MAIZE SAFETY, GROWTH DYNAMICS AND ADAPTATION DECISIONS IN THE POULTRY VALUE CHAIN IN NIGERIA

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ABSTRACT

MAIZE SAFETY, GROWTH DYNAMICS AND ADAPTATION DECISIONS IN THE POULTRY VALUE CHAIN IN NIGERIA

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Many countries in the global South have been experiencing a rapid transformation of their food systems in the last two decades. Nigeria, sub-Saharan Africa's most populous country and largest economy, has seen a rapid growth in poultry production as a result of rising incomes, urbanization, and increased demand for animal proteins. Despite this extraordinary performance, poultry businesses face several challenges. First, the poultry sector is characterized by a multitude of farm sizes, but little is known about the performance of each type or the processes that support their growth and modernization across space and time. Second, concerns related to higher temperatures linked to climate change are raising questions about the ability of poultry farms to protect their investments in order to maintain their current growth trajectories. Third, there is limited enforcement of food safety regulations in the country and no market mechanisms to regulate food safety challenges associated with maize, a key ingredient in poultry feed. The considerable presence of aflatoxins, deadly toxins produced by fungi, in domestically produced maize is therefore a major concern among poultry farmers due to its negative effects on the birds.

This dissertation therefore 1) examines the structure of growth patterns in the poultry sector, 2) investigates the adaptation practices of poultry farmers to higher temperature, and 3) explores a market-based solution to supply aflatoxin-safe maize on the Nigerian market. Using a multi-method approach, it draws from both quantitative and qualitative data collected in states that play a major role in the poultry value chain in Southern and Northern Nigeria. The first essay uses the concept of minimum investment threshold, to investigate the dynamics of poultry farm sizes and

its implication on the likely ability of farms to grow and withstand input price shocks. The second essay draws on a case study approach to examine poultry farmers' perceptions of higher temperatures, their effects on production and their adaptation strategies. The third essay uses a discrete choice experiment method to estimate maize traders' willingness to pay for aflatoxin-safe maize, a key quality attribute of the commodity.

The findings of this dissertation have both policy and practical implications for actors involved in the Nigerian poultry value chain. First, it provides evidence of multiple equilibria (low equilibrium and high equilibrium) in the poultry industry in Nigeria and the existence of a critical minimum investment threshold to operate a farm at or around the high equilibria. Moreover, firms at (or headed towards) the low equilibria are less likely to experience growth and more likely to exit the sector in the event of an input price shock. Second, this work highlights that poultry farmers clearly perceive that temperatures are increasing, and they are adopting adaptation practices suitable to the size of their farms. Lastly, it provides suggestive evidence that a market-based solution that incentivizes maize traders to supply aflatoxin-safe maize is attainable as long as the buyers of the commodity care enough to pay a price premium for that attribute.

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KEY TO ABBREVIATIONS

HE	High equilibrium
MNL	Multinomial logit
MXL	Mixed logit
MXL-EC	Mixed logit with error component
T	Threshold
WTP	Willingness to pay

1. INTRODUCTION

Many countries in the global South have been experiencing a rapid transformation of their food systems in the last two decades. Nigeria, sub-Saharan Africa's most populous country and largest economy, has seen a rapid growth in poultry production as a result of rising incomes, urbanization, and increased demand for animal proteins. The country experienced a two-fold increase in its poultry production between 1980 and 2008 (Liverpool-Tasie et al., 2017a). This is partly due to the low cost of production and barriers to entry of poultry compared with other livestock products (Heise et al., 2015). In addition, the share of maize allocated to the feed industry followed an upward trend between 2003 and 2015 with a 300% increase in volume (Liverpool-Tasie et al., 2017a). This rapid transformation of the poultry sub-sector has translated into about 85 million Nigerians being involved in small family poultry farming while over 14 million people benefit from employment in the commercial sector (PAN, 2017). These changes have positioned the poultry sector as a major source of affordable animal protein in the form of eggs for the country's large and growing population which is consuming more of this food form (Liverpool-Tasie et al., 2017a; United Nations; Zhou & Staatz, 2016).

Despite this extraordinary performance, poultry businesses face several challenges. First, the poultry sector is characterized by a multitude of farm sizes, but little is known about the performance of each type or the processes that support their growth and modernization across space and time. Second, concerns related to higher temperatures linked to climate change are raising questions about the ability of poultry farms to protect their investments in order to maintain their current growth trajectories. Third, there is limited enforcement of food safety regulations in the country and no market mechanisms to regulate food safety challenges associated with maize, a key ingredient in poultry feed. The considerable presence of aflatoxins, deadly toxins produced by fungi, in domestically produced maize is therefore a major concern among poultry farmers due to its negative effects on the birds.

The existing literature addresses some of the questions brought about by these challenges, but several remain unanswered. This dissertation aims to fill some of these gaps in knowledge by tackling three issues. First, the structure of the Nigerian poultry subsector is not well understood and the growth patterns for the industry are largely unexplored in the literature. Although some existing studies have explored the profitability of poultry production in the country, none (to our knowledge) have studied the growth pattern of farms and the underlying dynamics of poultry farm sizes. Second, there is a scant literature on livestock farmers' perceptions and adaptation strategies to climate change. Even when it is available, it tends to focus on large livestock owners leaving out small animals like poultry. Yet, this lack of evidence on small animal owners matters to poultry farmers in Nigeria. As such, part of this work examines how higher temperatures are affecting commercial poultry farmers as well as document how they are adapting. Third, little has been written on how a market-based solution can fill in the void left by the limited enforcement of food safety regulations for maize, a key ingredient for poultry feed. Thus, another portion of this dissertation is dedicated to understanding how maize suppliers can be incentivized to provide aflatoxin-safe maize. Together the first and second essays aim to examine the role of farm size on poultry farmers' ability to grow, bounce back from a shock and adapt to higher temperatures. The last essay evaluates a market-based mechanism which can provide aflatoxin-safe to buyers including those engaging in the poultry sub-sector.

The first essay investigates the underlying dynamics of poultry farm sizes in two major poultry producing states in Nigeria. It uses a non-parametric approach to determine whether poultry farms are characterized by convergent (a single stable equilibrium flock size) or bifurcated dynamics (multiple stable equilibria in flock size). Convergence means that all poultry farms are expected to grow over time towards one single equilibrium or particular farm size. Bifurcation implies the existence of more than one equilibrium flock size such as on the same growth trajectory some farms are at the low equilibrium while others are at a high equilibrium. Multiple equilibria are also characterized by the existence of a threshold. Farms right below the threshold grow to a lower equilibrium while those above grow to a higher equilibrium. Next, it uses parametric methods to test whether firms at different equilibria have a differential ability to withstand non-trivial shocks in the sector and if they face different growth opportunities. There is evidence of multiple equilibria showing that poultry farms at the low equilibrium are similar across both states but those at or near the high equilibrium in Kaduna operate on a much lower scale compared to Oyo. The threshold or minimum investment that farms need to grow to a high equilibrium is higher in Kaduna compared to Oyo (approximatively 1800 birds vs. 1200 birds). Beyond the specific numbers, the key takeaway from these results is that there exists a minimum investment for entrepreneurs interested in operating large farms in the long run as small farms are unlikely to grow. The results also consistently indicate that farms at (or headed towards) the low equilibrium are less likely to experience significant growth and continue to operate around that low equilibrium. While this might be considered sufficient for many farmers, we also find that these smaller farms are more likely to exit the sector in the event of an input price shock.

The second essay aims to bridge the knowledge gap on climate change adaptation by small animal producers using evidence from south west Nigeria. Using a case study approach, it examines poultry farmers' perceptions of higher temperatures, their effects on production and their adaptation strategies. The analysis reveals that poultry farmers are perceiving changes in temperature and are adopting strategies based on what they can afford. All farms irrespective of size use cheaper practices such as reducing the stocking density of the birds. However, large farms can better protect their farms by adopting additional costlier methods such as building new chicken houses that enable better air circulation. Many of the small and medium farmers expressed the desire to implement heat management measures in the future. Some of these include cheaper practices like planting trees around the chicken pens or more expensive ones such as building chicken pens with better ventilation.

The third essay uses a discrete choice experiment to estimate maize traders' willingness to pay (WTP) for an aflatoxin-safe product and explore if this willingness to pay varies with the expected (or known) demand for the same by their buyers. Maize traders provide a unique opportunity to explore this topic because they sell to a broad variety of buyers including wholesalers, maize retailers, food companies, small and large feed mills and household consumers. Results indicate that traders selling to other traders, large feed mills, food companies and retailers exhibit a higher WTP for certification compared to those who sell to small feed mills and consumers. The use of a trader's perception that a marketing channel will be willing to pay a price premium (rather than their actual experience with a marketing channel) confirms these results.

These three essays highlight that there exist viable avenues for tackling the challenges faced by the poultry sector, with some actors already actively implementing some of them. The findings have important empirical and policy implications. First, the diversity of farm sizes reflects the existence of a minimum investment required to operate at the high equilibrium which we have shown to be conducive to the likelihood of surviving an input price shock. Second, poultry farmers are not passively enduring the adverse effects of higher temperatures, but many small and medium farms face structural (e.g. access to electricity to feed the birds at night) and financial challenges in implementing some of these strategies. Third, the limited availability of information related to the negative health impacts of aflatoxin perpetuates the status quo. It is only by raising the awareness of buyers, who would in turn agree to pay a price premium for aflatoxin-safe maize, that traders can be incentivized to provide it. Overall, this dissertation sheds light on the structure of the poultry sector in Nigeria with implications for how some of the challenges it faces can be addressed so that the country can fully take advantage of this growth momentum.

2. ARE THERE DISTINCT GROWTH PATTERNS FOR POULTRY FARMS? EVIDENCE AMONG COMMERCIAL POULTRY FARMS IN NIGERIA

2.1. Introduction and motivation

Many countries in the global South have been experiencing a rapid transformation of their food systems in the last two decades (Reardon et al., 2009; Reardon et al., 2015). This transformation manifests at all levels along numerous commodity value chains. Downstream, urbanization and increases in incomes among both rural and urban consumers have resulted in higher demand for proteins over starchy staples (Muyanga et al., 2019). This filters to the midstream and upstream, where investments on the farm as well as in processing, trading and third-party logistics have increased due to a suite of policy reforms, facilitating entry into farming (Reardon et al., 2018; Tschirley et al., 2015). This phenomenon is evident in Nigeria where the poultry subsector has taken off in recent years as a result of urbanization, and increased demand for animal proteins (Sahel Capital, 2015; Zhou & Staatz, 2016). However, the poultry subsector is characterized by a multitude of farm sizes having access to different physical, social and financial capital and exhibiting different management styles (Adene & Oguntade, 2006; Akinwumi et al., 2010). The farm sizes vary greatly from a few birds for backyard producers to a rising number of commercial farms with hundreds and sometimes thousands of birds operating on different scales of intensive production systems. Many of these commercial farms with hundreds to thousands of birds are engaged in a more specialized form of poultry production and acquire their inputs on the market or are vertically integrated.

While the diversity of farm sizes is evident, there is little empirical work about the performance of firms of different sizes or the processes that support their growth and modernization across space and time. In general, the structure of the Nigerian poultry subsector is not well understood and the growth patterns for the industry are largely unexplored in the literature. Although some existing studies have explored the profitability of poultry production in the country (Kalla et al., 2007; Olasunkanmi et al., 2009), none (to our knowledge) have studied the growth pattern of farms and the underlying dynamics of poultry farm sizes. Thus, this study begins to fill this knowledge gap by examining the structure of growth patterns of poultry farms in Nigeria. We examine whether the growth patterns of poultry farms are characterized by convergent or bifurcated dynamics. Convergence means that all poultry farms are expected to grow over time towards one single equilibrium or optimal flock size. Bifurcation or divergence implies the existence of more than one equilibrium flock size. This implies that while there might be the possibility to operate at some level (e.g. with a few birds), there is some minimum investment necessary to get a poultry farm to a particular larger size (in terms of flock size) within the same industry. Such analysis informs whether those going into poultry production are likely to grow over time to one optimal flock size or if there are multiple optimal flock sizes possible depending on the size of birds one enters the industry at. We also explore the implications of identified equilibrium flock sizes on the ability of firms to grow as well as to withstand likely and non-trivial shocks in the sector.

A significant interest in agriculture has been observed by the Nigerian private sector (retired civil servants) and others trying to diversify their economic livelihood (Liverpool-Tasie et al., 2017). There is also a keen interest by the Nigerian government and some donors to encourage investments in the Nigerian poultry subsector as a means of fighting poverty and improving welfare (G. Thornton, 2017). Understanding the dynamics of poultry farm sizes and its implication on the likely ability of firms to grow and withstand likely and non-trivial shocks provides useful information to guide such stakeholders as they enter the business or encourage others to engage in it.

This paper makes several key contributions to the literature. First, this is the only study, to our knowledge, that explores the dynamics of flock size in poultry and uses it to test for the heterogeneity of firm growth. In general, the literature tends to focus on the general profitability of poultry farms without much attention given to the role of farm size on growth and productivity. Thus, this paper contributes to the limited literature on the role of starting firm size on the emergence of different growth patterns among enterprises in developing countries; particularly commercial small animal production. Second, this study provides insights on the relationship between firm size and the ability to survive a non-trivial but likely shock. Although the effects of shocks have been investigated in the literature, the focus tends to be on the effect of shocks on survival rates without much attention to the potential heterogeneity of survival depending on firm size.

We find evidence of multiple equilibria in the poultry industry in Nigeria. There is a low equilibrium around 500-550 birds and a higher equilibrium at 6450 and 3250 in Oyo and Kaduna, respectively. Additionally, the results suggest that there is a minimum investment of about 1200 birds in Oyo and 1800 birds in Kaduna for firms desiring to operate a farm at or around the high equilibria respectively. Beyond the specific numbers, the key takeaway from these results is that there exists a minimum investment to grow to a large farms as small farms are unlikely to grow. This result is consistent with previous findings from the literature on the growth of firms in sub-Saharan Africa which support that firms which start small rarely grow in later years. In addition, we found that operating at the low level equilibrium compared to the high one may not be inherently bad but firms at (or headed towards) the low equilibrium are less likely to experience growth and more likely to exit the sector in the event of an input price shock. These results are robust to multiple robustness checks and over different time periods. The remainder of this paper is structured as follows. Section 2 provides some background literature on firm size and growth. Section 3 describes the conceptual approach while section 4 discusses the data and sample. Section 5 presents the empirical strategy and section 6 the results. The last section summarizes the findings.

2.1.1. Minimum investment and firm growth

While there are many studies on the relationship between firm size and growth, the role of a minimum investment threshold (a minimum number of birds in our case) in a firm's growth has not been well studied in developing countries. Furthermore, the evidence on the relationship between firm size and growth is mixed. On one hand, some studies using samples in the manufacturing industry suggest that small sized firms tend to experience higher growth compared to large ones. Liedholm and Mead (1987) and Biggs and Srivastava (1996) investigate the relationship between firm size and firm growth in sub-Saharan Africa. Liedholm and Mead (1987) examine the percentage of workers in small firms versus large firms. They note that a larger share of workers is employed by small firms which also surpass the large ones in numbers. In their work. Biggs and Srivastava (1996) use employment as a measure of growth because it is easier to obtain compared to other measures such as profit or return on investment. They categorize the enterprises in their sample based on the number of employees at the start into five groups: micro (1-4), very small (5-9), small (10-49), medium (50-99) and large (100+). Then they present the mobility rate from the time the enterprises started to about 25 years later. They found that employment growth is faster among small enterprises compared to larger ones, but the former do not have an effect on employment levels. This is because the large firms in the data started large thus having fewer opportunities to add new workers while smaller firms are more likely to hire new workers. The small firms also have less than 5% chance of becoming large over time indicating that they are likely operating around a lower stable equilibrium level. Bigsten and Gebreeyesus (2007) also found that there is an inverse relationship between the size and employment growth rates of Ethiopian manufacturing firms. Similarly, Grimm et al. (2011) examine the patterns of capital returns among micro and small enterprises in West Africa. They split the data based on the distribution of initial investment and the size of the sample in each category. Their results suggest that low levels of capital are associated with high marginal returns (above 70% per month). In contrast, starting with a capital stock above a certain threshold (150 international dollars) leads to lower marginal returns of about 4-7% per month. The authors conjecture that the higher marginal returns at low levels of capital stock likely capture the high risks of operating below the threshold.

Also, the literature indicates that the initial high growth rate observed among small firms is likely to taper off as they hire more employees (McKenzie & Woodruff, 2006). This is what Van Biesebroeck (2005) found in a study based on a sample of manufacturing firms in nine countries in sub-Saharan Africa (Ethiopia, Burundi, Tanzania, Zambia, Kenya, Ivory Coast, Ghana, Zimbabwe, and Cameroon). Small firms are unlikely to grow to become large firms; and the latter experience higher growth rates in terms of productivity, employment, and value-added (Van Biesebroeck, 2005). This is consistent with evidence that supports that small firms are less likely to grow into large firms whereas firms which are initially large enjoy a higher growth rate over time due to gains from economies of scale and experience (Sleuwaegen & Goedhuys, 2002). Similar findings emerged from a study of manufacturing firms in Ethiopia where large firms demonstrated higher levels of physical productivity (value added per worker) compared to small firms (Söderbom, 2012). Additionally, the size of a firm has been shown to positively affect technical efficiency (producing the maximum possible output for any combination of inputs) among manufacturing firms (food, wood, textile and metal) in Kenya (Lundvall & Battese, 2000). The categorizations used in these studies do not emerge from the data but instead are based on an arbitrary grouping. Consequently, this study is innovative in that it determines the minimum investment based on the dynamics of the relationship between firm size at two time periods.

While the direction of the relationship between firm size and firm growth is not obvious, there are some factors that have been shown as being instrumental to the emergence of a large firm characterized by high growth. Based on the premise that access to financing is a key determinant of firms' growth (Ayyagari et al., 2008), Cabral and Mata (2003) show that financial constraints explain why some enterprises start out small whereas others start large. The literature on small and medium enterprises (SMEs) suggests that small firms face important financial constraints due to their limited access to formal financing mechanisms (Beck & Demirguc-Kunt, 2006). This is also consistent with the poverty trap literature where in the presence of multiple financial market failures, by virtue of being poor and unable to access financial resources, households/firms are unable to invest in growth enhancing technologies and thus remain poor/at a low equilibrium despite the possibility of attaining a higher equilibrium (Barrett & Carter, 2013; Carter & Barrett, 2006; Santos & Barrett, 2011). These financial failures become very important in areas with poor infrastructure. With poor infrastructure and the need for private investment in substitutes, financial limitations can prevent small firms from accessing technologies that could increase their productivity. On the other hand, large firms are able to make investments such as the adoption of new technologies which support positive productivity growth (Van Biesebroeck, 2005). Thus an investment climate that removes bottlenecks in key infrastructure such as power, transportation and telecommunication is also favorable to the emergence of large firms and hence higher growth rates (Page & Söderbom, 2015).

One distinguishing feature of large firms discussed in the literature is their ability to be resilient to shocks.[1] Unlike small firms, large firms (with 100 or more workers) have been found to be less vulnerable to shocks and less likely to exit in the presence of such shocks (Van Biesebroeck, 2005). The main reason for exit among smaller firms is prolonged negative productivity growth (Van Biesebroeck, 2005). Using a survey of manufacturing enterprises in Ghana, Frazer (2004) also shows that in general large firms are more likely to remain active while small ones exit. Moreover, in their study investigating the effect of input price shock among medium and large broiler producers in Nigeria, Padilla and Liverpool-Tasie (2019) found that compared to large farms, medium farms are not well equipped to survive high feed costs and increasing energy costs (with the adoption of technologies to deal with climate change). These medium farms end up shutting down their businesses once these costs are incorporated. These studies indicate the importance of recognizing the heterogeneity of profitability and ability to withstand shocks by firm size.

In this paper, we explicitly examine the effect of poultry farm size on the likelihood of exit in the Nigerian poultry sub-sector. Our study differs from other studies in that our categorization of birds is not arbitrary but comes from the identification of equilibrium flock sizes based on the dynamics of poultry flock size in our study context. Furthermore, this paper is situated in a rapidly growing but understudied firm sector in Africa; livestock.

2.2. Conceptual Framework

This study draws on insights that stem from the historical neoclassical growth model used to explain economic growth across nations. The neoclassical growth model assumed diminishing returns to productive assets that generate a stream of income. The implication of the neoclassical

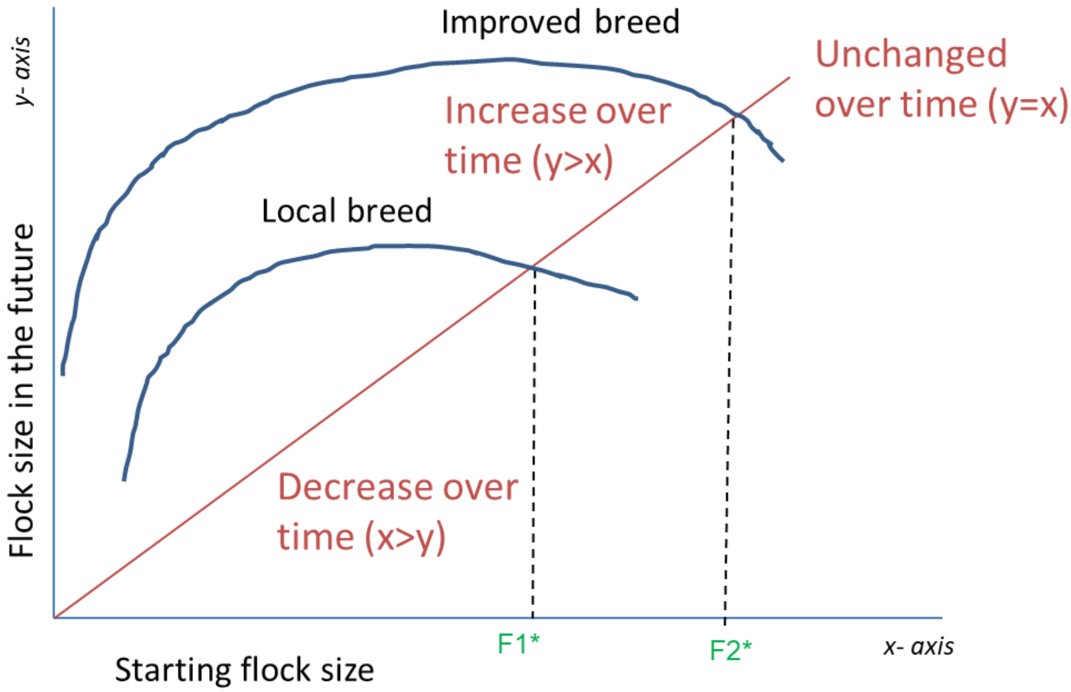
[1] The term resilience is used here to describe adaptive capacity (asset based resilience), the ability to withstand shock, or the ability to bounce back (return to a specific space) following a shock throughout this paper. It is different from ecological resilience which is an internal property of a system even in the absence of a shock.

growth model was that over time, incomes in poorer nations are expected to converge to incomes of richer nations (Solow, 1956; Swan, 1956). Observation of income growth patterns at odds with these predictions inspired further thinking about economic growth that gave rise to alternative theories including the idea of multiple equilibria and thresholds (Azariadis & Drazen, 1990). The idea of multiple equilibria posits that there could be a low-level equilibrium (poverty trap) related to thresholds at which the returns to productive assets are increasing locally. At the micro level, Carter and Barrett (2006) apply the idea of multiple equilibria to explore the dynamics of household income and poverty. In the presence of certain financial market failures (borrowing and investment constraints), household current consumption depends on the income that can be generated by their productive assets. In such circumstances, factors such as the ability to steadily accumulate assets or take advantage of new technologies determine the long-term poverty status of households (Carter & Barrett, 2006). One key implication of both the macro and micro approach to explaining income dynamics is that current income (asset holdings) can be used to predict where individuals will end up in the future. In other words, future wealth is a function of past wealth. This idea has also been applied as herd dynamics among pastoral populations in several countries where ex ante (insurance) and ex post (borrowing) safety nets are lacking (Barrett et al., 2006; Lybbert et al., 2004; Mogues, 2011; Santos & Barrett, 2016). They show that there is a minimum critical herd size necessary for households to effectively deal with shocks (not falling to a low-level stable equilibrium characterized by smaller herd sizes) such as rainfall variability which affect pasture and water availability.

We apply this concept to the poultry subsector to show how the dynamics of poultry flock sizes could follow similar patterns with the possibility of multiple equilibria in terms of the expected flock size of farms over time. On one hand, bird accumulation over time (within a particular economic, socio-cultural, and institutional context) could converge to a unique equilibrium or face multiple equilibria trajectories depending on the initial/past flock size. This can happen in poultry production if on average and all things being equal, as the number of birds a poultry farm increases, the probability of bird loss (e.g. due to disease) also increases such that bird holdings over time converge to some optimal number (see Figure 2.1). Note that in Figure 2.1, the equilibrium point is where the curve crosses the 45-degree line. Farms beyond the equilibrium point will experience a decline in size while those below it will tend to grow towards it because of diminishing returns to scale. This could be thought of for the number of birds per bird house or pen per farm. In such a situation the growth/accumulation strategy of a farm will likely be dependent on its ability to make significant fixed investments (such as buying or building another bird house) or facing a situation where the optimal flock size will converge on some equilibrium number equal to the optimal holding capacity of the bird house and/or farm. In such circumstances, evidence of this convergence can be captured by looking at the size of a farm in the current period as a function of the size of the farm in previous periods.

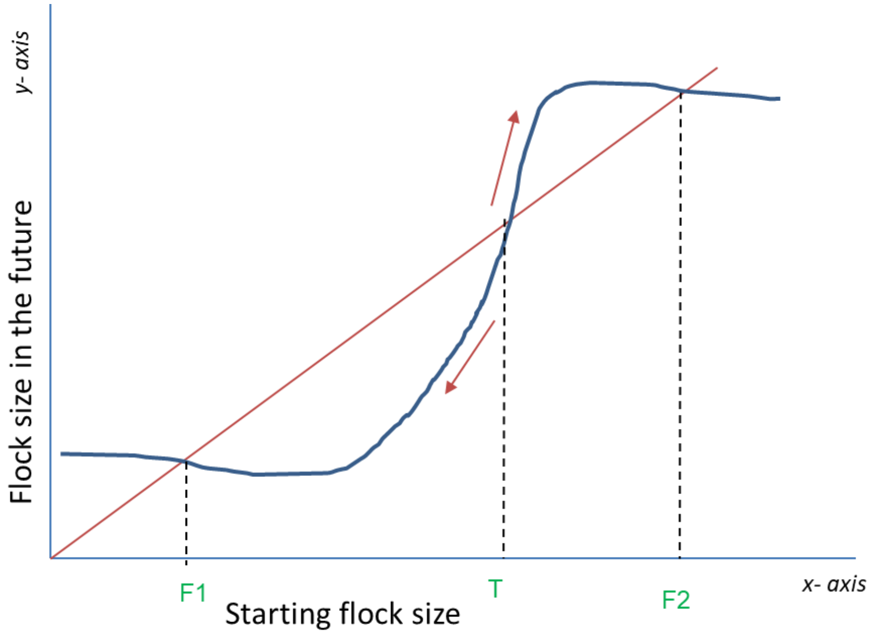
If some poultry farms have certain characteristics such as the breed of birds they raise which might be correlated with their susceptibility to diseases, this might imply that they follow different accumulation regimes with each converging to separate single unique equilibrium. In such a case the poultry industry could exhibit more than one single stable state for different kinds of farms. The equilibrium point at F1* in Figure 2.1 represents farms holding one breed (e.g. local breeds) while F2* represents farms with another breed (e.g. improved breed of chickens). The key assumption is that farms with improved breeds have the immutable characteristic of being less susceptible to diseases which enables them to grow to an equilibrium point that is above that of farms holding local breeds all other things being equal.

Figure 2.1. Example of a single equilibrium



Under the single equilibrium scenario, the driving mechanism is based on diminishing returns to scale. However, in the case of multiple equilibria, the driving mechanism is grounded on locally increasing returns to scale for different investment levels. Multiple equilibria require the existence of at least one unstable equilibrium or threshold (e.g. T in Figure 2.2 below) from which farms tend to move away. Some farms move away from that unstable equilibrium toward a low stable equilibrium level (F1 in Figure 2.2) while others move toward a high stable equilibrium level (such as F2 in Figure 2.2 which is located above the unstable equilibrium. This is possible in poultry production if there are fixed investments (of high costs) associated with certain practices or technologies that can enable higher productivity in raising birds. In such a context, farms who are not able to make such investments are likely to converge to a different equilibrium than those able to make the investments. Such bifurcation becomes a reality in countries such as Nigeria where productive assets such as a generator or a well or borehole are important for poultry production due to poor infrastructure which limits water and electricity access. For example, the importance of electricity for proper water and heat management for chickens makes the need for generators more pertinent. For broilers, proper heat management affects their consumption pattern and growth while for layers, electricity at night is necessary for the birds to eat and digest for increased egg production. Differentiated access to electricity can generate a high fixed cost if the farm needs to invest in a generator in order to keep the light at sunset for the continuous feeding of the birds. This means that only the poultry farms with access to sufficient financial capital either through credit or personal savings are able to make such an investment to take advantage of the increased productivity of the birds and able to successfully manage a much larger flock of birds on the same farm/area. Those unable to make this investment will likely find themselves unable to grow beyond a certain size as just increasing their flock size without adequate electricity will likely see them with increased death of birds and or inefficient egg production forcing their flock size down to some lower equilibrium. If the ability to invest in a generator is not equally accessible across different farmers, this could manifest in multiple equilibria in terms of flock sizes.

