Improving the market for livestock production households to alleviate food insecurity in the Philippines

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Suggested Short Title: Enhancing Livestock Markets for Food Security in the Philippines

Author Contributions: Conceptualization, M.-H.N. and M.-P.T.D.; methodology, M.-H.N.; software, M.-P.T.D.; validation, Q.-H.V. and M.-H.N.; formal analysis, M.-H.N., M.-P.T.D. and N.P.W.P.S; investigation, M.-H.N., M.-P.T.D. and N.P.W.P.S; resources, M.-H.N.; data curation, M.-H.N.; writing—original draft preparation, M.-H.N., M.-P.T.D., N.P.W.P.S and A.M; writing—review and editing, M.-P.T.D. and N.P.W.P.S; visualization, M.-H.N.; supervision, Q.-H.V.; project administration, Q.-H.V. All authors have read and agreed to the published version of the manuscript.

- We found that the challenges faced in production and selling processes substantially positively affect the likelihood of food insecurity likelihood among livestock smallholders in the Philippines. Nevertheless, these challenges' impact depends on the degree of food insecurity.
- The market plays a crucial role in facilitating not only livestock trading but also livestock production (e.g., purchase of feed and medicines).
- Market mechanisms can be used to alleviate food insecurity among livestock smallholders.

Abstract

Context: Food security is one of the major concerns in the Philippines. Although livestock and poultry production accounts for a significant proportion of the country's agricultural output, smallholder households are still vulnerable to food insecurity.

Aim: The current study aims to examine how livestock production and selling difficulties affect smallholder households' food-insecure conditions.

Methods: The study employed the Mindsponge Theory as its theoretical foundation for constructing the models. Subsequently, it applied the Bayesian Mindsponge Framework (BMF) analytics to analyze a dataset sourced from the Food and Agriculture Organization's Data in Emergencies Monitoring (DIEM) system. Key variables in the dataset were transformed into indicators, enabling a detailed examination of smallholder livestock farmers' difficulties in production or selling over the past three months. Production difficulties include hurdles in raising and producing livestock, covering aspects like resource acquisition, animal health, and breeding. Selling difficulties involve obstacles in selling livestock products, including issues related to market access, pricing, and transportation.

Key results: Production and selling difficulties significantly adversely affect food security in the Philippines, with varying impacts according to the severity of food insecurity. In particular, production and selling difficulties equally affect the households' likelihood of eating less healthy and nutritious food. However, the production difficulties have more negligible impacts on the possibility of skipping meals and even ambiguous impacts on the likelihood of not eating for a whole day compared to the effects of selling difficulties. Moreover, we also found that the market plays a crucial role in facilitating not only livestock trading but also livestock production (e.g., purchase of feed and medicines).

Conclusions: Our research highlights the complex connection between livestock, markets, and food security within the Philippine setting. It emphasizes the significant impact of selling difficulties, particularly the heavy reliance on nearby local and regional markets, in exacerbating the severity of food insecurity.

Implications: Based on these findings, we suggest that the livestock market needs to be expanded and regulated to balance livestock products and services used for livestock production and facilitate the product-exchanging mechanism.

Keywords: market, agricultural households, food security, Mindsponge Theory, information-processing, livestock trading

"— Wherever there is food, there is freedom!"

In "Dream"; *The Kingfisher Story Collection* (Vuong 2022a)

1. Introduction

Food security is "all people, at all times, have social, economic, and physical access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (Food and Agriculture Organization 1996; Lin *et al.* 2022). The requirement to produce more food aligns with the global priority of achieving food system sustainability, acknowledging the global concern regarding the food 'problem' (Garnett 2014). This is particularly important, considering the four main pillars of food security outlined by Lin *et al.* (2022): food availability, access to food, the stability of food supplies, and food utilization. The problems that arise in any pillar can lead to food insecurity.

1.1. *Global Food Security Challenges and Insights*

Food insecurity is a critical global public health issue, primarily affecting developing countries due to poverty (Abafita and Kim 2014; Shakeel and Shazli 2021; Mazenda *et al.* 2022). Developing nations account for a significant portion of the world's undernourished population, with 850 million out of 868 million people facing undernourishment (Rupasi *et al.* 2014), creating a substantial gap between global demand and development. As the global population is expected to reach about nine billion by 2050, the demand for animal products is projected to quadruple, adding further stress to food systems (Kharas 2010).

The Food Security Information Network estimated that 258 million people in 58 countries/territories (22.7% of the analyzed population) faced acute food insecurity in 2022, further emphasizing the severity of the situation (Food Security Information Network 2023). The challenges of food insecurity were exacerbated by the COVID-19 pandemic, which paralyzed the global food supply chain from farm to fork due to lockdowns (Torero 2020). Even in the United States (US), the world's leading economy, 34.4% of households with children ≤ 12 years old were reported to be food insecure by the end of April 2020, doubling 2018's proportion of 15.1% (Bauer 2020). Food insecurity is even worse in developing countries, including the Philippines. According to the Rapid Nutrition Assessment Survey (RNAS) conducted by the Food and Nutrition Research Institute, around 62.1% of Filipino households faced moderate to severe food insecurity during the COVID-19 pandemic (Food and Nutrition Research Institute 2021).

Various studies provide insights into global food security dynamics. Premanandh (2011) focuses on weather conditions, farming methods, land allocation, and government policies, offering knowledge of global food security challenges. Meanwhile, Banks *et al.* (2021) conducted a thorough exploration, unraveling complex interconnections among socio-economic intricacies, household spending patterns, the impact of International Monetary Fund (IMF) programs, and environmental considerations, such as climate change, loss of farmland, and trade restrictions. These factors directly impact food security among smallholder farmers (Mayberry *et al.* 2020; Shuvo *et al.* 2022). Additionally, Amao *et al.* (2023) shed light on the distinct influence of crop diversity, food expenditure, asset ownership, and geographical location on the food security issue in Nigeria. Aligning with these insights, the joint report by FAO (2023) further emphasizes global challenges related to food security, highlighting the dynamics of high food purchases across the rural-urban continuum.

1.2. *Agriculture and Livestock Dynamics in the Philippines*

In the face of global food security challenges, a closer examination of the Philippines reveals distinct vulnerabilities and dynamics. The agricultural sector employs 29% of the country's labor force, contributing 9% to the GDP (Barroga *et al.* 2020). Crops dominate production at 49%, while livestock and poultry closely follow at 25% (Barroga *et al.* 2020). Over the past 30 years, pig and poultry production surged by 195% and 332%, paralleling an 85% increase in the human population. Livestock production in the Philippines adopts a dualistic approach involving smallholder and commercial systems, with smallholders managing the majority. Smallholder production typically involves ownership of fewer than 21 adult animals or fewer than 41 young animals (Philippine Statistics Authority 2013; Alawneh *et al.* 2014).

Within these dynamics, Philippine smallholder livestock producers encounter both challenges and opportunities. The increasing demand for nutrient-dense diets and animal-origin proteins, fueled by population expansion, urbanization, income growth, and dietary changes, presents avenues for smallholders to alleviate poverty. Developing strategies for greater entry and sustained profitability within expanding livestock markets offers promising prospects for these farmers (Lapar *et al.* 2003; Akasha *et al.* 2021).

However, despite the potential to contribute to national food security (Roxas 1995), smallholder livestock producers in the Philippines encounter high risks of food insecurity. According to the World Food Programme Philippines's Food Security Monitoring survey in October 2022, around 25% of agricultural households experienced food insecurity, compared to only 9% of non-agricultural households (Cruz 2022). Challenges further intensified with the emergence of African Swine Fever (ASF) in 2019 and the COVID-19 pandemic in 2020. The pandemic disrupted livestock, poultry, and dairy logistics and access to conventional market outlets, impacting the entire supply chain. Simultaneously, ASF wreaked havoc on the swine industry, affecting as many as 12 regions, 50 provinces, and 541 cities/municipalities in the Philippines (FAO 2021; Briones and Espineli 2022). Due to the reduced income, agricultural households are more likely to adopt coping strategies to overcome food insecurity, such as borrowing money for food, purchasing food on credit, and spending savings. When the livestock smallholder farmers still have to borrow money for food or purchase food on credit, their contribution to maintaining national food security will be limited (Cruz 2022).

1.3. Market Participation and Livestock Farming Challenge

Market participation among smallholder farmers plays an important role in addressing global food security challenges. However, this process encounters numerous obstacles and complications despite its potential benefits. Previous studies intricately explore factors affecting market participation. The transformative potential of market engagement, emphasized by Arias *et al.* (2013) and Akrong *et al.* (2021), is finely shaped by age, gender, education, and farm output. Insights from Cele and Mudhara (2022) and Haile *et al.* (2022) contribute to understanding nuanced influences on participation decisions, revealing that elements like access to market information, output prices, and external factors significantly influence choices. Poole (2017) expands this perspective, illustrating how market activities by smallholder farmers are interconnected with broader environmental, economic, and resource management considerations.

Therefore, the current study aims to explore how the constraints faced by smallholder farmers influence their food insecurity, specifically examining whether production or trade constraints have a more severe impact. Using the Philippines as a case study, understanding the main factors contributing to the food insecurity of smallholder farmers will enable policymakers and governmental agencies to plan and implement appropriate policies and programs that can alleviate smallholder farmers' food insecurity and improve their food production efficiency.

Specifically, the study's analysis was separated into two main parts: statistical and descriptive analyses. For the statistical analysis, we employed the Bayesian Mindsponge Framework (BMF) analytics (Nguyen *et al.* 2022). Specifically, the Mindsponge Theory, an information-processing theory, was used to reason how the difficulties of smallholder farmers (i.e., production and trading difficulties) affect their food insecurity (Vuong 2023). Then, a Bayesian analysis was conducted on the dataset provided by the Food and Agriculture Organization to validate our theoretical assumptions and reasonings. Then, we employed descriptive analysis to identify factors causing the production and trading difficulties of the households.

2. Methodology

2.1. Theoretical Foundation

The current study employed the Mindsponge Theory as the theoretical foundation for constructing the models (Vuong 2023). It was originally referred to as the mindsponge mechanism, a conceptual framework explaining the dynamics of an individual's and organization's acculturation and global thinking (Vuong and Napier 2015). Later, by incorporating evidence from life and neurosciences, the mechanism is upgraded into theory. Mindsponge Theory is an information-processing theory that explains how a mind absorbs and processes information. The theory has been employed in multiple studies in various psychological and social disciplines (Lu *et al.* ; Kumar *et al.* 2022; Nguyen and Jones 2022a, 2022b; Ruining and Xiao 2022; Tanemura *et al.* 2022; Vuong *et al.* 2022a; Asamoah *et al.* 2023; Cheng *et al.* 2023; Santirocchi *et al.* 2023; Vuong *et al.* 2023).

