The Emergence of New Markets for Agricultural Technologies: The Case of Cowpea Storage in West Africa[1]

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Adoption of new agricultural technologies is critical to increasing productivity in sub-Saharan Africa (Byerlee, de Janvry and Sadoulet 2009). Most research on agricultural technology adoption focuses on the demand side, emphasizing the role of extension services, information provision and subsidies to encourage adoption. Yet supply-side factors play a critical and often overlooked role in facilitating technology adoption. In this paper, we study the adoption of an improved storage technology (PICS bags) for cowpeas in Niger, a major cash crop in West Africa. Despite the introduction and widespread distribution of the bags in Sahelian West Africa since the late 2000s, average adoption in Niger remains low, with high geographic variation in uptake. Using data from both farmers and traders in Niger, we demonstrate that these different adoption levels represent distinct equilibria, with relatively lower supply of PICS bags in low-adoption areas because of traders' beliefs about farmers' demand for the product. Lower supply is further constrained by supply relations between traders: Traders in the high-adoption areas have traditionally had relatively preferential access to PICS bags via an exclusive import contract during the early years of PICS promotion. From these observations, we develop a new theory of market development in which potentially credit-constrained suppliers and farmers learn from each other about the demand for and value of new technologies.

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The introduction, adoption and diffusion of new technologies is a central component of agricultural production. Such innovations help farmers to reduce their exposure to climatic risks and pest infestations, improve soil fertility and increase productivity (see, for example, Emerick et al 2016, 2013). Yet in many developing countries, adoption of improved agricultural technologies – including seeds, fertilizers and storage technologies - remains low, especially in sub-Saharan Africa.

This paper is centered around a puzzling adoption pattern for an improved storage technology in Niger. Cowpeas are a primary cash crop in Niger, as they are for 80% of households in West Africa. In 2010, 87% of the cowpeas produced in Africa were grown in Niger, Nigeria, and Burkina Faso (Murdock and Baoua, 2014). Yet cowpeas are highly susceptible to the cowpea weevil, an insect that destroys 25-30 percent of the output during storage, making the crop a semi-perishable commodity (Jackai and Daoust 1986, Murdock et al 1997).[4] Farmers and traders in West Africa have traditionally used a variety of storage technologies to deal with the pest, such as pesticides or airtight containers. While both technologies are effective in killing the weevil, pesticides can result in a number of health issues, from eye and skin problems to more severe illnesses.

In the early 2000s, a new technology was developed to improve cowpea storage: Hermetically-sealed, chemical-free bags, such as the Purdue Improve Cowpea Storage (PICS).[5] While these bags have proven agronomic success in minimizing storage losses, their adoption in West Africa is estimated at 46%, with great heterogeneity between and within cowpea-producing countries (Moussa et al 2014). In Niger, PICS adoption ranges from 7 to 38 percent, with strong variation by region (Moussa et al 2010, Baoua et al 2013), despite similar observables by agro-climatic zone, the extension margin of cowpea production, education levels and wealth.[6]

Using detailed farmer and trader survey data from Niger, we document three stylized facts about PICS adoption. First, we find that there is strong spatial heterogeneity in PICS adoption and demand by both farmers and traders, with relatively higher adoption in the west and near zero adoption in the east, despite the fact that all of these areas are major cowpea-producing regions and similar in terms of agro-climatic zones. These geographic differences in adoption persist even after controlling for gender, the

[4]In Niger, farmers have typically used double woven bags (with or without insecticide), airtight drums and airtight earthen mounds to store cowpea (Moussa et al 2011).
[5]The PICS project was designed to "help farmers access low-cost and chemical-free cowpea storage technology… to store their cowpeas at harvest affordably, with minimal loss, in order to take advantage of seasonal price variability." (Coulibaly et al 2012).
[6]The key innovation of the PICS bags is in their triple layer (Ibro et al 2014).

quantity of cowpea produced and storage and beliefs' about different storage technologies. Second, farmers' adoption and demand for PICS bags is significant lower than traders. Yet even though a majority of traders have heard of and know about PICS bags, traders in certain regions are still less likely to adopt than those in the west. And third, lower levels of adoption seem to driven not only by demand-side factors, but by the uneven supply of PICS bags throughout the country, traders' liquidity constraints and uncertainty about farmers' demand and an exclusive import contract that provided preferential access to the technology during the early stages of market development (Coulibaly et al 2012, Moussa et al 2014, Coulibaly et al 2012).[7] Overall, these data suggest a model of market emergence in which the two sides of the market learn from each other: Farmers in the high-adoption region have higher demand for PICS than those in the other regions, so that it is more profitable for traders to stock more PICS bags.

We then develop a simple model of supply and demand that explains these multiple equilibria. Farmers learn about the new technology from each other, but also from finding it in stock at vendors. If the technology is profitable, then demand increases as more farmers learn. Yet demand can only be maintained if the good is in regular supply at vendors. Vendors who face space and capital constraints make stocking decisions based on their beliefs about the demand for the new technology. Those beliefs are updated in response to sales of goods in stock and inquiries about goods not in stock. In this model of technology adoption, both sides of the market are central figures. The model predicts multiple equilibria. A new market emerges only if vendors maintain stocks long enough for a sufficient number of farmers to learn about the technology and continue to express demand for it.

Our paper adds to an active economics literature in the area of technology adoption and the emergence of markets for new goods. In the seminal work on agricultural technology adoption, Griliches (1957) examines the diffusion of hybrid corn seeds across regions of the US during the first half of the 20th century, focusing on the interplay between supply and demand. Most studies of agricultural technology adoption in developing countries have focused on demand-side factors, including difficulties in learning about a new technology (Foster and Rosenzweig, 1995, 1996; Conley and Udry, 2010; Suri, 2011) and the role of social networks as mechanisms of diffusion (Conley and Udry, 2001; Bandiera and Rasul, 2006; Matuschke and Qaim, 2009; Maertens and Barrett, 2012; Beaman et al., 2015).[8] While other studies abstract from the behavior of agricultural input suppliers (e.g., Suri 2011), and there is significant literature of the market for new goods that focus on the behavior of suppliers (Bresnahan and

[7]In 2013/2014, licensed PICS distributors in Niger sold about 98,500 bags, with an estimated 80,000 PICS bags imported informally from Nigeria. As of this time, the marketing of PICS bags is organized by the national distributor, the sole importer, 5 regional wholesalers, 61 semi-wholesalers and retailers.

