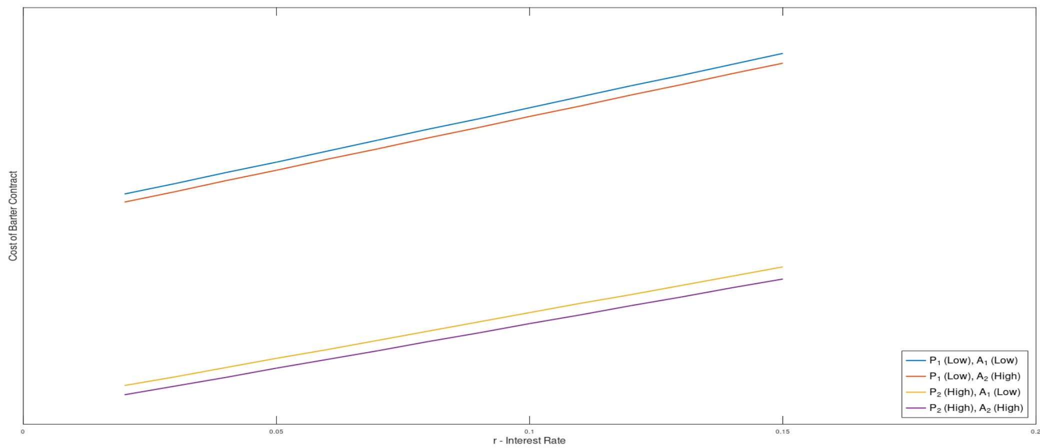
Table 4 reports the elasticity of contracted barter output with respect to the farmer's bargaining power. The negative elasticities indicate that greater bargaining power allows farmers to commit a smaller share of output to obtain the same inputs. Moreover, the elasticity increases in magnitude as bargaining power rises, reflecting a nonlinear effect in the Nash solution where stronger farmers capture a larger share of the surplus and reduce the barter burden more substantially. This pattern is consistent across price and productivity states, suggesting that the relationship is robust to different market and production conditions.

Note: $\varepsilon = \dfrac{\partial \ln B}{\partial \ln \phi}$ denotes the elasticity of the barter output cost with respect to the farmer's bargaining power.

6.3 Interest Rate Scenarios

Figure 7 depicts the relationship between the cost of the barter contract and the interest rate faced by the farmer. The results show a clear positive association: as the cost of credit increases, the cost of the barter contract also rises across all states of prices and productivity. This pattern reflects the substitution effect between credit and barter financing, when interest rates are low, farmers prefer conventional credit, but as borrowing costs rise, barter becomes relatively more attractive, despite its implicit cost. The level of each curve indicates that the barter cost shifts up in low-price and low-productivity states, where the farmer's liquidity constraints are tighter. In contrast, in high-price and high-productivity states, the barter cost is more moderate, as greater expected revenues mitigate the impact of rising credit costs on the farmer's financing decisions.

Figure 7: Effect of Interest Rate on the Barter Cost.



Source: Author's own elaboration. Benchmark economy with $\gamma = 1.5$, $\phi = 0.5$ and $r \in [0.02, 0.15]$.

Table 5 reports the elasticities of the contracted barter output with respect to the interest rate on credit financing, $\varepsilon = \frac{\partial \ln B}{\partial \ln r}$. The positive values indicate that higher interest rates are associated with a greater proportion of production committed under barter arrangements. This result reflects the substitution effect between formal credit and barter financing: as conventional credit becomes more expensive, farmers rely more on barter contracts to secure inputs. The magnitude of the elasticity increases with r, showing that the responsiveness of barter commitments intensifies as credit conditions deteriorate. The effect is slightly more pronounced in low-price and low-productivity states, consistent with the notion that financially constrained farmers are more sensitive to increases in borrowing costs.

Table 5: Farmer's Interest Rate Elasticities

States	r=2%	r=5%	r=8%	r=12%	r=15%
$P_{\text{Low}}, A_{\text{Low}}$	0.0509	0.1162	0.1657	0.2353	0.2831
$P_{\text{Low}}, A_{\text{High}}$	0.0513	0.1171	0.1670	0.2371	0.2703
$P_{\text{High}}, A_{\text{Low}}$	0.0512	0.1107	0.1777	0.2521	0.2873
$P_{\text{High}}, A_{\text{High}}$	0.0518	0.1119	0.1684	0.2390	0.2724

Note: $\varepsilon = \dfrac{\partial \ln B}{\partial \ln r}$ measures the elasticity of the contracted barter output with respect to the interest rate on credit financing.

6.4 Final Remarks and Policy Implications

This section analyzed how behavioral and market parameters influence the structure and implicit cost of Barter contracts within a Nash bargaining framework.

The results highlight three main mechanisms. First, risk aversion plays a central role: more risk-averse farmers are willing to commit a larger share of future output in exchange for input financing, using Barter as a form of implicit insurance against price volatility, though at the cost of lower expected surplus.

Second, bargaining power strongly affects the distribution of surplus. Farmers with limited bargaining power face higher implicit Barter costs, whereas stronger negotiation capacity leads to a more balanced allocation of gains without eliminating firms' incentives to participate.

Third, interest rates shape the relative attractiveness of Barter compared to traditional credit. As borrowing costs rise, farmers increasingly substitute credit with Barter, particularly in low-price and low-productivity environments.

Overall, the results suggest that Barter emerges as a structural response to imperfections in rural credit and risk markets, highlighting the importance of policies that expand credit access, strengthen farmers' bargaining capacity, and improve risk-management instruments.

7 Conclusion

This article demonstrated that barter financing, although deeply rooted in Brazilian agriculture, operates within a strategic bargaining environment in which farmers and input-supply firms jointly determine contract terms under uncertainty. The Nash bargaining framework developed in this work revealed that the quantity of future production transferred in the contract depends critically on farmers' degree of risk aversion, their bargaining power, and the overall macro-financial context that shapes outside options for both sides.

The simulations showed that higher risk aversion leads farmers to surrender a larger share of their harvest in exchange for stability, while asymmetric bargaining power systematically shifts surplus toward input-supply firms, reinforcing structural disadvantages faced by small and less informed producers. Results also indicate that rising interest rates increase the relative attractiveness of barter compared to traditional bank credit, since barter prices adjust more gradually and create a hedge-like effect that stabilizes farmers' expected costs. In addition, the model highlighted that price volatility and productivity shocks amplify the cost of barter for risk-averse farmers, making the contractual outcome highly sensitive to the stochastic environment and the farmers' outside options.

Taken together, these findings show that barter is not merely an alternative financing mechanism, but rather a sophisticated contractual arrangement shaped by power, information, and risk. The evidence suggests that public policies aimed at improving farmers' bargaining conditions, such as greater transparency in pricing, dissemination of market information, incentives for collective purchasing, and expansion of accessible credit alternatives, can significantly reduce the implicit costs embedded in barter operations. Ultimately, strengthening farmers' negotiating position is essential not only for reducing financing costs but also for promoting a more balanced, efficient, and sustainable structure for input financing in Brazilian agriculture.

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