Vuong (2023) suggests that "while the theory is mainly used to examine the human mind, all living systems can be considered "minds" in a broad sense – information collection-cum-processor – including organisms, biological systems, and societies of various complexity levels". This feature of the theory stems from the fact that the mindsponge theory was constructed based on evidence ranging from human perception and cellular levels to societal levels using three major mathematical reasoning tools: generalization, specialization, and analogy (Pólya 1954). Some studies have used mindsponge-based reasoning to explain information processing at the collective level (Vuong *et al.* 2021; Vuong *et al.* 2022a).

In the current study, through the lens of mindsponge theory, we view a household as an information collection-cum-processor, or a collective mind that all household members constitute. Such mind (or information-processing system) mirrors natural patterns in the biosphere, is dynamically balanced, involves cost-benefit optimization, follows the principle of energy saving, has a goal(s) and priority, and aims for the prolongation of the system's existence.

For the system to maintain its existence, energy is required. In the case of livestock smallholder farmers' households, food is required to sustain the survival of the household's members (or to prolong the system's existence). To obtain food, they need to exchange information with the surrounding environment, either by producing the food themselves (i.e., rearing livestock) or exchanging it with other households, traders, and suppliers (i.e., trading at the market) (Vuong *et al.* 2022b). As the livestock smallholder farmers' collection of information is optimized for rearing livestock (Nguyen *et al.* 2023), they tend to buy rearing resources from the market (e.g., feed, medicines, etc.) to produce livestock for self-sustaining and sell for money (which is used for later trading in the market).

Multiple factors can contribute to the information-exchanging processes of households to obtain food. Among them, information availability and accessibility are two common elements. Information availability refers to the physical existence of the information in reality, while information accessibility refers to whether the households can discern and access the information if it exists. Therefore, when the information required for livestock production (e.g., knowledge, feed, medicines, etc.) is lacking and cannot be obtained from the market (e.g., due to high prices, etc.), the production and subsequent trading processes are adversely affected. As a result, the food intake of the household will decline, increasing the likelihood of food insecurity (see Figure 1).

<<< Insert Figure 1 here >>>

Specifically, several studies have linked the production and trading difficulties to the effectiveness and efficiency of livestock. According to Balehegn *et al.* (2020), the greatest challenge in developing the livestock industry in many low-to-medium-income countries (LMICs) and achieving food and nutritional security is the lack of a sufficient supply of high-quality feed. The availability of adequate livestock feed is a challenge that requires farmers *et al.* 2022). Prem (1999) also highlighted that nutrition, animal health, animal genetics, and extension services are some challenges affecting farmers and agricultural household productivity. Knowledge and understanding of animal diseases, their control mechanisms, the availability of vaccines, and their usage are essential in promoting good animal health in a herd (Prem 1999).

Based on the above reasoning, we assumed households with livestock production and selling difficulties are more likely to experience food insecurity.

2.2. Model construction and analysis

2.2.1. Variable selection

Data was obtained from the Data in Emergencies Monitoring (DIEM) system of the Food and Agriculture Organization (FAO) (2021). The FAO's DIEM-Monitoring System collects, analyses, and shares shock and livelihood data in nations prone to multiple shocks. DIEM-Monitoring System updates information on how shocks affect farming communities' livelihoods and food security to influence decision-making. The data are collected from producers, traders, marketers, input suppliers, extension officers, and other key informants.

Through the DIEM system, the FAO conducted a household survey in 2021 to monitor agricultural livelihoods and food security in the Philippines. A random sampling strategy was utilized to select 2087 household representatives at the regional level (admin 1) for seven out of 18 regions of the country. The survey was undertaken between 31 August-31 October 2021 through telephone interviews using random digital dialing in the following provinces: Cagayan Valley, Calabarzon, Central Luzon, Ilocos, Soccsksargen, Western Visayas, and the Bangsamoro Autonomous Region in Muslim Mindanao (BARMM). Each survey interview had a duration of 20 minutes and was administered in one of the Philippines' official languages, English, Cebuano/ Bisaya, Tagalog/ Filipino, Ilocano, Pangasinan, Ilonggo/ Hiligaynon, and Maguindanao.

To measure the food insecurity of livestock smallholder farmers, we employed three variables retrieved from the DIEM's original dataset: *fies_whlday*, *fies_skipped*, and *fies_healthy*. These variables were transformed into *ExtremeFoodInsecurity*, *FoodInsecurity*, and *LessNutrition*, respectively, for the sake of presentation and interpretation. The selected variables correspond to the severity of the household's food insecurity, from lack of nutrition (*LessNutrition*) to skipping a meal (*fies_skipped)* and not eating for a whole day (*fies_whlday*) (see Table 1).

<<< Insert Table 1 here >>>

Variables *ls_proddif* and *ls_salesdif* in the original dataset were retrieved and transformed into *ProductionDifficulty* and *SellingDifficulty* to estimate whether the respondents' households had faced any production or selling of their products within the last three months. These two variables were used as predictor variables due to their direct relevance to the study's primary focus on understanding how challenges in livestock-related activities impact food security outcomes. Meanwhile, three variables about food insecurity were used as outcome variables, subsequently resulting in three different statistical models (see Subsection 2.2.2)

In the DIEM survey, when the respondents reported that their households had produced livestock or both livestock and crops for consumption and sale in the past 12 months, they were asked questions associated with the production and sale of livestock, including the difficulties. Specifically, households facing production and selling difficulties were asked about their main challenges when producing and selling livestock. The respondents' answers are presented in the subsection subsequent to the statistical analysis to specify the reasons behind the livestock production and selling difficulties of livestock smallholder households (see Subsections 3.1.4 and 3.1.5).

2.2.2. Statistical models

To identify the effects of livestock production and selling difficulties of smallholder farmers on their food insecurity, we constructed three models, each with similar predictor variables but a different outcome variable. Model 1 with *LessNutrition* as the outcome variable is presented as follows:

$$LessNutrition \sim normal\left(\log\left(\frac{\mu_i}{1-\mu_i}\right), \sigma\right) \tag{1.1}$$

$$\log\left(\frac{\mu_i}{1-\mu_i}\right) = \beta_0 + \beta_1 * ProductionDifficulty_i + \beta_2 * SellingDifficulty_i \tag{1.2}$$

$$\beta \sim normal(M, S) \tag{1.3}$$

The probability around the mean $\log\left(\frac{\mu_i}{1-\mu_i}\right)$ is determined by the form of the normal distribution, whose width is specified by the standard deviation σ. μ_i indicates the likelihood that smallholder farmer i is unable to eat healthy and nutritious food; $ProductionDifficulty_i$ indicates whether farmer i experiences any production difficulties; $SellingDifficulty_i$ whether farmer i experiences any selling difficulties. Model 1 has four parameters: the coefficients, β_1 and β_2, the intercept, β_0, and the standard deviation of the "noise", σ. The coefficients of the predictor variables are distributed as a normal distribution around the mean denoted M and with the standard deviation denoted S.

Similarly, Model 2, with *FoodInsecurity* being the outcome variable, and Model 3, with *ExtremeFoodInsecurity* as the outcome variable, are presented as follows:

$$FoodInsecurity \sim normal\left(\log\left(\frac{\mu_i}{1-\mu_i}\right),\sigma\right) \tag{2.1}$$

$$\log\left(\frac{\mu_i}{1-\mu_i}\right) = \beta_0 + \beta_1 * ProductionDifficulty_i + \beta_2 * SellingDifficulty_i \tag{2.2}$$

$$\beta \sim normal(M,S) \tag{2.3}$$

In this model, μ_i indicates the likelihood that smallholder farmer i skips a meal because of a lack of money or other resources to get food.

$$ExtremeFoodInsecurity \sim normal\left(\log\left(\frac{\mu_i}{1-\mu_i}\right),\sigma\right) \tag{3.1}$$

$$\log\left(\frac{\mu_i}{1-\mu_i}\right) = \beta_0 + \beta_1 * ProductionDifficulty_i + \beta_2 * SellingDifficulty_i \tag{3.2}$$

$$\beta \sim normal(M,S) \tag{3.3}$$

Here, μ_i indicates the likelihood that smallholder farmer i does not eat for a whole day because of a lack of money or other resources to get food.

2.2.3. Analysis and validation

The Bayesian Mindsponge Framework (BMF) analytics was employed as the analytical framework in the current study (Nguyen *et al.* 2022). Specifically, the analytics combines the reasoning capabilities of Mindsponge Theory and the inference advantages of the Bayesian analysis (Vuong *et al.* 2022b). We employed the Mindsponge theory to reason and construct models for examining how livestock production and selling difficulties affect food security in the Philippines (see Subsection 2.1 for the theoretical foundation and Subsection 2.2.2 for constructed models). The theory has been employed in various disciplines to study and explain many psycho-social phenomena.

One of the mindsponge theory's strengths is that it provides an information-processing analytical framework (with important principles) that enables us to construct parsimonious models (Bentler and Mooijaart 1989; Simon 2001; Cougle 2012). Such parsimonious models have more precise predictions and straightforward interpretations and reduce the risk of multicollinearity bias. However, parsimonious models might face the risk of endogeneity caused by the omitted variables and oversimplifying the model. In the current study, while the Mindsponge reasoning based on set theory and information processing logic helps theoretically safeguard the model from endogeneity, the Bayesian analysis also makes the problem less relevant because the Bayesian approach makes exact inferences on the data at hand, treats parameters (including unknown or unobserved ones) as random variables, and does not rely on asymptotic assumptions (Liu *et al.* 2007; Gill 2014; Wagenmakers *et al.* 2018). In case the endogeneity bias still exists in our constructed models, we also conducted a sensitivity analysis that incorporates variables that can potentially affect the household's food security (e.g., household representatives' age and gender, the head of household's educational levels, and the household's total income). If the estimated results of the more comprehensive model are similar to those of the parsimonious model, the parsimonious model can be considered robust.