[8] See Foster and Rosenzweig (2010) for a review.

Gordon 2008)., we know of no papers that attempt to formally model the interaction between suppliers and customers in forming a new market.. One is the body of work on the economics of new goods (A key theme in that literature deals with the entry and pricing decisions of firms competing to bring a new good onto the market (Hausman, 1996, Krugman, 1979; Romer, 1994; Broda and Weinstein, 2006).

Beyond the broader literature on agricultural technology adoption, our paper also speaks to a second strand of literature on storage and intra-annual price variation in sub-Saharan Africa. A number of recent papers have examined the tendency of some farmers to "sell low" and "buy high" because of storage and financing constraints (Stephens and Barrett 2011, Dillon 2016), as well as a number of interventions designed to address farmers' joint storage and credit problems (Coulter and Shepherd 1995, Burke, 2014, Basu and Wong 2015, Casaburi et al. 2014). By focusing on the adoption of a storage technology, we are able to provide additional insights into this research.

The rest of this paper proceeds as follows. In Section 2 we discuss the setting in Niger. In Section 3 we describe a set of farmer and trader surveys that were used to document PICS technology adoption, usage and willingness to pay. In Section 4 we present the document the stylized facts associated with PICS adoption and usage by both farmers and traders, as well as the marketing chain. In Section 5 we outline the foundations of the future theoretical model, and Section 6 concludes.

2. Setting

Cowpeas are the primary cash crop for over 80 percent of households in West Africa. Cowpeas are highly susceptible to the cowpea weevil, an insect that destroys 25-30 percent of output during storage, making the crop a semi-perishable commodity (Jackai and Daoust, 1986; Murdock et al., 1997). In Niger, farmers and traders have typically used double-woven bags, with or without insecticide, to store cowpea (Moussa et al., 2011). While hermetically sealed, chemical-free bags (such as the Purdue Improve Cowpea Storage (PICS) or GrainPro bags) have proven agronomic success in minimizing storage losses, adoption rates of hermetically sealed bags in Niger range from 7-46%, with high variation by region (Moussa et al., 2014). The key innovation of the PICS bags is in their triple layer, which induces hypoxia in weevils and ends their reproductive cycle.

With only one growing season per year and low average yields, cowpea markets tend to exhibit a marked degree of seasonality in prices. In Niger, the second-largest cowpea producer in the world, the intra-annual price fluctuation of cowpea ranges from 20 to 60% (Figure 1). Cowpeas are traded on a system of weekly markets, which range in size from 20 to well over 200 traders. The types of traders include retailers, intermediaries and wholesalers, who purchase from farmers from their villages or directly in the markets.

Despite the potential for farmers to take advantage of inter-temporal arbitrage, 78% of Nigerien farmers sell their cowpea production in the 1-2 months immediately after the October harvest.[9] Many of these households purchase smaller quantities of cowpea later in the year. This translates into an average loss of $80 per year in potential revenue, representing 50-65% of average total revenue from cowpea sales.

3. Sample and Data

The data for this paper are from farmer and trader surveys in three regions of Niger. The farmer survey preceded the trader survey, as we used information gathered from farmers about their primary markets to define the sampling frame for the trader survey.

3.1 Farmer survey

Farmers were selected from a set of participants in a series of randomized control trials that focused on adult education in the Dosso, Maradi and Zinder regions. None of these prior studies were related to agriculture or PICS storage. Out of a sample of 300 villages, we stratified by geography (region and department) and on prior treatment status to randomly select 63 villages.[10] In each village we attempted to survey all previous respondents, who were stratified by gender, which includes 16 respondents per village (8 women and 8 men) from Dosso, and 15 respondents per village (10 women and 5 men) in Maradi and Zinder, for a total of 966 respondents. Attrition was approximately 5%, with a total sample of 923 farmers (525 women, 398 men).

The farmer surveys took place in September-October 2016, immediately prior to the harvest for most villages. The survey asked questions about cowpea production, storage, and knowledge of and experience with PICS bags. Enumerators also elicited farmers' subjective expectations of the depreciation rates for different storage technologies, including PICS, and used a variant of the Becker-DeGroot-Marschak (BDM) mechanism to measure farmers' maximum willingness-to-pay (WTP) for a PICS bag. The detailed WTP methodology is included below.[11] While the timing of the WTP survey

[9] 78%-80% of households selling 95% of output, on average. Source: Household survey data collected by one of the authors.

[10] Previous treatment status included any adult education program or none, and, within adult education villages, whether they participated in a mobile phone-enhanced curriculum (ABC).

[11] After a brief introduction to the PICS bag, the individual was able to inspect the bag. The respondent was then able to state a bid for the item (with the distribution shown), and a random sale price was drawn from the distribution of prices. If the bid was greater than or equal to the drawn price, then the respondent was able to purchase the PICS bag, after a small "cooling off" period (ie, they had 1-2 hours to borrow money). If the bid was less than the drawn price, then the respondent was unable to purchase the PICS bag on that day.

may result in lower average WTP, especially if farmers were credit-constrained immediately prior to the harvest, we felt that it was important to ensure that questions of storage were "top of mind" for farmers. That being said, as a subset of our farmers had already begun harvesting, we are also able to assess whether WTP is correlated with production-related credit constraints.