Figure 2.2. Example of multiple equilibria



Numerous government and donor programs promote poultry as a low-cost investment possible to reduce poverty and grow incomes (Heise et al., 2015). Evidence of multiple equilibria in the poultry sub-sector can guide the design of such programs (e.g. in terms of initial flock size for startup packages) as well as to form realistic expectations about the potential outcomes possible from such start up packages. They also provide some guidance for private investments on their scale of operation and the idea that there is a minimum number of birds is likely necessary for operating a large-scale farm. It is important to note that this description makes no assumption about the superiority of one equilibrium over another at this point. Further exploration about farms at different equilibria is necessary. Given the nature of poultry production and management, it might be perceived as optimal to maintain a flock size at a low equilibrium (with minimal investments and thus greater ability to withstand shocks). Alternatively, a larger flock size with potential economies of scale (in terms of lower average labor and or energy costs associated with larger sizes) might be necessary to withstand price and other shocks in the industry. This is an empirical question that this study also tries to understand.

2.3.Data and sample

The analysis for this essay uses data collected in 2017 from poultry farmers across two states in Nigeria, Africa's most populous country that has seen a rapid growth in poultry production over the last decade (Sahel Capital, 2015; United Nations, 2017). Within Nigeria two states (Kaduna and Oyo) were selected as major production zones for consumption centers in the northern and southern regions of the country respectively. The sampling strategy used in both locations was purposive and random to allow us to capture heterogeneity over space and size. From the listing of household farms at the local government (LGA) level, the two LGAs with the largest production of chickens were selected.[2] Next, the wards within the selected LGAs were stratified into low, medium and high production areas. Focusing on the medium and high production wards within in each LGA, the study distinguished between household and -household farms. The household farms were categorized into four groups according to the number of birds held: zero to less than or equal to five birds, five to less than or equal to 30 birds, 30 to less than or equal to 100 birds, and more than 150 birds. The final sample for the household farms consists of a random selection of 150 households from each of the four categories mentioned above. For the non-household farms, all the farms identified from the list of the PAN and with the help of community leaders within the different LGAs were included in the sample. The universe of farms that had been identified as no longer in operation for the last five years is also included in the sample. In all, the survey collected information on 1,619 farms in total; 803 farmers in Oyo state and 816 in Kaduna state.

The survey gathered information on poultry farmers and characteristics of their farms as well as their management and marketing practices. The main information used in this essay comes from a recall data of poultry farm sizes from 2006 to 2016 and the first year of operations. One of the

[2] Local government areas are the third tier of government administration in Nigeria, similar to a county in the USA.

limitations of the data we collected is that we do not have many farms with more than 10,000 birds to capture the very large farms. Instead, we focus on poultry farms owning between 100 and 8000 birds. Since they are a good representation of the majority of commercial farms in the country, the analysis provides some valuable insights on the structure of the subsector. This leaves us with a sample of 540 farms; 231 in Oyo and 309 in Kaduna.

2.4.Empirical Strategy

Two main empirical strategies are adopted to explore the dynamics of poultry farm sizes and its likely effect on potential growth in the Nigerian poultry industry. First, we use non-parametric estimation techniques to explore whether the dynamics of poultry farm sizes exhibit convergence or divergence under normal circumstances. We confirm the robustness of these findings to different specifications and cuts of the data using transition matrices and parametric estimations on farm growth over time. Then, conditional on evidence of bifurcated dynamics, we explore the ability of farms at (or headed towards) different equilibria to withstand an industry wide shock here in terms of an input price hike.

To explore whether the poultry sector is characterized by multiple equilibria or a single equilibrium we first use a non-parametric analysis of flock size. This method (widely adopted to explore household income and asset dynamics) has also been applied to the study of herd dynamics among pastoralist communities to test the theoretical hypotheses of convergence, and bifurcation (Barrett et al., 2016; Lybbert et al., 2004; Santos & Barrett, 2016). Following the same empirical strategy as in these studies, we use recall data on average bird holdings from our sample. We combine a flexible non-parametric method (which has the advantage of not imposing a functional form to the data) with behavioral models (which explore the effect of initial flock size on the likelihood of growth and exit) in the subsector. This will be done to validate the non-parametric analysis and assuage some of the empirical challenges associated with the identification of thresholds indicative of bifurcated paths based on non-parametric methods.

When the sample size is too small, one may not detect a threshold due to heteroscedasticity and positively correlated errors around that point (Barrett, 2005). Using data from over 500 farms for a 10 year period helps minimize the small sample concerns.[3] When using non-parametric methods one must adhere to the strong assumption that the dynamics (data-generating process) do not change over time for all the cases in the data (Barrett et al., 2016). To capture periods reflective of the normal data generating process we select subsets of our 10-year period and subject our results to several robustness checks including in and out of sample predictions. Finally we note that a non-parametric estimation approach may not be able to distinguish between single equilibria and multiple equilibria when there are two types of single equilibria (i.e. one for improved breeds and another one for local breeds for instance) (Santos & Barrett, 2016).

The basic specification for the non-parametric estimation is an expression of flock size at time $t + x$ where $1 \leq x \leq 10$ as a function of flock size at time t (define here to be the year 2012) (see equation (1) below).[4] Flock size is defined as the average number of birds stocked per cycle on a farm in one year.

$$F_{i,t+x} = f(F_{i,t}) \quad (1)$$

2.5. Results

2.5.1. Non-Parametric estimations

The main specification used to analyze flock size dynamics considered flock size change between 2012 and 2015. The choice these two years is motivated by two important factors. First, the fact

[3] Lybbert et al (2004) and Santos and Barrettt (2016) use a sample of 833 and 120 pastoralists households, respectively.
[4] $f(F_{i,t})$ is a polynomial function of initial-period flock size.

that we want to capture flock dynamics over a normal period without any system wide shocks in the poultry sector. The second factor is to ensure that the dynamics is explored with the most credible data on flock size that minimizes recall error. In 2008, there was an outbreak of avian influenza whose effect on the poultry market might have affected flock dynamics. Then in 2016, there was a significant maize price shock that significantly affected the profitability of poultry production (FewsNet Data, 2018; Padilla & Liverpool-Tasie, 2019). Thus, we exclude data from 2016 onwards. Though we collected data on flock size from farmers from the time their farm was established and then between 2006 and 2016, it was observed that farmers were most certain about their flock size at time of farm establishment and then between 2012 and 2016. Only 32% (520/1,619) of the farmers had information on their flock sizes for both 2006 and 2016. Thus, we restricted the initial analysis to flock size dynamics between 2012 and 2015 and then extend it to cover other time periods, including from the year of establishment until 2015 (on average a seven-year span) as part of a robustness check.

Following Lybbert et al. (2004) and Santos and Barrett (2016) another important consideration is the unit of analysis which is done for this study at the farm level. In 2016 farms holding up to 8000 birds in our sample have on average one pen and this tends to be the case across different scales of farming operation.[5] In addition, the median size of pens is about 30 square meters. However, the median number of birds per pen varies by farm size. Overall, the small farms (0-100 birds) stock about 25 birds per pen, the medium farms 300 birds and the large farms 2000 birds.[6] However, in both Oyo and Kaduna, the number of birds per pen also increases with the size of the farm. This shows that farms are generally similar in size and number of pens but differ in terms of

[5] Using flock size in 2016, we ranked poultry farms from the smallest to the largest and divided the data into three segments to obtain the terciles presented in table A-1 in the appendix

[6] A poultry farm can have a battery cage system where rows of cages are stack on top of one another or a deep litter system where wood residue is used as litter and the birds are roam freely in the pen.

the number of birds per area. This may be because differences in median flock sizes per pen capture differences in investment abilities to acquire for instance a technology (e.g. generators, independent water supply or investing in vaccine against diseases) that can help sustain a larger flock size (see Table A - 1 in the appendix).

For the non-parametric estimation, we estimate Nadaraya-Watson non-parametric regressions with the Epanechnikov kernel i.e. a kernel-weighted local polynomial smoothing regression (Nadaraya, 1964; Watson, 1964). The kernel estimator provides a linear transformation of the outcome variable (flock size in 2015). This procedure estimates zero-degree local polynomials (i.e. at the mean) of the explanatory variable (flock size in 2012) within a neighborhood given by a bandwidth. It does not make any assumptions about the functional form of the expected value of the outcome variable given an explanatory variable. The bandwidth was selected based on Silverman (2018) rule of thumb bandwidth estimator used by the statistical package Stata. The local polynomial regressions are supplemented with linear regressions of flock size at time t on flock size at time t to generate the 45-degree line. This makes it possible to identify the equilibrium points that depend on how the path of the local polynomial curve relates to the 45-degree line. A stable equilibrium point exists where the curve crosses the 45-degree line from above.

Figure 2.3 provides graphs of the non-parametric analysis.[7] We find evidence of bifurcated flock dynamics in both study states. In Oyo state, we find a low equilibrium (at 550) and a high equilibrium at 6450.[8] As in many developing countries, there are multiple financial market failures in Nigeria including borrowing constraints. Thus, compared to the farms at the low equilibrium,

[7] Because of the large confidence intervals and the desire to use transition matrices and the thresholds to confirm robustness of the results, we have presented the graphs without the confidence intervals. These same graphs with confidence intervals can be found in the Appendix (Figure 2A- 1)

[8] One assumption we are making here is that the farms near the low or high equilibria points are going to remain on that path in the long run because they are stable states

those at the high equilibrium likely have a larger liquidity base they can use to make investments that improve productivity on their farms. They might also enjoy economies of scale since big fixed cost investments can be averaged out across a larger number of birds. We also find an unstable equilibrium or threshold at 1200 birds. This implies that farms with less than 1200 birds are expected to converge to the low equilibrium (at 550) while those with more than 1200 birds are expected to move to the higher equilibrium of about 6450. This is consistent with the idea that there is a minimum investment necessary in the poultry industry in Oyo for a farm to operate at the medium to large scale. Rather than emphasizing the specific number of birds found in the data for the threshold, this result confirms that there exists a minimum investment to grow to a large farm and that those interested in operating at that level should be mindful of its existence.

Owing to the interest demonstrated by some donors (African Farming, 2017) to having women champion poultry production in Nigeria, we also explore how flock dynamics varies by the gender of the farmer (an immutable characteristic). For this, we estimate our flock dynamics separately for male and female owned farms. We find that both male and female-managed farms in Oyo exhibit bifurcated flock dynamics with two stable equilibria and one unstable one. For males, there is a low equilibrium at 750 birds (higher than the combined equilibria of 550) and a high one at 6350 birds. With an unstable equilibrium at 950, male poultry farmers with less than 950 birds are expected to converge to the low equilibrium while those who own more than 950 converge to the high equilibrium of about 6350 birds. The low equilibrium for female farmers in Oyo is the same as for their male colleagues at 750 birds. Interestingly, for female managed-farms in Oyo, the high equilibrium point is higher than for their male counterparts at 7950 birds (vs 6350 for male managed farms). This means that due to gender specific management factors, female farm managers are able to grow a larger poultry farm than males in Oyo, conditional on them making a minimum investment in the sector that puts them on the trajectory towards the high equilibrium. However, our results also indicate that female farmers in Oyo need a larger flock size (than male farmers) to be able to converge to the higher equilibrium in expectation. Compared to the unstable equilibrium of 950 for male farmers, female managed farm aiming to move towards the higher equilibrium need more than 1500 birds. By way of summary, our results indicate that female managed farms face a higher threshold, but they also grow to a higher equilibrium compared to male managed farms. Two key implications emerge from these results. First, the fact that women farmers need a higher minimum investment to grow suggests that they might need a larger flock size to enable them make the necessary investments (or adopt technologies or practices) that allow them to move to a different growth trajectory compared to men. Given that many poultry farmers operate in a credit constrained environment, this suggest that women farm managers face a more challenging environment in terms of financing options compared to men. Second, women farm managers who start above the threshold tend to grow their farms to a high equilibrium that surpasses that of male farm managers. This implies that female farm managers likely have better farm management skills compared to men. This is further supported by the fact that men managed farms are unable to sustain a flock size above the high equilibrium over time.

Poultry farms in Kaduna also exhibit bifurcated flock dynamics with a low equilibrium at 500 birds and a high one at about 3250 birds. While the low equilibrium point is similar to that observed in Oyo, the high equilibrium is significantly lower; about half that of Oyo. This suggests that while small farms in Kaduna tend to be similar to those in Oyo, larger farms in the state tend to be smaller than those in Oyo. It might indicate that Kaduna is a more challenging environment for poultry production compared to Oyo or that the nature of poultry demand and the poultry value chain Kaduna poultry farmers participate in limits the viability of very large farms. We also find that the unstable equilibrium in Kaduna is higher than in Oyo. Farmers in Kaduna with less than 1800 birds are expected to end up in the low equilibrium. This is almost double the unstable equilibrium for male farmers in Oyo and about 1.5 times higher than that for Oyo poultry farms generally. Contrary to Oyo, both male and female managed farms in Kaduna experience a low equilibrium at 500 birds (750 birds for both in Oyo). However, while male farmers face a high equilibrium at 3400 birds, female farmers face a high equilibrium that is lower at 2800 birds. However, we do see that female farmers in Kaduna with more than 1400 birds tend to converge to the high equilibrium point of 2800 birds compared to males, who need to have 2250 to be able to converge to the high equilibrium of 3400 birds. In sum, female managed farms face a lower threshold as well as a lower high equilibrium in terms of flock size compared to male managed farms. This likely indicates that females and male poultry farmers in Kaduna face significantly different opportunities in the industry and likely have gender specific experience in their access to inputs and markets. There is a clear contrast in the gender dynamics between Kaduna and Oyo where female managed farms face a higher threshold and grow to a higher high equilibrium compared to male managed farms. We also find that female farmers in Kaduna are not able to maintain a flock of birds above the high equilibrium point of 2800. All the farms which held more than 2800 birds in 2012 are expected to converge back to that same spot in 2015. This indicates that male farm managers in Kaduna might have better farm management practices compared to their female counterparts; and they might also have access to better financing options given the higher threshold required to grow. Table 2.1 presents a summary of the findings that emerges from the non-parametric estimations.

Table 2.1. Summary of equilibria and threshold points by state and gender

State	Key results from the non-parametric estimations
Oyo	• Low equilibrium is the same for male and female farms • High equilibrium for female higher than male farms • Threshold for female is higher than male farms
Kaduna	• Low equilibrium is the same for male and female • High equilibrium for male is higher than female farms • Threshold for male is higher than female farms • Female farms decline to High equilibrium
Oyo vs Kaduna	• Low equilibrium is similar • High equilibrium in Oyo higher than Kaduna • Threshold is higher in Kaduna than Oyo

Figure 2.3. Non-parametric estimates of flock size in 2012 on flock size in 2015 for Oyo and Kaduna

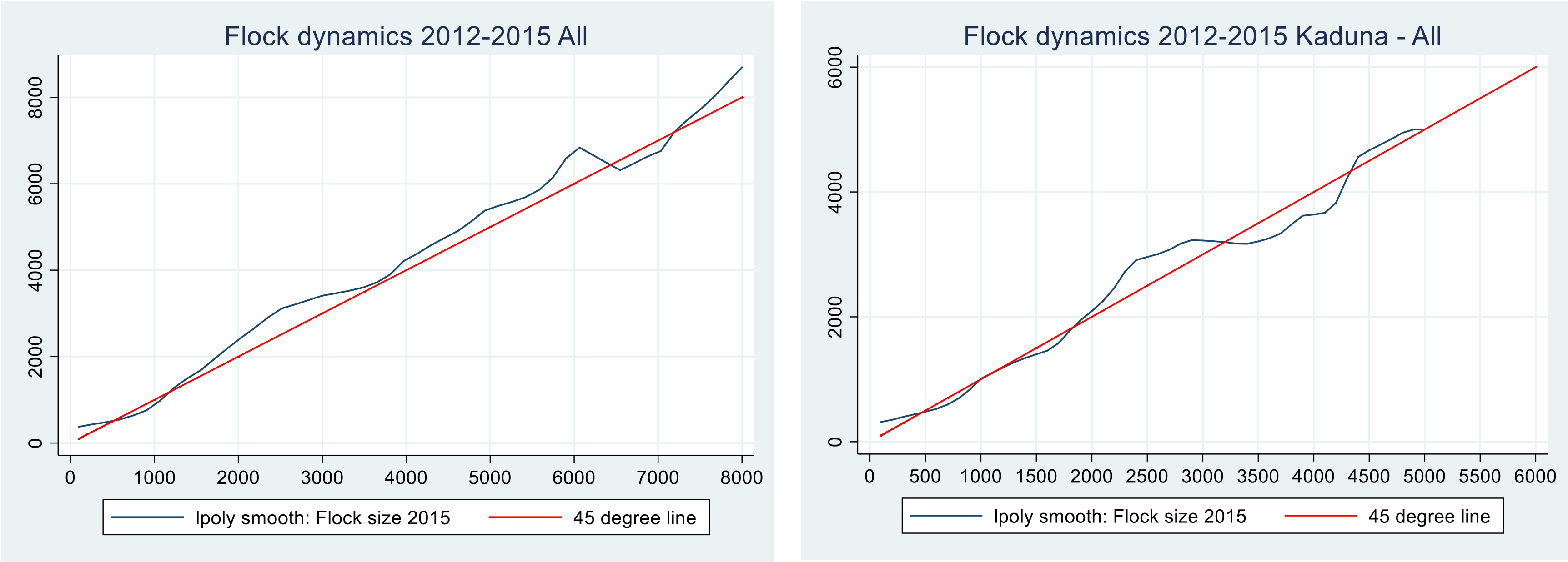
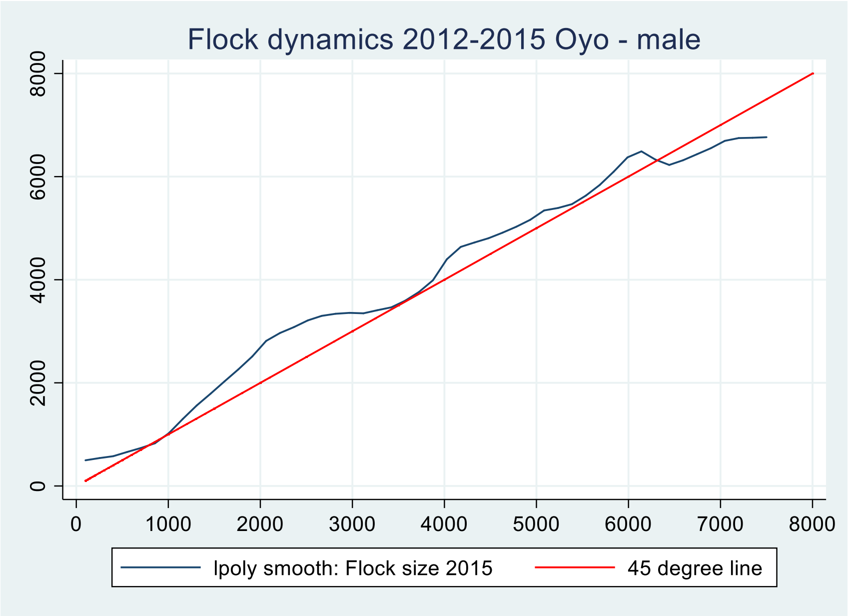


Figure 2.3 (cont'd)



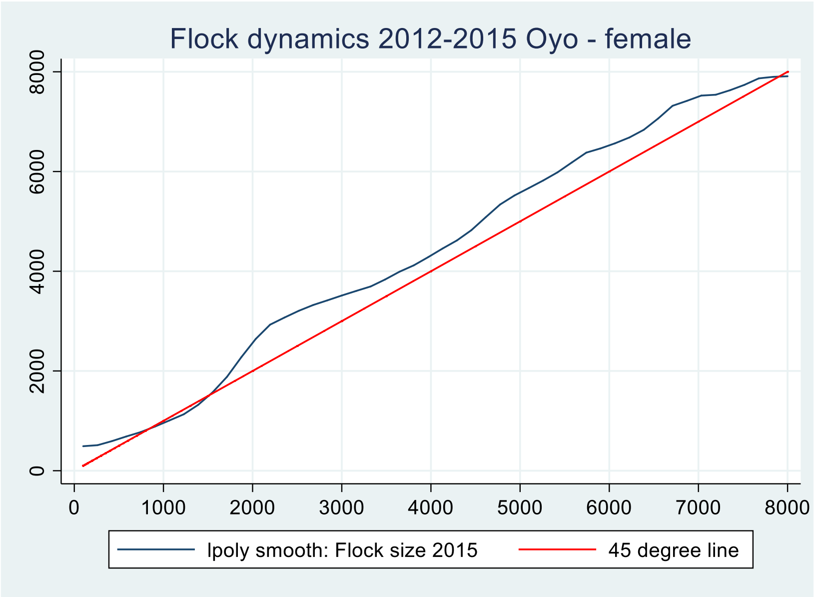
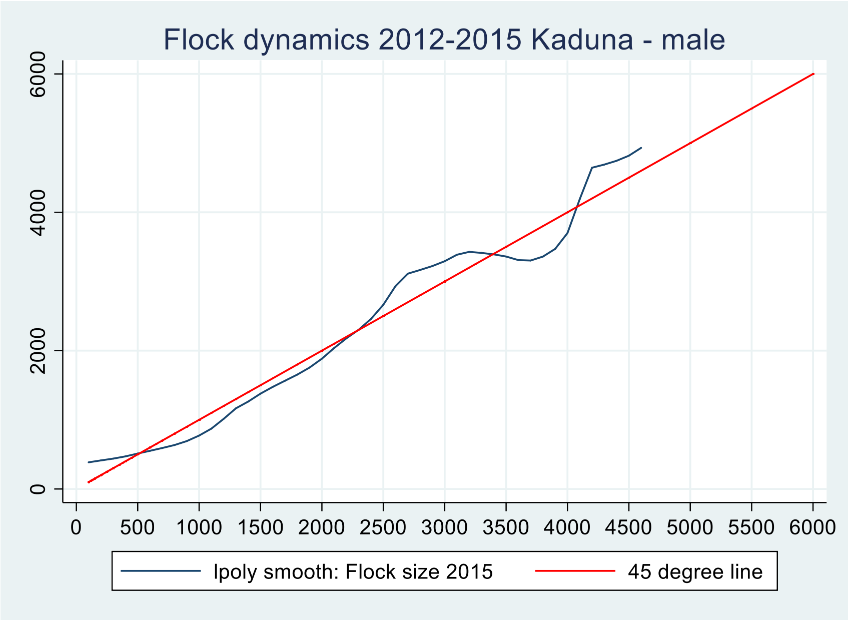
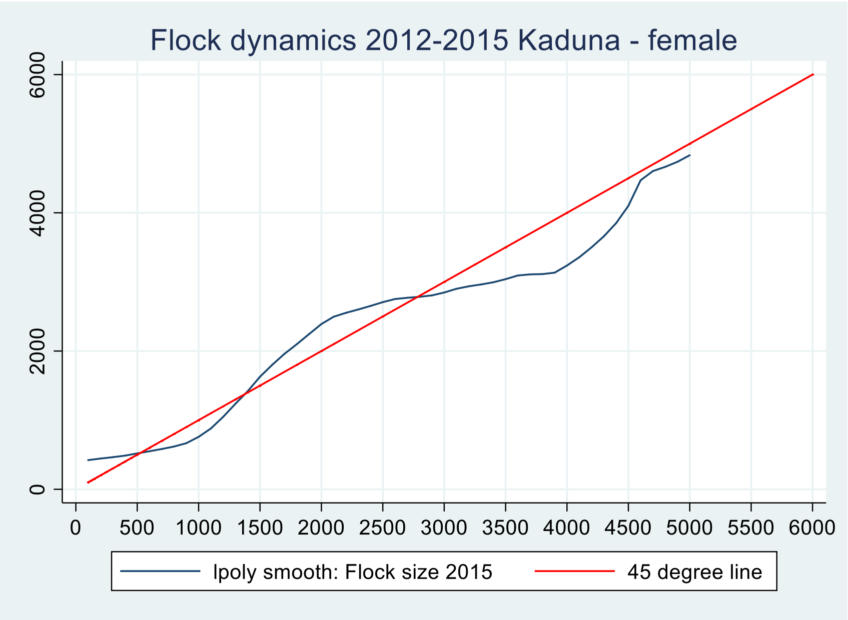


Figure 2.3 (cont'd)





2.5.1.1. In and out of sample analysis using Transition matrices

Next, we use transition matrices applied in and out of the main study sample to validate the non-parametric estimates. The non-parametric estimations suggest that there are two stable equilibria in terms of flock size in the study states. Farms around these two stable points in each state are expected to continue to operate around that level. However, the presence of multiple stable equilibria implies that there also exists one threshold point which distinguishes farms which are expected to move towards the low equilibrium from those which are expected to move towards the high equilibrium. Transition matrices can be used to capture for the same farm, the group it belongs to (based on the number of birds it stocks at time t) relative to the equilibrium points and unstable threshold) and the group it belongs to at a future period $t + x$, where x is the number of years since period t. The movement (or lack of movement) across groups over time can be used to confirm the predictions of the non-parametric estimates. First, we use the stable equilibrium points in the non-parametric estimations to categorize farms in both states into low and high equilibrium groups.[9] Then we categorize farms based on their location (at initial period) relative to the unstable equilibria; i.e. their long term expected equilibrium. For both categorizations, we compare farms actual movements across groups over time (using the transition matrices) to their expected movements as predicted by the non-parametric results. We apply this in sample (the time period used for the analysis) and then out of sample (out of the time period used in the main estimation: 2012-2015) as a robustness check to confirm the validity of the model predictions. We also consider multiple limits for the equilibrium points to account for the relatively large confidence intervals around the smoothed curves of the non-parametric estimates.

[9] i.e. the point where the curve depicting the changes in average flock sizes over time cuts the 45-degree line from above)

2.5.1.2. Transition matrices for poultry farms based on the stable equilibria

For each state, we group farms based on the stable equilibria points identified in the non-parametric estimates. For Oyo, we have stable equilibria at 550 birds and 6450 birds. Thus we generate two groups of farms based on flock size in 2012 relative to the equilibria. Group one includes farms with 0- 550 birds that are expected to be moving towards that equilibria over time based on the non-parametric estimates. Group two includes those farms with more than 6450 birds; operating above the high equilibrium and thus expected to remain at or around 6450 birds in the long run. Thus, farms in both equilibrium groups are expected to remain in those groups over time if the underlying dynamics of the industry were appropriately captured in the non-parametric estimates. Transition matrices confirm the non-parametric estimates if farms in group 1 and 2 tend not to move to other groups over time. The in-sample transition probabilities should be consistent and close to the non-parametric estimates that determined them. However, their validity of the transition probabilities "out of sample" confirms the validity of the non-parametric analysis in predicting the flock dynamics in the study states. Applying the same principle in Kaduna (where the two stable equilibria are 500 and 3250), group 1 includes farms with up to 500 birds, group 2 includes farms with more than 3250 birds. In both states, we conduct the transition matrix analysis for farms generally and then for male and female managed farms separately.

The transition tables confirm that farms that start with a small flock size (less than 550 birds for Oyo and less than 500 birds for Kaduna), tend to be confined to that group with limited growth (*Table 2.2*). In Oyo as expected, those in the lowest group tend to remain there. The probability of remaining in that group is eighty-five percent (85% after three years and 93% since year started). It should also be noted that of the 15% that moved, about 60% are likely experiencing a stochastic growth pattern and are expected to fall back to or near the low equilibrium in the long run.[10] In Kaduna, this probability of remaining below the low equilibrium point is 90% between 2012 and 2015 and about 83% between the year started and 2015. These farms face a 10% probability of moving. For the farms in the higher equilibrium, the probability of moving below this state is about 30% in both Oyo and Kaduna, though 50% in Oyo (100% in Kaduna) of those who fell still remain above the unstable threshold and are thus expected to converge back to the high equilibrium. This indicates that the farms that start with a relatively large number of birds are between 85% and 100% likely to maintain or increase their flock size over time in the two study states. Therefore, the transition matrices confirm that there is limited movement around these two main stable equilibrium states. Farms which start small remain small while those with a larger number of birds tend to continue to operate at this higher flock size over time.

Movements away from the equilibrium groups, analyzed by the gender of the farm manager, follows a similar pattern. In Oyo, farms managed by both male and female farmers have a high probability of remaining in the lowest group but with significant differences in that probability. Male-managed farms that start in the lowest group in 2012 have an 85% chance of remaining in that group in 2015. In contrast, female-managed farms face a higher probability (95%) of remaining in that group. This indicates a higher rate of persistence at the low-level equilibria for female managers compared to their male counterparts in Oyo. In Kaduna, male-managed farms have an 89% chance of remaining in the lowest group three years later compared to 93% for female-managed farms. For the farms in the higher equilibrium group, the probability of moving back away from the higher equilibrium is 66% for male managed farms in Oyo (0% in Kaduna)

[10] Among the farms which move, those above the low equilibrium but below the unstable equilibrium or threshold are expected to converge back to the low equilibrium while those above the threshold are expected to end up at or around the high equilibrium. These movements are further analyzed in the next section.

and 0% for female managed farms (50% in Kaduna).[11] Again it should be noted that of the 34% of male farms that fell below the high equilibrium, the majority of them remained above the unstable equilibrium (100%) and are thus expected to converge back to the higher equilibrium in the long run. However, the gender disaggregated analysis clearly shows that the gender of the farm manager matters differently in both states for the farms located near the high equilibrium. In Oyo, female-managed farms around the high equilibrium are much more likely to maintain that status compared to Kaduna.