Other advantages of Bayesian analysis also make the BMF analytics preferential in this study. With the support of the Markov chain Monte Carlo algorithm, Bayesian analysis can produce a more precise estimation with a small sample size, comparatively with methods dependent on the asymptotic assumption, as it only utilizes the data at hand for inference (Dunson 2001; Uusitalo 2007). The current study's sample size is relatively small, so employing Bayesian analysis can help improve the precision of the estimated results. Moreover, as stated by Halsey, the fickle *p*-value is a major reason causing irreproducible results, causing crises in various disciplines (including psychological and social sciences) (Halsey *et al.* 2015; Open Science Collaboration 2015; Camerer *et al.* 2018). The Bayesian analysis depends on credible intervals, which are theoretically more advantageous than confidence intervals and can be visually plotted for result interpretation, so the *p*-value is not required for evaluation (McElreath 2018; Wagenmakers *et al.* 2018).

We employed the bayesvl R package to perform Bayesian analysis due to its user-friendly operating style, capability to depict attention-grabbing images, and cost-effectiveness (Vuong 2018; La and Vuong 2019). For the simulation set-up, we used four Markov chains, each with 5,000 iterations (of which the first 2,000 were designated warmup iterations), to fit the models. As the current study is explorative, we applied uninformative priors for all parameters to avoid subjective bias. After the models were fitted, the effective sample size (*n_eff*) and Gelman-Rubin shrink factor (*Rhat*) were evaluated to determine whether the Markov chains were well-convergent. When the *Rhat* values are equal to 1, and the *n_eff* values are greater than 1,000, it indicates that the Markov chain's parameters have converged well. If so, the Markov property can be deemed held. The trace, Gelman-Rubin-Brooks, and autocorrelation plots were also used to confirm the Markov chains convergence.

3. Results

3.1. Impacts of livestock production and selling difficulties on food insecurity

3.1.1. Model 1: LessNutrition as the outcome variable

As can be seen from Table 2, all the *n_eff* values are larger than 1,000, and *Rhat* values are equal to 1, so Model 1's Markov chains can be deemed convergent. The trace plots shown in Figure 2 confirm the convergence. In particular, after the warmup period (2,000th iteration), all the Markov chains fluctuate around a central equilibrium, showing a clear signal of convergence.

<<< Insert Table 2 here >>>

<<< Insert Figure 2 here >>>

Figure 3 demonstrates the *Rhat* value of each parameter's simulated value. The value shrinks rapidly to 1 after some finite iterations, implying the convergence of the chains. Also, the Markov property, or the memoryless property of the stochastic simulation process, can be evaluated through the autocorrelation plots. The autocorrelation levels of all parameters decline swiftly to 0, validating the existence of Markov property during the simulation (see Figure 4).

<<< Insert Figure 3 here >>>

<<< Insert Figure 4 here >>>

Estimated results in Table 2 indicate that both *ProductionDifficulty* and *SellingDifficulty* have positive impacts on *LessNutrition* ($M_{ProductionDifficulty\_LessNutrition}$= 1.03 and $S_{ProductionDifficulty\_LessNutrition}$= 0.46; $M_{SellingDifficulty\_LessNutrition}$= 1.10 and $S_{SellingDifficulty\_LessNutrition}$= 0.46). The results suggest that livestock production and selling difficulties are statistically significant and linked to a higher likelihood of consuming food with lower nutritional value. The impact of livestock selling difficulties on the likelihood of consuming food with lower nutritional value is similar to livestock production difficulties (see Figure 5).

<<< Insert Figure 5 here >>>

Posterior distributions of the parameters are illustrated in Figure 5. All of the distribution of *ProductionDifficulty* and *SellingDifficulty* lie on the positive sides of the *x*-axis, suggesting highly reliable positive associations of *ProductionDifficulty* and *SellingDifficulty* with *LessNutrition*. The estimated distributions of *ProductionDifficulty* and *SellingDifficulty* using the model incorporating control variables also show similar results estimated using the parsimonious model (see Table S1 in the Supplementary), so the effects of *ProductionDifficulty* and *SellingDifficulty* on *LessNutrition* can be deemed robust.

3.1.2. Model 2: FoodInsecurity as the outcome variable

Based on the *n_eff* and *Rhat* values, we can deem that Model 2's Markov chains are all well-convergent (see Table 3). The trace plots (see Figure 6), Gelman-Rubin-Brooks plots (see Figure A1), and autocorrelation plots (see Figure A2) also confirm their convergence.

<<< Insert Table 3 here >>>

<<< Insert Figure 6 here >>>

<<< Insert Figure 7 here >>>

As can be seen from Table 3, both *ProductionDifficulty* and *SellingDifficulty* have positive impacts on *FoodInsercurity* ($M_{ProductionDifficulty\_FoodInsercurity} =$ 0.85 and $S_{ProductionDifficulty\_FoodInsercurity} =$ 0.47; $M_{SellingDifficulty\_FoodInsercurity} =$ 1.45 and $S_{SellingDifficulty\_FoodInsercurity} =$ 0.46). However, the effect of *SellingDifficulty* has a larger magnitude on *FoodInsercurity* than that of *ProductionDifficulty.* To elaborate, the findings imply that farmers facing difficulties in livestock production and selling were more likely to skip meals due to a lack of money or other resources. The impact of livestock selling difficulties on food security conditions is stronger than livestock production difficulties (see Figure 7).

In Figure 7, both the posterior distributions of *ProductionDifficulty* and *SellingDifficulty* lie on the positive side of the axis, indicating highly reliable positive associations of *ProductionDifficulty* and *SellingDifficulty* with *FoodInsercurity*. The estimated distributions of *ProductionDifficulty* and *SellingDifficulty* using the model incorporating control variables also show similar results estimated using the parsimonious model (see Table S2 in the

Supplementary), indicating that the effects of *ProductionDifficulty* and *SellingDifficulty* on *FoodInsercurity* are robust.

3.1.3. Model 3: ExtremeFoodInsecurity as the outcome variable

The statistical diagnosis values (i.e., *n_eff* and *Rhat*) and visual diagnoses of trace, Gelman-Rubin-Brooks, and autocorrelation plots confirm the convergence of Model 3's Markov chains (see Table 4 and Figures 8, A3, and A4). Thus, the estimated results can be used for interpretation.

<<< Insert Table 4 here >>>

<<< Insert Figure 8 here >>>

Table 4 indicates that only *SellingDifficulty* has a positive impact on *ExtremeFoodInsercurity* ($M_{SellingDifficulty\_ExtremeFoodInsercurity} = 9.56$ and $S_{SellingDifficulty\_ExtremeFoodInsercurity} = 1.18$), while the effect of *ProductionDifficulty* on *ExtremeFoodInsercurity* is ambiguous ($M_{ProductionDifficulty\_ExtremeFoodInsercurity} = 1.18$ and $S_{ProductionDifficulty\_ExtremeFoodInsercurity} = 1.45$). These findings imply that difficulties in selling the livestock are linked to a higher likelihood of experiencing extreme food security conditions (i.e., not eating for a whole day), but difficulties in producing the livestock are not.

The estimated posterior distribution of *SellingDifficulty* lies entirely on the positive side of the *x*-axis, indicating a highly reliable positive association between *SellingDifficulty* and *ExtremeFoodInsercurity*. Meanwhile, the distribution of *ProductionDifficulty* shows an unclear pattern (see Figure 9). The results estimated using a model with control variables also demonstrate similar results (see Table S3 in the Supplementary), suggesting that the estimated results using the parsimonious model are robust.

<<< Insert Figure 9 here >>>

3.1.4. Livestock production difficulties

According to Figure 10, the primary challenges to raising livestock are finding feed (35%) and controlling livestock diseases (33%). The challenges associated with buying feed are caused by a number of problems, including a lack of supply, high pricing, and insufficient market access. On the other side, livestock diseases have a serious negative impact on animal health, which results in decreased output, higher rates of mortality, and financial hardship for farmers. On the other side, livestock diseases have a serious negative impact on animal health, which results in decreased output, higher rates of mortality, and financial hardship for farmers.

Other factors, such as limited pasture access (9%), difficulty accessing veterinary services (7%), difficulty in accessing veterinary inputs (5%), and other variables related to labor, security, and access to the livestock market (11%) also contribute to these challenges (Figure 10). For livestock farmers, these issues pose considerable obstacles that harm their productivity and profitability.

<<< Insert Figure 10 here >>>

3.1.5. Livestock sales difficulties

According to Figure 11, the main factors contributing to difficulties in livestock selling are higher marketing costs (24%) and low prices (23%). Higher marketing costs include transportation, storage, and promotion of livestock products. These costs can significantly impact the profitability of livestock selling and cause difficulties for farmers in finding buyers or accessing profitable markets. Farmers may face financial difficulties and struggle to cover their production costs when prices are too low.

<<< Insert Figure 11 here >>>

Other factors influencing livestock trading difficulties include local customers or regular traders not buying as much as usual (18%), damage or losses resulting from delays or inability to access markets physically (13%), difficulties processing products other than closure of slaughterhouses (lack of access to processing inputs, equipment) (8%), closure of slaughterhouse or difficulties accessing slaughterhouse (4%) and others as well. (Figure 11).

4. Discussion

Employing the Bayesian Mindsponge Frameworks analytics on the DIEM dataset, we found that livestock production and selling difficulties are crucial factors contributing to food insecurity in the Philippines. Specifically, the three most prominent reasons behind the selling difficulties are market accessing costs, low selling prices, and low demand for livestock products. These challenges could be attributed to low off-take, limited access to market information, tacit knowledge, inadequate and poor infrastructure, poor livestock conditions, and insufficient livestock numbers to cover pre-slaughter transaction costs and satisfy formal market demand (Marandure *et al.* 2020; Malusi *et al.* 2021). Higher marketing costs also affect household marketing behavior and marketing channel choice and discourage market participation (Namonje-Kapembwa *et al.* 2022). Additionally, marketing old and malnourished animals is a disadvantage in commercial marketplaces that primarily sell young, well-conditioned animals (Nyam *et al.* 2022).

Meanwhile, three main production difficulties are feed purchasing difficulties, livestock diseases, and limited access to pasture. Various challenges associated with livestock production, including pasture and feed availability, access to water resources, animal breeding and management, climate change and fluctuation, and socio-economic constraints, have been highlighted by various studies (Mbatha 2021; Eeswaran *et al.* 2022). Prem (1999) emphasized that challenges affecting farmers and agricultural household productivity include nutrition, animal health, animal genetics, and extension services. Overcoming these challenges is possible by utilizing locally available resources and inexpensive food by-products with anti-helminthic, anti-bloat, and nutraceutical properties beneficial to livestock (Mahachi *et al.* 2023). Households may also raise livestock breeds with feed and production efficiencies, allowing them to thrive in their production systems under various environmental stressors and still meet desired market requirements (Olagbegi *et al.* 2023). Knowledge and understanding of animal diseases, their control mechanisms, the availability of vaccines, and their usage are essential for promoting good animal health in a herd (Prem 1999).