3.2. Trader Survey

During the farmer survey, farmers were asked for the names of markets where they bought and sold cowpeas since the previous year's harvest, and where they purchased their storage technologies. Farmers identified approximately 45 markets in each region. From among these, we stratified by sub-region and selected 10 markets per region for the trader survey, for a total sample of 30 markets. We prioritized the markets that were cited most often. Within each market, on the day of the survey, the survey team conducted a census of all cowpea traders and vendors of storage technologies, with substantial overlap between the two. Within each market, 10 traders were randomly selected, stratifying by trader type (wholesaler, intermediary/retailer and bag seller).

The trader survey took place in November and December 2016, immediately after the annual cowpea harvest. Traders constituted both potential sellers and users of PICS bags. With no clear dividing line between sellers and buyers, we asked all traders questions that covered primary trading activities, purchase and sales markets, other economic activities, use and sales of cowpea storage technologies (including PICS), beliefs about cowpea storage depreciation associated with different storage technologies, and the same WTP BDM mechanism used with farmers.

3.3. Farmer Sample Characteristics

Table 1 presents the summary statistics for the farmer study sample, by region (department). As described above, the proportion of males and females varies slightly by region, with 50% female in Dosso and 60% female in Maradi and Zinder (Panel A). Over 90 percent of respondents grew cowpeas during the previous agricultural season, and over 80 percent of households stored cowpea at some point. The amounts produced varied widely by region, with 248 kg in Dosso and 72 kg in Zinder.[12]

Variation in the storage equilibrium for PICS bags is also apparent across the regions: 96% of farmers in Dosso had heard of PICS bags, and 57% of farmers have used them at some point. 62% of

[12] The differences in cowpea production can, in part, due to the sampling differences (of men and women) as well as the farm sizes in Dosso versus Zinder. Conditional on gender, the average differences in cowpea production are slightly smaller, but still remain. While all of our sample zones are in the same latitude, some of the areas in Dosso are farther to the south, and hence receive more rainfall and are less subject to drought. In addition, average farm sizes in our survey sample area of Dosso are larger than those in our survey sample area of Zinder.

farmers in Maradi had heard of PICS, and with only 17% using them. Adoption is lowest in Zinder: While 48% had heard of PICS, and only 6% had ever used them. The relationship between awareness and usage is noteworthy. In Dosso, just over half of farmers who have heard of PICS were using them, while these figures are 1 out of 4 in Maradi and 1 out of 8 in Zinder. This suggests that awareness is not selectively driven by likelihood of usage.[13]

This historical pattern of PICS adoption across regions is replicated in the adoption of storage technologies. While nearly half of farmers in Dosso used PICS, adoption rates in Maradi and Zinder were 12% and 3%, respectively. Traditionally, farmers in Dosso and Maradi store in some type of 100-kg bag – either traditional bags (with pesticides or plastics) or PICS bags, whereas farmers in Zinder are more likely to store in plastic jugs, which hold 20 kg and can be hermetically sealed.[14] These storage patterns are similar for those farmers storing more than 100 kg, suggesting that the packaging – i.e., 100-kg bags as compared with 20-kg plastic containers – cannot be the sole driver of differences in adoption.[15]

Across all storage technologies, self-reported cowpea storage losses are similar. In both Dosso and Maradi, average losses during storage are 6%, with slightly higher rates in Zinder. However, storage losses are only comparable over a set period of time, and farmers encountering higher depreciation rates may choose to sell earlier. While we do not know the timing of cowpea sales, but we can compare storage losses for those households that did not sell any of their 2015-2016 cowpea harvest. Among this subgroup, storage losses are range from 7% in Dosso to 14% in Zinder, respectively. Hence, cowpea stored in PICS appear to depreciate at less than half the rate of other methods.

3.4. Trader Sample Characteristics

Table 2 presents summary statistics from the trader surveys. Almost all traders are male. Traders in Dosso are slightly older and more experienced than their Maradi and Zinder counterparts. On average, traders operate in 5 markets, and approximately 90% have a "stand" at the market. Approximately 75% of traders have paid employees.

Coinciding with the farmer data, cowpea storage technology adoption patterns are similar across regions. Traders in Dosso and Maradi are more likely to store in bags – either PICS or traditional bags – than those in Zinder. While Zinder traders are more likely to use plastic canisters than those in other regions, although approximately 80% use traditional bags – suggesting that perhaps the quantity of

[13] If farmers most likely to adopt PICS bags were selectively learning about the technology by searching for new storage options, we would have expected the highest rate of use, conditional on awareness, to be in the region with the lowest level of awareness (Zinder), which is not the case.
[14] Pesticides in this case are used during storage, not cultivation, to combat potential weevil infestation.
[15] Nevertheless, only 15% of the sample of farmers in Zinder produced more than 100 kg.

cowpea stored may be an important factor for traders. In contrast to the farmers, however, nearly all traders had heard of PICS bags. Yet, less than half of traders in Maradi and Zinder have ever used them to store cowpeas, compared with 94% of Dosso traders.

While PICS adoption rates amongst traders is relatively higher, their sales of PICS bags are still low: Roughly a quarter of traders in Dosso have ever sold or are currently selling PICS bags, although 95% indicate that PICS are available somewhere in the market on the day of the interview. In Maradi and Zinder, 10-14% of traders have sold PICS at one point, with 25-40% of traders stating that the bags could be found on the market.

4. Results

In light of the above adoption patterns, we start off by documenting correlates of potential demand for PICS adoption: beliefs about new technology, perceived demand and willingness to pay.