2.5.1.2.1. Out of sample predictions

For the out of sample predictions we consider the flock dynamics for the period between the year a farm was established and 2015.[12] Here as well, we find strong confirmation of the predictions of the non-parametric estimates in terms of the limited movement of farms in the two groups. In Oyo, those in the lowest group have a 93% (83% for Kaduna) chance of remaining in the lowest group from the time they started their farm (slightly higher than in the in-sample prediction). This result is maintained for male and female managed farms where the probability of remaining at that low level of flock size is 92% (85% for Kaduna) for male farmers and 95 % (75% for Kaduna) for female farmers over that period. Thus, in Kaduna female managed farms have a lower probability of staying near the low equilibrium over longer time periods (i.e. they have a higher probability of moving to the high equilibrium). Similarly, in both Oyo and Kaduna we find that 60% and 70% of the farms that are above the high equilibrium remain in that group between when they started and 2015, respectively. Again, this holds for both female and male managed farms as the majority of farms which started near the high equilibrium group persists in that state.

[11] Given that we have a small sample of farms for the high equilibrium group, the patterns of movement observed are only indicative.
[12] On average in our sample this is about 6.2 years (6.4 years in Oyo and 6.0 in Kaduna).

Table 2.2. Flock size transition matrices using the stable equilibria for the cut off points

	Oyo		Kaduna	
	Stayed	Moved	Stayed	Moved
Group 1 (low equilibrium)	61 (85%)	11 (15%)	141 (90%)	16 (10%)
Group 2 (High equilibrium)	4 (66%)	2 (33%)	5 (71%)	2 (29%)
	Male			
Group 1 (low equilibrium)	35 (85%)	6 (15%)	103 (89%)	13 (11%)
Group 2 (High equilibrium)	1 (33%)	2 (66%)	3 (100%)	0 (0%)
	Female			
Group 1 (low equilibrium)	37 (95%)	2 (5%)	38 (93%)	3 (7%)
Group 2 (High equilibrium)	3 (100%)	0 (0%)	3 (50%)	3 (50%)

2.5.1.3.Accounting for large confidence intervals

Because of the large confidence interval for some portion of the non-parametric estimations, the possible range for the cut-off points for the different equilibria were quite large. Thus, we also generate transitional tables which use as cutoff points the points where the lower confidence curve cuts the 45-degree line. In Oyo the stable equilibria are at around 500 and 3200 birds while in Kaduna they are found at 500 birds and 2400 birds. In comparison, when using the upper confidence interval to determine the cutoff points, we only have one equilibrium point in both Oyo and Kaduna at 500 birds.

These transition tables further support that farms that start with a small flock size (less than 550 birds in Oyo and 500 Kaduna), remain near the stable low equilibrium. In Oyo, those in the lowest categorization have an 85% chance of remaining in that zone three years later. In Kaduna this probability is 90% between 2012 and 2015. At the higher equilibrium levels, the probability of remaining in that state is high: 88% for the farms in Oyo and 87% for those in Kaduna. For male and female managed farms in Oyo, the probability of remaining near the low equilibrium between

2012 and 2015 is about 85%. On average, close to 90% of the male and female managed farms in Kaduna remain in the lowest group between 2012 and 2015. As before, it remains that farms at the high equilibrium level are relatively safe from falling towards the lower equilibrium level.

Table 2.3. Flock size transition matrices using low confidence interval for the cut off points

	Oyo		Kaduna	
	Stayed	Moved	Stayed	Moved
Group 1 (low equilibrium)	60 (85%)	11 (15%)	141 (90%)	16 (10%)
Group 2 (High equilibrium)	42 (88%)	6 (12%)	27 (87%)	4 (13%)
	Male			
Group 1 (low equilibrium)	31 (86%)	5 (14%)	103 (89%)	13 (11%)
Group 2 (High equilibrium)	2 (50%)	2 (50%)	3 (100%)	0 (0%)
	Female			
Group 1 (low equilibrium)	33 (87%)	5 (13%)	38 (93%)	3 (7%)
Group 2 (High equilibrium)	26 (93%)	2 (7%)	12 (92%)	1 (8%)

2.5.1.4.Transition matrices for poultry farms based on unstable equilibria (thresholds)

Next, we consider transition matrices of farms using a categorization based on their location relative to the unstable equilibrium (threshold). We confirm the validity of the non-parametric results and its predicted flock dynamics over time. We do this by checking how many farms that are initially below the threshold (and thus expected to converge to the low equilibrium flock size) actually converge or at least move towards the low equilibrium in the future period; and how many farms above the threshold (and are expected to grow towards the high equilibrium) actually move towards the high equilibrium as expected. Again, we conduct this analysis in and out of the sample period to confirm the validity of the predictions.

For each state, we generate three groups using the unstable equilibrium as a reference point.[13] The first group includes those with birds above the low equilibrium but below the threshold, the second group includes those with birds above the threshold but below the high equilibrium and the last group include those with birds above the high equilibrium. In Oyo, the unstable equilibrium is at about 1,200 birds for all farms and 950 and 1500 birds for male and female-managed farms respectively. In Kaduna they are at about 1800 for all the farms and 2250 and 1400 birds for male and female managed farms respectively.

The results in Table 2.4 confirm the predictions of the non-parametric estimates. Farms that start below the threshold tend to remain below the threshold in the future while those that start above the threshold are more likely to move towards the higher stable equilibria. None of the farms that start below the threshold end up above the high equilibrium point. In Oyo, 93 percent of the farms that start below the threshold remain below the threshold and 83 percent of the farms starting in 2012 with a flock size above the threshold but below the high equilibrium point of 6450 birds grow towards the high equilibrium three years later in 2015. The same is apparent in Kaduna where 91 percent of the farms starting below the threshold of 1800 birds remain at that level while 80% of those starting with more than 1800 birds but less than 3250 birds maintain their growth trajectory (17% end up above the high equilibrium and only 2% decline). The same observations hold for female and male managed farms in both states.

[13] For both Oyo and Kaduna we have two threshold but we omit the second threshold in this analysis because 1) there is no stable equilibrium after that point, and 2) it captures the dynamics for very large farms which are few in our data.

Table 2.4. Flock dynamics above and below unstable equilibrium

		Oyo	
2012		2015	
	below T=1200	above T=1200 but below HE	above HE
below T=1200	91	7	
above T=1200 but below HE	8	90	10
above HE	1	1	4

		Male	
	below T=950	above T=950 but below HE	above HE
below T=950	38	5	
above T=950 but below HE	4	71	7
above HE		2	1

		Female	
	below T=1500	above T=1500 but below HE	above HE
below T=1500	40	1	
above T=1500 but below HE	2	34	2
above HE			3

		Kaduna	
2012		2015	
	below T=1800	above T=1800 but below HE	above HE
below T=1800	210	20	1
above T=1800 but below HE	1	33	7
above HE		2	5

		Male	
	below T=2250	above T=2250 but below HE	above HE
below T=2250	177	6	
above T=2250 but below HE	3	9	4
above HE			

		Female	
	below T=1400	above T=1400 but below HE	above HE
below T=1400	55	1	
above T=1400 but below HE	0	9	6
above HE	34	9	9

Note: T is threshold or unstable equilibrium, HE means high equilibrium.

2.5.1.4.1. Out of sample period predictions

To confidently assert that the dynamics we captured are not spurious and that our selected time period adequately captures the typical situation in the poultry industry, the same dynamics should be evident regardless of the time period considered as long as we have not included a period during with the industry experienced some general shock. Thus, we also explored flock size changes for farms below and above the same unstable equilibrium points (thresholds) from the main analysis for three normal periods: 2010 and 2015, 2006 and 2011 and between the year the farm was established and 2015. We confirm that our results are robust to the time period selected. In both Oyo and Kaduna, 90% of the farms that start below the threshold in 2010 end up below the threshold in 2015. This percentage is still high at 85% when they have a flock size below the threshold in 2006 compared to 2011. Between year started and 2015, 85% of the farms in Oyo which start below the threshold end up below the threshold while in Kaduna it is 90%. The trend in male and female managed farms are similar to what we observe when both types of farms are pooled. These results confirm that it is unlikely for farms which start below the threshold to grow above the threshold in both states and regardless of the gender of the managers of the farms irrespective of the years selected for the analysis.

Similarly, for those above the unstable equilibrium but below the high equilibrium, the patterns of movements suggest that only a small percentage fall below the threshold. Among the farms that start above the threshold but below the high equilibrium in 2010, about 10% collapse below the threshold in Oyo (0% in Kaduna) in 2015. About 80% of these farms remain in their starting category in both states. The gender disaggregation shows that the movements of male managed farms in both states shows that 10% fall below the threshold between 2010 and 2015. None of the female farm managers which started above the threshold but below the high equilibrium decline below the threshold in both states. The direction of the movements across groups between 2006 and 2011 are somewhat similar. Close to 10% of the farms in Oyo and Kaduna which started above the threshold but below the high equilibrium decline below the threshold. In Oyo 82 % of the farms remain where they started (above threshold but below high equilibrium) compared to about 65% in Kaduna. Among the male managed farms 10% of those in Oyo (22 % in Kaduna) decline below the threshold while 40% (55% in Kaduna) do not move. As with the 2010-2015 sample, none of the female managed farms decline below the threshold.

Lastly, a look at the movements of the farms which started above the threshold but below the high equilibrium from when they started to 2015 shows that about 7% of those in Oyo (2% in Kaduna) fell below the threshold. In contrast, close to 90% of them remained above the threshold in both Oyo and Kaduna. These farms either grew or are expected to grow to the high equilibrium in the future. In Oyo, about 7% of both male and female managed farms which started above the threshold fell below it while 90% remained above the threshold. The patterns in Kaduna based on the gender of the farm manager depict a slightly different story. Three percent of the male managed farms which started above the threshold fall below the threshold compared to none of the female managed farms. Overall these patterns confirm that farms which start above the threshold rarely fall below the threshold in the next period.

2.5.2. Does the initial number of birds predict farms' ability to grow over time?

We also validate the non-parametric results (and its predictions) using parametric estimations. The non-parametric results provided threshold points which can be used to infer farms' expected growth pattern and the transition matrices confirmed the predictive power of these results. Farms below the low equilibrium are expected to move towards the low equilibrium which is a stable point. Farms above the low equilibrium but below the threshold are expected to move backwards towards the low equilibrium point as can be seen by the gradient of the curve. On the other hand, farms above the threshold and below the high equilibrium are on an upward sloping portion of the curve where the gradient indicates the direction of movement is up towards the stable high equilibrium. Farms above the high equilibrium point are expected to either not move or decline to that stable point depending on their proximity to the equilibrium point. Thus, farms can be categorized into each of these four groups based on their initial flock size. Since both the low and high equilibrium are stable points, farms around these points are not expected to move a lot. Thus, of the four groups identified above, we expect that growth is more likely for farms above the threshold and below the high equilibrium compared to the farms in the other three groups. This can be tested with the following hypothesis:

Ho: Farms above the unstable equilibrium (threshold) but below the high equilibrium grow faster than other farms

Ha: Farms above the unstable equilibrium(threshold) but below the high equilibrium do not grow faster than other farms

To test this hypothesis, we estimate the effect of being in any of the four groups on the probability of growth. We estimate the following model:

$$G_{it} = \alpha_0 + \beta_0 D_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 Experience + \beta_5 Distance \qquad (2)$$

$$+ \beta_6 Male + \sum_{i=1}^{10} \gamma_i \, LGA + \varepsilon_{it}$$

where G_{it} is a continuous variable that represents change in flock size between two periods. Additionally, we use 2012 flock size to categorize the farms into the four groups. Since there are very few observations around the equilibrium points, we use a 50-bird bandwidth (i.e. 50 birds less than each equilibrium point) to establish the cutoff points for the groups.[14] Each of these dummy variables takes the value of one if the number of birds on the farms is within the range considered, and zero otherwise. More specifically, D_0 equals 1 if flock size is between 100 and low equilibrium minus 50, D_1 equals to 1 if flock size is above high equilibrium minus 50, D_2 equals to 1 if your flock size is between threshold and high equilibrium minus 50, and D_3 equals to 1 if flock size is between low equilibrium minus 50 and threshold. The sign of the coefficient of these dummy variables tells us whether farms are more likely to grow or decline relative to D_0. We also include some additional control variables expected to affect poultry farm management and hence growth but largely exogenous. $Male$ specifies that the farm manager is a male. This variable is exogeneous and we include it because the non-parametric estimations demonstrated that there are important gendered differences. $Experience$ is the number of years the manager has been active in poultry farming. This variable likely captures the ability of farm managers to implement best practices based on their experience. From the non-parametric estimation, we found that there are clear regional differences. As such, the farm location is captured by LGA dummies. Lastly, the ability of a poultry farm to access inputs or distribute the products from the farm to different markets is linked to proximity to road. Thus, we include $Distance$ which reflects distance to the nearest highway.

Equation (2) is estimated using robust ordinary least squares. *Table 2.5* shows the effect of being in any of the 4 groups on change in flock size between 2012-2015. For robustness, we also estimate the same regression for years out of the sample period used for the non-parametric estimations; specifically, the growth in flock size from the year the farm started to 2015. This out of sample estimations are important to confirm or refute the findings from the main estimation.

[14] For additional robustness, we also estimate the model using a cutoff of 20, 10, and 5 birds below the low and high equilibrium. The results remain unchanged.

Column (1) presents the results for the main period 2012-2015. Consistent with the non-parametric estimation predictions, farms between the unstable equilibrium (threshold) and the high equilibrium experience a positive change in flock size of about 360 birds compared to those below the low equilibrium. The results are maintained (at 10%) for the out of sample period (from start of business till 2015) as show in column (2). Other factors that explain growth in flock size are the farms location and the experience of the farm manager. Experienced farm managers are more likely to be aware of good practices. Lastly, the location of the farm has both an enabling and detrimental effect. Compared to the South west, the farms in the LGAs of Kaduna North, Egbeda, Lagelu and Ona Ara experience a reduction in flock size over time. On the other hand, farms in Akinleye and Oluyole experience a positive change in flock size.

Table 2.5. Effect of initial flock size on the change in flock size

	(1) Change in size between 2012 and 2015	(2) Change in size between start and 2015
	Coefficient	
Dummy equal to 1 if initial flock size is above high equilibrium minus 50	95.079	726.068
	(276.970)	(1,388.152)
Dummy equal to 1 if initial flock size is between threshold and high equilibrium minus 50	359.541***	1,402.749*
	(132.624)	(715.857)
Dummy equal to 1 if initial flock size is between low equilibrium minus 50 and threshold	-5.544	335.348
	(129.023)	(749.940)
Base - Dummy equal 1 if initial flock size is between 100 and low equilibrium minus		
Male (0/1)	-122.418	-730.430
	(109.650)	(625.137)
Number of years in poultry farming	-1.900	101.825**
	(8.086)	(43.659)
Igabi	89.482	-250.485

Table 2.5 (cont'd)

	(138.914)	(809.035)
Kaduna North	1,389.665***	-456.551
	(485.841)	(2,488.697)
Kaduna South	530.000	2,308.603
	(1,151.674)	(6,736.987)
Akinleye	-487.441*	-270.387
	(293.867)	(1,288.933)
Egbeda	312.551*	-157.066
	(176.273)	(1,056.479)
Ido	-147.987	-756.146
	(226.643)	(1,289.450)
Lagelu	-72.696	2,665.591***
	(188.425)	(1,014.895)
Oluyole	94.166	1,199.712
	(326.289)	(1,802.785)
Ona Ara	1,136.794***	1,628.867
	(287.040)	(1,448.434)
South west (base)		
Distance to nearest highway (Km)	0.156	-2.864
	(1.821)	(7.912)
Constant	105.407	-282.608
	(161.319)	(878.649)
Observations	527	573
R-squared	0.095	0.044

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

2.5.2.1.Robustness check

To further confirm the reliability of these results we estimate the same model using a different categorization. Instead of the four groups, we use the predicted long-term equilibrium status of the farm based on the position of the starting flock size relative to the threshold. In this case all farms below the threshold are considered to have a long term expected flock size at the low equilibrium and all those above the threshold are considered to have an expected flock size at the high equilibrium. The results in Table 2.6 also confirm that farms with flock size above the threshold experience a positive change in flock size relative to farms with flock size below the threshold. Farms with an expected long-term high equilibrium (i.e. farms with flock size above the threshold) exhibit a positive change in size of about 330 birds (1,140 birds between the year started and 2015) compared to farms with an expected long-term low equilibrium at 1% (10 %) significance. The results further confirm that compared to the South west, the LGAs of Kaduna North, Lagelu, Egbeda, and Ona Ara are not favorable to positive changes in flock size but Oluyole is.

Table 2.6. Effect of long-term equilibrium status based on the change in flock size

	(1) Change in size between 2012 and 2015	(2) Change in size between start and 2015
	Coefficient	
Dummy equal 1 if your long term expected equilibrium is high	328.392***	1,137.959*
	(119.094)	(625.259)
Base - Dummy equal 1 if your long term expected equilibrium is low	-	-
Male (0/1)	-116.532	-695.773
	(109.109)	(621.230)
Number of years in poultry farming	-2.112	102.824**
	(8.064)	(43.452)
Igabi	90.919	-202.383
	(138.189)	(801.390)
Kaduna North	1,414.907***	-418.283
	(483.595)	(2,467.835)
Kaduna South	529.053	2,233.621
	(1,146.891)	(6,726.397)
Akinleye	-478.549	-161.302
	(292.991)	(1,274.985)
Egbeda	324.587*	-52.954
	(175.549)	(1,041.800)
Ido	-149.174	-654.840
	(226.083)	(1,280.048)
Lagelu	-61.342	2,702.774***
	(187.511)	(1,007.515)

Table 2.6 (cont'd)

Oluyole	112.428	1,303.149
	(324.840)	(1,792.285)
Ona Ara	1,163.751***	1,747.657
	(284.907)	(1,434.428)
South west (base)		
Distance to nearest highway (Km)	0.307	-2.500
	(1.811)	(7.883)
Constant	95.618	-246.645
	(158.212)	(860.918)
Observations	527	573
R-squared	0.094	0.043

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

2.5.3. Does the initial number of birds predict farms' ability to hold a flock size above the threshold?

Still in the spirit of confirming the reliability of the non-parametric results we examine the effect of initial flock size on growth using a different definition of growth. Earlier, we defined growth as change in flock size over two periods. Now, we define growth as the ability of a farm to attain a flock size above the threshold at the end of the period, 2015. Based on the non-parametric results and the existence of multiple equilibria, we expect that farms above the threshold at the initial period (2012 or start of business) are more likely to have a flock size above the threshold in 2015. On the other hand, we expect that farms above the low equilibrium and below the threshold at the initial period will have a lower probability of attaining a flock size above the threshold in 2015. We test these two hypotheses by estimating the same model as above with an outcome variable that defines growth as holding a flock size above the threshold in 2015.

The results in Table 2.7 suggest that farms which start with a flock size above the threshold are more likely to attain a flock size above the threshold in the future. More specifically, farms which started with a flock size above the threshold and below the high equilibrium in 2012 are 50 percentage points more likely of attaining a flock size above the threshold in 2015 compared to those which started below the low equilibrium. Farms between the low equilibrium and below the threshold are only 15 percentage point more likely to maintain a flock size above the threshold compared to those below the low equilibrium. The results for the out of sample in column (2) support the same with probabilities close to what we observe for 2012-2015. This confirms that the threshold value obtained in the non-parametric estimations is valid and is instrumental in defining flock dynamics in the poultry sub-sector.

Table 2.7. Effect of initial flock size on the probability of attaining a flock size above the threshold in the future

	(1) Flock size in 2015 above threshold (2012-2015)	(2) Flock size in 2015 above threshold (start-2015)
	Marginal effects	
Dummy equal to 1 if initial flock size is above high equilibrium minus 50	0.526***	-
	(0.078)	
Dummy equal to 1 if initial flock size is between threshold and high equilibrium minus 50	0.500***	0.572***
	(0.030)	(0.024)
Dummy equal to 1 if initial flock size is between low equilibrium minus 50 and threshold	0.151***	0.128***
	(0.030)	(0.031)
Base - Dummy equal 1 if initial flock size is between 100 and low equilibrium minus 50		
Male (0/1)	-0.035	0.005

Table 2.7 (cont'd)

	(0.026)	(0.030)
Number of years in poultry farming	-0.002	-0.001
	(0.002)	(0.002)
Igabi	0.025	-0.014
	(0.031)	(0.039)
Kaduna North	0.005	0.126
	(0.102)	(0.133)
Kaduna South	-	-
Akinleye	-0.063	-0.082
	(0.055)	(0.054)
Egbeda	0.085*	0.046
	(0.051)	(0.056)
Ido	-0.053	-0.059
	(0.042)	(0.060)
Lagelu	-0.046	-0.011
	(0.042)	(0.052)
Oluyole	0.033	0.095
	(0.068)	(0.098)
Ona Ara	-0.073	-0.014
	(0.053)	(0.073)
South west (base)		
Distance to nearest highway (Km)	-0.000	0.000
	(0.000)	(0.000)
Observations	537	587

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

2.5.4. Does expected long term equilibrium status predict the ability of a poultry farm to withstand a generalized shock in the poultry sub-sector?

Conditional on the consistent evidence in favor of multiple equilibria in terms of flock size in the Nigerian poultry industry, we explore the ability of farms to withstand an industry-wide shocks. More specifically we explore the likelihood of exit upon an input price shock in the industry. As mentioned earlier, the non-parametric results tell us about the dynamics of the sub-sector and indicates that there are multiple equilibria in terms of flock sizes. However, it does not really tell us much about the viability of farms at the different equilibria and if one is more amenable or capable to withstand shocks. On one hand smaller farms might be more resilient to shocks if their size is smaller because the farm managers stand to incur lower financial losses. On the other hand, large farms might be more able to withstand the high feed costs because they have access to a diversity of responses including requesting a credit line for feed or the ability to negotiate feed prices, diversify feed sources and or more opportunities to substitute other inputs such as labor. Both scenarios are plausible. To test this hypothesis, we identify the expected long-term equilibrium of farms based on their position below or above the threshold. Farms holding a flock size below the unstable equilibria are categorized have a long term expected flock size at the low equilibrium and those above the threshold have a long term expected flock size at the high equilibrium. Since smaller farms in Nigeria tend to have fewer response options (such as access to credit), we hypothesize that farms with a long-term expected low equilibrium (below the threshold of 1,200 bird in Oyo and 1,800 birds in Kaduna) are more likely to exit the sub-sector following a shock compared to farms with a long term expected high equilibrium (above the threshold). In other words, farms with a long-term expected low equilibrium have a better adaptative capacity. This can be tested with the following hypothesis:

Ho: Farms with a long term expected high equilibrium are less likely to exit than other farms

Ha: Farms with a long term expected high equilibrium are not less likely to exit than other farms

Here, it is the presence of multiple equilibria that enables us to test whether there is a difference in a farm's ability to withstand a shock based on its long-term expected equilibrium status. We capitalize on the fact that there was a significant shock in terms of feed prices in 2016/2017 to test if farms at the different equilibria exhibit different abilities to withstands shocks. During that period, many poultry farms in Nigeria were said to have shut down (Fisayo et al., 2016; Onehi et al., 2016). However, which kinds of farms were more likely to exit is not obvious.

Thus, we empirically test for any differences in the probability of a firm exiting during the shock period (2016-2017) depending on a farm's long-term expected equilibrium status as determined by the non-parametric estimations. In this regard, farms that were lower than the unstable equilibrium had a long-term expected flock size at the low equilibrium and those above the threshold had a long term expected flock size at the high equilibrium. To empirically explore the effect of long-term equilibrium status on the probability of exit conditional on a vector of additional farmer and farm controls, we estimate the following model:

$$E_{it} = \alpha_0 + \beta_0 T_0 + \beta_1 T_1 + \beta_2 Experience + \beta_3 Distance + \beta_4 Male + \beta_5 Water \quad (3)$$
$$+ \beta_6 Generator + \sum_{i=1}^{10} \gamma_i \, LGA + \varepsilon_{it}$$

E_{it} (exit of firm i in period t) is an indicator variable that takes a value of one if the farm exited in 2016-2017, and zero otherwise. T_0 and T_1 are dummy variable that identifies the expected long-term equilibrium status of a farm based on flock size in 2012. T_0 takes the value of one if the expected long-term equilibrium of a particular farm is low (i.e. flock size in 2012 is below the threshold), and zero otherwise. T_1 takes the value of one if the expected long-term equilibrium of the farm is high (i.e. flock size in 2012 is above the threshold). The importance of long-term equilibrium status in determining a farm's ability to withstand a shock is inferred from the sign of the coefficient of T_1 relative to T_0 which is chosen as the base. The other variables and the rational for including them are defined as before but now include the ownership of key assets. Water and access to electricity are essential assets for poultry farms. The majority of farms in our data own a borehole or an open-well to facilitate access to water because it is essential to a good feed conversion ratio. Thus, $Water$ takes the value of one if the farm has a borehole or a well. Nigeria has a rampant electricity problem and many businesses rely on the use of generators to meet their needs (Heise et al., 2015). Poultry farms which one a generator can for instance feed their birds at night when it is cooler to improve feed conversion ratio (Sanou et al., 2019). Therefore, we add $Generator$ which takes the value of one if the farm has a generator.

We estimate the model using a probit estimation approach where the response probability depends on a vector of parameters which are a function of the standard normal cumulative distribution. Table 2.8 shows the effect of long-term expected equilibrium status on the probability of a firm exiting during the shock period (2016-2017). The results in column (1) suggest that farms with a long term expected high equilibrium are 6.8 percentage points less likely to exit compared to farms with a long-term expected low equilibrium. Controlling for farm assets such as a generator or a water source like a borehole or a well reduces the likelihood of exit of the farm with a long-term expected high equilibrium by 10 percentage point. However, both specifications support the hypothesis that farms with expected long-term high equilibrium are less likely to leave the industry compared to those in the expected low equilibrium group. These findings are consistent with those of another study that used the same data and a dynamic programming approach to examine the effect of high input costs on commercial poultry firms (Padilla & Liverpool-Tasie, 2019). The study found that under the pressures of increased feed prices and higher energy requirements, the optimal decision of medium poultry farms holding broilers (defined to have between 100 and 1000 birds) is to leave the sub-sector. This lends credence to the importance of being aware of the different equilibrium sizes of poultry farms in the Nigerian context.

From column (2), managers that have more years of experience are more likely to exit the sub-sector in years of shocks. This is surprising, as one would expect experience to reduce the likelihood of exiting in the presence of a shock. However, this might be because they are less willing to endure the effects of the shocks compared to managers of new farms who still need to recover their investments. Compared to South west (Oyo), farms that are in the local governments of Igabi (Kaduna) and Egbeda (Oyo) are less likely to exit the poultry farming when there is an input price shock. This likely implies that those LGAs have some coping mechanisms. Owning a water source on the farm such as a borehole or a well is associated with a 10.6 percentage point probability of not exiting during a shock period. This attests to the importance of a water source for a thriving poultry farm.

Table 2.8. Probability of exiting during the shock period (2016-2017)

	Probit	
	Marginal effects	
	(1)	(2)
Dummy equal 1 if long-term expected equilibrium is high	-0.068**	-0.057*
	(0.033)	(0.033)
Base - Dummy equal 1 if long-term expected equilibrium is low	-	-
Male (0/1)	0.021	0.024
	(0.028)	(0.027)
Number of years in poultry farming	0.003	0.003*
	(0.002)	(0.002)
Distance to nearest highway (Km)	0.000	0.000
	(0.000)	(0.000)
Igabi	-0.137***	-0.165***
	(0.037)	(0.038)
Kaduna North	-	-
Kaduna South	-	-
Akinleye	-	-
Egbeda	-0.136***	-0.139***

Table 2.8 (cont'd)

	(0.043)	(0.048)
Ido	0.015	0.039
	(0.081)	(0.087)
Lagelu	-0.078	-0.082
	(0.053)	(0.055)
Oluyole	-	-
Ona Ara	-0.030	-0.005
	(0.096)	(0.110)
South west (base)		
Generator (0/1)		-0.028
		(0.029)
Borehole or well (0/1)		-0.106***
		(0.032)
Observations	499	499

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

2.5.5. Falsification test

The occurrence of an increase in feed prices in 2016-2017 formed the basis of our hypothesis that farms' ability to withstand a shock depends on their expected long-term equilibrium. To check that our results are not spurious we conduct a falsification test. The falsification test consists of estimating the same model as above during a year without shock and testing the null hypothesis that the coefficient on the variable of interest (long-term expected equilibrium status) is not statistically different from zero. In 2015, there was no major shock in the poultry sub-sector in Nigeria, which means that other factors were responsible for farms' decision to close down. Consequently, the outcome variable takes a value of one if the farm exited in 2015, and zero otherwise. The result of the falsification test in Table 2.9 shows that the coefficient on the explanatory variable "long term expected equilibrium is high (0/1)" is not statistically significant in both columns 1 and 2. This confirms our earlier results that a farm with a long term expected high equilibrium is more likely to be able to withstand a shock compared to one with a long term expected low equilibrium.

Table 2.9. Probability of exiting during a normal year (2015)

	Probit	
	Marginal effects	
	(1)	(2)
Dummy equal 1 if your long term expected equilibrium is high	-0.006	0.002
	(0.020)	(0.020)
Base - Dummy equal 1 if your long term expected equilibrium is low	-	-
Male (0/1)	0.008	0.010
	(0.018)	(0.016)
Number of years in poultry farming	0.001	0.001
	(0.001)	(0.001)
Distance to nearest highway (Km)	-0.003	-0.007
	(0.003)	(0.005)
Igabi	0.023	0.012
	(0.019)	(0.017)
Kaduna North	-	-
Kaduna South	-	-
Akinleye	0.088	0.085
	(0.071)	(0.068)
Egbeda	0.023	0.029
	(0.025)	(0.028)
Ido	-	-
Lagelu	0.004	0.022
	(0.020)	(0.030)
Oluyole	-	-
Ona Ara	-	-
South west (base)		
Generator (0/1)		0.003
		(0.020)
Borehole or well (0/1)		-0.084***
		(0.023)

Table 2.9 (cont'd)

N	456	456

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

2.6. Discussion

In both Oyo and Kaduna, we found evidence of multiple equilibria which suggests that there is a minimum investment necessary for poultry farmers wishing to operate at the high equilibrium. At the high equilibrium there are some economies of scale which enable poultry farmers to make productivity enhancing high fixed cost investments that can be spread out across a larger number of birds. New entrants into the poultry subsector may have different motivations for starting a farm but it is likely necessary for those seeking to establish farms capable of growing over time to start with a flock size above a certain threshold. Investors, policy makers and practitioners should be aware of the existence of this minimum investment if their goal is to encourage and support the growth of large commercial farms in the country. Moreover, small farms rarely grow to become large farms over time. This demonstrates the Nigerian poultry sub-sector behaves like other small enterprises in sub-Saharan Africa in the sense that there is very little room to contribute to the reduction of unemployment. In effect, the contribution of small enterprises, in terms of productivity value-added and employment has been shown to be insignificant (Van Biesebroeck, 2005).