The effects of production and selling difficulties on different severity of food insecurity vary. Specifically, production and selling difficulties contribute equally to the households' likelihood of eating less healthy and nutritious food. However, the production difficulties have smaller impacts on the likelihood of skipping meals and even ambiguous impacts on the likelihood of not eating for a whole day compared to the effects of selling difficulties. These differences can be explained with more details from the information-processing perspectives and the underlying reasons for production and selling difficulties.

As explained above, to acquire food, the household must exchange information with the surrounding environment by producing livestock or trading them for other types of food. Difficulty producing or selling livestock can adversely affect the households' food security. However, households facing selling problems are more vulnerable to food insecurity (i.e., skipping meals) and extreme food insecurity (i.e., not eating for a whole day) than those facing production difficulties due to their dependence on the market.

Smallholder farmers are often poor, having limited capital and land and therefore relying on direct sales of livestock products like milk, eggs, and dung for the generation of capital regularly, as well as sporadic sales of live animals, wool, meat, feathers, and hides (Ahuja 2013). It is reported that Asian countries have been experiencing a chronic feed shortage and are heavily dependent on the importation of feed and feed additives; therefore, any changes to trade or price volatility will affect the animal and feed industry and ultimately compromise food security (Ahuja 2013).

The market plays a crucial (or even indispensable) role in households' livestock production. While the importance of the market for livestock sales is clear, livestock production is also significantly influenced by the products and services purchased from the market. Without access to the market, feed, medicines, and veterinary services cannot be acquired, intensifying the largest production problems (e.g., difficulty in purchasing feed and livestock diseases). In particular, the challenge of livestock diseases is in line with those who postulated that, unlike in developed countries, livestock diseases are a challenge commonly attributed to poor control as most are preventable (Grace *et al.* 2015). Although market access is useful for solving production problems, it requires the participants to have sufficient capital.

When households fall into food insecurity (i.e., skipping meals) and extreme food insecurity (i.e., not eating for a whole day) situations, it also means that their saving has been depleted significantly. Such saving depletion subsequently makes them rely more on the market, expecting to sell livestock for money. However, why do the household not consume their own livestock products?

According to the Mindsponge Theory, a system is more likely to optimize behaviors based on its priority, which is greatly influenced by the perceived availability and accessibility of resources. In this case, the households' priority should be prolonging their existence. Livestock products are generally more nutritious than crop-based products (Rizvi *et al.* 2021), making them more expensive. With a given amount of money, households can sustain their existence for longer by consuming crop-based food (i.e., rice) rather than livestock products. Therefore, households with limited resources and choices might consider fasting or starving as a survival strategy to wait until the livestock products can be sold (Vuong 2022a, 2022b; Nguyen *et al.* 2023). The likely length of the fasting and starving period should be investigated further as it can contribute to the efforts of mitigating food insecurity among smallholder farmers. Acosta *et al.* (2021) and Bahta (2022) consistently reported that livestock sales were used as a coping strategy against drought and climate shock for household income and consumption support. Other studies postulated that except for functions or times of extreme need, the farmers hardly ever eat or sell their livestock but keep them as a source of wealth (Nuvey *et al.* 2022). With this reasoning approach, the varying impacts of production and selling difficulties on various households' food insecurity situations can be explained.

The current study is not without limitations (Vuong 2020). Although the total number of observations of the dataset is adequate, the number of respondents who produce livestock is limited, reducing the representativeness of the current study results. Further studies with larger sample sizes should be conducted to validate the current study's findings. Although we provided detailed reasons underlying the households' production and selling difficulties, we could not examine how much these reasons affect the households' food insecurity situations due to the limited sample size.

5. Policy implications

Given the sensitivity of livestock smallholder households to the market, especially those with limited saving resources, we propose the following recommendations for policy-making to alleviate food insecurity:

- The livestock market should be regulated to balance the prices of livestock products and products and services needed for livestock production. However, rather than advocating for strict price controls, the focus is on creating a regulatory framework that fosters fair competition, transparency, and ethical practices (Hernandez *et al.* 2022). Such a regulated market offers numerous advantages over a free market solely influenced by supply and demand forces.
- A well-regulated market ensures fair competition, preventing monopolies and unfair practices that distort market dynamics (Guyomard *et al.* 2021). This regulation promotes transparency and accountability among market participants, enhancing trust and stability within the market ecosystem. Moreover, it safeguards consumer interests by setting quality standards and ensuring product safety, preventing the exploitation of farmers and consumers, and promoting fair pricing and ethical practices throughout the supply chain (Sinclair *et al.* 2019). Beyond these benefits, regulation plays a crucial role in mitigating market failures and externalities that may arise in an unregulated environment, such as information asymmetry, negative environmental impacts, and social inequalities. By imposing rules and standards, regulators can promote efficient resource allocation and sustainable market growth (Sinclair *et al.* 2019; Guyomard *et al.* 2021).
- Strengthening information exchange mechanisms is important to complement market regulation, s. The information exchanging mechanism (e.g., information and knowledge dissemination channels, product transportation, and service provision) should be bolstered to create more livestock demand and increase the supply of products and services required for livestock production and transportation.
- Furthermore, credit-supporting systems should be implemented and expanded to reach poor livestock smallholder households. Balana and Oyeyemi (2022) postulated that certain smallholders' lack of participation in the credit market might not be due to their inability to receive credit but rather to their risk aversion or lack of access to relevant information about available loan sources and their terms.
- While the proposed solution of regulating the livestock market offers several benefits, it is essential to acknowledge potential drawbacks. One drawback could be the risk of overregulation, leading to bureaucratic inefficiencies and increased compliance burdens for market participants (Blackmore *et al.* 2022). Keeping the right balance between regulation and market flexibility is crucial to avoid stifling innovation and responsiveness to changing conditions. Additionally, there may be challenges in enforcement and monitoring, especially in regions with limited regulatory capacity, which could undermine the effectiveness of the proposed regulatory framework. Policymakers need to carefully consider these challenges and design regulations that are effective, adaptable, and responsive to the diverse conditions within the livestock market. Regular assessments and adjustments may be necessary to ensure the intended benefits are realized without unintended negative consequences.

6. Conclusions

The study used the Bayesian Mindsponge Framework analytics to analyze food insecurity among livestock smallholder farmers in the Philippines. The study findings showed that production and selling difficulties significantly adversely impact livestock smallholder farmers in the Philippines, resulting in varying degrees of food insecurity. While the effects of production and selling difficulties on the probability of less nutritious food consumption are equally significant, the production difficulties have smaller effects on the likelihood of skipping meals and even ambiguous impacts on the likelihood of not eating for a whole day compared to the effects of selling difficulties. The findings underscore the critical role of market dynamics in exacerbating food insecurity, especially the challenges related to market access costs, low selling prices, and low demand for livestock products. The study highlights the need for policy interventions and regulatory measures to mitigate the adverse impact of production difficulties and establish a well-regulated market for addressing the food insecurity problem among livestock smallholder farmers in the Philippines.

Data Availability Statement

The data used in this study was kindly provided by the Food and Agriculture Organization (United Nations) and Data in Emergencies Hub (Food and Agriculture Organization. The data is accessible at: https://microdata.fao.org/index.php/catalog/2086

Conflicts of Interest

The authors declare no conflicts of interest.

Declaration of Funding

This research did not receive any specific funding.

Acknowledgments

We would like to express our gratitude to the Food and Agriculture Organization (United Nations) and Data in Emergencies Hub (Food and Agriculture Organization) for providing us with the dataset.