4.1. Beliefs about Relative Storage Technologies

One key component of the technology adoption process is learning about the features and uses of a new technology, relative to the existing options. To understand farmer and trader perceptions of the depreciation rates of different storage technologies, we used a standardized set of questions to elicit subjective expectations about cowpea losses over a 9-month period.[16]

The results from this exercise are shown in Table 3, by region. There is notable consistency in beliefs, both across regions and between traders and farmers. In all possible comparisons, respondents indicate that PICS bags have the lowest depreciation rate, followed by traditional bags with pesticides and traditional bags alone. Both farmers and traders estimate that almost the entire amount stored would be lost at the end of nine months by using a traditional bag without some complementary input, although farmers are, on average, more optimistic than traders. By contrast, farmers and traders estimate that about 70% of cowpea would remain using traditional bags with pesticides. While differences across regions are slight for traditional bags and pesticides, on average, traders in Dosso are more likely to believe that losses would be higher using the traditional technology. Beliefs about losses associated with PICS bags are remarkably consistent across regions and between farmers and traders, estimating that 90% of the

[16] Respondents were presented with the following scenario. Suppose that you have 10 tia (25kg) of cowpea to store at harvest time. Using technology X, what quantity of cowpea do you expect will survive until the cold season (which is roughly 3 months later)? What quantity will survive until the hot season (6 months)? And the rainy season (9 months)? We asked these questions three times, for the following choices of X: traditional bags with nothing else, traditional bags with the addition of pesticides or other protective amendments, and PICS bags.

quantity stored would remain after 9 months. Nevertheless, farmers in Zinder are generally more pessimistic about PICS bags' performance than farmers in Dosso or Maradi.

One of the key takeaways from Table 3 is that knowledge and beliefs about PICS bags diffuse easily and uniformly amongst farmers and traders and across high and low-adoption (and exposure) regions. This differs from many agricultural technologies, such as hybrid seeds, agro-chemicals or planting techniques, for which learning may be slowed by the stochastic nature of the production process and when output is determined by a large number of observed and unobserved factors. It would appear that everyone who has heard of PICS bags believes in their superiority as a cowpea storage technology.

4.2. Traders' Perceptions of Demand for PICS Bags

The supply of PICS bags should only emerge in areas where there is sufficient demand to warrant it. However, when traders and other input suppliers decide whether to stock PICS, they must do so based on their perceptions of demand, which may not match actual demand, particularly for a new good. As was evident above, the supply of PICS bags on our sample markets was much lower than traders' adoption, especially in the Maradi and Zinder regions. In those regions, less than 10% of traders were selling PICS bags during the harvest, and approximately 25-40% reported that the bags were available on the market that day.

To better understand cowpea traders' and bag vendors' perceptions about potential demand for this new technology- either from other traders or from farmers - we elicited traders' beliefs about the demand curve for PICS and for traditional storage bags.[17] Prices for this exercise were chosen based on the observed market prices of each technology, ranging from 200-300 CFA for traditional bags and from 750-1250 for PICS bags. Table 4 shows the mean and median purchase prices (from farmers and traders) and sales prices (from traders) for traditional and PICS bags as reported in the surveys. As is clear, the price options used in the elicitation exercise span the range of observed prices, and include at least one price weakly above or below the mean and median prices of each bag type in each department.

Figure 2 shows traders' average perceived demand curves for both traditional and PICS bags.

[17]In particular, for each type of bag, we posed the following scenario: "Suppose that you arrive at this market, today, with 100 bags to sell. If you offered these bags today at [PRICE], how many bags do you think you would sell today?" The reference prices for each bag around the observed mean price of those bags on local markets, in order to trace out a few points on the subjective demand curve for each trader.

Unsurprisingly, regional variation in perceived market size is apparent, with Zinder having the greatest demand for traditional bags and the lowest demand for PICS bags. This ordering is largely reversed in Dosso. While perceived demand for traditional bags in Maradi falls in-between the Dosso and Zinder perceived demand curves, traders in Maradi believe that demand is less elastic at high PICS prices (e.g., 1250 CFA) than traders in Dosso. This may be due, in part, to the observed prices for PICS bags on these markets, where Maradi has the highest average price.

4.3. Actual Demand for PICS Bags

This section reports the results of the incentivized BDM mechanism used to elicit WTP for a PICS bag by both traders and farmers. In eliciting WTP from traders – rather than willingness-to-accept - we implicitly focused on their contribution to the demand side of the PICS market, leaving aside the fact that many cowpea traders are also suppliers of the bags. While some respondents may have conditioned their WTP on the possibility of re-selling the bags, during our follow-up survey with a subset of respondents one year later, resale rates were low amongst farmers.

Elicitation of WTP from each respondent took the form of a two-stage, incentive compatible BDM. After presenting the respondent with the PICS bag and explaining its attributes, as well as explaining the game, the respondent was presented a sequence of hypothetical prices, ranging from 10 CFA (free) to 5000 CFA.[18] For each price, the respondent was asked to indicate whether he or she would be willing to pay that amount, that day, to purchase the bag. Once the respondent provided an answer for all prices, the enumerator confirmed the highest price that the respondent was willing to pay that day, i.e., the maximum WTP. During the second stage, a price was randomly drawn from those on the list. If the respondent's maximum WTP was greater than or equal to the drawn price, a PICS bag was sold to the respondent at the drawn price. Otherwise, no sale took place. This `spot' transaction had to be completed before the team left the village that day, thereby providing respondents with a "cooling off" period, as

[18]The prices used for this exercise were the following, all in CFA: 10, 250, 400, 500, 600, 750, 900, 1000, 1100, 1250, 1400, 5000, with the highest and lowest prices meant to provide the X and Y intercepts, respectively. While the lowest price offered should have been 0 CFA, several pilots suggested that respondents felt uncomfortable with a "free" (0") price, and so 10 CFA was used. Almost all respondents were willing to pay 10 CFA, suggesting that the non-zero price is not a primary concern.

well as time to gather cash or tap their networks for a loan. In practice, very few respondents (less than 1%) did not pay the drawn price if they won.

For a respondent who fully understands the game and has no deceptive intentions, this mechanism should induce a truthful revelation of the maximum WTP from among the list of prices. Aggregating WTP data across respondents would provide a lower bound estimate of the demand at each price, as the respondent's true maximum WTP could lie in-between two of the price options, in which case he or she will choose the lower option. We decided to accept this slight coarsening from utilizing the price list, rather than allow open-ended responses, because of its tractability.