Male managed farms in Kaduna and female managed farms in Oyo face a higher minimum investment and tend to operate at a high equilibrium that is higher compared to their peers. This suggests that female farm managers in Kaduna and male farm managers in Oyo can learn about poultry management practices from their peers of the opposite gender. Therefore, there is a need to facilitate exchanges between these groups. Additionally, given that women farm managers in Oyo and male farm managers in Kaduna face a higher threshold, it is important to design programs that can make facilitate access to capital for these groups. They are the most productive groups, yet they first need to overcome a significant hurdle related to a relatively high starting capital.

Operating at the high equilibrium is associated with a better adaptative capacity. We found that these farms were less likely to exit in the event of an input price shock. Thus, it seems that farms at the high equilibrium are better positioned to invest in technologies or make changes that strengthen their adaptability to major changes. For instance, one study found that in the face of higher temperatures, large commercial poultry farmers change their roofs from iron-sheets to aluminum roofs as the later attract less heat (Sanou et al., 2019). The small and medium farms invest in other practices which are not as effective. also found that compared to large farms, medium farms are not well equipped to survive high feed costs and increasing energy costs (with the adoption of technologies to deal with climate change). These medium farms end up shutting down their businesses once these costs are incorporated.

2.7.Conclusion

As part of a rapid transformation of food systems taking place across Africa, there has been a rapid growth in commercial farms to meet the growing demand for animal protein. However, there is limited information about the dynamics of rapidly growing sectors (such as poultry and fish) and some of the conditions likely necessary to be able to grow and survive in such sectors. To contribute to filling this knowledge gap, this paper investigates the underlying dynamics of poultry farm sizes in two major poultry producing states in Nigeria, Africa's most populous country and largest economy. We use a non-parametric approach to determine whether poultry farms are characterized by convergent (a single stable equilibrium flock size) or bifurcated dynamics (multiple stable equilibria in flock size). Then we test whether firms at different equilibria have a differential ability to withstand non-trivial shocks in the sector and if they face different growth opportunities.

We find evidence of multiple equilibria confirmed by various in and out of sample transition matrices and multiple parametric estimations. In Oyo state, there is a low equilibrium at 550 birds and a higher one at 6450 birds. In Kaduna, a low equilibrium is observed at around 500 birds while a high equilibrium occurs at approximatively 3250 birds. This shows that poultry farms at the low equilibrium are similar across both states but those at or near the high equilibrium in Kaduna operate on a much lower scale compared to Oyo. Additionally, farmers in Kaduna aiming to grow towards the high equilibrium face a higher threshold than in Oyo (1800 compared to 1200 birds). Beyond the specific numbers, the key takeaway from these results is that there exists a minimum investment for entrepreneurs interested in operating large farms in the long run as small farms are unlikely to grow.

We find gendered differences in the equilibria levels of poultry farms across the study states. Both male and female managed farms in Oyo exhibit a low equilibrium at 750 birds (higher than the average for both at 550 birds). Similarly, the high equilibrium for female managed firms is also significantly higher than that for males at 7950 relative to 6350 birds. However, female managed farms tend to face a much higher threshold (1500 birds compared to 950 birds for male-managed farms) to be able to grow towards the high equilibrium. The situation is quite different in Kaduna. In Kaduna, while both male and female-managed farms have a low equilibrium at 500 birds, the high equilibrium for female managed farms is lower at 2800 birds compared to 3400 birds for their male counterparts. However, when female farmers are able to get more than 1400 birds, they are able to move towards that higher equilibrium while males need over 2000 birds to grow to the high equilibrium. Taken together, these results suggest that female farm managers in Oyo and male farm managers in Kaduna implement better practices for poultry farm management than their counterpart.

Our results consistently indicate that farms at (or headed towards) the low equilibria are less likely to experience significant growth and continue to operate around that low equilibria. This is similar to the findings of the literature on firm growth in sub-Saharan Africa which support that small enterprises rarely grow to big ones (Biggs & Srivastava, 1996). While this might be considered sufficient for many farmers, we also find that these smaller farms are more likely to exit the sector in the event of an input price shock. Thus, operating at the low level equilibrium compared to the high one is not inherently bad except in the event of a shock. With the increasing likelihood of shocks triggered by changes in climate variables such as higher temperature, it seems that it is not sustainable to operate at the low level equilibrium. Both of these results are robust to multiple robustness checks and analyses conducted over different time periods.

This research does not capture very large farms in the study area. Our farm size consideration is between 100 and 8,000 but tends to reflect the current composition of the commercialized poultry sector in terms of actors. Further research on mega farms alongside research on the investment profile, management practices and productivity of farms at or headed toward the various equilibria would be helpful.

APPENDICES

APPENDIX 2A: SIZE DISTRIBUTION OF POULTRY PENS

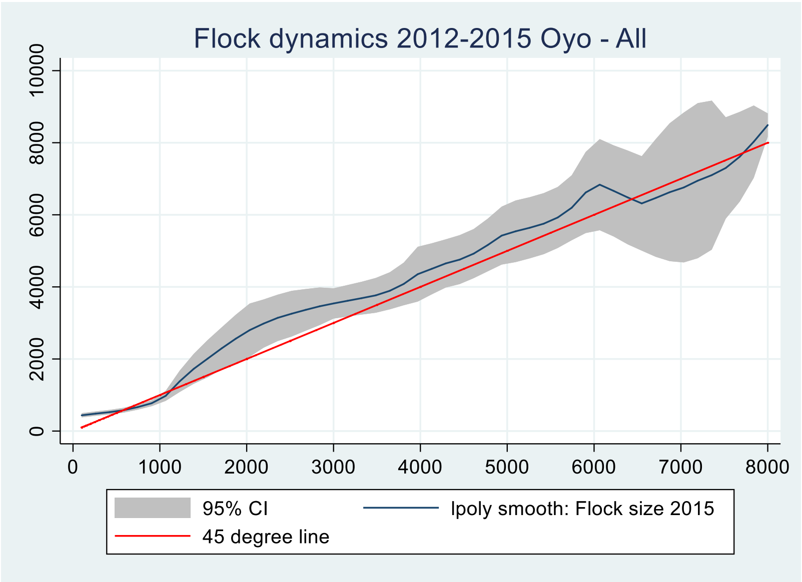
Table 2A- 1. Size distribution of poultry pens

	All				Oyo				Kaduna			
	All	T1	T2	T3	All	T1	T2	T3	All	T1	T2	T3
Median total number of pens	1	1	1	1	1	1	1	1	1	1	1	1
Mean total number of pens	1.0	1.0	1.0	1.3	1.1	1.1	1.3	1.5	1.0	1.0	1.0	1.2
Median size per pen (square meters)	30	30	30	30	30	30	30	30	30	30	30	30
Mean size per pen (square meters)	31.4	30.1	31.6	124.8	37.7	29.4	60.2	265.8	30.4	30.3	30.8	31.5
Median number of birds per pen	200	25	300	2000	500	30	350	2000	100	25	300	2000
Number of observations	1217	465	380	372	675	281	180	214	542	184	200	158

Note: T1 is 0-100 birds, T2 is 100-1000 birds and T3 is 1000-8000 birds

APPENDIX 2B: NON-PARAMETRIC ESTIMATES WITH CONFIDENCE INTERVALS

Figure 2A- 1 Non-parametric estimates of flock size in 2012 on flock size in 2015 for Oyo and Kaduna with confidence intervals



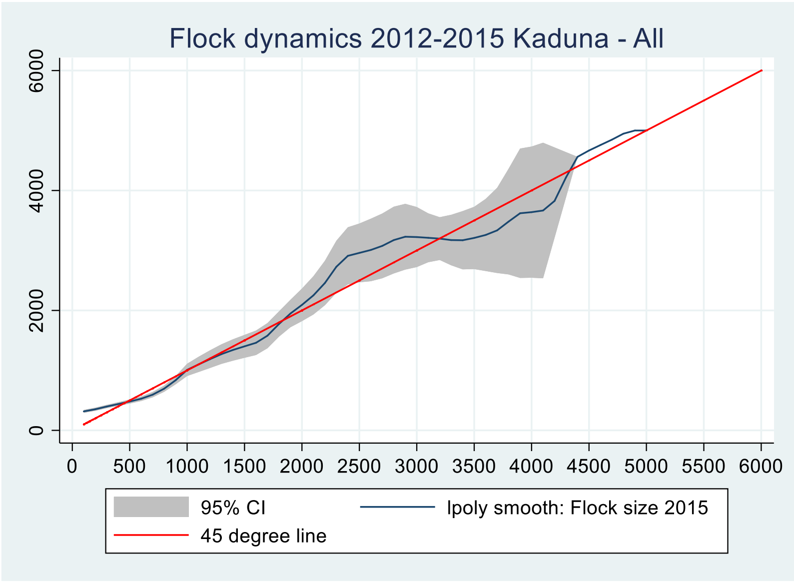
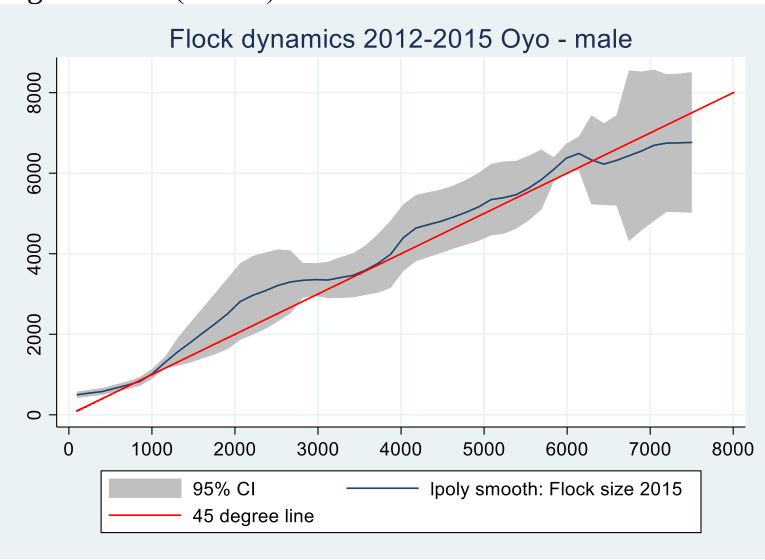


Figure 2A- 1 (cont'd)



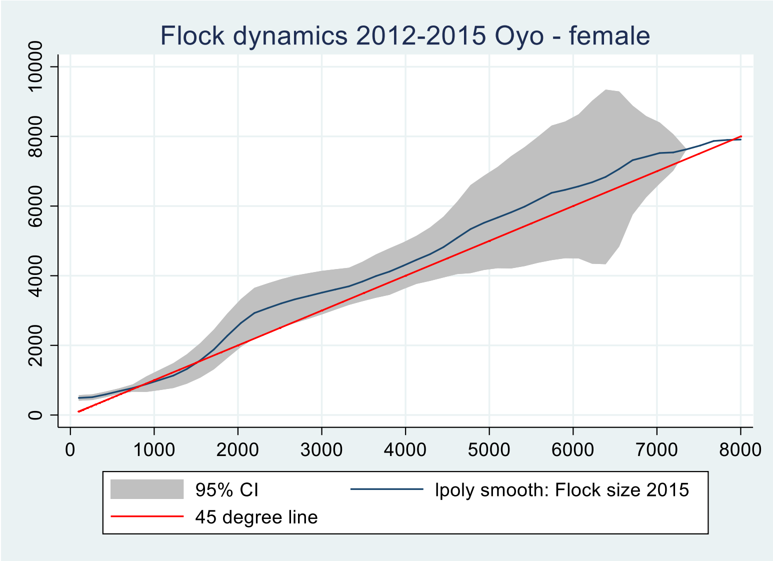
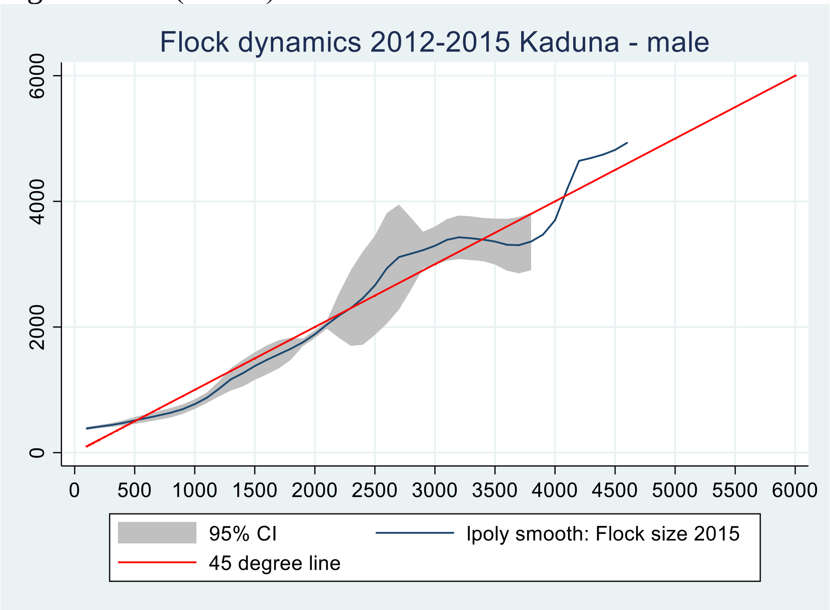
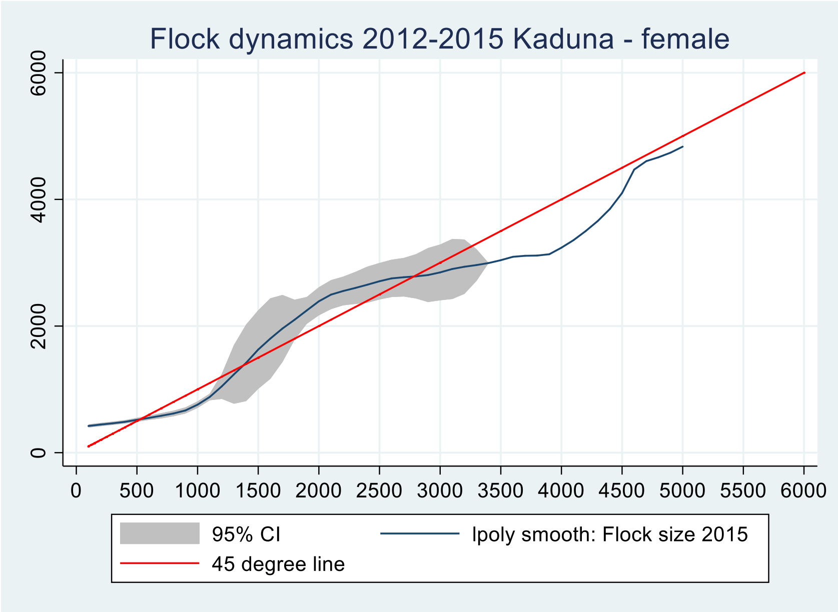


Figure 2A- 1 (cont'd)





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3. PERCEPTION AND ADAPTATION TO HIGHER TEMPERATURES AMONG POULTRY FARMERS IN NIGERIA

3.1.Introduction

Studies support that the negative effects of climate change will be most felt among poor communities in Africa and other tropical areas (Mendelsohn & Massetti, 2017). Climate change is a combination of increases in temperature together with high variability and erratic rainfall, changing seasonal trends and more frequent occurrence of extreme climatic events (Lipper et al., 2018). Such changes are likely to threaten the food security and livelihoods of communities whose activities depend on climate in food and agricultural systems. Using long-term climate simulation models to estimate changes in the normal daily maximum temperature for the warmest month between 2000 and 2050, Hassan et al. (2013) estimated an increase of 1.5 to 2C in southern Nigeria, the setting of this study. This indicates that the region is already experiencing higher temperatures which are likely to negatively affect the poultry sub-sector. Higher temperatures have been associated with reduced productivity in food and agricultural production(Mendelsohn & Massetti, 2017).

There is an abundance of studies on crop farmers' perceptions of climate change as well as their adaptations to it (Ayanlade et al., 2018; Ayanlade et al., 2017; Hitayezu et al., 2017; Mulenga et al., 2017; Sesmero et al., 2017). This is contrasted with a scant literature on livestock farmers' perceptions and adaptation strategies to climate change which tends to focus on large livestock owners (Debela et al., 2015; Silvestri et al., 2012; Zampaligré et al., 2014). While these provide useful evidence on the potential impacts of climatic changes on these groups, they leave out small animals like poultry. This lack of evidence on small animal owners matters to a country like Nigeria which has experienced growth in poultry production in recent years due to increased demand and relatively low barriers to entry compared to other livestock products (Heise et al., 2015; Liverpool-Tasie et al., 2017a). Commercial poultry farms play a key role in this growth as they are the main suppliers of poultry meat and eggs to the country's large population. In order to support this growth momentum, it is important to understand how higher temperatures are affecting commercial poultry farmers as well as document how they are adapting. As far as the authors are aware, only one study has investigated these issues in the Nigerian context using data from a representative sample of farms in two major poultry producing states in Nigeria that is analyzed using quantitative methods (Liverpool-Tasie, Sanou, et al., 2018). While the study finds evidence of heterogeneity in strategies adopted by farms depending on their size, it does not explain the reasons for this heterogeneity in adaptation strategies across farms by scale. It also does not explore potential variation in adaptation strategies within farms of similar sizes due to the small sample size and the lack of variability in the strategies reported within groups.

This essay aims to bridge this knowledge gap on climate change adaptation by small animal producers with evidence from south west Nigeria. We use a case study approach to examine poultry farmers' perceptions of higher temperatures, their effects on production and their adaptation strategies. Poultry farmers are best positioned to help generate a reliable body of knowledge that can inform policy and climate change adaptation program design in this subsector. The study makes two main contribution to the literature on climate change adaptation. First this is the first study to provide an in-depth analysis of how poultry farmers are adapting to higher temperatures with adequate information about the reasons for their adoption of particular strategies. Furthermore, this study explores a broader set of adaptation strategies than those explored in Liverpool-Tasie et al. (2018), the only other study found on this topic. The findings of this in-depth analysis will be useful to commercial poultry farmers, investors and extension agents involved in the sector.

The essay begins by providing an overview of the poultry sector in Nigeria and temperature trends in Nigeria. It then presents a summary of the literature on the effects of climate change on livestock farmers, their perceptions of these changes and their adaptation strategies. Following the section on the analytical approach and the data, the results section presents the farmers' perceptions and adaptation strategies to higher temperatures. The last section presents the conclusions.

3.2.Background

3.2.1. Overview of the poultry subsector and climate trends

The poultry sector in Nigeria has experienced tremendous growth in recent years. The country experienced a two-fold increase in its poultry production between 1980 and 2008 (Liverpool-Tasie et al., 2017a). This is partly due to the low cost of production and barriers to entry of poultry compared with other livestock products (Heise et al., 2015). In addition, the share of maize allocated to the feed industry followed an upward trend between 2003 and 2015 with a 300% increase in volume (Liverpool-Tasie et al., 2017a). This rapid transformation of the poultry sub-sector has translated into about 85 million Nigerians being involved in small family poultry farming while over 14 million people benefit from employment in the commercial sector (PAN, 2017). These changes have positioned the poultry sector as a major source of affordable animal protein in the form of eggs for the country's large and growing population which is consuming more of this food form (Liverpool-Tasie et al., 2017a; United Nations; Zhou & Staatz, 2016). However, the predicted changes in climatic variables, mainly temperature, poses a serious threat to the observed growth momentum (Liverpool-Tasie, Sanou, et al., 2018).

Evidence from the literature suggest that temperature has been increasing in Nigeria and in the study region. Using data from the Nigerian Meteorological Agency from 1901 to 2005 Akpodiogaga-a and Odjugo (2010) found that mean annual temperatures increased by 1.1 degrees Celsius over the period of 105 years. In the Ibadan region of Oyo state (south west Nigeria), the setting of this study, the analysis of temperature trends between 1971 and 2012 further supports an increase in annual and seasonal mean temperatures (Abatan et al., 2018).[15]

3.2.2. Effects of higher temperatures on poultry and other livestock

While there is a substantial body of literature that supports that climate change will have adverse effects on livestock systems, there is very limited evidence for poultry. Changes in temperature and precipitation regimes will affect grassland productivity during the dry season and the quality of grazing fields as well as feed crops (Descheemaeker et al., 2018; P. Thornton et al., 2007; Wheeler & Von Braun, 2013). Although both changes in temperature and precipitation are detrimental to livestock, the effects of heat stress are particularly important because of its the direct impact on the animals (P. Thornton et al., 2009). In the intensive poultry farming systems of Africa and Asia, heat stress has been linked to the loss of production due to increased mortality, reduced growth rate as well as a drop in egg production and quality (Bhadauria et al., 2014). In the Caribbean, the increased frequency of periods of heat stress decreases egg production and quality in layers and lowers growth rate for broilers. For other types of livestock such as small ruminants and pigs, higher temperatures disrupt their food intake and internal thermoregulation (Lallo et al., 2018). Nyoni et al. (2018) also summarize scientific literature finding that under heat stress, chickens reduce their feed intake to regulate their internal temperature. It is important to note that

[15] There are two main seasons in Nigeria. The rainy season spans the months of April-September and the dry season starts approximately in August and ends in December

there are likely differences in the way climate change impacts small and large farms. Large farms tend to suffer more from increases in temperature because they do not have the flexibility of small farms of switching to different types of animals that are heat tolerant or abandoning livestock farming for crop farming (Seo & Mendelsohn, 2007). Changes in climate variables like temperature therefore pose a threat to the livelihoods of livestock owners (Debela et al., 2015). Yet, the lack of empirical evidence on the effects of these changes on small animal owners like poultry farmers limits policy response mechanisms.

3.2.3. Livestock farmers' perceptions and adaptation strategies

The prevailing literature focuses on large livestock owners, leaving out of the debate the perception of small animal owners like poultry producers who play an important role in the agricultural sector in Nigeria. Farmers' perceptions of changes in climatic variables like temperature affect their adaptation strategies (Arbuckle Jr et al., 2015; Tripathi & Mishra, 2017). As such, understanding their experiences with the changes that are occurring may provide some insights on their choices of adaptation strategies. Studies that document cattle farmers' perceptions of changes in temperature and rainfall patterns in sub-Saharan Africa report that they are concerned about increases in temperature, higher dry season temperatures, longer dry seasons, later onset of rainfall and decreased average rainfall (Ayanlade et al., 2017; Silvestri et al., 2012; Zampaligré et al., 2014).

To supplement the existing evidence on livestock farmers' adaptation strategies, this study explores poultry farmers' adaptation strategies in a tropical region of the world. In response to the changes in temperature and rainfall patterns, livestock farmers have developed adaptation strategies. Some of their adaptation strategies consist of managing higher temperatures, the occurrence of new diseases as well as diversifying feed sources and activities (Ayanlade et al., 2018; P. Thornton et al., 2007). For instance, some pastoralists practice mixed crop-livestock systems or switch to holding smaller livestock (sheep, goats and chickens) which require less water and fare better under a warmer climate rather compared to cattle (Ou & Mendelsohn, 2017; Zampaligré et al., 2014). To adapt to warmer temperatures, some poultry producers prefer holding indigenous breeds because they tolerate higher temperatures better than exotic/imported ones (Lallo et al., 2018). Higher temperatures and variable rainfalls also negatively impact the yield and the quality of crop residue fed to livestock. To address this issue, farmers can diversify their portfolio of crops with legumes to provide other feed sources (Descheemaeker et al., 2018). To deal with the higher incidence of diseases, farmers follow more closely the vaccination calendars of their livestock (Kichamu et al., 2017). Lallo et al. (2018) recommend that to reduce the effect of heat stress on chickens, broiler producers invest in cooling technologies, improve litter management to prevent ammonia build-up, reduce stocking density in poultry pens, sell the birds at a younger age and add vitamins and supplements such as chromium and zinc to their diet.

3.3.Conceptual framework

The analytical approach for this study is organized around the different aspects of poultry farming that influence both farmers' perceptions of changes in temperature trends and their strategies for adapting to those changes. More specifically, the conceptual approach helps to answer three related questions: 1) what are poultry farmers' perceptions; 2) what are the effects of higher temperatures on poultry farms; 3) what are poultry farmers' adaptation practices. To document poultry farmers' perceptions, we draw on the theory of drought perception developed by Taylor et al. (1988) while being mindful that changes in temperatures and drought are different environmental events. This framework stipulates that drought perceptions are formed by experience, individuals' definition of the phenomenon and what they remember, as well as their expectations of future droughts which are instrumental in shaping behavior. This approach is useful for generating a holistic picture of adaptation strategies as they relate to poultry farming because different components of the activity may be affected heterogeneously by changes in temperatures. Perceptions represent a set of judgments, beliefs and attitudes (Taylor et al., 1988) and are a pre-requisite to adaptation (Arbuckle Jr et al., 2015; Tripathi & Mishra, 2017). Since perceptions and adaptation strategies are connected, this conceptual approach also provides a broader understanding of the former. This theory of drought perception is only used to establish any relationship that may emerge between perceptions and adaptation strategies and does not intend to draw any causality, that is the effect of perceptions on adaptation strategies.

3.4.Material and methods

This work uses a case study approach to investigate commercial poultry farmers adaptation strategies to higher temperatures. There are several definitions of what constitutes a case study and how it should be done. Following Creswell (2013)'s definition in this study, a case represents a poultry farm from the time it was established until the present, and each case is investigated using in depth interviews which are subsequently analyze to generate common case themes. The choice of this method is appropriate because we want to gain an in-depth knowledge of the mix of strategies available to different types of farms. As such, the data collection used structure semi-interviews and probed around the topics that are relevant to the study.

3.4.1. Data collection

To understand how poultry farmers respond to perceived changes in climate the interviews were constructed around four themes shown in Table 3.. The main objective was to document poultry farmer's adaptation strategies. However, the literature supports that farmers' perceptions influence their responses (Arbuckle Jr et al., 2015; Tripathi & Mishra, 2017). As such, we also included questions about their perceptions of changes in temperatures. To avoid asking leading questions and bias in the answers, we started the interviews by asking respondents to describe the temporal changes in farming practices as well as the challenges on the farm over time as they remember and define them. By organizing the data collection as described, we can tease out perceptions that result from farmers' direct observations on the farm as well as those which emerge from their experience acquiring inputs used on the farm. Discussion of their responses to their perceptions of changes in temperatures then leads to discussion of their adaptation strategies (see the interview protocol in the appendix).

Table 3.1. Interviewing strategy including the sequence of questioning

Question sequence	Question topics		Purpose
First set	Temporal changes in poultry farming practices	Specific challenges in poultry farming over time, their causes, and steps to address them	Understand changes in poultry farming over time without revealing that climate change adaptation is the interviewer's topic of interest. Establish the context of the overall poultry farming operation.
Second set	Perception of changes in climate trends		Start to focus on the specific area of interest; learn the specific ways in which climate change affects poultry farmers.
Third set	Climate change adaptation practices		Discuss climate adaptation strategies within the larger context of the overall operation and with respect to specific challenges that interviewees have introduced.

The data used in this analysis is primarily based on semi-structured in-depth interviews with commercial poultry farms in Oyo state. This is because commercial poultry farmers make important investments that they are keen to protect against adverse climate events. We interviewed commercial farmers in Oyo state because it is home to a growing number of medium and large-scale poultry farms in the country. For this study, we started with a representative sample of 1,619 poultry farmers in Oyo state conducted by Liverpool-Tasie, Sanou, et al. (2018). Then we selected all commercial farms within the sample that had been active long enough to be able to discuss long-term changes in climate variables.

The random sample by Liverpool-Tasie, Sanou, et al. (2018)[16] showed that in Oyo, 40% of the farms hold less than 100 birds, 24% hold between 100 to 1,000 birds, and 36% hold more than 1,000 birds. Farms with less than 100 birds hold less than 1% of the total number of birds held by these farms. Farms with 100-1,000 birds and more than 1,000 birds hold 4.8%, and 95% of the total number of birds, respectively. Thus, farms holding more than 100 birds supply the bulk of birds to markets.

To capture only commercial farms in this study, we focused on farms holding more than 100 birds. To ensure that respondents could speak to changes in the climate, we further focused on farms which have been active for more than 15 years. Given that the average numbers of years of experience of poultry farmers in the representative sample is about eight years, the choice to focus on farms in operation for at least 15 years (instead of more than 20 or 30 years) generated a heterogeneous and sufficiently large number of cases to address the research questions. Sixteen poultry farms out of the total sample of 1,619 met the selection criteria for this study and all of them were interviewed from late February to early March 2018. The 16 farms held between 100 and close to 90,000 birds. After ordering the 16 farms from the smallest to largest, we divided the data into three groups or terciles as follows: 100-1000, 1,000-5,000, and more than 5,000 birds (*Table 3.2*). Throughout the study, we refer to these categories as small, medium, and large farms, respectively.