Appendix

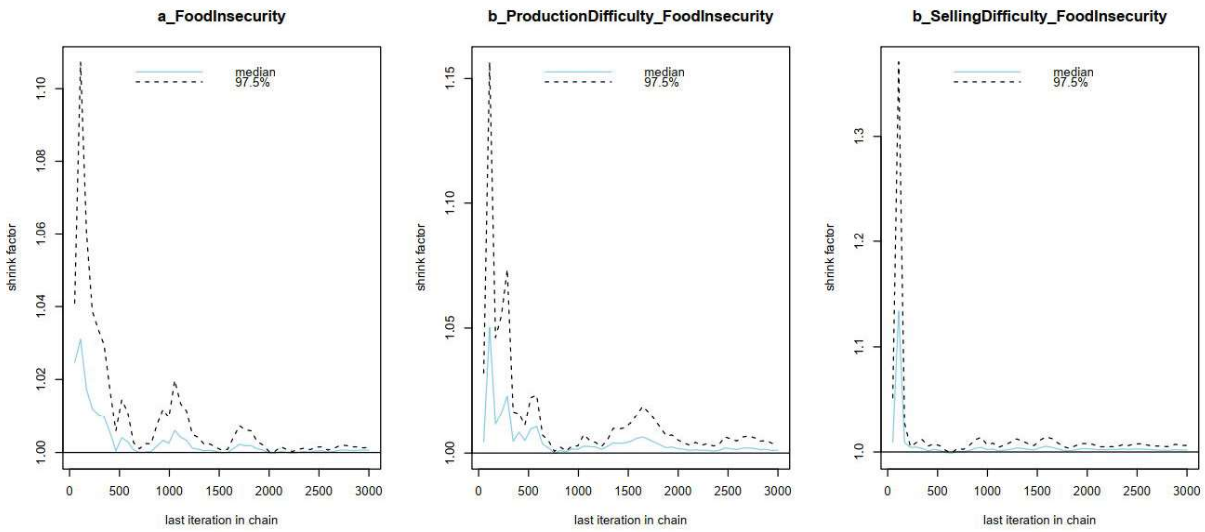

Figure A1: Model 2's Gelman-Rubin-Brooks plots

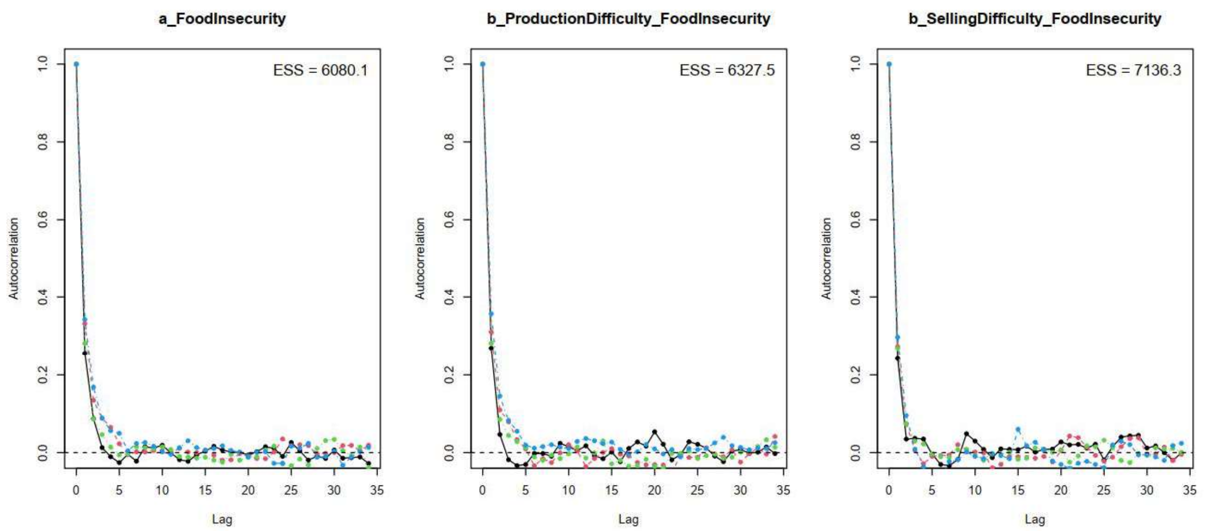

Figure A2: Model 2's autocorrelation plots

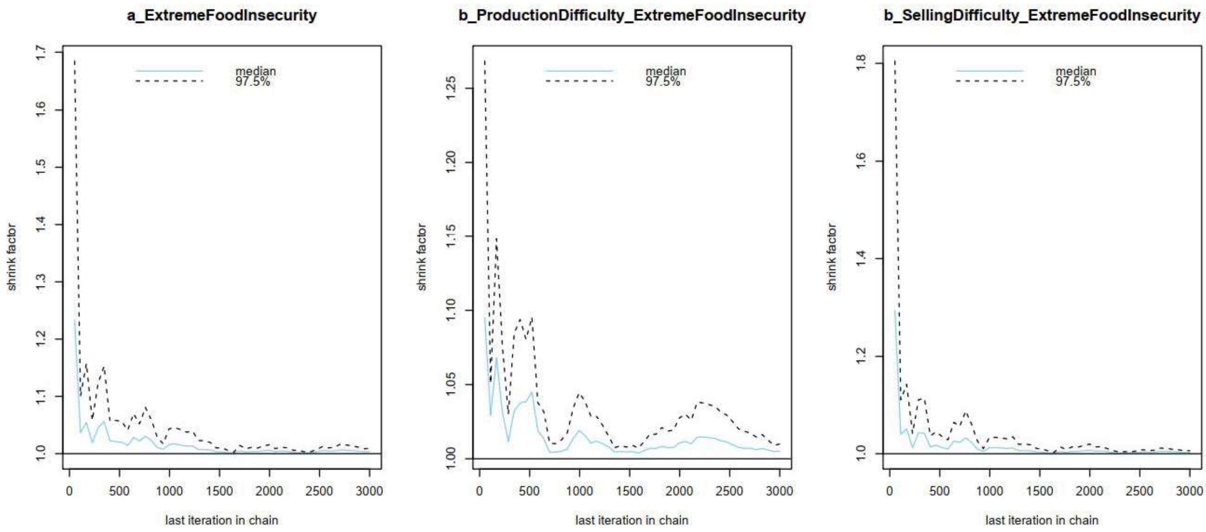

Figure A3: Model 3's Gelman-Rubin-Brooks plots

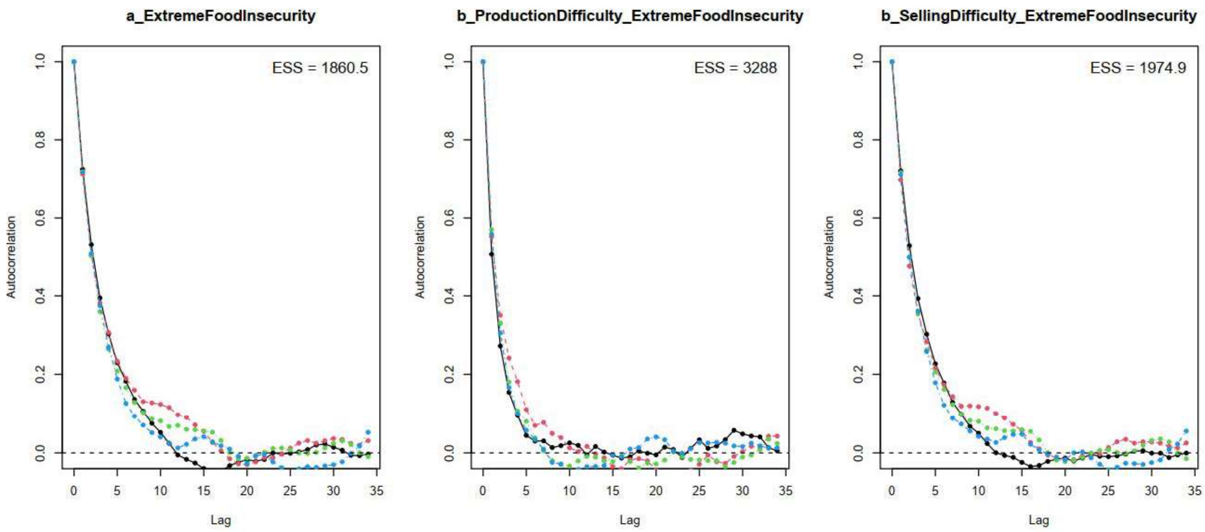

Figure A4: Model 3's autocorrelation plots

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Figure 1: Households' information-exchanging processes with the livestock and the market (generated using draw.io and images from storyset and macrovector on Freepik)