The region-specific demand curves for farmers and traders are shown in Figure 3. The difference in the ranges of the horizontal axes is driven by the sample sizes, as there are approximately 300 farmers and 100 traders per region. No one in either sample answered 'Yes" when asked whether they would pay 5000 CFA, the maximum price, which therefore bounds the demand curve. However, the points associated with a price of 5000 CFA are not depicted, for clarity.

Perhaps the most striking aspect of Figure 3 is the between-department variation in farmer demand. At any price, more farmers in Dosso are willing to pay for a PICS bag than farmers in either of the other two regions. The gaps are significant: For example, at a price of 750 CFA, farmer demand in Dosso is greater than the sum of farmer demand from Maradi and Zinder combined. Beyond the Dosso-Maradi/Zinder comparison, farmers in Maradi exhibit demand greater than or equal to that of farmers in Zinder at almost any price.

In contrast, Panel B shows that traders exhibit much less inter-regional variation in demand. The exception is in the range of prices just below the current market price, for which 900 CFA is a safe lower bound. As the price falls below 900, Dosso traders become dramatically more willing to buy the bags; traders in the other regions do not exhibit a similar level of demand to those in Dosso until the price falls to 400 CFA, which is less than half the price in some markets.[19]

[19]This may be driven by regional variation in the thickness of the market for PICS bags. Dosso traders may believe that demand is greater below a price of 1000 CFA than do their counterparts (Figure 2). This perception is likely

As mentioned above, the gender composition of the farmer samples differed by region, with half the sample women in Dosso (as compared with 60% in Maradi and Zinder). If women are more credit-constrained, or are less likely to be responsible for cowpea storage and hence relatively less inclined than to spend their available resources on PICS, then the greater demand for PICS in Dosso could simply be the gender composition of our sample. To better understand this and other sources of variation in farmer WTP, we estimate potential determinants of WTP with our farmer sample in the following estimation:

$$(1) \qquad maximum\ WTP_i = \partial + \propto female + maradi + zinder + \beta X_{io} + u$$

where *maximum WTP is* the maximum amount that farmers were willing to pay for a PICS bag during the BDM game (in CFA); *female* is a binary variable if the respondent was female; *maradi* is a binary variable for if the respondent was in the Maradi region, 0 otherwise; *zinder* is a binary variable for the Zinder region, 0 otherwise; and X_{io} are other individual characteristics potentially correlated with WTP. Standard errors are corrected for heteroscedasticity and clustered at the village level.

The results of these regressions are shown in Table 5. In column 1 we condition on region, gender, and an indicator of whether the farmers had previously heard of PICS. Whereas average WTP amongst male Dosso farmers is 805 CFA – still below market price - female farmers have significantly lower WTP than male farmers. The point estimate of -188.6 CFA on female represents a 23% reduction from the mean WTP of male farmers in Dosso, and with a similar gender differential across regions (not shown). Regional differences in WTP remain significant even after conditioning on gender, suggesting that our differences in sample composition are not driving differences in WTP.

In column 2 we examine whether spatial variation in WTP is driven by variation in production levels or beliefs about the relative merits of PICS. The regression shown in Column 2 includes controls for the quantity of cowpea produced last season, the quantity stored, and the farmer's three-month subjective depreciation rates for traditional and PICS bags. While these are endogenous and all highly correlated, none of these variables has a statistically significant association with WTP. The only coefficient that is of substantial magnitude is the PICS depreciation rate, which indicates a negative

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correct, as evidenced by the higher PICS trading volumes in Dosso (Table 2). Greater WTP by Dosso traders when the price falls below 900 CFA may be driven by a low-cost opportunity for arbitrage.

relationship between beliefs about PICS quality and WTP. Furthermore, the estimated coefficients on the gender and region fixed effects are only slightly attenuated after controlling for other farmer-specific characteristics. This suggests that the lower expressed demand for PICS in Maradi and Zinder may be related to some additional set of factors, beyond beliefs about or relevance of PICS bags.

4.4. Supply of PICS Bags

Despite the fact that a majority of traders had heard of PICS bags (Table 2), a majority of our sample of traders had never sold PICS bags. Why is this the case? The breakdown of (non-exclusive) responses is provided in Table 6.

In Panel A, most Dosso traders who do not sell PICS bags do not sell any kind of storage bag", with similar responses in Maradi and Zinder. That being said, there are numerous other reported impediments to selling PICS, including a lack of familiarity with the product, not knowing PICS suppliers, believing that farmers will not buy PICS, and stating that wholesale PICS prices are too high.

In Panel B, we restrict attention to the subset of traders who sell storage bags; in this case, the largest differences between Dosso and other regions are credit constraints, either sufficient financing ("lack of money" or "too expensive"). Nearly half of Dosso traders indicate that financing is a constraint, focusing on "lack of money", whereas the traders in Maradi and Zinder focus on the price. There is a subtle but important difference between these responses. When "Lack of money" is an option but a respondent chooses "Too expensive", that is more suggestive of a concern about the potential profit margin than of a financing constraint. Traders in Maradi and Zinder are not convinced that stocking PICS is profitable. Further support for this interpretation is from the higher response rate for "Farmers will not buy PICS" in Maradi and Zinder than in Dosso, which aligns with the trader perception of relatively weaker demand in those regions (Figure 2).

A small number of traders had carried PICS bags in the past, but had since decided to stop, but no longer do so. While sample sizes are small, traders outside of Dosso stopped carrying PICS because they perceived too little demand or felt that margins were too small, whereas respondents in Maradi indicated either "Farmers did not buy them", "Wholesale price too high", or both.

4.5. Drivers of PICS Adoption

We turn now to the primary motivating question for the empirical portion of the paper: what underlies the

spatial variation in PICS adoption and demand? A few key themes emerged in the previous sections that are worth emphasizing. On the demand side, while all farmers appear to have similar beliefs about the efficacy of PICS bags, farmers in Dosso are more aware of these bags, more willing to use them and more willing to pay for them than their counterparts in other regions. These differences persist even after conditioning on gender, production and storage. On the supply side, traders in Dosso are more optimistic about the size of the market, believing that they can sell higher volumes of PICS bags than their counterparts in Maradi and Zinder. Dosso traders also appear to have access to better wholesale prices for PICS, though these discounts are potentially offset by lower retail prices (Table 4).