[16]See Liverpool-Tasie, Sanou, et al. (2018) for a detailed explanation of how the representative sample was obtained.

Table 3.2 shows that the majority of the farmers interviewed are male. This is similar to the representative sample of poultry farmers in Oyo where 57% of farmers holding more than 100 birds are male (Liverpool-Tasie et al., 2018). Three out of the four women own medium farms (the fourth one operates a small farm). Among the men, five manage small farms, four are in charge of medium farms and three operate large farms. This is also similar to the representative sample for Oyo. All the farms produce layers and nine of these also produce broilers. The broiler producers are equally distributed across farm sizes. Asset holdings vary with 11 farmers owning generators, nine owning a well but only seven owning a borehole as it is more expensive to drill compared to a well. In the Nigerian context it is important to own a generator because of the unreliable electric grid. Additionally, for a thriving poultry enterprise, it is necessary to have access to water. According to the poultry farmers, a borehole is more expensive than an open-well, but it does not face the risk of drying up during the dry season like the latter.

Table 3.2. Farmers and key farm characteristics

	No.
Female	4
Male	12
Average age (years)	59
Farm size (number of birds)	
100-1000	6
1000-5,000	7
>5,000	3
Type of farm[1]	
Layers	16
Broilers	9
Number of years farming	
15-20	7
21-30	6
>30	3
Assets	
Own generator	11

Table 3.2 (cont'd)

Own well	9
Own borehole	7

[1]Some farms raise both layers and broilers.

3.4.2. Data analysis and validity

In qualitative research, the researcher is most concerned with internal validity which refers to the credibility of the findings (Chung, 2000; Yin, 2013). There are a variety of ways to achieve internal validity in qualitative research including recording and transcribing interviews verbatim and collecting information from different types of sources. These approaches reduce the risk of misrepresenting the information collected from respondents and lend credence to the credibility of the findings. In this study, the interviews were recorded then transcribed verbatim to ensure that we remain faithful to the words of the respondents. Additionally, this enabled us to avoid making erroneous inferences or conclusions based on our subjective interpretation. We collected information from farms of different sizes to ensure that the accounts reflect the general sentiment of a diverse group of commercial farms. Great care was also taken to avoid asking leading questions directly related to adaptation strategies. Instead the interviews used poultry farmers' answers to questions related to their challenges and changes on the farms to ask probing questions. By not having a checklist of items to go through across respondents, we minimize social desirability bias because each of them shared what they felt mattered the most. One implication of this approach is that the results represent the minimum number of times themes are mentioned but not necessarily the maximum. This is because we did not have a check list of items that we systematically went through with each respondent. Thus, it is possible that two respondents shared the same point of view about a topic, but one mentioned it in the flow of the conversation while the other did not.

We used an inductive thematic analysis of the transcripts to assign codes that resonated with the questions being explored in this study (Rubin & Rubin, 2011). This enabled the emergence of individual and cross-case themes from the data. More specifically, we followed a five-phased cycle outlined by Yin (2016): (i) compiling, (ii) disassembling, (iii) reassembling, (iv) interpreting, and (v) concluding. The computer program Dedoose was used for the coding process. In the first phase of data analysis, three transcripts were reviewed to assign labels or meaning to the portions of the texts relevant to the issues of interest. The labels thus generated are called first order codes. These codes were further refined as we reviewed the remaining 13 transcripts to capture nuances across respondents. The next step in this first phase is to aggregate first order codes which convey the same idea into higher order codes called second order codes (see *Table 3A- 1* in the appendix). The second order codes are also the themes for this study. Together, the first order and second order codes are used to develop a temporary coding framework.

In the second phase, the remaining transcripts are assigned the appropriate first order codes using the temporary coding framework which was updated as necessary based on the emergence of new codes. In the third phase, a final and harmonized coding framework is created using all the transcripts. The themes from this final coding framework are then organized according to the research questions as a way of organizing the findings which emerge from the data. This process allows a holistic analysis of the cases from which individual case themes and cross-case themes emerge. In the fourth phase the themes or second order codes were combined to generate interpretations which form the basis of our findings. In the last step, the set of interpretations under each research question were used to generate a conclusion. The thematic analysis has the advantage of generating answers to the central research question from the farmers' standpoint.

3.5. Results and discussion

This section presents narratives from poultry farmers on their perceptions of changes in temperatures, the effects of these changes on their activity and the ways they have adapted to the observed effects. It is organized around the four main themes that emerged from the thematic analysis. These themes, which are defined in *Table 3A- 1* with examples, are: temperature patterns have changed, effects of heat on the birds/farms, responses to higher temperatures, and desired response to heat. These themes link closely to the research questions for the study. The analysis and the organization of the results relies on the themes, using quotes that support the interpretation of the findings. More specifically, the themes guided the emergence of results presented below. Some of the quotes presented demonstrate the technical knowledge of poultry farmers on the adaptation approaches which are appropriate for their farms. The interviews were based on open-ended questions, without a checklist of items to confirm across respondents. One consequence of this approach is that the numbers of farmers reported as mentioning specific themes are conservative indications.

3.5.1. Have poultry farmers noticed changes in temperatures?

The first research question for this study explores what poultry farmers have noticed about changes in temperatures from the time they were teenagers until now. The average age of a farmer ranges from 44 to 70 years old. This means that the study captures perceptions over a period of approximately 30 to 50 years. Fourteen of the sixteen poultry farmers in this study agree that temperatures are warmer than in the past while the other two did not notice any changes (Table *3.3* shows the breakdown of responses by farm size). Twelve of the sixteen farmers gave examples to show that that the high heat period starts earlier in the year compared to when they were teenagers. For instance, a male farm manager in his 50s commented:

Last year we started experiencing [the] high heat period around October which is unusual to us… we [used to] expect the heat in December/January/February. But it started since October. (L2)[17]

Table 3.3. Summary of responses describing changes in some climate variables

	Temperature increased
Farm size	
100-1000 (6)	5
1000-5,000 (7)	6
>5,000 (3)	3
Proportion of farmers	14/16

Note: Number of farmers are in parentheses.

Additionally, six farmers noted that compared to the past, the hot hours of the day set in earlier or the intensity of the heat in their coastal state has increased. As explained by a 68-year-old farmer, "*In the olden days, at this time of the day, the heat is usually not this much, but now the intense heat begins as early as 10 a.m." (M8)*. These accounts are similar to those collected among the inhabitants of another coastal state in Nigeria *(*Amos et al., 2015*).*

Respondents reported that the increased intensity of the heat is uncomfortable and even the rains do not have as much of a cooling effect as in the past. Moreover, the harmattan[18] season which used to be known as the cold period of the year is not as cold as it used to be. As a 67-year-old farmer put it:

I am not a meteorologist but if you see the pattern of harmattan we are having right now, it comes along with heat, whereas in those days, when there is harmattan you know there is harmattan, but right now we feel harmattan and we feel heat at the same time. (L1)

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[17] The quotes are labelled with a code for each respondent. The letter (L, M, S) corresponds to the size of the farm where L represents large (>5000 birds), M represents medium (1000-5000 birds), and S represents small (100-1000 birds).

[18] The harmattan occurs during the dry season in Nigeria

These observations are consistent with the meteorological trends and farmers' perceptions (Abatan et al., 2018; Akpodiogaga-a & Odjugo, 2010; Ayanlade et al., 2017) reported by other studies set in Southwestern Nigeria.

3.5.2. What are the effects of warmer temperatures on poultry farms?

Farmers report that heat stress brought about by higher temperatures has far-reaching consequences for poultry production (see Table 3.4 for a breakdown of the effects reported by farm size). Higher temperatures affect the productivity of poultry farms via effects on the health and the metabolism of the chickens. This is consistent with the scientific results reviewed by Nyoni et al. (2018) that under heat stress, chickens reduce their feed intake to regulate their internal temperature. As discussed further below, from the data we observe that some poultry farmers are also incurring higher production costs due to increased heat. This is due to the additional investments they need to make in anti-heat stress drugs or special feed formulations better suited for hotter temperatures. In addition, about half of the poultry farmers have learned to recognize how their birds react to higher temperatures through experience. The poultry farmers also noted that the drinking water available to the birds tends to be warm because of higher temperatures which are sometimes exacerbated by a prolonged hot season. According to six of the farmers, this can either lead to reduced water intake or death in some cases. The manager of a farm of 4000 birds illustrated this point by explaining that

> *Once there is heat, their [the chickens'] water will be warm and sometimes hot. Once they drink such water, it may result in shock which can lead to death. You can even enter the pen and meet like 10 dead birds without any prior sickness. (M5)*

Table 3.4. Effects of increased heat, by farm size

	Small	Medium	Large
Drop in the production of eggs	✓	✓	✓
Reduction in movement of birds	✓		✓
Reduction in feed intake	✓	✓	
Reduction in movement of birds	✓		✓
Increased mortality	✓	✓	✓

The respondents also stated that the health effects of high temperatures on chickens range from increased lethargy to higher mortality rates. This is similar to the findings of the scientific literature reviewed by Nyoni et al. (2018), which support that temperatures above 30C trigger a reduction in body weight, foster higher mortality rates. Respondents of this study reported that the main causes of mortality are heat stroke and dehydration. According to one farmer, *"The immune level [of the birds] breaks down easily when the weather is very hot than when it is cold." (S11).*

The manager of a farm of 5,000 birds was the only one to point out that the accumulation of ammonia under warmer temperatures also impedes the relaxation of the bird. In his own words, *"For the battery cage, you know their [the birds'] litters will emit ammonium acid, ..., and when it is hot, it generates faster than when it is cold." (M4).*

Besides the health effects, 14 of the farmers noted experiencing a reduction in the production of eggs because of higher temperatures in recent years. This is consistent with the findings of an earlier study that showed that heat stress is associated with a drop in egg production and the quality of egg shells (Abidin & Khatoon, 2013). In effect, when temperatures are too high, chickens eat less. As explained by a 57-year-old female farm manager, *"When [the] heat is too much, it affects their laying, maybe they have been laying 35 before, and it can drop to 31 or 32." (M7).*

A female manager with 23 years of experience in poultry farming provided a more technical explanation:

[Heat] is bad. You know their temperature should not exceed 26 degree centigrade which is thermo neutral zone for the birds, anything above that is abnormal…They will not eat well and lay well, mortality will increase. (M6)

3.5.3. How do poultry farmers adapt to higher temperatures?

3.5.3.1.Current adaptation strategies

Through the adaptation of adaptation strategies, poultry farmers aim to provide their birds with a cooler environment and maintain productivity levels even under warmer temperatures. Their adaptation strategies can be divided into low-cost and high-cost practices adopted by individual farmers. Low-cost practices do not require a large initial monetary investment and are relatively not too demanding in terms of the labor time. High cost practices are characterized by a sizeable upfront investment. It is important to emphasize that this distinction is only a rough categorization as some of the practices reported in this study could be categorized as one or the other. Table 3.5 summarizes some of the recurring adaptation practices that poultry farmers mentioned. It includes only those that at least three farmers in each farm size category mentioned.

Table 3.5. Adaptation practices reported, by farm size

	Small	Medium	Large
Low cost practices			
Seek expert advice on how to manage heat with specific breeds	✓		
Fetch water right before giving it to the birds	✓		
Reduce the number of birds per cage	✓	✓	✓
Fill up water tanks intermittently during the day to provide the birds with cold water (and not stored warm water)		✓	
Release hot water from storage tanks two to three times per day when it is too hot			✓
Add locally concocted substances to drinking water		✓	
Plant trees around pens		✓	
High cost practices			
Add anti-heat stress vitamins to drinking water	✓	✓	✓
Add vitamin C to drinking water			✓
Give birds vitamins	✓	✓	✓
Increase the frequency at which vaccines are administered		✓	
Follow vaccination schedule and use anti-biotics			✓
Add ice blocks to drinking water		✓	✓
Feed birds at night by powering generator		✓	
Change the roof of pens to aluminum sheets		✓	
Increase the height of the roof in pens			✓
Adjust feed formulation to avoid heat stroke in birds			✓

Note: The practices in the tables are from first order codes. We report those that appear across at least three respondents. Owning a borehole is not listed because it was not mentioned as a climate adaptation practice.

The first type of low-cost adaptation practice is providing chickens with water of adequate temperature. To achieve this, the managers of poultry farms have devised new measures of providing cold drinking water to chickens. Small, medium and large farms are all able to implement this strategy because they can rely on the labor that performs other activities on the farm. The practice of finding an alternative measure when the status-quo no longer functions has also been adopted by large animal farmers. When existing pastures become degraded, livestock farmers find new grazing land (Ayanlade et al., 2018).

One method of providing cold drinking water to chickens is to release the hot water stored in water tanks two to three times per day. One issue with this method is that it is wasteful. Another method consists of filling up the water tank intermittently during the day to provide the birds with cold water. Farmers who do not have water tanks, pump up cold/fresh water from the borehole or the open-well immediately before giving it to the birds.[19] One farmer described the first method as well as the rationale behind it:

> *Every twelve noon we open all our water from pipe. We waste everything… We do observe during that heat the water inside that pipe that supply to nipple also increases the heat intensity of the water in the pipe. When we open it at the outlet, we feel the temperature change that the water has turned warm and warm water is not good for the birds. (L2)*

In contrast to this lower-cost practice of providing cold water to the birds, adding ice blocks in their drinking water during the hot time of the day is a costlier practice. It is restricted to the farmers who can afford the costs of procuring ice blocks. One of the medium farmers described his reasons for using ice blocks in the following terms:

> *What I do at times, I get ice block, when it is 11 o'clock, I will add ice block to their water. If it will help them, because if they see cold water. …. When you add [ice] block to it, they will now see that, this is good. For broiler that is what I was doing because they have to convert what they are eating as fast as possible. I have to ensure they don't exceed 8 weeks, if they do, I would lose more money. (M4)*

The second type of low-cost adaptation practice aims to provide a cooler environment to the birds. Since it is costly to build new poultry houses, the small and medium farms resort to using

[19] The majority of farms incur a one-time cost for drilling an open-well or a borehole.

other means of controlling temperatures in existing structures. The larger farms can also avail of these cheaper practices. In one small poultry house, the owner added palm leaves under the steel sheet roofs to reduce the intensity of the heat. Three of the farmers (one small and two medium) reported planting trees such as plantain trees around their poultry pens to create some shade in order to reduce the intensity of the heat that the birds feel. They noted doing so after their interaction with fellow poultry farmers and poultry experts. To improve ventilation in deep litter systems[20] and battery cages, six of the farms (one large, four medium, one small) reduced the number of birds per square foot for a lower stocking density. Though reducing the stocking density is a relatively cheap adaptation measure to implement, holding fewer birds decreases the revenue of the farm.

We have identified three sets of high cost adaptation practices. There are some that aim to improve the immune system of the chickens while some others address the reduction of food intake caused by higher temperatures. The first set of high cost adaptation strategies aim to improve the immune system of the birds. The two farms with more than 10,000 birds in the data compound their feed with consideration of the sensitivity of birds to temperature, as the immune system of chickens is more vulnerable under hot weather conditions (Lallo et al., 2018). In an experimental study Kadim et al. (2008) showed that under high temperatures ascorbic acid improves feed intake, body weight gain and feed conversion ratio. As a precautionary measure, six farmers (medium and large) increase the rate at which they administer vaccines to their birds to reduce their exposure to diseases. This raises operating costs for the farms. Thus, it is not surprising that it was reported only by medium and large farms. Similarly to these poultry farmers, livestock farmers closely

[20] Deep litter is an open space poultry rearing system covered with sawdust while a battery cage is one where each bird has a designated space in cages organized in rows.

follow the vaccination calendars of their cattle to deal with the higher incidence of diseases (Kichamu et al., 2017). This strategy has proven to be effective as one of the farmers noted: "*I have not lost any bird, because once the heat starts like that, …, I do my calculation. If I vaccinate now, in another three weeks I vaccinate again"* (M9).

For the farms which make their own feed (six out of 16 in our sample), adjusting the feed formulation improves the birds' immune system but it is also costly. Adjustments are made to the feed formulation for several reasons. The manager of a farm of close to 90,000 birds noted that they adjust the formulation of their feed so that the "*the birds do not put on fats which will result to heat stroke"* (TN1). Another manager of a farm of about 900 birds with 24 years of experience in poultry farming explained why he stopped using his own feed formulation considering the heat stress:

> *Before I was using my own formulation, but I found out that my own formulation cannot withstand the [heat] stress. Those concentrate[s] maybe they have anti stress that I don't have, so by the time I started using those concentrate[s] I notice the production improve and the stress was less on the birds. (S11)*

The second group of high-cost adaptation practices is concerned with improving food intake by feeding birds at night when it is cooler. It is a high cost because it requires the availability of a reliable source of electricity. None of the farms interviewed depend on the public electric grid system because it is highly unreliable. All the medium and large farms have fuel-powered generators which they use to pump up water or to generate electricity on the farm. In Oyo state, two medium farmers and one large farmer reported feeding their birds at night during the hot season to take advantage of cooler temperatures compared to the day. However, for the birds to eat when it is dark outside, they need light. *"The only thing I do is to power the generator from*

6:30 P.M. to 12, to extend their day" (M9). However, this practice is not available to everyone as described by one of the farmers: "*Even the one [practice of feeding the birds at night] I am trying to do, I still can't perfect it because of the electricity problem." (M4).* Not all the farmers can afford the cost of a generator and the fuel needed to run it.

The third and last group of high cost adaptation practices is to make changes to the physical structure to provide better ventilation. This is the most expensive of all those reported by the farmers as it requires important upfront investment. It requires making changes to the physical structure of the poultry houses which means that only the medium and large farms can avail of the important upfront investment needed. These practices include increasing the height between the floor and the roof for better ventilation. More specifically the manager of the largest farm in our sample noted: *"The new construction we are putting in place, we normally use, 30 feet at the center of the ridge, then 11 feet instead of 9 and 13 feet instead of 11, to increase ventilation."* (TN1).

Along the lines of improving ventilation in the poultry houses, one medium poultry farmer reported that he does not use cement blocks; instead he uses chain link fences to allow better air circulation. Moreover, one medium farm uses aluminum sheets for the roof because they reflect the heat better compared to galvanized steel sheets. These measures do not pose any risk of mal-adaptation because temperatures in the region do not drop enough for the cold to be a concern for poultry farmers.

3.5.3.2.Desired adaptation practices

Besides the practices being currently implemented, many farmers expressed the desire to adopt more "sophisticated" technologies in the future depending on their liquidity position. The three farmers holding more than 5000 birds did not report anything on these. This may indicate that they are satisfied with their existing practices, which aligns with data from the rest of the sample as some of the practices mentioned by the small and medium farms are already implemented by the large farms. An alternative interpretation is that they might be at the frontier of their knowledge of adaptation practices. These practices include installing ceiling fans or air conditioning units in poultry pens; or being mindful of the exposure of new poultry houses to the sun since this is a new concern. The farmers shared that they have not yet implemented these practices because of their limited financial resources. The manager of a farm of 4000 birds that was established in 1987 explained why the positioning of the poultry pen in relation to sunrise and sunset is important:

M5: There is a direction the pen is supposed to face. The length is supposed to face and all like that. I think the sun starts in the east and ends in the west. Your pen, the birds is supposed to face the two, so that the length will face the north and south. For instance, any farm that place the length to face the east and the west, will have much problem during the heat period.

Interviewer: Where do your pens face now?

M5: They face the east and the west.

Table 3.6. Examples of desired adaptation practices by types of farms

	Small	Medium	Large
Low cost practices			
Plant trees around pens	✓	✓	
High cost practices			
Build more spacious cages	✓		
Increase the height of the roof in pens	✓	✓	
Build new pens with the direction of the sun in mind		✓	

Note: The practices in the tables are from first order codes.

3.6. Discussion

Commercial poultry farmers' perceptions that temperatures have been increasing over the last decade are validated by meteorological data trends. In a country like Nigeria where there are a limited number of meteorological stations, subjective views of changes in temperature could be used to identify what communities are experiencing at the local level. The use of these types of information can better inform the design of inclusive and comprehensive climate change adaptation strategies. Further, the incorporation of local narratives into decision making frameworks may even reveal subtle changes in climate that we may not otherwise identify from large scale meteorological data which could hide enormous variability (Aswani et al., 2015).

The cases used in the analysis were drawn from a representative sample of commercial poultry farmers but there is not an even distribution across types of farms. The selection of cases relied on two key criteria: 1) farms with more than 100 birds, and 2) farms which had been active for at least 15 years. This generated a total of six farms holding between 100 and 1,000 birds, seven farms holding between 1,000 and 5,000 birds and three farms holding more than 5,000 birds. The fact that we interviewed relatively few large farms compared to medium and small farms might have impacted the breadth of the findings. Nevertheless, this does not negate the validity of the accounts we collected among large farms. It simply means that our findings are conservative.

Small and medium farms appear to draw some of their desired adaptation practices from what large farms are already doing, while managers of large farms remained silent on what other adaptation practices they could implement. It is possible that the small number of large farms among the cases did not enable us to capture which additional adaptation practices large farms could implement in the future. On the other hand, large farms could be at the limit of their knowledge of adaptation practices. The organization of South-South exchanges with poultry farmers from other regions experiencing similar changes and using similar production systems could help tackle this apparent knowledge gap.

There are several stakeholders who stand to benefit from the findings of this work. This study recorded the vast array of adaptation practices currently being implemented across farm types. The in-depth interviews enabled us to capture what each of the farms are doing in response to higher temperatures. As such, it provides development practitioners, policy makers and extension agents with a better picture of what farmers are already doing and the state of adoption of adaptation practices across farm types. This information could be useful for addressing gaps in strategies aiming to support the poultry subsector deal with the effects of rising temperature. Poultry farms can also benefit from these findings by learning about what their peers are doing. Although the focus of this study is on commercial poultry farmers holding more than 100 birds, some of the adaptation practices implemented by small farms could be relevant for backyard poultry farms holding as few as 25-30 birds. This means that donor agencies like the Bill and Melinda Gates Foundation which is supporting rural women in Nigeria rear between 25-30 birds (African Farming, 2017) could incorporate the relevant adaptation practices into their training and extension toolkits.

One important finding of this study is that the types of adaptation practices vary by farm size. This indicates that the size of farms should be considered in the targeting of responses supporting farmers deal with higher temperatures, i.e. there is a need to design responses which are suitable at different scales of production. In addition, some of the existing low-cost adaptation strategies are not being widely implemented. The organization of educative campaigns could help raise farmers' awareness of their existence. Lastly, there is an opportunity for innovators and development practitioners to design low-cost solutions which can help the farms lagging behind better protect their investments in the face of increased heat stress.

3.7.Conclusion

Though climate change adaptation in agriculture is increasingly studied across the globe, most studies focus on crop farmers and large livestock owners. Using a case study methodology and in-depth interviews with a group of 16 commercial poultry farmers in southern Nigeria, we explored poultry farmers' perceptions and adaptation strategies to higher temperatures. This is the first study to our knowledge that uses this methodological approach among commercial poultry farms which have been active long enough to share their insights on these topics.

Poultry farmers perceive changes in temperature and are adopting strategies that they can afford. The study shows that poultry farmers clearly perceive that temperatures are increasing. The effects of these changes are noticeable on the farms through reduced productivity. This is because higher temperatures are linked to a drop-in egg production, increased mortality rates, and a higher incidence of disease.

The adaptation practices adopted by poultry farmers vary according to the size of their farms. All farms irrespective of size use cheaper practices such as reducing the stocking density of the birds. However, large farms can better protect their farms by adopting additional costlier methods such as building new chicken houses that enable better air circulation. In contrast to the small and medium farms, large farms can spread the costs of big investments across a larger number of birds. Farms' readiness to respond to the changes brought about by higher temperatures also include practices which farmers hope to implement in the future. Many of the small and medium farmers expressed the desire to adopt heat management measures which they haven't yet implemented for a diversity of reason including limited financial means or time. Some of these include cheaper practices like planting trees around the chicken pens or more expensive ones such as building chicken pens with better ventilation.

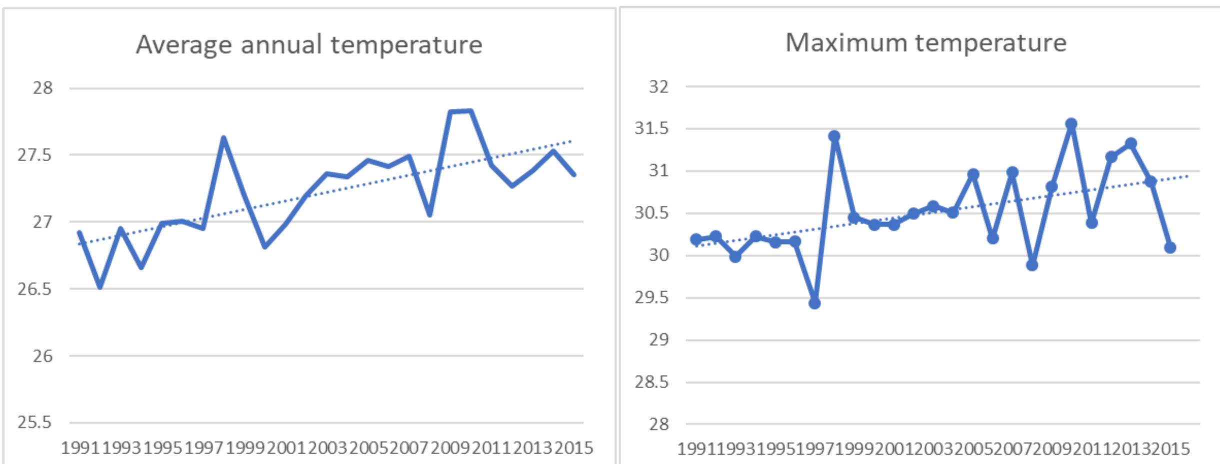
In all, this study demonstrates that poultry farmers are knowledgeable and are not passively enduring the adverse effects of higher temperatures. While all the farmers are aware of strategies to deal with heat, the small and medium farms have access to fewer options compared to the large farms. This implies that not all the farms will be able to make the changes necessary to adapt to higher temperatures without adequate support.

APPENDICES

APPENDIX 3A: CLIMATE TRENDS IN NIGERIA

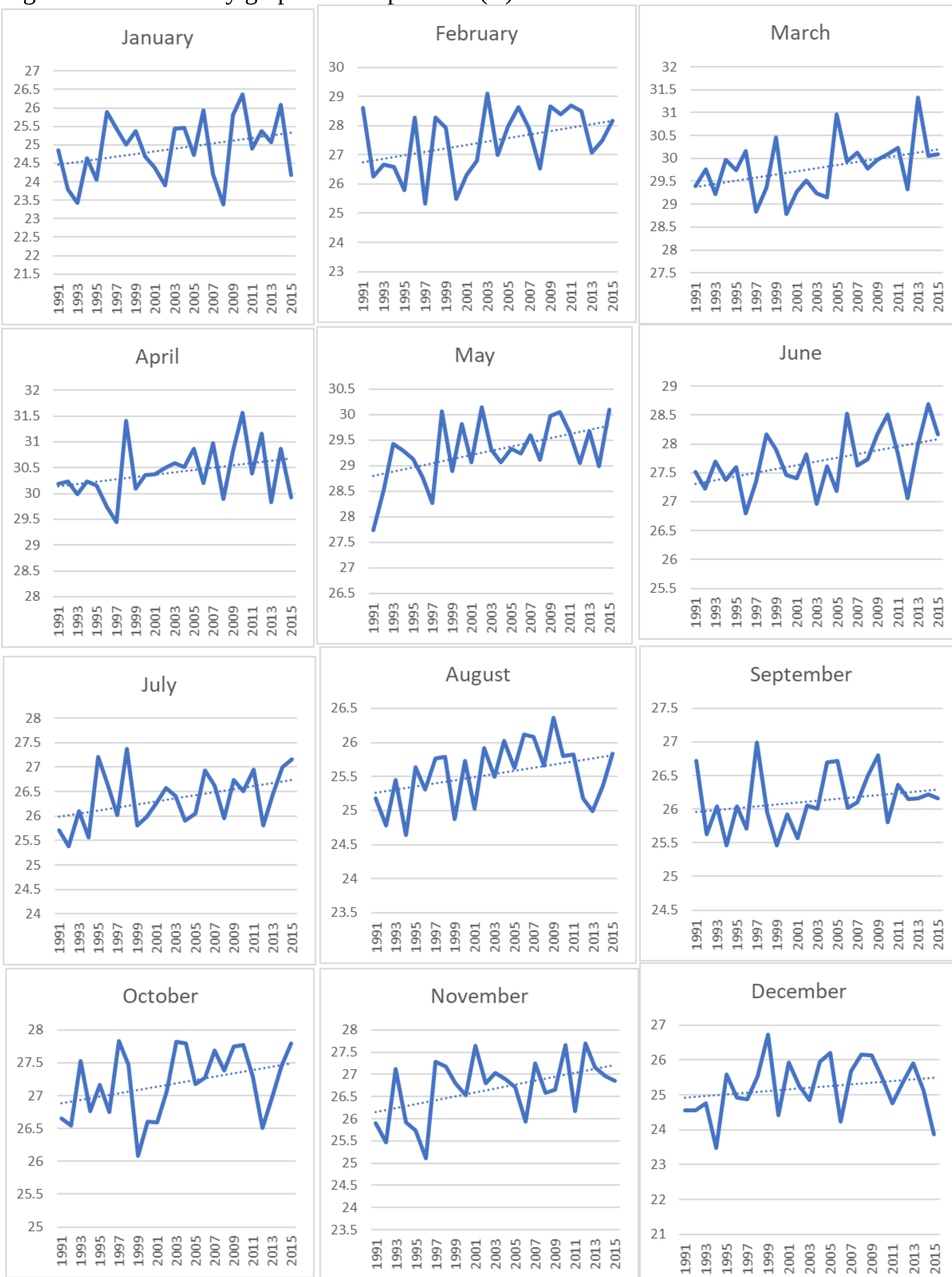
Using temperature data from the World Bank climate change knowledge portal we generate graphs showing the long-term trends. In the absence of data for the study region a look at the trends at the country level can be informative. In Figure 3A-1 and Figure 3A- 2, the increasing trend line for the average annual temperature as well as the maximum temperature between 1991 and 2015 shows that temperature is changing upward. The distribution of temperature across seasons in Figure 3A- 2 also suggests that this trend is maintained throughout the year.