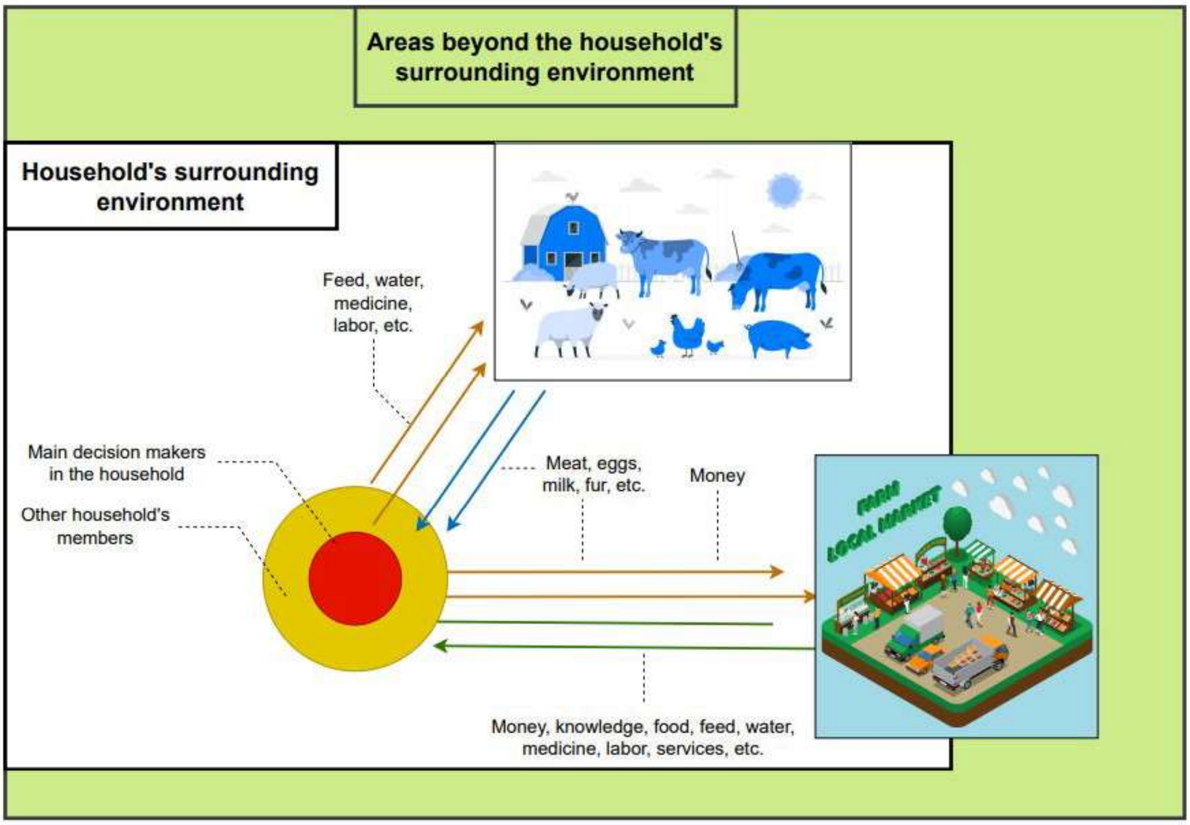


Figure 2: Model 1's trace plots

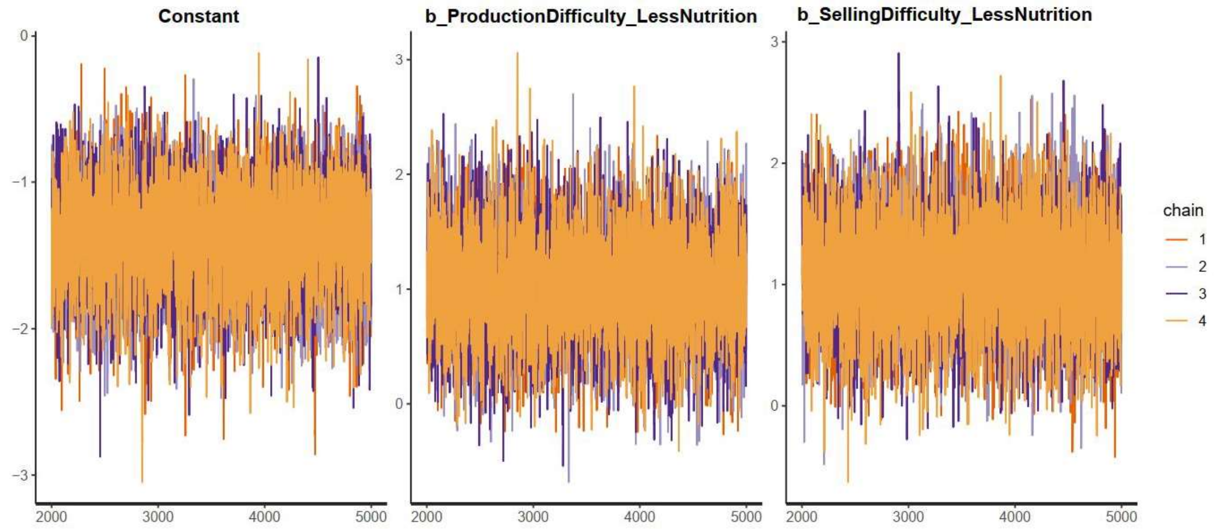


Figure 3: Model 1's Gelman-Rubin-Brooks plots

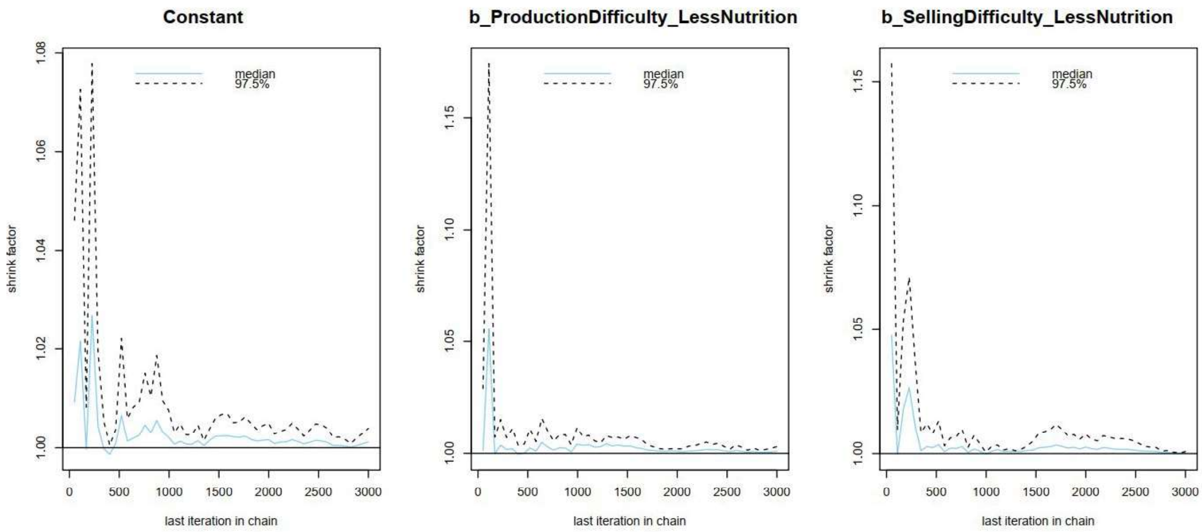


Figure 4: Model 1's autocorrelation plots

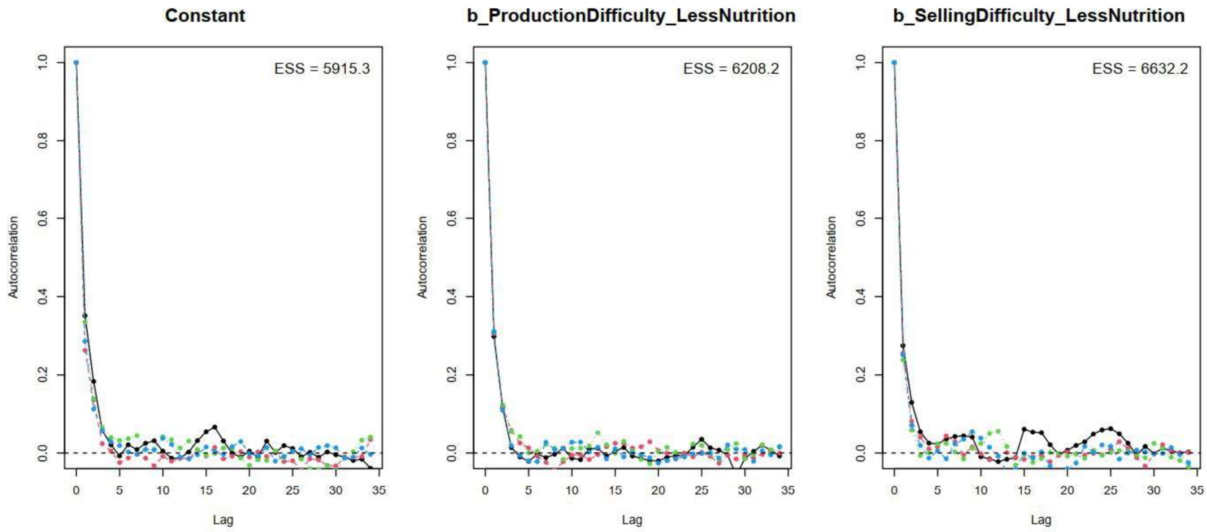


Figure 5: Model 1's posterior distributions

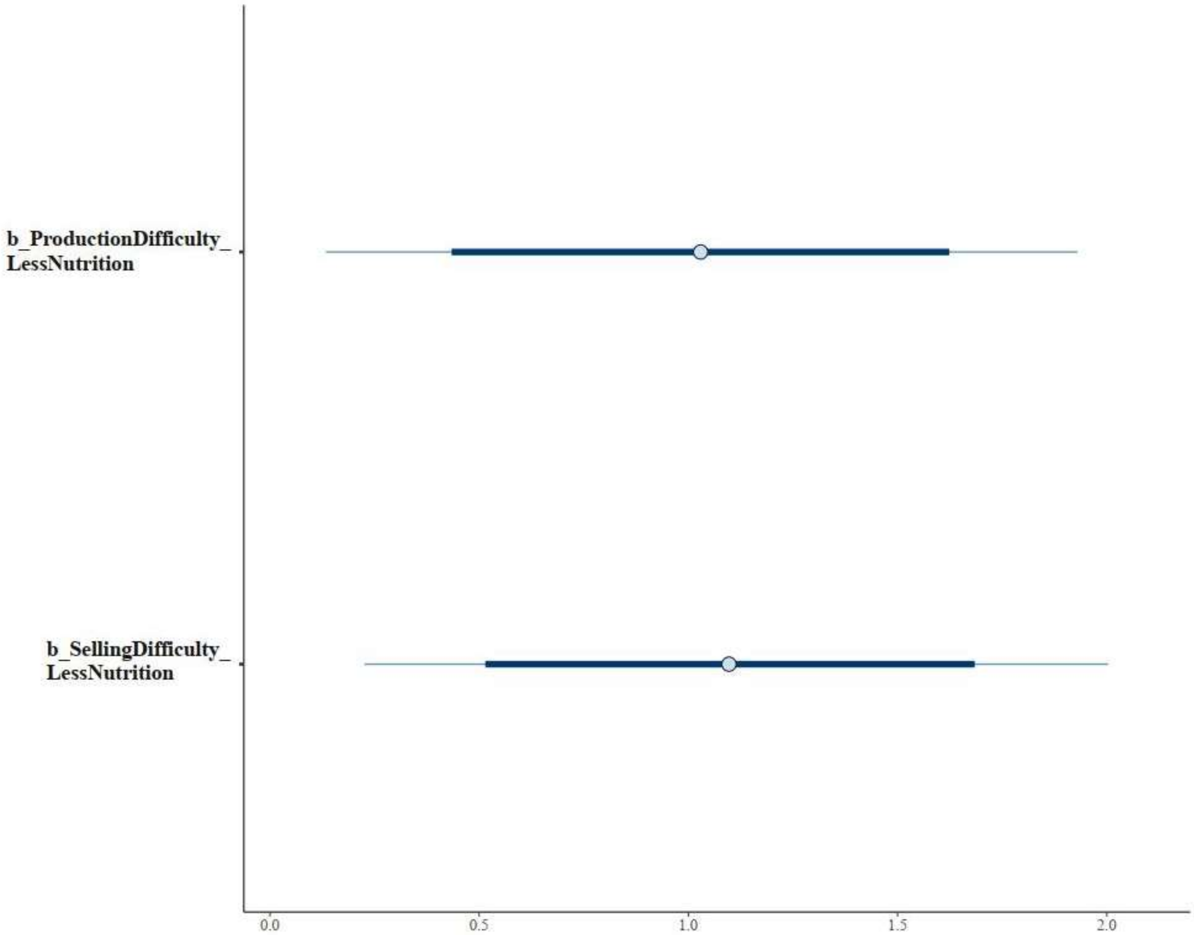


Figure 6: Model 2's trace plots

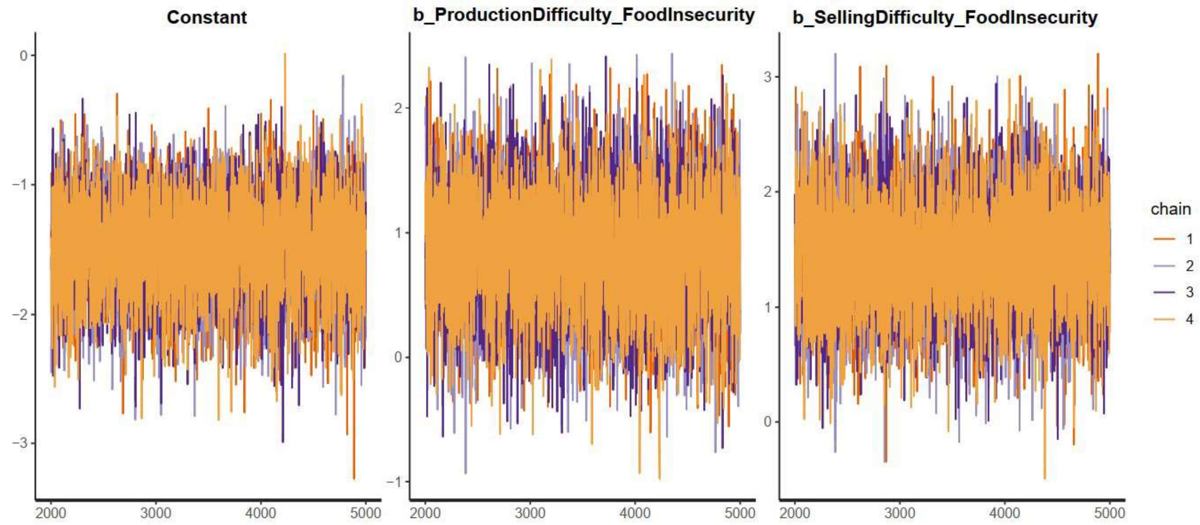


Figure 7: Model 2's posterior distributions

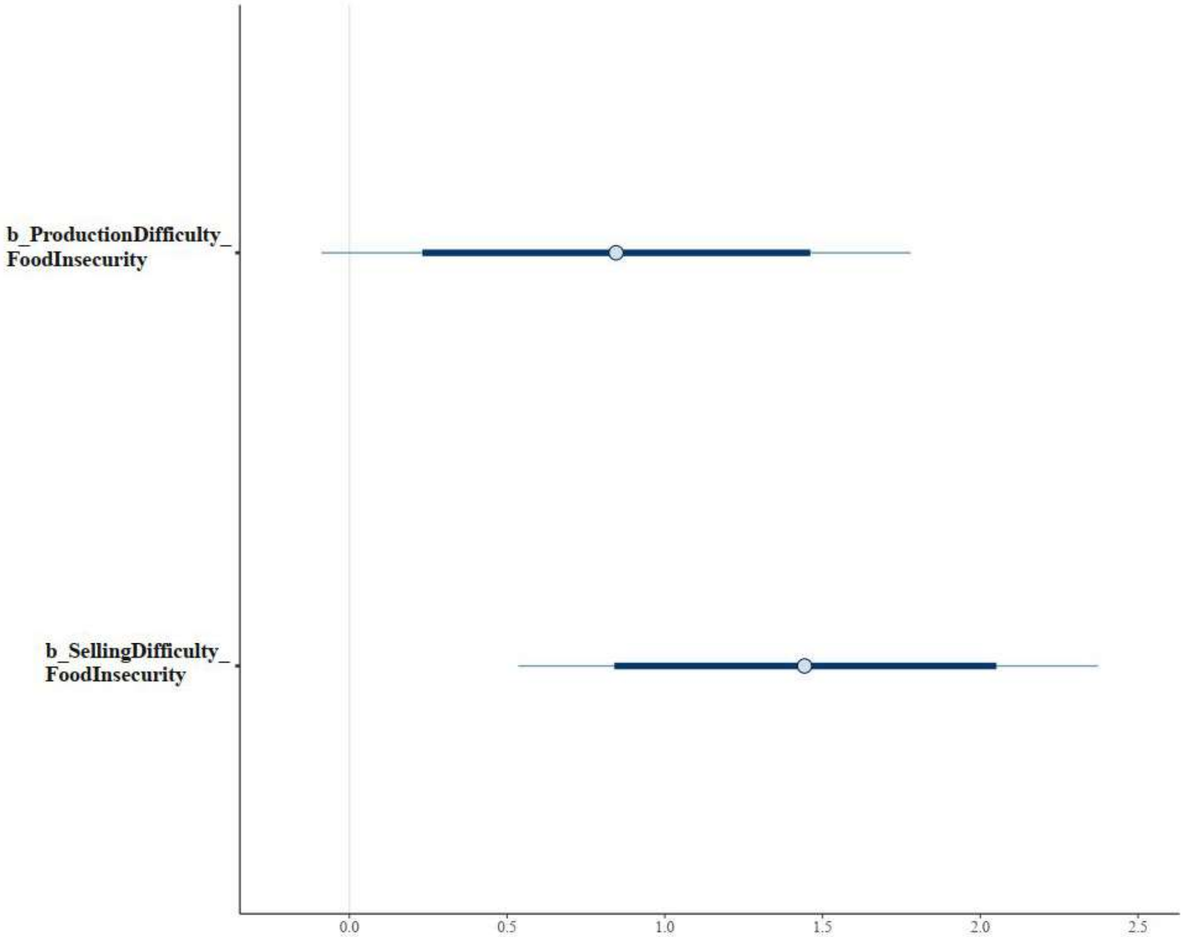


Figure 8: Model 3's trace plots

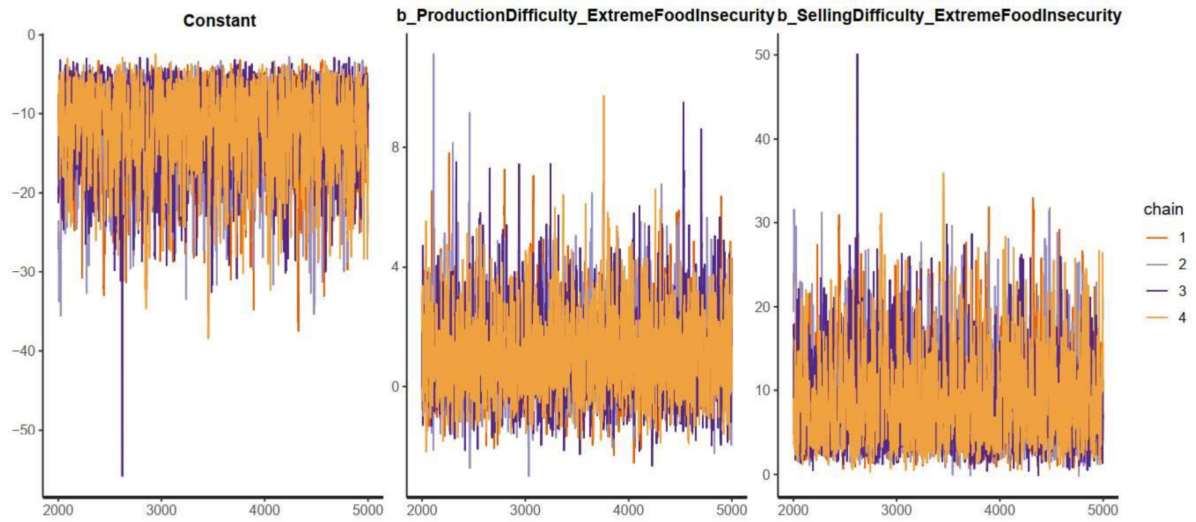


Figure 9: Model 3's posterior distributions

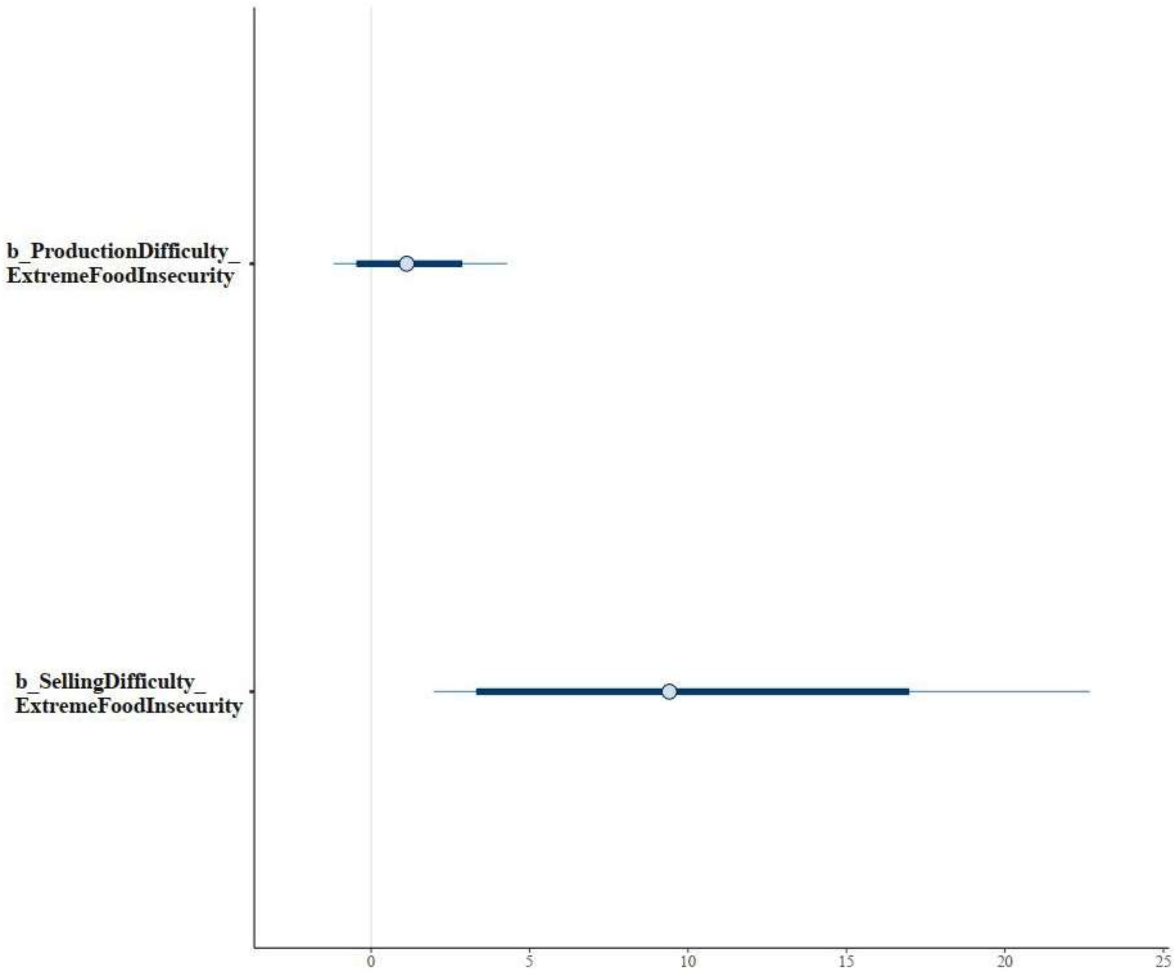


Figure 10: Main Factors Affecting Livestock Production Challenges

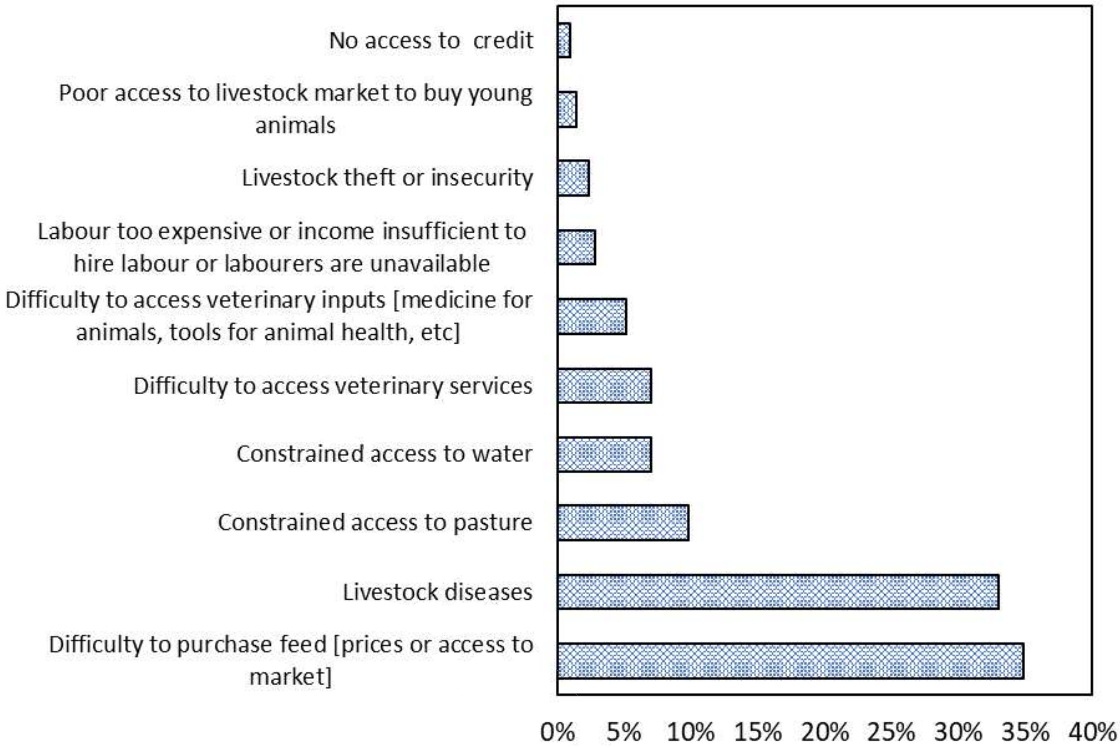
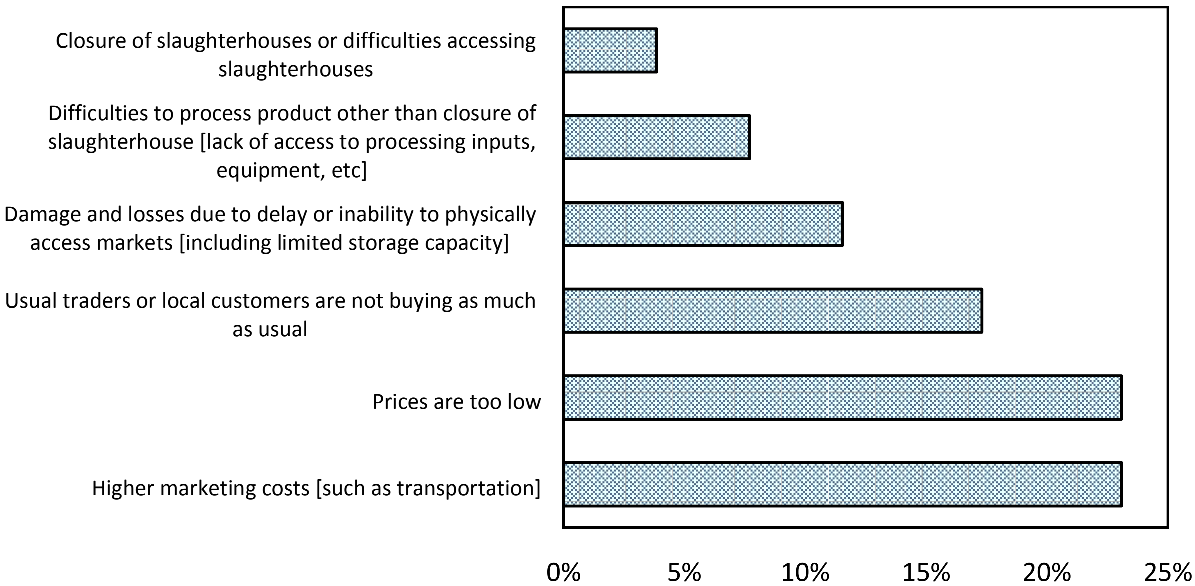


Figure 11: Main Factors Affecting Livestock Trading Challenges



Tables

Table 1. Data descriptions

Variable name	**Explanation**	**Coded variable(s) in the dataset**	**Value**
ExtremeFoodInsecurity	Whether the respondent's household did not eat for a whole day because of a lack of money or other resources to get food during the last 30 days	*fies_whlday*	1 = Yes 0 = No
FoodInsecurity	Whether the respondent's household skipped a meal because of a lack of money or other resources to get food during the last 30 days	*fies_skipped*	1 = Yes 0 = No
LessNutrition	Whether the respondent's household was unable to eat healthy and nutritious food because of a lack of money or other resources to get food during the last 30 days	*fies_healthy*	1 = Yes 0 = No
ProductionDifficulty	Whether the respondent's household had faced any difficulty with livestock production over the last 3 months	*ls_proddif*	1 = Yes 0 = No
SellingDifficulty	Whether the respondent's household had faced any difficulty with selling the products over the last 3 months	*ls_salesdif*	1 = Yes 0 = No

Table 2: Model 1's simulated posterior coefficients.

Parameter	Mean	Standard deviation	n_eff	Rhat
Constant	-1.38	0.35	6057	1
b_ProductionDifficulty_LessNutrition	1.03	0.46	6577	1
b_SellingDifficulty_LessNutrition	1.10	0.46	7154	1

Table 3: Model 2's simulated posterior coefficient

Parameter	Mean	Standard deviation	n_eff	Rhat
Constant	-1.49	0.37	6307	1