These patterns are suggestive of markets at different equilibria. Yet that still begs the question: what led to the surge of interest in PICS in one region? The answer appears to lie in the initial structure of the PICS market, established to coordinate the marketing of this new and valuable product to Nigerien farmers. While we do not have survey data on the origins of the PICS supply market, Coulibaly et al. (2012) provide a detailed characterization of the initial PICS supply chain in Niger, which remained fairly stable until 2016. While PICS bags were distributed for free to farmers throughout the country – including Dosso, Maradi and Zinder - PICS bags were commercially imported under an exclusive import license, based in Dosso, who disseminated the technology in the region using existing commercial contacts. This therefore created a supply chain with thick markets in Dosso, whereby traders could easily have access to PICS In urban and rural areas, and more limited access in Maradi and Zinder (Coulibaly et al 2012). The import market was only recently opened in Niger to other importers as of 2016.

Our survey data suggest that the initial marketing push from this contractual relationship set the Dosso region on a faster adoption path as compared with other regions. Traders in Dosso learned about PICS earlier, and, as members of an exclusive vendor network, were incentivized to promote PICS adoption by farmers. While the import market for PICS bags was less restricted as of 2016, uptake in Maradi and Zinder was still low. [20]

Given that the emergence of a new market is a dynamic process, we cannot be certain that the PICS markets in our sample regions have settled into their long-run equilibria. Efforts are ongoing to promote PICS adoption throughout the cowpea-producing areas of Niger. In 2015, an international NGO, Catholic Relief Services, instituted a large-scale demonstration and promotion campaign, which was accompanied by the distribution of 5,000 free PICS bags to farmers in the Dosso, Maradi and Zinder regions, amongst others.[21] Even if this campaign had a noticeable impact on PICS demand in Maradi and

[20]In all three regions, the majority of traders who purchased PICS recently reported buying the bags directly from a supplier in Nigeria.

[21] See the project page for "Strengthening Value Chains in Niger", https://www.crs.org/stories/strengthening-value-

Zinder, it was not sufficient to explain the equilibrium market levels in Dosso.

5. Theoretical Framework

Given the multiple equilibria observed above, in this section we develop a model that emphasizes the interaction between supply and demand in the formation of a new market. The intuition for the model is as follows. If sellers believe the market for a good is small, they will not stock the good. If the good is not in stock, then consumers are unable to purchase. That, in turn, raises the costs to a consumer who must travel elsewhere to purchase the good, and thereby slows the rate at which consumers learn about the new good from each other, further dampening demand. This interaction between the supply and demand sides suggests a multiple equilibrium problem: An exogenous action must spur one side of the market, for a long enough duration, to allow the other side to adjust. Once sellers' beliefs about demand are aligned with actual consumer demand at some positive trade volume, a market emerges and eventually settles on an equilibrium price. Without some force to motivate sellers to stock a new good or consumers to inquire about it, the market cannot emerge.

In future versions of this paper, we will set the theoretical framework described above: farmers' demand for traditional storage technologies and learning about a new technology, as well as suppliers' beliefs about the demand for the technology and their credit constraints. We use the model of the two sides of the market to show how multiple equilibria can arise, and then make predictions about how a shock to the demand or supply side of the market can result in a new single equilibrium.

6. Conclusion

Using farmer and trader survey data from Niger, we document the rates of adoption, usage and demand for an improved storage technology – PICS bags – in Niger. Despite the efficacy of the technology in reducing storage losses as compared with traditional technologies, as well as the relative price as compared to other alternatives (the bag is more expensive, but can last for three years), PICS adoption varies considerably by region and by gender. This variation in adoption and demand by region cannot solely be explained by existing beliefs about the technology and cowpea production and storage. We then turn to a theoretical framework for the emergence of a new market, showing that the intersection of supply and demand can result in multiple equilibria unless a significant shock occurs to either side of the market.