Figure 3A-1. Average annual temperature (C) and maximum temperature (C) trends from 1991 to 2015



Source: Authors’ estimation using data from the World Bank climate change knowledge portal.

Figure 3A- 2. Monthly graphs of temperature (C) trends from 1991 to 2015



Source: Authors' estimation using data from the World Bank climate change knowledge portal.

APPENDIX 3B: INTERVIEW PROTOCOL

Thank you for your time to talk with me today. I am currently a member of a research team comprised of researchers at Michigan State University (MSU) in collaboration with University of Ibadan and Ahmadu Bello University. We are studying the poultry farming segment of the poultry value chain in order to make recommendations to policymakers and the private sector. The information will not be reported as individual, and thus will be fully anonymous, without identity revealed. If you have any concerns or questions after this interview, you can contact Mr. Iredele Ogunbayo at +234-807-307-0050 or doex310@yahoo.com. Do you wish to continue with the interview? ____ 1. Yes; ____ 2. No”

For our conversation today, I would like to find out what your experience has been raising chickens. The length of today’s conversation will depend on how much you would like to share. You can refuse to answer a question at any time. I’d also like to record this conversation with an audio tape so that I make sure to accurately reflect your thoughts and ideas. Is that alright with you?

After I finish recording, I will transcribe, type out, our conversation. All your identifying information will be removed from this transcript and it will not be shared outside of this research without your consent. Do you have any questions before I begin the recording?

Preliminary questions

- What is your name?
- How old are you?
- What is your role in the farm? (if not head of the household/farm manager, what is your relationship to the head of the household/farm manager?)

    - How long have you held this role?

- When did you start poultry farming? How many birds do you have on your farm now? What about when you first started?

First, tell me about what it takes to raise chickens on your farm now

1. What are the things involved in running your farm? [*items + skills required*]

Now, let's talk about your farm when you first started

2. What did you have on your farm when you first started i.e. what did it take then?
3. What are the main differences between when you first started and now?

Based on what you are saying, things are different between now and when you first started.

4. What led you to make changes in XYZ? [*XYZ refer to specific things that are different between when the farmer first started and now]*

Now, I would like us to talk about the challenges you face as a chicken farmer and your adaptation strategies [*probe to go beyond challenges related to cost of production and sales]*

5. Can you walk me through the different challenges you face currently?
    a. What are the causes of these challenges?
    b. What have you been doing to address each of them?
6. What were the challenges you faced when you first started?
    a. What were the causes of these challenges?
    b. What did you do to address each of them?

Finally, I would like to ask you some questions about a couple of things that did not come up until now

7. One of the objectives of this work is to find out how poultry farmers' perception of climate change affects their practices on the farm. We have heard from some farmers that the climate has changed over the past 20-30 years. What are some of your own observations?
    a. How has this affected how you run your farm now? [*in terms of management practices and technologies available on the farm*]
8. Over the last 20 years, did you face any problems on your farm that you associate to climate change?
    a. What were they and how many times did you have to deal with them over the last 20 years? When was the last time this occurred?
    b. Tell me the story of what it was like and the process of getting back on your feet after the event
9. Based on your own observation of changes in climate, what are you doing to prepare your farm for unexpected climate events in the future?
10. You mentioned that you use input X on your farm. Was there any time when you struggled to get it?
    a. If so, tell me story of what happened
    b. Why do you think this happened?

APPENDIX 3C: CODING RULES, DEFINITIONS AND EXAMPLES

Table 3A- 1. Coding rules, definitions and examples

	Definition	Rule	Example
Temperature patterns have changed	Temperatures are now warmer compared to the past and the harmattan season is hotter	Apply to any data where compared to the past, the interviewee describes higher temperatures, early start of high temperature during the day, increased intensity of heat, and warmer cold season	Hah! I am over 60. There are a lot of changes. You can predict rainy season and dry season. The weather wasn't as hot.
Effects of heat on the birds/farm	Impact of hotter days on the farm and birds that did not occur in the past	Apply to any data where the interviewee describes new challenges on the farm linked to hotter days, and increased intensity of heat	The birds react to heat as it does not allow them to eat. The heat starts by as early as 11am and lasts till 4pm during which that period the birds lack agility and are unable to eat.
Responses to heat/high temperature	Strategies that farmers undertake to respond to heat	Apply to any data where the interviewee describes strategies on the farm to deal with high temperatures, increased intensity of the heat	Regarding heat, what I do is to bring them out to where there is better ventilation or sometimes I will reduce the number of birds in each room to enhance ventilation
Desired response to heat	Strategies that farmers wish they can implement to deal with climate	Apply to any data where the interviewee describes strategies he/she hopes to implement in the future	The step I think one can take is to plant trees around.
Challenges in recent years	Description of any challenges on the farm	Apply to any data where the interviewee describes some of the challenges related to running a poultry farm	Number one challenge still remains capital, two is the prices of materials that we use like maize, soya (feed ingredients). There is no fixed price, the prices get skyrocketed at times. Before now, the highest price for maize per kilogram is 65 but now it varies between 95 naira to over 1000 naira per kilogram.

Table 3A – 1 (cont'd)

			Last year we bought maize over a 100 naira per kilo.
Responses to challenges	Responses to challenges not linked to climate	Apply to any data where the interviewee states some of the strategies he/she implements to deal with challenges on the farm	For instance, instead of using fish meal, we have decided to be using soymeal, as substitute to fish meal. We use plant proteins to replace animal protein, yet the cost is still high.

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4. INTRODUCING SAFETY LABELS IN COMPLEX FOOD SUPPLY CHAIN: EVIDENCE FROM A CHOICE EXPERIMENT IN NIGERIA

4.1. Introduction and motivation

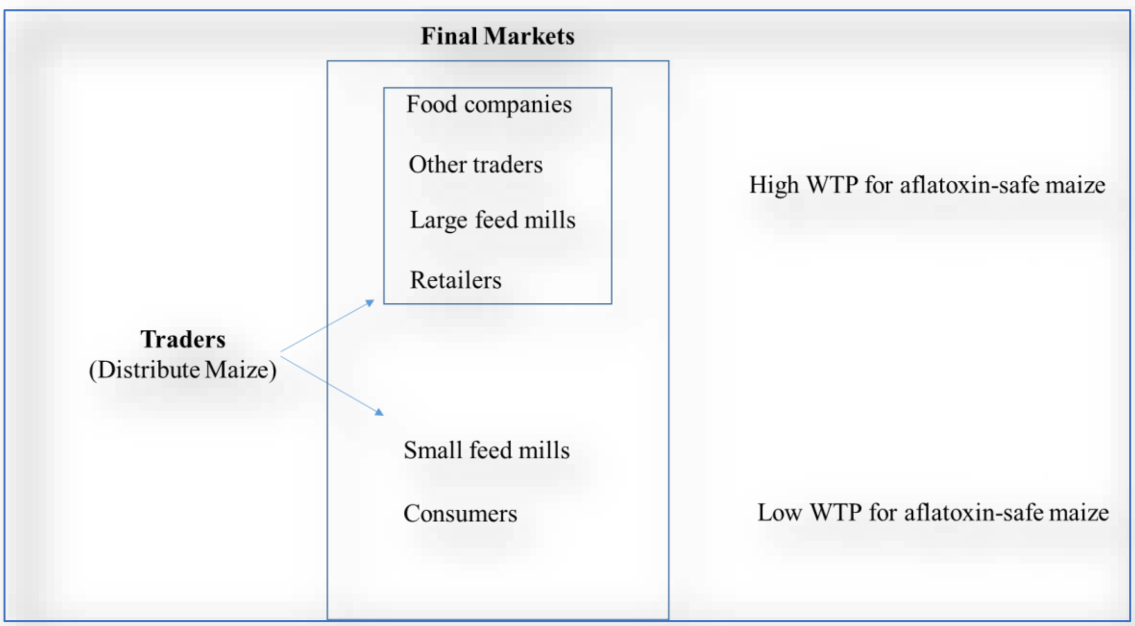
The public health and economic impacts of the poor enforcement of food safety regulations are often overlooked in developing countries. These effects are exacerbated when important attributes of food products are unobservable. For example, while consumers can use their judgement to evaluate insect infested grains, this becomes difficult or impossible when product attributes are invisible and/or tasteless (Hoffmann & Gatobu, 2014; Kadjo et al., 2016). This is the case with certain highly toxic poisons produced by *Aspergillus flavus* and *Aspergillus parasiticus* fungi called aflatoxins. While the growth of these fungi has been linked to hot and humid conditions on the field, poor storage practices, and the use of mechanical shelling and dehulling, aflatoxins can be present without visible fungal growth (Diedhiou et al., 2011; Fandohan et al., 2006; Hell et al., 2011; Prieto et al., 2017). This poses a global food health challenge as the consumption of aflatoxin-contaminated food has been linked to a host of human and animal health concerns. For humans, aflatoxins cause liver cancer (hepatocellular carcinoma, HCC) and has been linked to acute liver toxicity and immunotoxicity (Wu et al., 2014). Aflatoxins have also been associated with retarded growth in children (Wu et al., 2011). In animals, aflatoxin contaminated feed has health and productivity effects. In chickens for instance, the consumption of aflatoxin contaminated feed results in a reduction in weight, brittle egg shells, and decreased egg production (Bandyopadhyay, 2013)

Maize is an important crop across sub Saharan Africa (SSA). It is currently one of Africa's dominant food crops with about fifty different species (IITA, 2013). In addition to being a key food staple; accounting for 30% to 50% of low income household expenditures in East and

Southern Africa, maize is increasingly being used as an input for numerous industrial products such as livestock feed (IITA, 2013). Africa accounts for 7% of global maize production with Nigeria among the top two large producers (FAOSTAT, 2017). Seventy-eight percent of maize in Nigeria is said to be cultivated for human consumption (USDA, 2012). As incomes and urbanization have increased in the country, animal protein consumption has skyrocketed and Nigeria's demand for maize for feed has also dramatically increased. Between 2003 and 2015, the volume of feed used in Nigeria increased from 300 thousand to 1.8 million tons; a 600% increase(Liverpool-Tasie et al., 2017b). This increase in direct and indirect demand for maize raises important challenges related to food safety as maize is one of the commodities in Africa typically affected by aflatoxins (Kimanya et al., 2008).

While Nigeria has established standards on the acceptable levels of aflatoxin in maize, there is limited enforcement of these standards and no market mechanisms to encourage their enforcement for consumers (SON, 2008). Furthermore, there is limited knowledge among direct maize consumers about aflatoxins and the dangers of consuming aflatoxin contaminated maize products. In a study of consumers in an open market in South West Nigeria, found that less than 10% of consumers had heard of aflatoxins and only about 5% had some knowledge about what aflatoxins really were. This limited awareness results in the absence of a known premium tied to the supply of aflatoxin-safe maize products. However, certain indirect consumers of maize have a clear preference for high quality maize. For example, industrial food processors and major livestock feed producers are very particular about the quality of their product and hence its inputs (Moser & Hoffmann, 2015). Reasons for this include export considerations as well as traceability and brand reputation (Moser & Hoffmann, 2015). Consequently, this study capitalizes on the heterogeneity in preferences for maize attributes related to food safety to explore the potential for a market-based solution to provide aflatoxin-safe maize to consumers. We use a discrete choice experiment survey conducted with maize traders (wholesalers) in Nigeria. Maize traders provide a unique opportunity to explore this topic because they sell to a broad variety of buyers including other wholesalers, maize retailers, food companies, small and large feed mills and household consumers (see Figure 4.1). Since different kinds of consumers have different incentives and/or reasons to care about certain attributes for maize (including quality and safety), this creates differential incentives for their maize supplier (maize traders) to also care about these attributes. Thus, we explicitly explore if maize traders are willing to pay a higher price for an aflatoxin-safe product and if this willingness to pay varies with the expected (or known) demand for the same by their buyers.

Figure 4.1. Marketing channels of maize traders and hypothesis on WTP for aflatoxin-safe maize



This paper makes three key contributions to the literature. First, this is the first study, to our knowledge, that uses discrete choice experiments among actors along the supply chain other than producers or consumers. In general, the food safety literature tends to focus on either producers, located at one extreme end of the supply chain (upstream), or consumers located at the other extreme end (downstream). Very limited attention is given to key actors in the midstream of the value chain that are instrumental for the efficient interaction between upstream and downstream. These actors located in the midstream of the value chain such as traders and processors are often overlooked. The value chain literature refers to them as the hidden middle because though they are dynamic and important for the operation of the supply chain, they are absent in the research and policy debate (Liverpool-Tasie, Reardon, et al., 2018).

Second, this paper contributes to the scant literature on market-based mechanism for the provision of safe food; aflatoxin-safe maize in this case. This study investigates maize traders' willingness-to-pay for aflatoxin-safe maize based on the marketing channel they sell to. The supply of aflatoxin-safe maize by traders is predicated on the assumption that there is a demand for this feature on the part of their buyers. Accordingly, we hypothesize that a wholesaler's willingness to pay (WTP) for aflatoxin-safe maize depends on their buyer. One of the means of signaling the aflatoxin levels to buyers is to use certification labels on tested maize. Thus, we design a hypothetical discrete choice experiment in which one of the attributes of maize is aflatoxin-safe certification. This method is appropriate since we are interested in valuing traders' demand for an attribute that is not yet available in the market.

Third, this is the first study to, our knowledge, that simultaneously evaluates WTP for aflatoxin-safe maize and low moisture content. Low moisture content is often used in studies as an incomplete measure of the absence of aflatoxin in products. Consequently, it is worthwhile undertaking to investigate how the WTPs for these two attributes compare. This means that we are able to provide additional insights on the value of introducing aflatoxin-safe certification despite the existence of a proxy.

The paper proceeds as follows. Section 2 summarizes the literature on market access and food safety issues in developing countries with an emphasis on studies that have used the choice experiment methodology. Section 3 describes the conceptual approach and the research hypotheses while section 4 covers the data and methodology. Section 5 presents the analysis of the data and the results are presented in section 6. The last section concludes.

4.2.Market access and food safety

The lack of enforcement of food safety regulations in developing countries generates economic losses through limited access to export markets and a substantial burden of disease (Hoffmann & Jones, 2018). However, as incomes and the urban middle class grow, it is expected that consumers will increasingly demand safer food (Ortega & Tschirley, 2017). In China, for instance, consumers have strong preferences for food safety labels and certifications, regardless of the types of retail channels (traditional wet market, domestic and international supermarket)(Ortega et al., 2015).

For observable attributes, it is usually easier to impose penalties for the sales of low quality products. Kadjo et al. (2016) examine how insect damage affects the prices of maize in Benin. The authors found that buyers discount maize prices for grains that are damaged by insects. There is an inter-season variability in the discount rate applied to damaged grain that decreases as the planting season gets closer and the levels of stored grains are low. Some key players along the food value chain such as food processing companies are careful to provide food items that comply with safety regulation for fear of losing their customer base (Moser & Hoffmann, 2015). Other actors along the food value chain do not behave similarly when the attributes are unobservable.

For credence attributes, which are unobservable to buyers, the use of food safety certifications and/or labels can facilitate the enforcement of food safety regulations or reward those who supply such goods to the market. Consumers who are concerned about food safety tend to be more knowledgeable about certification schemes (My et al., 2017). In addition, several studies evaluate preferences for food safety labels different demographic groups. Ifft et al. (2012) examined Vietnamese consumers' willingness to pay for safely produced free-range chicken. They found that there is a 10-15 percent premium associated with a safety label. The provision of a price premium has been shown to promote the adoption of aflatoxin control practices among commercial farmers. In Kenya, Hoffman (2018) examines differences in adoption rates for a post-harvest technology among subsistence and commercial farmers. Behavior differs between farmers who grow maize for their own consumption and those who sell it. Farmers who consume the maize they produce are more likely to invest in the technology compared to those who sell it. However, the proportion of maize sellers who adopt the technology increases once they can sell the said maize at a higher price. These are both consistent with the idea that this study explores; i.e whether knowledge (and consequent incentives (personal health or a price premium) translates into low WTP for aflatoxin-safe maize.

When given full information about the attributes of maize, consumers demonstrate a higher willingness to pay for maize that does not threaten their health. For instance, smallholder farmers in Western Kenya value more the unobservable quality and safety attributes of self-produced maize compared to maize purchased on the market (Hoffmann & Gatobu, 2014). Self-produced maize benefits from a 21 percent price premium compared to maize available on the market. This coincides with earlier findings that showed that in the Kenyan context, self-produced maize has lower levels of aflatoxin compared to commercial maize (Hoffmann et al., 2013). In Nigeria, there is room for availing of the advantages of providing information because very few consumers are aware of the negative health impacts of aflatoxin (V Caputo & Liverpool-Tasie, 2018).

Many of the studies that estimate buyers' willingness to pay for food safety labels use discrete choice experiments because the attributes of interest do not exist in the market. This method enables researchers to analyze consumers' preferences toward hypothetical goods. The extant literature on preferences for aflatoxin-safe products tends to focus on household consumers or producers. Table lists preference studies that have examined individuals behavior in relation to aflatoxins. Johnson (2017) estimated poultry farmers and feed millers' WTP for aflatoxin-safe maize in Nigeria using discrete choice experiments. Although the study found that these stakeholders are willing to pay a price premium for aflatoxin-safe maize, agribusinesses possessing prior knowledge of aflatoxin pay a lower price premium compared to those without any knowledge. In that situation, prior knowledge of aflatoxin increased confidence in existing aflatoxin contamination prevention practices (Johnson, 2017).

Some other studies estimate traders' preferences for low moisture content. This is because moisture content is a sign of maize quality and can be a proxy for aflatoxin-safe products. The growth of the fungi responsible for aflatoxin contamination is favorable when the moisture content is above 13 percent (McCoy et al., 2016; Prieto et al., 2017). Additionally, it is also much cheaper to measure moisture content than to measure aflatoxin levels in maize.[21] McCoy et al. (2016) estimate maize traders' WTP for low moisture content in maize using experimental auctions. They found that maize with less than 13 percent moisture content enjoys a price premium among traders. Similarly, Ordonez (2016) estimates maize traders' WTP when provided with moisture content

[21] As an aside, it is worth noting that a low level of moisture content does not prevent the growth of the fungi in maize grains.

labels. The results suggest that those who value lower moisture levels in maize exhibit the highest willingness to pay. The estimated WTPs are even higher when the respondents know that they can receive a purchasing price premium on the market. In addition, the WTP for aflatoxin-safe maize was the double of what the study estimated for low moisture content. This result is not surprising given that the presence of aflatoxin is a stronger signal of exposure to serious health risks.

Table 4.1. Preference studies on aflatoxins

Study	Location	Population of interest	Attribute of interest
Hoffman and Gatobu (2014)	Kenya	Maize farmers	Aflatoxin
McCoy et al. (2016)	Senegal	Maize traders	Moisture content
Ordonez (2016)	Kenya	Maize traders	Moisture content and aflatoxin
Johnson (2017)	Nigeria	Poultry farmers & feed millers	Aflatoxin

4.2.1. Trust in certification schemes

The credibility of a food safety certification is uncontestably important for take-up among buyers. For a certification label to be effective, consumers must trust it. Studies in developing countries have shown that consumers pay attention to the entity that issues the health and food safety certification. One study used GlobalGap certification, a third-party certification mechanism available to Indian exporters for European markets. They found that by providing consumers with knowledge about food safety and certification labels for grapes they prefer labelled grapes to non-certified ones (Birol et al., 2015).

Additionally, whether the certification is domestic or international also matters. In India, in studying consumers' willingness to pay for high-iron pearl millet, Banerji et al. (2016) found that consumers prefer an international certification agency to a state-level one. For the certification of safety, quality and nutrition attributes in food items such as fruits and vegetable, Vietnamese consumers trust the government the most (Umberger, 2018). In Thailand consumers exhibit a high willingness to pay for both government and private food safety labels for cabbage, indicating that they treat both entities as equally credible (Wongprawmas & Canavari, 2017). The existing literature provides some insights on how different groups evaluate food safety and the need to explore which types of certification schemes that are likely to work in a particular context. This study explicitly explores this issue for the study context, Nigeria.

4.3.Conceptual background and research hypotheses

Post farm-gate, maize wholesalers perform the first quality check and then ensure the distribution of the commodity to various buyers. This makes them a force to reckon with in terms of actions aimed at enforcing aflatoxin regulations in Nigeria. The maize wholesalers in this study tend to procure the maize directly from farmers at different markets. Then they sell to a variety of buyers including other wholesalers, maize retailers, food companies, small and large feed mills and household consumers. Their activities extend beyond their primary locations as some of the traders based in the North supply maize to customers in the South.

To reiterate, traders are the primary link with different categories of subsequent buyers including feed mills, consumers, the food industry, retailers, other wholesalers (see Figure 4.1). Additionally, maize traders could be instrumental in reducing the risks of aflatoxin contamination. For instance, they can adopt some post-harvest strategies such as proper sorting, drying, and storage to reduce the risk of aflatoxin contamination (Wu et al., 2014). As noted earlier, different types of maize buyers have different levels of knowledge about and subsequent interest in the quality of maize that they procure. In this study consumers are individuals who buy maize for their own consumption. They care about the moisture content of the grain because they associate high moisture content with probability of mold which they recognize as not being suitable for human consumption. Small feed mills are usually established in neighborhoods and they cater to relatively small farms (poultry, pigs, etc.) and households rearing livestock. The feed they sell is not branded and they tend to have less stringent quality requirements. The maize they procure is often used to make feed for customers, like poultry farmers and pig breeders, who seek out cheap feed (often of lower quality) for their animals. Together, consumers and small feed mills form a category of buyers who are likely not aware of aflatoxin nor its negative health impacts. In turn, the maize trader does not have an incentive to offer them high-quality maize, including aflatoxin-safe maize.

Retailers buy the maize in bulk from wholesale traders and then sell it in smaller quantities to different types of buyers such as household consumers, small feed mills and others. In some of the markets, retailers behave as wholesalers because of the large volumes of maize they supply to some of their buyers. This means that they are likely to deal with customers who care about the quality of the maize they buy, including aflatoxin-safe maize. Their repeated interactions with these buyers create an incentive to protect their reputation by offering them high-quality maize.

Large feed millers tend to buy maize to produce branded animal feed or feed for their own farms if they are part of a vertically integrated poultry farm. They care about providing high quality feed to their birds or building trust in the quality of their product among their customers. As such, feed millers pay attention to the cleanliness and the moisture content of the maize they procure. Unlike the other nodes, feed mills can use a binding chemical which can be mixed with maize during the production of feed to reduce the absorption of aflatoxin by the digestive system of the animal (Johnson, 2017). This is likely to have some implications on how this node will value aflatoxin-safe certification in the study. Like large feed mills producing branded feed, food companies care about the reputation of their products among their customers. In Kenya for instance, Moser and Hoffmann (2015) found that aflatoxin contamination rates were lower for higher priced maize flour. This is because some manufacturers invest more in food safety in fear of losing reputational capital. Food companies in Nigeria pay attention to the cleanliness and moisture content of the maize they procure. Some of them run a series of tests on the maize before purchasing it. The exact nature of the tests is often unknown to traders but some wholesalers reported having some of their lot of maize rejected because it did not meet the internal standards set by these companies.

Maize wholesalers who buy from other traders, as opposed to those who buy from farmers, tend to re-sell the commodity to large feed millers and food industry companies. Some of them are even brokers for specific food companies. Just like the large feed mills and the food companies, they do not buy maize that does not meet certain cleanliness requirements and moisture-content levels. The lack of labels guaranteeing that the maize meets certain standards means that many of the retailers, large feed mills, food companies and other large traders tend to rely on their repeated interaction with the trader for obtaining high quality maize. That is, they rely on the maize trader to supply them with the best quality of maize in the lot because they tend to procure large quantities of maize. Such a behavior is plausible for a profit maximizing trader who wants to secure the continued patronage of a large buyer. In addition, since maize traders are aware that large feed millers and food companies conduct tests of maize quality prior to disbursing payments they have an incentive to procure them with good quality maize.

The categories of maize buyers that we have laid out have different quality and preference requirements for the grain. This serves as the basis of the hypotheses that are tested for each category of buyer in the maize value chain. First, we hypothesize that

H_1: Willingness to pay for aflatoxin-safe maize varies depending on a traders marketing channel and final buyer.

H_2: Traders' WTP for aflatoxin-safe maize does not vary across marketing channels.

This hypothesis which is depicted in Figure 4.1 captures the idea that traders who largely sell to other large traders, retailers, the food industry and large feed mills are likely to pay a higher price premium for aflatoxin-safe maize compared to those who sell to small feed mills, and consumers. We first test this hypothesis using the volume of sales traders make to different channels to categorize them. As an alternative, we also estimate traders' WTP for aflatoxin-safe maize categorizing them based on their perception that some kinds of buyers will pay a price premium rather than on their actual sales to those kinds of buyers, Again, we expect that traders who perceive that their buyers will pay a price premium for aflatoxin-safe maize will have a higher WTP for aflatoxin-safe maize compared to those who do not. We can restate the hypothesis above formally as:

H_3: Traders who perceive that particular kinds of buyers will pay a price premium for aflatoxin-safe maize have a higher WTP for aflatoxin-safe maize compared to those who do not.

H_4: Traders' WTP for aflatoxin-safe maize based on their perceptions does not vary across marketing channels.

In line with the incentives of the different marketing channels discussed above, we expect that traders who perceive that other traders, food companies, large feed mills and retailers will pay a higher price premium than those who do not. The use of traders' perception enables us to estimate their WTP for aflatoxin-safe maize even if they do not currently sell to a particular marketing channel. Even if a trader does not sell to any of the four marketing channels of larger buyers, they are likely aware of this information from their interactions with other traders and/or their knowledge of how these buyers operate. For this reason, we hypothesize that the belief that a buyer belonging to any of the four-marketing channel will pay a price premium translates into a trader exhibiting a higher WTP compared to one who does not.

Finally, we examine traders' trust attitudes toward different certification programs. As noted earlier, trust attitudes towards certification programs also have an impact on their successful implementation. Studies have found that individual may trust local or foreign sources of certification (Banerji et al., 2016; Umberger, 2018; Wongprawmas & Canavari, 2017). In Nigeria, one study found that that when consumers trust the quality of a local product, they prefer it to a comparable product that is imported (V Caputo & Liverpool-Tasie, 2018). Cases of distrust in foreign health products like vaccines have also been reported in the Northern part of the country (Ghinai et al., 2013; Obadare, 2005). Together, these studies seem to suggest that a domestic certifying agency might carry more weight than a foreign one in Nigeria. Consequently, we hypothesize that traders are more likely to trust an aflatoxin-safe certification program implemented by a domestic certifying entity over a foreign one. This hypothesis can be written formally as:

$\mathbf{H_5}$: Traders are more likely to trust a certification program implemented by a domestic certifying agency over a foreign one

$\mathbf{H_6}$: There is no difference in trust attitudes towards certification programs implemented by a domestic certifying agency and a foreign one.

Transactions in maize wholesaling tend to be governed by informal agreements built on trust. Trust plays a major role in the way traders conduct their businesses and evaluate new opportunities. The certification program can be implemented by different agencies including a local university or research institute, a local regulatory agency, or a foreign entity. We expect that many of the traders trust a certification program implemented by a domestic regulatory agency like NAFDAC (instead of other entities). That is because many wholesalers trust that NAFDAC, as opposed to other entities, is appropriately equipped to carry out this task. In effect, NAFDAC is considered as a trustworthy entity in the country because it already certifies common consumer items, such as sachet water, that are bought by many traders.

4.4.Materials and Method

4.4.1. Choice experiment: selection of attributes and attribute levels

The characteristics of the product, maize, were chosen to reflect the information contained in a large survey of maize traders conducted in Nigeria between May and June 2017, three months prior to the experiments (see Liverpool-Tasie, Reardon, et al. (2018) for more details on the survey). This survey captured the characteristics of the maize being traded, maize traders' demographic characteristics, and their buying and selling behavior throughout the year. The attributes of the product were therefore selected based on interaction with key informants, a thorough review of the literature and a descriptive analysis of the survey data. The final set of attributes of the product include color, price, moisture content and aflatoxin-safe label (see Table 4.2)

Table 4.2. Attributes and attribute levels in the choice experiments

Attributes	Description	Attribute levels
Price*	Purchase price (in Naira/100 Kg)	Plateau state: ₦ 7,800, ₦ 8,800, ₦ 9,800 Oyo state: ₦ 10,500, ₦ 11,500, ₦ 12,500,
Certification	Aflatoxin safe maize	Maize is certified below 4ppb for total aflatoxin, not certified
Moisture level	The acceptable level of moisture content to avoid fungal growth is 13%	Low (<13%), medium (14-15%), high (17-19%)
Color	Yellow maize is for human and feed consumption while white maize is for human consumption only	Yellow, White

Note: The price attribute has different values for Oyo and Plateau state because they reflect differences in actual market prices. 4 ppb of total aflatoxin is the allowable level set by the Standards Organization of Nigeria (SON)

To choose the levels of the color attribute, we examined the survey data and the literature. Maize wholesalers mostly deal with yellow and white maize. Yellow maize is produced for both the feed industry and direct human consumption while white maize is exclusively reserved for human consumption (FAO, 2013). This indicates that wholesale markets mostly offer two options for the color attribute in combination with other attributes. It is possible that a maize wholesaler caters to both types of customers. Therefore, yellow and white are the levels of the color attribute.