b_ProductionDifficulty_ FoodInsercurity	0.85	0.47	6431	1
b_SellingDifficulty_FoodInsercurity	1.45	0.46	6643	1

Table 4: Model 3's simulated posterior coefficient

Parameter	Mean	Standard deviation	n_eff	Rhat
Constant	-12.45	5.68	1666	1
b_ProductionDifficulty_ ExtremeFoodInsercurity	1.18	1.45	2678	1
b_SellingDifficulty_ ExtremeFoodInsercurity	9.56	5.73	1649	1

Robustness check

Table S1: The simulated posterior coefficients of Model 1 with and without control variables.

Parameter	Without control variables				With control variables			
	M	S	n_eff	Rhat	M	S	n_eff	Rhat
Constant	-1.38	0.35	6057	1	1.78	1.13	3789	1
b_ProductionDifficulty_LessNutrition	1.03	0.46	6577	1	1.22	0.52	5275	1
b_SellingDifficulty_LessNutrition	1.10	0.46	7154	1	1.34	0.51	5029	1
b_resp_age_rng2_LessNutrition (Age of the respondent)					-0.18	0.13	4830	1
b_hh_education_LessNutrition (Educational level of the head of the household)					-0.86	0.34	3782	1
b_resp_gender2_LessNutrition (Gender of the respondent)					-0.19	0.52	5747	1
b_tot_income_LessNutrition (Total income of the respondent)					0.00	0.00	7668	1

The effects of *ProductionDifficulty* and *SellingDifficulty* on *LessNutrition* are almost unchanged when other variables are added in the models, suggesting that their effects in the parsimonious model are robust. In addition to that, the existence of older people (i.e., the respondent) in the household and the educational level of the head of the household are also found to negatively predict the likelihood of consuming food with lower nutritional value. These predictions are highly reliable as the absolute values of the mean are much higher than the values of the standard deviation.

Table S2: The simulated posterior coefficients of Model 2 with and without control variables.

Parameter	Without control variables				With control variables			
	M	S	n_eff	Rhat	M	S	n_eff	Rhat
Constant	-1.49	0.37	6307	1	0.63	1.09	2118	1

b_ProductionDifficulty_ FoodInsercurity	0.85	0.47	6431	1	0.90	0.51	2902	1
b_SellingDifficulty_FoodInsercurity	1.45	0.46	6643	1	1.64	0.51	2982	1
b_resp_age_rng2_FoodInsercurity (Age of the respondent)					-0.12	0.13	2713	1
b_hh_education_FoodInsercurity (Educational level of the head of the household)					-0.49	0.33	2452	1
b_resp_gender2_FoodInsercurity (Gender of the respondent)					0.47	0.53	2348	1