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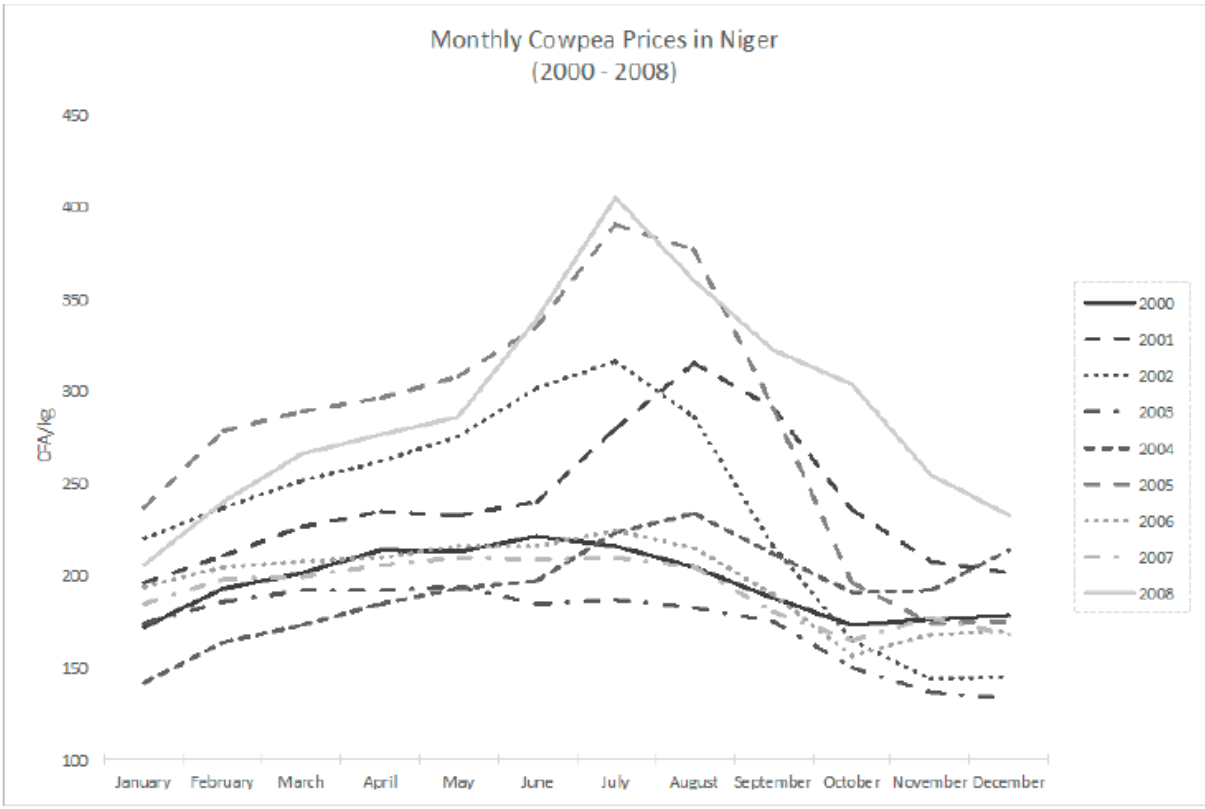
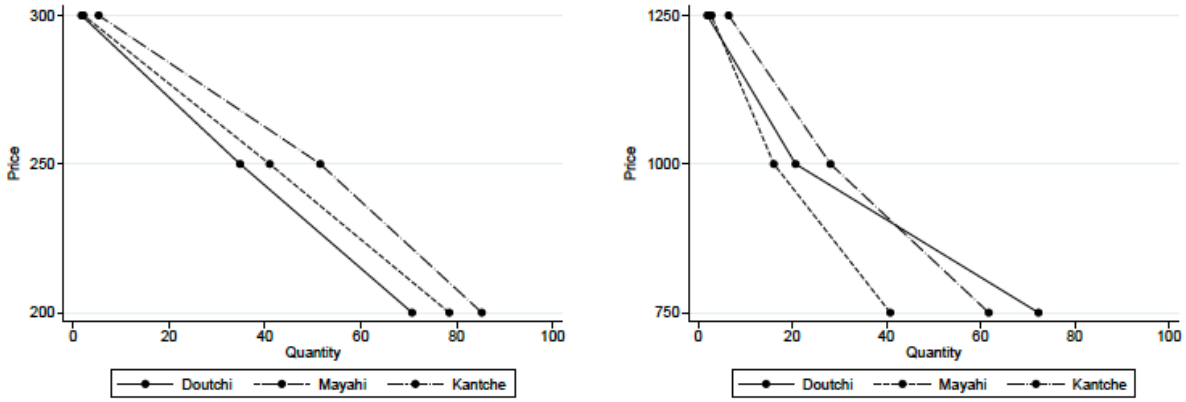
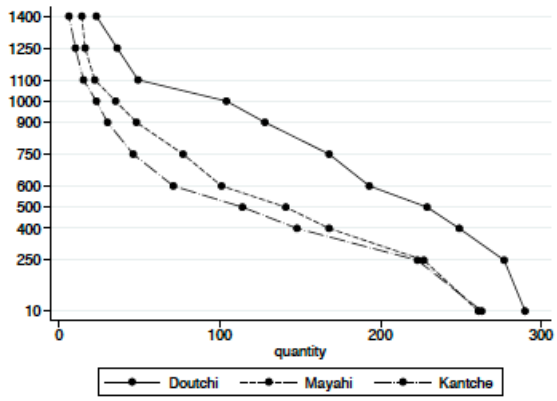


Figure 1: Monthly cowpea prices in Niger

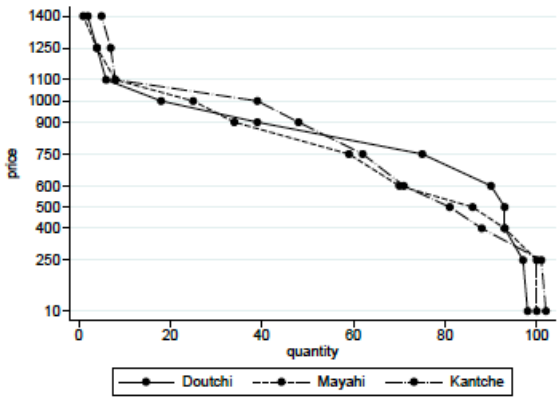


A. Traditional B. PICS

Figure 2: Traders' perceptions of storage demand curves



A. Farmers



B. Traders

Figure 3: Demand for PICS by sample farmers and traders

Table 1: Farmer summary statistics by department

	Doutchi	Mayahi	Kantche
General characteristics			
Female (=1)	0.49	0.61	0.61
Age in years	44.0	40.0	34.2
Owns cell phone (=1)	0.45	0.27	0.28
Production, storage, and PICS			
Started 2016 harvest (=1)	0.76	0.48	0.86
Harvested cowpea in 2015-2016 (=1)	0.97	1.00	0.91
Quantity cowpea produced in 2015-2016 (kg)	248	170	72
Stored cowpea after 2015-2016 harvest (=1)	0.84	0.93	0.80
Quantity cowpea stored in 2015-2016 (kg)	143	88	40
Cowpea stored in (not exclusive):			
Traditional bag	0.27	0.66	0.23
PICS bag	0.48	0.12	0.03
Canister	0.44	0.31	0.80
Barrel	0.00	0.00	0.00
Other	0.02	0.07	0.03
If storage $\geq$ 100kg, cowpea stored in (not exclusive):			
Traditional bag	0.32	0.75	0.32
PICS bag	0.66	0.18	0.12
Canister	0.20	0.18	0.68
Barrel	0.01	0.00	0.00
Other	0.02	0.04	0.00
Bought traditional storage bags (=1)	0.21	0.55	0.14
No. of traditional bags purchased (if $>$ 0)	2.40	1.92	1.33
Bought PICS bags (=1)	0.37	0.08	0.01
No. of PICS bags purchased (if $>$ 0)	2.29	2.20	2.25
Bought pesticides for storage (=1)	0.35	0.76	0.53
Bought plastics for storage (=1)	0.02	0.58	0.15
Lost cowpea to weevils (=1)	0.22	0.15	0.36
Lost cowpea to rats (=1)	0.09	0.04	0.08
Share of stored cowpea lost to pests	0.06	0.06	0.12
Share of stored cowpea lost to pests, if never sold	0.07	0.12	0.14
Expenditure on cowpea storage, past season (CFA)	1877	993	963
Expenditure on cowpea storage, past season (USD)	3.0	1.6	1.6
Sold cowpea after 2015-2016 harvest (=1)	0.77	0.90	0.54
Bought cowpea after 2015-2016 harvest (=1)	0.53	0.48	0.76
Heard of PICS bags (=1)	0.96	0.62	0.48
Ever used PICS bags (=1)	0.57	0.17	0.06