The price attribute in the choice sets is per 100-kilogram (Kg) bags because that is the unit in which maize is traded in wholesale markets. The lowest price represents the base price, which reflects the average market price prior to the start of the experiment. The other two levels capture possible premiums associated with the aflatoxin-safe certification. There are two price vectors in this experiment to capture differences in actual maize prices on the markets included in the experiment. We visited markets in Plateau and Oyo states. The northern part of Nigeria where Plateau state is located produces the bulk of the maize in the country. This maize is then transported to the southern part of the country where Oyo state is located. On average the price of maize is lower in Plateau state compared to Oyo state. To reflect this difference in the experimentally designed products, we used two price vectors.

Moisture content is also an important attribute in maize markets in Nigeria. This is aligned with the behavior found among maize traders in West Africa (Bakoye et al., 2017). The regulation of moisture content also happens to be the principal means to avoid the development of fungi in maize (Hell et al., 2011). To avoid fungal growth during the storage stage, it is recommended that farmers dry maize within three days of harvest to less than or equal to 13.0 percent of moisture content (McCoy et al., 2016). High moisture content in maize during storage also increases the likelihood of the growth of the mold that causes aflatoxin. Consequently, it is important to estimate wholesalers' preference for this attribute they are already familiar with. The levels chosen are comparable to those in McCoy et al. (2016). The first level (low) is related to the ideal moisture content to avoid fungal growth, while the second and third levels are both favorable to the development of mold but capture distinct moisture-content levels.

Aflatoxin-safe certification is the attribute that does not exist on Nigerian maize markets. Certification for aflatoxin-safe maize is potentially an important attribute among maize wholesalers. A trustworthy certification program is likely to reduce wholesalers' transaction costs and facilitate the supply of aflatoxin-safe maize to buyers who pay a price premium for this attribute. Several studies have examined the level of aflatoxins in maize in West Africa, including Nigeria. These studies tested aflatoxin levels in maize samples on the farm, market, and along the maize chain. In a study to detect aflatoxin levels in maize samples in Nigeria and Ghana, Perrone et al. (2014) found that 54% of farm sample (30 % of market samples) were contaminated, with the mean total aflatoxin level ranging from 0.5-480 parts per billion (ppb) for market samples to 0.1-1900 ppb for farm samples. Liverpool-Tasie, Turna, et al. (2018) tested aflatoxin levels in maize samples collected along the maize value chain. Seventy-five percent of farmer-stored maize had total aflatoxin levels above 4ppb, 90 percent of the feed had total aflatoxin levels above 20 ppb and branded and non-branded maize-based food products had total aflatoxin levels above 4ppb. These ranges are considerably above the allowable levels of below 4 ppb for total aflatoxins (B1, B2, G1, G2) set by the Standards Organization of Nigeria (SON) for human consumption and the limit of 20ppb set by the United States Food and Drugs Administration (USFDA) for animal consumption (Liverpool-Tasie, Turna, et al., 2018). In the choice experiment, we used two levels for the certification scenario. One level corresponds to the presence of a label signaling that total aflatoxin content is below 4 ppb, and the other is the absence of such a label.

4.4.2. Experimental design and survey procedure

Basic descriptive statistics from the traders' survey revealed that there is very little differentiation in maize via branding or other maize characteristics. For this reason, we use unlabeled alternatives, that is the products presented to the respondents did not have any meaning attached to them such as the name of a commonly known brand. With unlabeled experiments there is no need to capture the universe of alternatives available to traders because a single generic alternative (or product) can capture many specific ones. In choosing the appropriate type of experimental design, we considered the behavior of interest (willingness to pay for maize certified to be aflatoxin safe) and subsequent effects that the experiment aims to recover. We opted for an orthogonal optimal in the difference fractional factorial design, also known as D-optimal design. This design assumes that all attribute parameter priors are simultaneously equal to zero and defines optimality in terms of the differences in levels for the same attribute across alternatives. We did not implement a pilot experiment to recover priors because of logistical considerations. Furthermore, the maize markets we visited for this experiment have unique characteristics that would not have been captured in a pilot conducted in other markets. The traders in Plateau markets have a unique history of selling maize to large feed mills and the food industry while those in Oyo state cater to the growing number of small feed mills in the region.

The choice experiment questions were generated following the procedures suggested by Street and Burgess (2007). More specifically, two steps were undertaken. In the first step, we used the selected attributes and attribute levels earlier described to perform an orthogonal fractional factorial design. The design resulted in 36 choice tasks only including the first alternative i.e. a profile of the product including all the attributes. In the second step, we generated the second alternative from the 36 alternatives obtained in the orthogonal design by using the generator (1, 1, 1, 1). This generated a total of 36 choice tasks comprised of two experimentally designed alternatives. To reduce the incidence of respondent fatigue, the 36 choice sets were divided into six sets of six choice sets called blocks. Each trader was randomly assigned to one of the six blocks and faced six choice tasks. The six blocks are later pooled at the analysis stage to preserve the properties of the orthogonal fractional factorial design. Overall, each choice task comprised two experimentally designed alternatives or purchase options (i.e. where each of the attributes are not empty), and one no-buy alternative or opt-out option. To further improve respondents' understanding of the choice tasks, illustrated visual aids were used. A sample choice set is shown in Figure 4.2. Each respondent had to choose one option from the three alternatives.

Figure 4.2. Example choice task for Plateau state

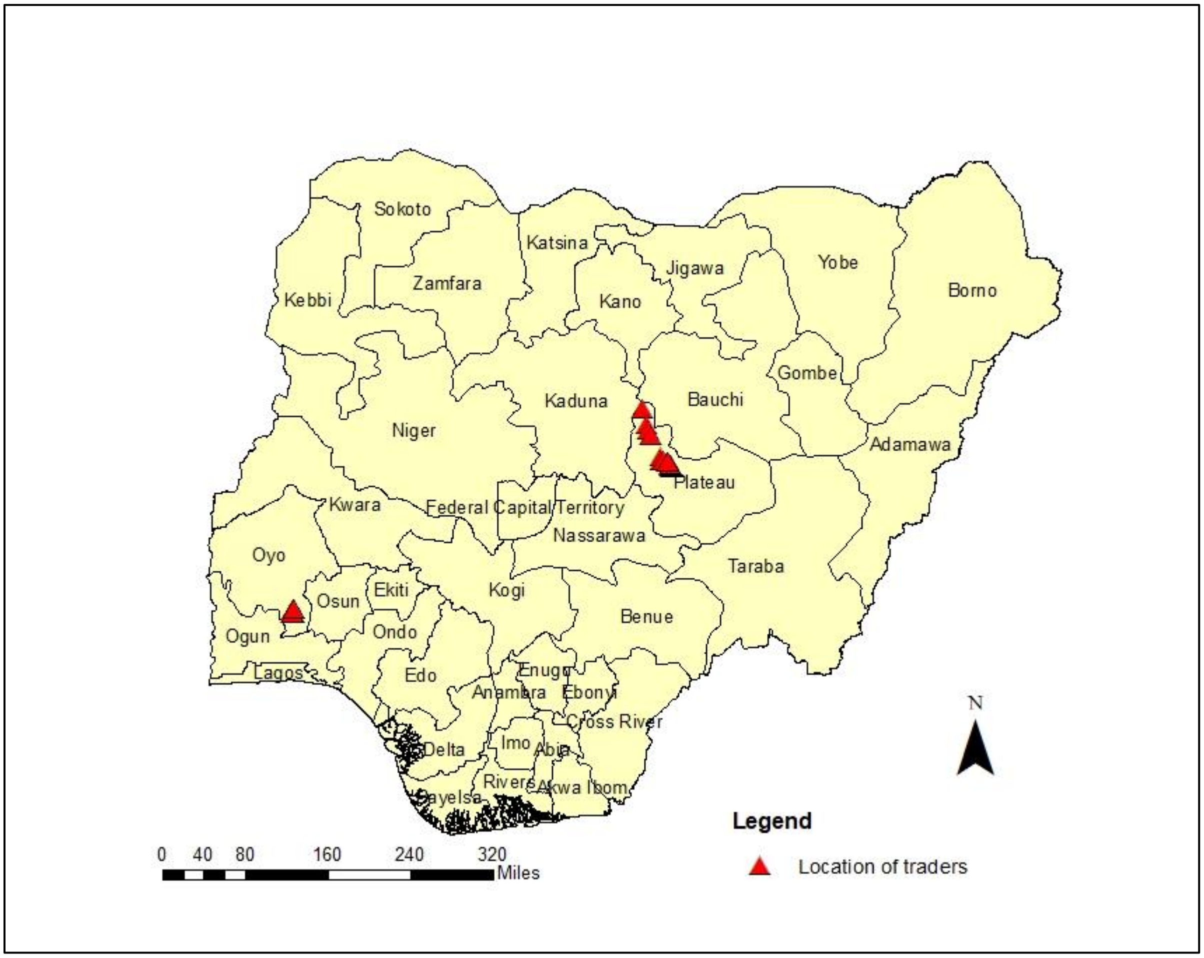
	Alternative A	Alternative B	None of these
Price (Naira/100 Kg)	**₦9,800**	**₦7,800**	Neither A, nor B. I would not buy
Maize is certified below 4 ppb for total aflatoxin	 **Yes**	**No**	
Moisture level	 **Low (<13%)**	 **Medium (14-15%)**	
Color	 **White**	 **Yellow**	
			CEB1_1

In addition to the choice task, we collected information on traders' demographic and socio-economic characteristics, as well as their procurements and sales behavior. The questionnaire administered along with the choice experiment gathered information on traders' maize-handling practices and knowledge of aflatoxin. The survey and choice tasks were administered with traders in maize markets on days designated as market days. In each market, the first step was to get in touch with the head of the market to explain the objectives of the survey and obtain the necessary permission. We were given access to all the markets included in our sample. Next, to identify the traders, we called those with working phone numbers (obtained from the list of traders secured through the larger survey exercise (citation) and/or asked other traders to help us locate them. Further, to ensure that choices were made under comparable knowledge levels about aflatoxins, each respondent was provided the following information: "*Aflatoxins are mycotoxins produced by a family of molds called Aspergilus. In Nigeria, it is very common in maize and groundnuts. The growth of aflatoxins can start during maize production and continue in storage under certain environmental conditions such as high moisture or if the maize is infested with insets. The contamination is possible without visible signs of the mold. Consumption of food contaminated with aflatoxins have been associated with disease and death in poultry and humans.*"

4.4.3. Sampling

The choice experiment was implemented with maize wholesalers in Oyo and Plateau states between February and March 2018. A listing of traders in city and regional markets was conducted in both states. In Oyo state, a listing of the traders in the Ibadan region constitutes the universe included in the sample as there are no regional maize markets. In Plateau state, the listing exercise identified traders in both city and regional markets. A census of all the traders in city markets was conducted. From the top five regional markets in Plateau state, 30 traders were randomly selected. This resulted in a total of 128 traders in Oyo and 207 traders in Plateau state (see Figure 4.3). For the discrete choice experiment, we visited all the traders included in the original trader survey. However, due to non-responses the sample for this analysis includes 193 traders in Plateau state and 122 traders in Oyo state.

Figure 4.3. Map of the location of traders



4.5.Data Analysis

The choice experiment approach is consistent with Lancaster's theory of consumer choice. According to this theory, individuals derive utility from the characteristics or attributes of the goods rather than just from the goods themselves (Lancaster, 1966). The econometric model is based on McFadden's random utility theory, which describes discrete choices in a utility maximizing framework (McFadden, 1974). Let U_{njs} denote the latent indirect utility that trader n will derive from alternative j (one of the three alternatives in each choice task) and in choice situation s (one of the six choice tasks presented to the trader). This utility may be partitioned in an observed or modelled component, V_{njs}, and an unknown stochastic component, ϵ_{njs}, such that:

$$U_{njs} = V_{njs} + \epsilon_{njs} \quad (4)$$

Assuming V_{njs} is linear in parameters, the functional form of the utility function for alternative *j* can be expressed as:

$$V_{njs} = \boldsymbol{\beta X}_{njs} \quad (5)$$

where $\boldsymbol{X}_{njs}$ is a vector of observable attributes and attribute levels, and $\boldsymbol{\beta}$ is the corresponding vector of parameters to be estimated; ϵ_{njs} is an unobserved error term, which is assumed to be independent and identically distributed (iid) extreme value type I. In this study, V_{njs} can be expressed as follows:

$$V_{njs} = ASC + \beta_1 Price + \beta_2 Price * Oyo + \beta_3 Color + \beta_4 Low\ Moisture + \beta_5 High\ Moisture \quad (6)$$

where *price* indicates the maize price in Plateau state; *Price*Oyo* is an interaction term between the price and a dummy variable equal to 1 if the survey took place in Oyo; *Color* is a dummy variable equal to one if the maize is yellow and zero otherwise; *Low Moisture* and *High Moisture* are dummy variables equal to one if the moisture level is low and high respectively (medium moisture is the base).

Depending on the assumptions about the functional form of equation (2), distributional assumptions of taste variation (traders' preferences over the alternatives), or the distribution of ϵ_{njs} in equation (1), alternative econometric models can be estimated. We noted earlier that each trader faces six choice tasks. The panel data thus generated is subject to correlation among trader preferences in the six choice sets. To account for this, the study incorporates random taste heterogeneity instead of homogeneous preferences (which assumes that there is no variation in preferences over alternatives in each choice situation). By adopting this approach , we capture correlations in the observed characteristics of the traders among alternatives in each of the six choice situations (Train, 2009). In other words, we use observed data to explain unobserved effects that are correlated among alternatives and across choice situations among the sample of maize traders. This is done by allowing for correlation over these alternatives and choice situations.

In this study, the analysis was conducted using the mixed logit (MXL) model (or random parameter logit model (RPL)) (Train, 2009). The MXL allows us to account for random taste variation among the traders, and correlation patterns. It also relaxes the IIA assumption which is defined below. Formally, mixed logit models allow a continuous representation of heterogeneity whereby the utility parameters vary randomly over individuals (Adamowicz & Swait, 2011). Following Train (2009), the conditional probability of choice in the MXL model for each time period $\mathbf{i} = \{i_1, \ldots, i_T\}$ is given by the product of logit formulas:

$$\boldsymbol{L}_{n\mathbf{i}}(\beta) = \prod_{t=1}^{T} \left[\frac{\exp(\beta'_n x_{nit})}{\sum_{j=1}^{J} exp(\beta'_n x_{njt})} \right] \tag{7}$$

Since we do not observe β_n but know the density $f(\beta_n|\theta)$, following Train (2009) we can derive the unconditional probability that the individual chooses an alternative as the integrals of standard logit probabilities as below:

$$P(y_n|\theta) = \int P(y_n|\beta_n) f(\beta_n|\theta) \; d\beta_n \tag{8}$$

In the mixed logit model the distribution of β is specified to be continuous. The choice probabilities therefore depend on θ and not the values of β. It is common to specify the integral of $f(\beta_n|\theta)$ (and not closed form) to have a normal or lognormal distribution and use simulations to estimate the model.

The advantages of the mixed logit model are linked to the limitations of the multinomial or conditional logit model (MNL) model. As a reminder, the MNL relies on a more restrictive set of assumptions. It assumes that preferences are homogeneous across respondents meaning that it does not capture systematic taste variation. It also has the independence of irrelevant alternatives (IIA) property which states that the choice made when presented with one set of alternatives is independent of the one made under a different set (Adamowicz & Swait, 2011).[22] First, the MXL enables us to obtain unbiased estimates by capturing preference heterogeneity. Second, it captures correlation in unobserved factors over time, thus considering the panel structure of discrete choice data. Third, it allows unrestricted substation patterns, meaning that it captures correlation in the unobserved factors across alternatives for common random coefficients. Fourth, the mixed logit model enables us to perform more accurate policy recommendations based on the distributional impacts of simulated changes or policy actions.

Furthermore, respondents may differently evaluate the no-buy alternative in relation to the experimental alternatives in each choice task. This can have systematic effects on the results because the distribution of the variance of the unobservable utility of the no buy alternative is likely different from the variances of the unobservable utilities of the purchase option (Ben-Akiva & Bolduc, 1996; Ben-Akiva et al., 2001; Brownstone & Train, 1998). To account for the fact that the correlation patterns in the utilities of the experimental alternatives and the no-buy option are different over different choice tasks, we estimate a MXL model with an error component model (MXL-EC)(Herriges & Phaneuf, 2002; Scarpa et al., 2005). This model enables the experimental

[22] More formally, the IIA property states that "the ratio of the choice probabilities in independent of the presence or absence of any other alternative in a choice set"(Hensher et al., 2015)

alternatives to share an extra zero mean error component which is not present in the utility of the no-buy alternative. Now, the utility function has two unobserved random terms ($\mu_n Z_{nsj} + \epsilon_{nsj}$):

$$U_{nsj} = \beta_n X_{nsj} + \mu_n Z_{nsj} + \epsilon_{nsj} \quad (9)$$

X_{nj} and Z_{nsj} are vectors of observed variables where Z_{nsj} is a categorical variable equal to one for the two experimental alternatives and zero otherwise. β is fixed while μ is a vector of random terms with zero means. As before ϵ_{nj} is iid extreme type one value. μ_n are the error components and can be used to obtain various correlation and substitution patterns. This specification takes care of the restrictive property of the MNL that comes with the IIA assumption (restricted substation patterns). Like in the case of the MXL model, the mixing distribution captures variance and correlations in unobserved factors. The primary advantage of the MXL-EC model is that one can specify variables such as they model the correlations over alternatives to generate substitution patterns that are closer to reality (Hensher et al., 2015). These models have been largely used in discrete choice experiment studies to assess consumers' demand for various food characteristics (Birol et al., 2015; V Caputo et al., 2013; Ortega et al., 2015; Wongprawmas & Canavari, 2017) and producers' preferences for product attributes (Waldman et al., 2017).

4.6.Results

4.6.1. Descriptive statistics

Table 4.3 describes the socio-demographic characteristics of the respondents in Oyo and Plateau state. The average age of the traders is 45 and about 60 percent of the sample are male with significantly more women traders in Oyo state. Just over 80 percent of the traders have an education level above primary school with approximately 13 years of experience. Traders in Oyo state have more experience than their peers in Plateau with about 19 years of selling maize. Traders in Plateau tend to sell large quantities of maize as more than 84 percent register monthly sales above 32 tons compared to only 25 percent in Oyo. Close to all the traders (100% for Oyo and 98% for Plateau) consume the maize they sell but just 18 percent store maize in both states.

Many more traders in Plateau take measures to prevent the growth of mold in maize (61 percent) compared to Oyo (30 percent). The practice of sorting maize is important for reducing the risks of aflatoxin contamination. Just over 90 percent of traders in Oyo sort maize, which is three-fold the number of traders in Plateau. Less than five percent of all traders control the quality of the maize they sell by adding a chemical binder (which is believed to reduce the toxicity of aflatoxin) or ash (which deters attacks by insects and other pests during storage). Additionally, just over 20 percent of all the traders dry maize, but this average is driven by those in Plateau as only 2 percent of Oyo traders dry the maize they sell. Very few traders (2%) are aware of the moisture content above which the aflatoxin growth is likely. This is significantly lower compared to the 16 percent reported among Kenyan traders (Ordonez, 2016). This is not surprising because unlike Kenya, Nigeria has not experienced an acute aflatoxicosis (Wu et al., 2014). The maize sold is rarely tested and a quarter of the traders in Plateau state believe that it is safe for humans to consume moldy maize. This might be due to beliefs that such maize could be washed off or is still safe after processing and cooking. The differences in means between Oyo and Plateau are statistically significant at the one percent level.

Table 4.3. Characteristics of the traders

	All	Oyo	Plateau
Age (years)	44.87	44.31	44.91
Male (0/1)	0.61	0.34	0.64
Literate	0.84	0.80	0.84
Number of years selling maize	12.95	18.77	12.47
Large trader -monthly sales >32 tons (0/1)	0.80	0.25	0.84
Consume maize sold (0/1)	0.98	1.00	0.98
Store maize (0/1)	0.18	0.20	0.18
Prevent the growth of mold in maize (0/1)	0.49	0.30	0.61
Sort maize (0/1)	0.34	0.91	0.29
Know optimal moisture content (0/1)	0.02	0.00	0.02
Use chemical binder (0/1)	0.04	0.09	0.04
Use ash (0/1)	0.02	0.02	0.02
Dry maize (0/1)	0.22	0.02	0.23
Maize tested before sales (0/1)	0.11	0.00	0.12
Number of observations	315	122	193

We also collected information on the traders' knowledge of aflatoxin. Approximately 12 percent of the traders in Plateau have heard of aflatoxin compared to none in Oyo. This difference in means is statistically significant at the 10 percent level. Additionally, the percentage of traders in Plateau who had heard of aflatoxin is lower compared to the one reported by other studies. Johnson (2017) reported that 42 percent of poultry producers and feed millers in the sample of a study in Nigeria had heard of aflatoxins. James et al. (2007) found that maize traders' awareness of aflatoxin stood at 44, 6.8, and 11 percent in Ghana, Togo and Benin, respectively. A study in Kenya found that 79 percent of maize traders had heard of aflatoxin (Ordonez, 2016). Conditional on being aware of aflatoxin, 47 percent of Plateau traders know the causes and 37 percent reported undertaking steps to control its growth.

We further assessed traders' knowledge of aflatoxin by asking them a series of questions presented in Table 4.4. This section is only relevant to traders in Plateau given that none of the Oyo traders had heard of aflatoxins. In general, the traders who are aware of aflatoxin also know the characteristics associated with contaminated maize except in a few cases. The fact that one-quarter of the traders believe that moldy maize is safe for human consumption is a public health concern. Very few traders are aware of the link that exists between the method of shelling or dehulling and aflatoxin contamination. In effect, only seven percent of the maize traders recognized that mechanical shelling or dehulling increases the probability of aflatoxin contamination. Additionally, the large majority of maize traders incorrectly associate aflatoxin contamination with maize discoloration.

Table 4.4. Knowledge of maize safety

	All	Oyo[1]	Plateau
Knowledge of aflatoxin and mold			
Heard of aflatoxin (0/1)	0.10	0.00	0.11
Know causes of aflatoxin build up in maize (conditional on knowing aflatoxin)	0.47		0.47
Implement steps to control for aflatoxin (0/1) (conditional on knowing aflatoxin)	0.37		0.37
Traders who believe it is safe for humans to consume moldy maize (0/1)	0.23	0.01	0.25
Share of traders who picked the correct answer (for those who heard of aflatoxin)			
Maize infected with aflatoxin will always have high moisture content (T)	0.57		0.57
Maize with high moisture content allows infection with aflatoxigenic mold (T)	0.58		0.58
Maize infected with aflatoxin will sometimes have mold (T)	0.69		0.69
Maize infected with aflatoxin will sometimes have insects or pests (T)	0.72		0.72
Aflatoxin contamination is higher for maize that is stored when it is wet (T)	0.84		0.84
Do you think that it is likely for your maize to have aflatoxin if mechanical shelling is used? (T)	0.07		0.07
Do you think that it is likely for your maize to have aflatoxin if mechanical dehulling is used? (T)	0.07		0.07
In your opinion does aflatoxin negatively influence human health if consumed? (T)	0.74		0.74
In your opinion does aflatoxin negatively influence chickens' health if consumed? (T)	0.70		0.70
Maize infected with aflatoxin will always be discolored (F)	0.07		0.07
Number of observations	315	122	193

[1] Since no trader reported hearing about aflatoxin in Oyo, there is no data for the questions that are conditional on this knowledge.

Table 4.5 shows maize sales prices during the high season and low season across states. It shows that prices are heterogeneous across different types of buyers in each state. During the high season when the quantity of maize available is high, maize traders in Oyo receive a premium from sales to consumers; but in Plateau feed mills and companies in the food industry pay the highest prices for maize. During the low season, traders in Plateau still enjoy a price premium from food companies and feed mills while those in Oyo receive high prices from the food industry and other wholesalers. In Oyo, the low season prices are surprisingly higher than the high season prices.[23] Informal communication with a few traders in Oyo revealed that in 2017 the period specified in the survey as low season (May-October) coincided with the religious of period of Ramadan when Muslims fast and consume more maize based meals. During Ramadan, the demand for maize increases thus leading to higher prices.[24] Overall, these patterns seem to indicate that the food industry and feed mills are important buyers for traders in Plateau. This is not the case in Oyo state where maize traders receive a price premium from different types of buyers depending on the season.

Table 4.5. Average maize prices

	All	Oyo	Plateau
	Mean		
High season (November-April) maize prices per 100 kg bags			
Food industry	8788	12089	8517
Feed mill	8694	11491	8518
Retailers	8776	12564	8487
Other wholesalers	8588	12131	8439
Consumers	8820	13409	8376
Low season (May-October) maize prices per 100 kg bags			
Food industry	13818	8563	14306
Feed mill	14181	9664	14472
Retailers	13535	8899	13894
Other wholesalers	13740	8417	13961
Consumers	13655	10736	13928

Note: The number of observations is not reported because it varies for each marketing channel across states. The difference of the mean prices between Oyo and Plateau are statistically significant at the 1% level.

[23] This pattern was observed both in our experiment data and a larger dataset collected from the same markets in Oyo and Plateau states

[24] As maize is more of a staple in the north, changes in demand due to Ramadan might not be as significant.

4.6.2. Estimation results

Using the data collected during the CE, we estimated four models namely, a MNL, a MXL, a random parameter logit model with error component (MXL-EC), and a random parameter logit model with error component (MXL-EC) with correlation. Table 4.6 presents the information criteria of these various models such as the BIC and AIC, which can be used to discuss their relative fit. The lower the information criterion value, the better is the fit. Results from table 6 clearly indicate that MXL-EC with correlation outperforms all the other econometric models. This finding is consistent with previous studies showing that the inclusion of an error component of this type improves substantially the model performance (Van Wezemael et al., 2014). Accordingly, the subsequent analysis was performed using a MXL-EC model.

Table 4.6. Comparison of information criteria

Model	Log-Lik	Parameters	BIC	AIC
MNL	-1429.76	7	2882.46	2873.5
MXL	-1280.12	11	2596.28	2582.2
MXL-EC	-1232.26	12	2503.84	2488.5
MXL-EC with correlation	**-1154.66**	22	**2381.40**	**2353.3**

Table 4.7 reports coefficients from the MXL-EC with correlations. As predicted by the economic theory, the price coefficient is negative and statistically significant at 1% level. This means that on average, higher prices are associated with a lower probability of purchase. In other words, traders derive disutility (negative utility) from the high price variable. The coefficient on the interaction of price and the trader being in Oyo state (β_2) is positive. This means that compared to traders in Plateau, those in Oyo derive less disutility from higher prices. This is not a surprising result because the bulk of the maize in Nigeria is produced in the North, closer to Plateau, then transported to the South in states like Oyo. Thus, traders in Oyo face higher maize prices on average compared to their peers in Plateau state. For this study, the price levels used in Oyo were

higher to reflect the real market conditions between the two states. The coefficient on the alternative specific constant for the opt-out option shows that the utility derived from the no-buy alternative is on average lower than the utility derived from the two experimentally designed alternatives. This means that the majority of the traders preferred to pick any of the two purchase alternatives over not choosing anything.

The coefficient estimates of certification and low moisture content are positive and statistically different from zero at 1%, indicating the highest marginal utility is derived from low moisture content followed by certification. On average, certification increases utility by 1.5 percentage points while the increase from low moisture content is about 3.2 percentage points. This is not surprising since traders generally tend to use moisture content as a proxy for the quality of maize. This also provides suggestive evidence that traders derive additional positive marginal utility from certification. The introduction of a certification would provide an additional signal of quality to buyers and likely improve the quality of the maize available in the market. We note that the higher marginal utility associated with low moisture content does not imply that certification would be obsolete in maize markets. Low moisture-content maize can still be aflatoxin-contaminated. Additionally, the fact that certification remains relevant even in the presence of the low moisture attribute seems to indicate that buyers don't perceive moisture level to be a perfect predictor of quality. Thus, there is still room for adding value as well as improving the confidence levels of buyers by introducing certification.

In addition, the coefficient estimate of high moisture content is negative and different from zero at 1%, implying that higher moisture content is associated with a lower likelihood of purchase. This is consistent with the result for low moisture content and confirms that traders use moisture level as a proxy for the quality of maize. Lastly, the coefficient estimate for color (yellow maize) is statistically insignificant indicating that it does not have an effect on traders' utility. However, the standard deviations for color are statistically significant indicating that about 40 percent of maize traders prefer yellow maize versus white maize.

Table 4.7. Random parameter with error component (MXL-EC) model results

	MXL-EC			
	Mean	St. Errors	Standard deviation	St. Errors
Parameters				
Opt-out	-2.941***	(0.895)		
Price	-0.329***	(0.101)		
Price Oyo	0.182***	(0.041)		
Certification	1.488***	(0.156)	1.177***	(0.149)
Yellow maize (color)	-0.144	(0.104)	0.742***	(0.152)
Low moisture	3.232***	(0.304)	2.544***	(0.267)
High moisture	-3.706***	(0.364)	2.789***	(0.283)
Model statistics				
Number of respondents		315		
Number of observations		1890		
Log likelihood		-1154.658		
McFadden's pseudo R^2		0.444		

Note: Standard errors are in parentheses, *, **, and *** denote significance at the 0.10, 0.05 and 0.01 level, respectively. Medium moisture content is the reference.
Models were estimated using NLOGIT 6.0. 1000 Halton draws were used to estimate the MXL models.