b_tot_income_FoodInsercurity (Total income of the respondent)					0.00	0.00	3955	1

The effects of *ProductionDifficulty* and *SellingDifficulty* on *FoodInsercurity* in the model with control variables are not dissimilar to those in the original model. This similarity indicates a good robustness of the estimated results. In addition to that, the existence of older people (i.e., the respondent) in the household and the educational level of the head of the household are also found to negatively predict the likelihood of skipping a meal because of a lack of money or other resources to get food during the last 30 days. Meanwhile, the head of the household being male positively predicts the likelihood. Comparison between the absolute values of the mean and standard deviation suggest that the effect of the head of the household's educational level is highly reliable, while other effects are only moderately reliable (i.e., the absolute values of the mean are almost equal to those of standard deviation).

Table S3: The simulated posterior coefficients of Model 3 with and without control variables.

Parameter	Without control variables				With control variables			
	M	S	n_eff	Rhat	M	S	n_eff	Rhat
Constant	-12.45	5.68	1666	1	-9.95	6.00	2023	1
b_ProductionDifficulty_ ExtremeFoodInsercurity	1.18	1.45	2678	1	0.91	1.62	3202	1
b_SellingDifficulty_ ExtremeFoodInsercurity	9.56	5.73	1649	1	9.82	5.41	2101	1

b_resp_age_rng2_ExtremeFoodInsecurity (Age of the respondent)					-0.61	0.32	4196	1
b_hh_education_ExtremeFoodInsecurity (Educational level of the head of the household)					0.24	0.88	3646	1
b_resp_gender2_ExtremeFoodInsecurity (Gender of the respondent)					0.77	1.43	4482	1
b_tot_income_ExtremeFoodInsecurity (Total income of the respondent)					0.00	0.00	5983	1

The effects *ProductionDifficulty* and *SellingDifficulty* on *ExtremeFoodInsercurity* are almost identical when new variables are inserted into the model. This implies that the estimated results using the parsimonious model are robust. In addition, only the existence of older people (i.e., the respondent) in the household negatively predicts the household's probability of not eating for a whole day because of a lack of money or other resources to get food during the last 30 days (high reliability).