Notes: Authors' calculations from farmer survey data.

Table 3: Expected depreciation rates using different storage techniques

	Doutchi		Mayahi		Kantche	
Crop depreciation after...	Qty remaining (1)	Deprec. rate (2)	Qty remaining (3)	Deprec. rate (4)	Qty remaining (5)	Deprec. rate (6)
Farmers						
Traditional bags:						
3 months	3.93	0.61	4.23	0.58	5.82	0.42
6 months	1.91	0.81	1.83	0.82	3.57	0.64
9 months	0.78	0.92	0.77	0.92	1.84	0.82
Traditional bags with pesticides:						
3 months	9.26	0.07	9.13	0.09	9.38	0.06
6 months	8.39	0.16	8.23	0.18	8.47	0.15
9 months	7.57	0.24	7.47	0.25	7.49	0.25
PICS bags:						
3 months	9.87	0.01	9.73	0.03	9.53	0.05
6 months	9.76	0.02	9.50	0.05	9.06	0.09
9 months	9.66	0.03	9.32	0.07	8.61	0.14
Traders						
Traditional bags:						
3 months	2.78	0.72	2.81	0.72	3.78	0.62
6 months	0.97	0.90	0.86	0.91	1.42	0.86
9 months	0.26	0.97	0.25	0.98	0.52	0.95
Traditional bags with pesticides:						
3 months	9.13	0.09	9.43	0.06	9.52	0.05
6 months	7.91	0.21	8.75	0.12	8.51	0.15
9 months	6.40	0.36	7.89	0.21	7.57	0.24
PICS bags:						
3 months	9.86	0.01	9.95	0.01	9.84	0.02
6 months	9.85	0.01	9.92	0.01	9.72	0.03
9 months	9.84	0.02	9.88	0.01	9.58	0.04

Notes: Authors' calculations from farmer and trader survey data.

Table 4: Prices of traditional bags and PICS bags

	Doutchi		Mayahi		Kantche	
Price as reported by:	Mean (1)	Median (2)	Mean (3)	Median (4)	Mean (5)	Median (6)
Farmers						
Purchase of traditional bag	287	250	206	200	210	200
Purchase of PICS bag	1073	1000	924	1000	1000	1000
Traders						
Purchase of traditional bag	228	250	230	250	240	200
Purchase of PICS bag	962	1000	1070	1000	1023	1000
Selling price of PICS bag	979	1000	1125	1125	1045	1000
Lowest price on market today, PICS	906	900	875	1000	912	1000
Highest price on market today, PICS	1029	1000	1021	1100	1060	1100

Notes: Authors' calculations from farmer and trader survey data.

Table 5: Farmer WTP for PICS, using results of BDM elicitation

Dependent variable: Maximum WTP for a PICS bag on the spot		
	(1)	(2)
Mayahi (=1)	-201.7***	-189.2***
	(35.3)	(33.5)
Kantche (=1)	-267.8***	-238.0***
	(36.9)	(38.8)
Female (=1)	-188.6***	-175.0***
	(24.8)	(25.4)
Heard of PICS (=1)	42.0*	34.4
	(22.6)	(22.3)
Quantity of cowpea produced (100 kgs)		8.9
		(8.9)
Quantity of cowpea stored (100 kgs)		20.8
		(15.4)
3 month subjective depreciation rate, traditional		-23.6
		(47.2)
3 month subjective depreciation rate, PICS		-150.9
		(127.4)
Constant	805.1***	776.1***
	(35.6)	(49.7)
Observations	827	827
R-squared	0.20	0.21
Mean of dep. variable	565.3	565.3

Notes: Authors' estimates from survey data. Standard errors clustered at the village level. ***: significant at 1%; **: significant at 5%; *: significant at 10%. Results are unchanged using interval regression.

Table 6: Trader survey: Why have you never sold PICS bags?

All those who have never sold PICS			
Not familiar with PICS	0.00	0.11	0.14
Do not sell storage bags	0.75	0.62	0.64
Do not know PICS suppliers	0.06	0.21	0.16
Lack of money	0.19	0.04	0.08
Farmers will not buy PICS	0.05	0.14	0.22
Already too many PICS sellers	0.02	0.01	0.00
Too expensive	0.05	0.27	0.31
Other	0.03	0.05	0.18
N	64	85	77
Conditional on selling storage bags			
Not familiar with PICS	0.00	0.16	0.18
Do not sell storage bags	0.00	0.00	0.00
Do not know PICS suppliers	0.25	0.41	0.14
Lack of money	0.44	0.06	0.21
Farmers will not buy PICS	0.19	0.25	0.36
Already too many PICS sellers	0.06	0.00	0.00
Too expensive	0.19	0.50	0.50
Other	0.13	0.06	0.29
N	16	32	28

Notes: Authors' calculations from trader survey data.