The derived standard deviations are statistically significant for certification, color, low moisture and high moisture indicating that there is heterogeneity around the mean parameter estimate over the sample of traders. This means that all the information in the distribution is not captured by the means. Following Train et al. (2009) and Vincenzina Caputo et al. (2018), we also estimate the share of individuals with negative preferences for each of the attributes.[25] We obtain the amount of dispersion that exists around the sample population. It is not surprising that 90

[25] We estimate these statistics using the mean and standard deviation for each attribute in a cumulative distribution function.

percent of the traders dislike high moisture content. Maize wholesalers seem to treat certification and low moisture content similarly. In effect, only 10 percent of them dislike these two attributes. This could also be an indication that traders are ready to accept aflatoxin certification as a plausible alternative to their informal means of measuring moisture content.

To further evaluate preference heterogeneity we examine the estimated Cholesky matrix, and implied correlation coefficient matrix (See Table 4A- 1 and Table 4A- 2 in the appendix).[26] Results from the Cholesky matrix indicate that preference heterogeneity persists, even after allowing for cross-correlations across attribute parameters, as evidenced by the statistical significance of the non-zero diagonal elements. Significant below-diagonal elements in the Cholesky matrix suggest the existence of cross-correlations among the random parameter estimates that otherwise would be confounded within the standard deviation parameter estimates. From the implied correlation matrix, for example, it can be seen that preferences for certification are more positively correlated with preferences for low moisture content than color (yellow maize). On the other hand, preferences for certification are negatively correlated with preferences for high moisture content. This indicates that those who value certification tend to like maize with low moisture content. Maize traders who like low moisture content also tend to like high moisture content indicating that preference for the former does not result in the rejection of maize with high moisture content. Preferences for yellow maize are positively correlated with preferences for both low and high moisture content. This means that traders do not associate maize color with a certain level of moisture level.

[26] In the presence of more than one random parameter as it is the case here, the standard deviations are no longer independent. The Cholesky matrix decomposes the standard deviations for each random parameter (Hensher et al., 2015).

4.6.3. WTP for certified aflatoxin-safe maize

We use the estimates from the model reported in Table 4.7 to calculate the unconditional (or population) WTP values for the key attributes such as aflatoxin certification and moisture attributes. Results are reported in Table [27].

Maize traders have a positive WTP for certification in Oyo and Plateau states. Maize prices in Oyo are typically higher than in Plateau, which we capture in the experimental setup, thus reflecting the higher WTP values in the former. For each 100 Kg bag of maize, traders are willing to pay a price premium of ₦10,122 in Oyo and ₦4,523 in Plateau for certification. This supports that a certification label adds value as a signaling mechanism for the quality of maize. As expected, the WTP for low moisture is greater than that for certification in both states. These results are not surprising because Nigerian traders routinely use moisture content to assess the quality of the maize they buy. They do this either by biting the grain between their teeth or by inserting a metal instrument with a sharp edge in the maize bag to assess the flow of the grains. Again, as expected, no trader is willing to pay a positive price premium for high moisture content in maize.

Table 4.8. Traders' willingness to pay

Attributes	Oyo	Plateau
	Mean	
Certification	10122	4523
Low moisture	21986	6824
High moisture	-25210	-11211
Number of observations	122	193

[27] The WTP is the ratio of the coefficient on the non-price attributes and the coefficient on the price attribute. For instance, the WTP for certification the coefficient on the certification attribute divided by the coefficient on the price attribute.

Next, we examine traders' conditional WTPs for certification across different marketing channels. We use the estimates from the model reported in Table 4.7 to calculate the conditional (or individual specific) WTP distributions (See Hensher et al. (2015) and Train (2009) for computational details). For this task, it is important to define each trader's marketing channel to obtain mutually exclusive groups. Only six percent of the traders sell to only one buyer. To overcome this challenge, we define as the main marketing channel the one to which a trader sells the highest percentage of its maize. The survey data provide us with information on the trader's maize sales during the high and low season in 2015/16, the high and low season in 2010/11 and their last transaction prior to the survey. First, we used sales volumes during the high season in 2015/16 to identify each trader's main buyer. Second, some of the traders reported selling equal proportions of maize to more than one buyer. To identify their main buyer, we used sales volumes from different transactions in the following order: sales from the last transaction prior to the survey, sales during the low season 2015/16, sales during the high season in 2010/11 and finally sales during the low season in 2010/11. In the end we could not determine the main marketing channel of 37/315 traders. They were dropped from the comparison of WTP values which is based on a sample of 278 traders. Table 4.9 present trader's WTP for certification based on their main marketing channel for Oyo, Plateau and both states.

There are differences across states in the ordering of the WTPs based on the traders' main marketing channels. In Oyo, wholesalers who sell to other big traders are willing to pay the highest mean price premium followed by those who sell to retailers and the food industry. Oyo traders who sell to consumers have a lower WTP, and the only trader in the Oyo sample who sells to small feed mills exhibits a negative WTP. Plateau traders' WTP for certification across marketing channels mirrors that of their peers in Oyo. The median WTP values show that traders who sell to other traders are willing to pay the highest price premium of about ₦5,900, followed by those who sell to retailers, large feed mills and the food industry. As before, traders who sell to consumers have a lower WTP. Unlike in Oyo state, traders in Plateau state who sell to small feed mills have a positive WTP that is just below that of those who sell to large feed mills. Overall, these results are aligned with our main hypothesis that traders who sell to buyers who procure large quantities including large feed mills and food industry customers with stringent quality requirements will pay a higher price premium for aflatoxin-safe maize compared to consumers and small feed mills.

Several key points stand out about the heterogeneity of maize trader willingness to pay for certification based on their final market. First, the marketing channel "other traders" is largely composed of agents who re-sell the maize to large feed mills and the food industry. This likely explains the high magnitude of the WTP we observe for this marketing channel. Visits to the maize markets and informal exchanges with agents and maize brokers revealed that large feed mills and the food industry are very particular about maize quality. They run a battery of tests on the maize they buy from agents. The lot of maize that fails the tests is subsequently returned to the agent who often sells it at a loss/lower price to smaller feed mills or pig breeders. Many maize traders also shared that they tend to sell their highest quality maize to agents who buy large quantities of grain for feed mills and companies in the food industry.

Second, traders who sell directly to large feed mills and companies in the food industry have a high WTP for certification because they likely enjoy a guaranteed market that they maintain by providing high quality maize. This is evident in Plateau state, which is home to several large food companies and large feed mills. In the state, large feed mills and food industry buyers are known as customers who give traders fair prices. They also tend to have specific requirements such as only buying dry maize. Even though these companies do not test the maize before they buy it, they have devised techniques to ensure that the maize they procure meets their standard, at least for observable attributes such as dryness. For instance, one food industry buyer noted that based on the harvest time of the maize they can estimate by which month they can procure dry maize. Moreover, the fact that the magnitude of the WTPs in Plateau is low relative to Oyo can be explained by the historical context. In fact, compared to Oyo, traders in Plateau have more frequent interactions with the food industry. Repeated interactions have been shown to be as effective as formal agreements like contracts that hold parties to providing goods with specific characteristics or facing penalties otherwise. Consequently, traders in Plateau may consider the existing mechanisms (tests performed by the food industry and using moisture level as a proxy for quality) to be as effective as an aflatoxin-safe label.

Third, maize wholesalers who sell to retailers exhibit a high WTP for aflatoxin-safe maize. The majority of the retailers sell small quantities of maize to directly to consumers. However, in some of the markets in Oyo and Plateau, some retailers also sell large quantities of maize thus behaving like wholesalers in terms of their WTP for aflatoxin-safe maize. This implies that retailers likely have a reputation to uphold with some of their customers. Consequently, to maintain their customer base, it is likely that retailers have quality requirements like those of the other buyers included in the group of large buyers (other traders, food companies, large feed mills). This is reflected by the high WTP for aflatoxin-safe maize exhibited by the maize traders who sell to retailers in both states.

Table 4.9. Traders' WTP for certification across main marketing channels (Oyo state)

	Other traders	Small feed mills	Large feed mills	Food industry	Retailers	Consumers
Oyo and Plateau						
Median	8471	3402	5278	5708	5920	4612
Mean	9348	3561	4282	5674	6468	6634
Standard errors	516	446	832	619	438	1739
N	101	37	14	46	67	13
F-test[a]			0.0000			
H-test[b]			0.0001			
K-test[c]			0.0000			
Oyo						
Median	11562	-3030		8749	8285	7443
Mean	11426	-3030		8663	8703	8203
Standard errors	607	-		1468	823	2002
N	67	1		13	24	10
F-test[a]			0.004			
H-test[b]			0.016			
K-test[c]			0.311			
Plateau						
Median	5913	3405	5278	3420	5562	1947
Mean	5253	3744	4282	4496	5220	1401
Standard errors	427	419	832	529	399	817
N	34	36	14	33	43	3
F-test[a]			0.034			
H-test[b]			0.035			
K-test[c]			0.007			

Note: N=number of observations
[a]P-value from F-test testing the null hypothesis of equality of means across marketing channels
[b]P-value from the Kruskal-Wallis H test testing the null hypothesis of equality of means across marketing channels
[c]P-value from K-sample test testing the null hypothesis of equality of medians across marketing channels

4.6.4. WTP for certification based on perception

We also examine WTP for certification based on traders' perception that a buyer would be willing to pay a price premium for aflatoxin-safe maize. To define the different samples of interest, we asked traders to rank on a Likert scale of 1 to 5 (do not firmly believe to firmly believe) who they believe would be willing to pay an extra price premium for certified aflatoxin-safe products. We split the sample based on the use of the maize and the order of the magnitudes of the WTP values obtained across marketing channels in the section above (other traders, retailers, food industry and large feed mills). The results are shown in Table 4.10.

First, we examine large buyers who procure maize for their own consumption i.e. food companies and large feed mills. We compare two groups of traders: those who firmly believe (meaning they picked 5 on the Likert scale) that the food industry or large feed mills would be willing to pay an extra price premium, and all other traders (i.e. those who did not choose 5 on the Likert scale). This comparison reveals that traders who perceive that the food industry and large feed mills would be willing to pay a price premium for aflatoxin-safe maize exhibit a WTP that is ₦2,107 higher than their peers. This result suggests that the traders' behavior is conditioned by what they believe about the final buyer. That is, if customers begin to value the certification then traders will have an incentive to provide aflatoxin-safe maize in Nigerian markets.

Next, we focus on large buyers who purchase maize for resale. We make the same comparison between 1) traders who firmly believe (meaning they picked 5 on the Likert scale) that other wholesale traders and retailers would be willing to pay an extra price premium, and 2) those traders who did not choose 5 on the Likert scale. Again, the results provide suggestive evidence that traders behave accordingly to what their buyers demand. Traders who perceive that other wholesalers and retailers will be potential buyers of a certification label are willing to pay approximately ₦2,200 more than their peers who think otherwise. This is consistent with the previous results. Moreover, the WTP values based on perception show that traders believe that the food industry and large feed mills are likely to pay a slightly higher price premium. Since the differences in WTP based on perception for Oyo state only are not statistically significant, it is not possible to draw cross-state comparisons.

Table 4.10. WTP for certification as a function of perception that a buyer will pay a price premium

	Food industry and large feed mills	Other buyers	VS	Traders and retailers	Other buyers
Oyo and Plateau					
Median	7787	5680		7765	5547
Mean	7826	6282		7467	6288
SE	469	317		394	348
N	86	229		111	204
F-test[a]	0.009			0.034	
H-test[b]	0.003			0.003	
K-test[c]	0.002			0.000	
Oyo					
Median	10218	10113		10957	9817
Mean	10709	9873		11186	9702
SE	671	604		700	584
N	39	83		36	86
F-test[a]	0.425			0.162	
H-test[b]	0.178			0.057	
K-test[c]	0.437			0.074	

Table 4.10 (cont'd)

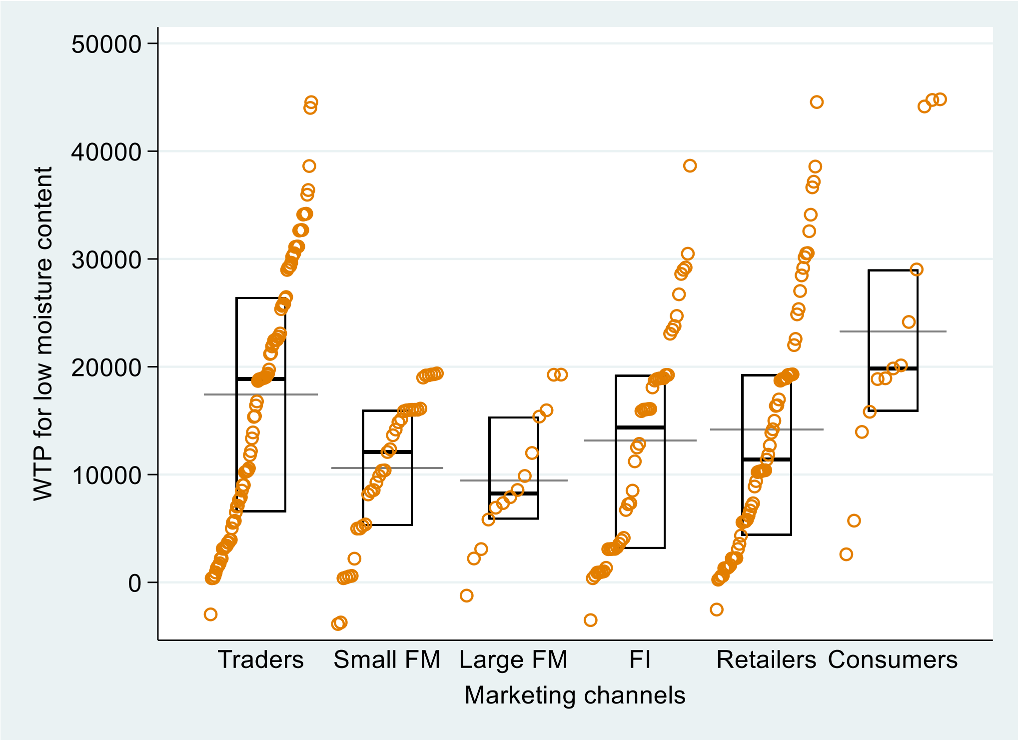
Plateau				
Median	5950	4369	6192	3405
Mean	5434	4240	5681	3799
SE	401	228	313	240
N	47	146	75	118
F-test[a]	0.029		0.000	
H-test[b]	0.017		0.000	
K-test[c]	0.049		0.000	

[a]P-value from F-test testing the null hypothesis of equality of means across marketing channels
[b]P-value from the Kruskal-Wallis H test testing the null hypothesis of equality of means across marketing channels
[c]P-value from K-sample test testing the null hypothesis of equality of medians across marketing channels

4.6.5. WTP for low moisture content

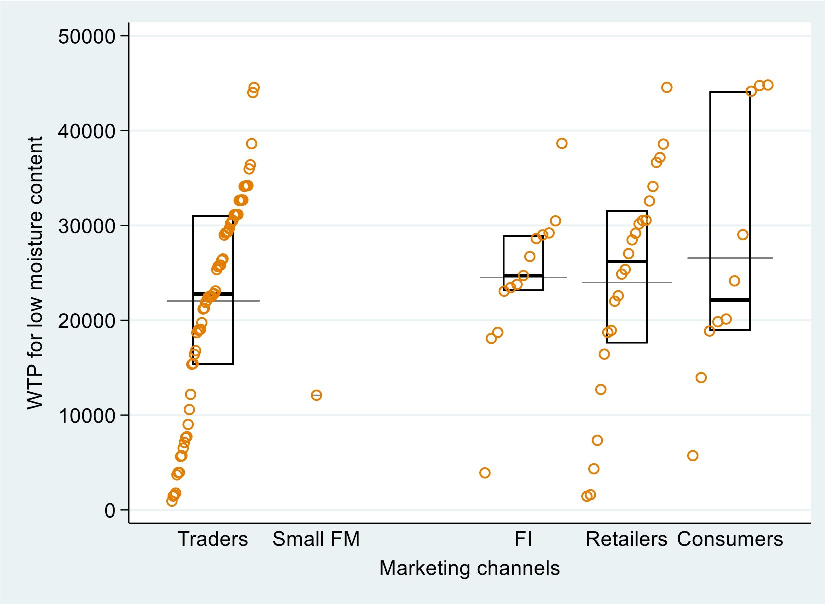
Moisture content is used as a proxy for maize quality in Nigerian maize markets. In addition, it is cheaper to test moisture content compared to aflatoxin. For this reason, some studies argue that the enforcement of moisture content testing could be a viable policy alternative to aflatoxin testing (McCoy et al., 2016; Ordonez, 2016). Table 4.8 shows that WTP for low moisture content is higher than WTP for aflatoxin certification. Thus, we also check WTP for low moisture content across the different marketing channels. The results from the pooled estimation in Figure 4.4 shows that the WTP values are not equal across marketing channels. We found that WTP for low moisture content is highest for traders who sell to consumers with a median value of ₦19,846 per 100 Kg bags. Besides consumers, the other marketing channels value moisture content in descending order as follows: other traders, the food industry, small feed mills, retailers and lastly large feed mills (see Table 4A- 3 in the appendix). Therefore, the marketing channels that care the most about moisture content are consumers, other traders, and the food industry. The differences in WTP for low moisture content based on the marketing channels for Oyo (Figure 4.5) and Plateau (Figure 4.6) are not statistically significant.

Figure 4.4. Graph of WTP for low moisture content by marketing channel (pooled)



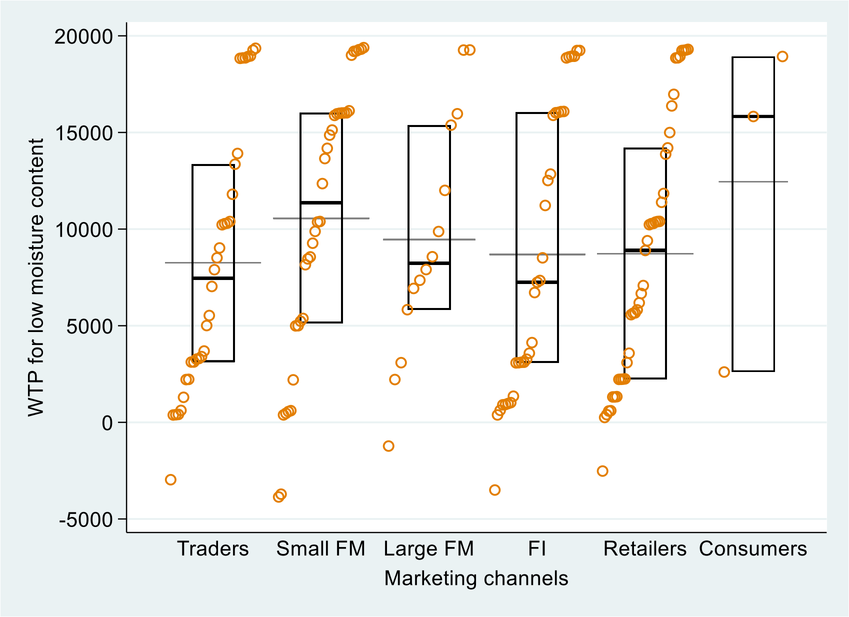
Note: Boxes show median and quartiles. The added bars are the means. Small FM is small feed mills, large FM is large feed mills, FI is food industry

Figure 4.5. Graph of WTP for low moisture content by marketing channel (Oyo)



Note: Boxes show median and quartiles. The added bars are the means. Small FM is small feed mills, large FM is large feed mills, FI is food industry

Figure 4.6. Graph of WTP for low moisture content by marketing channel (Plateau)



Note: Boxes show median and quartiles. The added bars are the means. Small FM is small feed mills, large FM is large feed mills, FI is food industry

These results highlight that there are differences in the way traders evaluated the low moisture and certification attributes in the experiment. First, traders who sell to consumers and small feed mills are willing to pay a high price premium for low moisture, but not for certification as shown above. This is consistent with what one would expect under the status-quo. Consumers and small feed mills who buy maize for their own consumption evaluate the quality of the maize using moisture content. Since traders know from their interaction with consumers and small feed mills that they pay close attention to the moisture content, it is not surprising that those who sell to these buyers exhibit a higher WTP for low moisture compared to those who do not. Second, the fact that the food industry cares about low moisture content confirms that this is an important attribute in their buying decisions. Third, traders who sell to large feed mills care the least about low moisture. Recall that traders who sell to large feed mills are among those who have a high WTP for certification. Islam et al. (2015) document that the higher the moisture level, the lower the quality of the feed. Consequently, the low WTP for low moisture is not linked to the fact this attribute is unimportant for large feed mills. Instead, it seems to indicate that large feed mills are not responsive to mechanisms that reveal the true moisture level, in the same way as aflatoxin contamination, because they have other means of dealing with it.

4.6.6. Trust in certifying agency

Trust in the agency implementing a certification mechanism is key to encouraging take-up among maize traders. We found that maize wholesalers are more likely to trust an aflatoxin-safe certification program implemented by domestic agencies such as NAFDAC, or a research institute like the International Institute of Tropical Agriculture (IITA). We asked traders which certifying entity they are more likely to trust to implement an aflatoxin-safe certification for maize. Traders picked a number on a Likert scale of 1-5 where one is strongly disagreeing and five is strongly agreeing. A trader who chooses four or five on the Likert scale is categorized as trusting a certifying agency. Table 4.11 shows the share of traders who trust different certifying entities. In

Oyo state, traders are more likely to trust a certification scheme implemented by NAFDAC by itself or NAFDAC together with a university based in Nigeria. By itself, a university based in Nigeria does not carry that much trust since only 50 percent of Oyo traders would trust it. In Plateau state, traders are more likely to trust an aflatoxin-safe label certified by NAFDAC, NAFDAC and a university in Nigeria, or a research institute by itself. Conversations with traders in Plateau state during the field work are aligned with these findings as many shared that they do not believe a foreign certifying agency would care about their health as much as a Nigerian one. In Oyo, a university based in the country is not as trustworthy as other entities. On average, traders are less likely to trust a university based outside of Nigeria or a professional association to implement the certification scheme. These trends in trust hold across large and small traders as well as across markets in both states.

Table 4.11. Trust in the certifying authority

	NAFDAC	University in Nigeria	University overseas	NAFDAC+University in Nigeria	NAFDAC+Univerty overseas	Research institute	Professional association
All	0.87	0.72	0.56	0.87	0.76	0.83	0.66
Oyo	0.78	0.50	0.39	0.78	0.67	0.68	0.37
Plateau	0.93	0.85	0.67	0.92	0.82	0.92	0.85
Across types of traders							
Large traders (Oyo)							
	0.81	0.56	0.39	0.78	0.68	0.64	0.41
Small traders (Oyo)							
	0.75	0.44	0.38	0.78	0.67	0.71	0.33
Large traders (Plateau)							
	0.92	0.86	0.69	0.92	0.85	0.92	0.86

Table 4.11 (cont'd)

Small traders (Plateau)	0.95	0.84	0.63	0.93	0.77	0.91	0.84
Across markets							
Panyam (28)	0.89	0.89	0.75	0.96	0.86	0.96	0.96
Kombun (29)	0.93	0.90	0.62	0.93	0.83	0.93	0.79
Mangu (28)	0.93	0.89	0.71	0.93	0.79	1.00	0.86
Jengre (30)	0.97	0.83	0.60	0.90	0.87	0.80	0.73
Bokkos (30)	0.87	0.90	0.63	0.93	0.73	0.87	0.80
Satellite (14)	1.00	0.71	0.57	0.93	0.79	0.93	0.86
Farin Gada (2)	1.00	1.00	0.50	0.50	0.50	0.50	0.50
Laranto Katako (17)	0.88	0.88	0.65	0.82	0.76	0.94	0.94

Table 4.11 (cont'd)

Vom (10)	1.00	0.60	0.80	1.00	1.00	1.00	1.00
Bukuru (5)	1.00	0.80	1.00	1.00	1.00	1.00	1.00
Bodija* (74)	0.77	0.51	0.36	0.74	0.61	0.74	0.34
Oja Oba* (48)	0.79	0.48	0.42	0.83	0.77	0.58	0.42

*denotes markets in Oyo. The numbers in parentheses denote the number of traders in that market.

4.7.Conclusion

This paper uses a discrete choice experiment to estimate maize traders' willingness-to-pay (WTP) for aflatoxin-safe maize in Nigeria. This work departs from previous preference studies in three important ways. First, while previous studies have focused on subgroups (nodes of the supply chain) such as farmers and consumers, this study focuses on maize traders; key actors in the maize supply chain that serve as a key intermediary between millions of maize producers and millions of maize consumers for feed and food. To explore the potential to introduce a market-based solution to food safety challenges associated with maize, the study exploits the fact that maize traders sell to different categories of buyers (with different preferences for product attributes) to estimate the heterogeneous WTP for quality certification of maize.

Second, we also estimate WTP for aflatoxin-safe maize based on traders' perception (subjective knowledge of what different marketing channels value, even if they do not sell to that channel) about a category of buyer's willingness to pay a price premium for aflatoxin-safe maize. Third, we evaluate maize traders' WTP for low moisture content, an attribute that is sometimes used as a proxy for aflatoxin-contamination. The inclusion of both low moisture and aflatoxin in the choice experiment enable us to separately evaluate preferences for these two attributes. This is the first study we are aware of to do this. Given that low moisture content is an imperfect proxy of an aflatoxin safe product, finding that traders are willing to pay a price premium for certification over and above that for low moisture content indicates that there is a perceived additional value for certification in the maize market. This is an important finding for governments and development practitioners interested in promoting food safety in Nigeria and worthy of consideration for maize and other similar value chains in developing countries with weak regulations or enforcement.

Third, the successful implementation of a certification mechanism is contingent on how it is perceived by different stakeholders. Thus, we also elicit traders' trust attitudes towards different candidate implementing agencies. We find consistent evidence that traders prefer certification schemes implemented by local agencies compared to foreign ones.

Different maize buyers have different preferences for maize quality. These preferences depend on factors such as their use of the product and or need to maintain brand reputation. In line with our hypothesis that traders' willingness to pay for certification will vary with their belief about their final customers value of such certification we explore the heterogeneity of the WTP for certification by market channel. We find that traders selling to other traders, large feed mills, food companies and retailers exhibit a higher WTP for certification compared to those who sell to small feed mills and consumers. The use of a trader's perception that a marketing channel will be willing to pay a price premium (rather than their actual experience with a marketing channel) confirms these results. Traders who believed that other traders, retailers, large feed mills and food companies would be willing to pay a price premium for aflatoxin-safe maize exhibited a higher WTP for aflatoxin-safe maize compared to others. Consequently, our findings consistently reveal that traders will purchase aflatoxin-safe maize if they know or believe that there is a market for it.

Additionally, the examination of the estimated WTP for low moisture across marketing channels reveals that consumers, other traders and the food industry care the most about this attribute while large feed mills and retailers care the least. Differences in the way traders evaluated the WTPs for certification and low moisture based on their main buyers suggest that a certification scheme would appeal to large buyers like food companies and large feed mills while a low moisture labeling would benefit consumers. Lastly, a certification scheme implemented by a domestic agency would be more credible than one established by a foreign one.

These findings have important policy implications for the functioning of maize markets in Nigeria. From a policy perspective, the introduction of an aflatoxin certification scheme should be accompanied by an information campaign highlighting the negative health impacts of the toxin. This would increase awareness among different categories of buyers and ultimately influence the characteristics that matter to them when purchasing maize. This is predicated on the assumption that if the trader knows that a buyer cares enough to pay a price premium for aflatoxin-safe maize then he/she will be willing to provide it. From a public health safety point of view, the use of moisture labels as a proxy for aflatoxin contamination is not ideal. Consumers already value moisture level in their buying decisions but that does not protect them against buying aflatoxin contaminated maize. They are still exposed to the negative health impacts that are associated with the consumption of aflatoxin-contaminated maize.

APPENDICES

APPENDIX 4A: CORRELATION MATRICES

Table 4A- 1. Correlation matrix from MXL-EC with correlation model

	1	2	3	4	5
Certification (1)	1.000	0.68	0.386	-0.242	-0.368
Color (2)		1.000	0.133	0.123	-0.052
Low moisture (3)			1.000	0.578	0.344
High moisture (4)				1.000	0.741
ERC (5)					1.000

Table 4A- 2. Cholesky matrix from MXL-EC with correlation estimates

	1	2	3	4	5
Certification (1)	1.177***				
Color (2)	0.504***	0.544***			
Low moisture (3)	0.980***	-0.449*	2.304***		
High moisture (4)	-0.674**	1.091***	2.278***	0.971***	
ERC (5)	-0.997***	0.733**	1.596***	0.503	1.730***

APPENDIX 4B: WTP FOR LOW MOISTURE CONTENT

Table 4A- 3. Traders' WTP for low moisture content across main marketing channels (Pooled)

	Other traders	Small feed mills	Large feed mills	Food industry	Retailers	Consumers
Oyo and Plateau						
Median	18859	12093	8238	14367	11387	19846
Mean	17416	10594	9458	13154	14193	23290
Standard errors	1183	1145	1675	1533	1402	3866
Number of observations	101	37	14	46	67	13
F-test[a]				0.000		
H-test[b]				0.002		
K-test[c]				0.049		
Oyo						
Median	22765	12093		24718	26191	22143
Mean	22063	12093		24491	23993	26541
Standard errors	1369			2268	2425	4376
Number of observations	67	1		13	24	10
F-test[a]				0.597		
H-test[b]				0.740		
K-test[c]				0.605		
Plateau						
Median	22765	12093		24718	26191	22143
Mean	22063	12093		24491	23993	26541
Standard errors	1369			2268	2425	4376
Number of observations	67	1		13	24	10
F-test[a]				0.597		
H-test[b]				0.740		
K-test[c]				0.605		

[a]P-value from F-test testing the null hypothesis of equality of means across marketing channels

[b]P-value from the Kruskal-Wallis H test testing the null hypothesis of equality of means across marketing channels

[c]P-value from K-sample test testing the null hypothesis of equality of medians across marketing channels

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