Shocks and Cherries: The Production of Vulnerability among Smallholder Coffee Farmers in Jamaica

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Abstract.

Coffee is a global commodity that supports the livelihoods of 100 million people worldwide, many of whom are smallholder farmers. While smallholder farmers are known to be vulnerable to social and environmental changes, the complex interactions that shape their vulnerability have not been adequately explored. This analysis identifies the determinants of that vulnerability in the Blue Mountains of Jamaica and discusses how these determinants interact and have evolved. We use mixed methods consisting of household surveys of 434 farmers, focus group discussions, key informant interviews, and archival research of coffee industry reports. We show that vulnerability is manifest in low coffee harvests that result from the interacting stressors of climate variability, plant diseases, and market conditions. The impacts of shocks and stressors are further aggravated by low resource endowments that influence the capacity to manage these persistent challenges as well as a political economy characterized by unequal market relations, national policies that promote a vulnerable coffee variety, and a retraction of public investments in smallholders. Using regression methods we show that among the farmer resources, the ability to invest in agricultural inputs and tools as well as altitude are importantly associated with production outcomes. We argue that the context of these smallholder farmers produces a Gordian Vulnerability whereby the determinants interact, are changing in form, and appear intractable. Consequently, strategies to reduce vulnerability need to be complex and multifaceted, which makes them difficult to implement. We argue that reductions in vulnerability will only come about by investments in multiple strategies.

1. Introduction

Coffee is a global commodity that supports the livelihoods of 100 million people worldwide (Pendergrast, 2010). In 2014 alone, 26 million farmers in 52 countries cultivated more than 8.5 million tons of coffee with a value of US$39 billion (Hirons et al., 2018). Coffee cultivation is largely from countries in Latin America, Asia, and Africa where small-scale farming systems produce approximately 70% of the world's coffee (Bacon, 2005). That smallholder farmers are particularly vulnerable to climate events, market conditions, and other social and environmental changes has been well documented (Bacon, Sundstrom, Stewart, & Beezer, 2017; Eakin & Wehbe, 2009; O'Brien & Leichenko, 2000). However, the complex interactions that shape the vulnerability are not fully understood in general (Baca, Läderach, Haggar, Schroth, & Ovalle, 2014; Preston, Yuen, & Westaway, 2011; Sachs, Cordes, Rising, Toledano, & Maennling, 2019) and are also in part idiosyncratic due to the uniqueness of a coffee system. Moreover, few studies have addressed the evolution of vulnerability in relation to changes in the broader political economy (Fawcett, Pearce, Ford, & Archer, 2017).

This paper employs the lens of vulnerability to explore the changing dynamics of the coffee-farming system in the Blue and John Crow Mountains of Jamaica (BMs). We adopt a viewpoint of vulnerability that emphasizes the social context in which the exposure, sensitivity, and adaptive capacity—the three common elements of vulnerability—are embedded. As stated by Eakin and Wehbe (2009, p 357): '…vulnerability in our view is not simply the degree of experienced or potential harm to which a population or system is exposed (e.g., its sensitivity to shocks and stress), but also its capacity to respond. Capacity, in turn, is circumscribed by the political economy of resource access and entitlements.' This perspective frames vulnerability as being both a function of external and internal social and environmental dynamics. We operationalize this view to characterize the determinants of coffee farmer vulnerability in the smallholder agricultural system of the BMs. In particular, we focus on how these determinants interact.

We draw on a large random sample of in-depth household surveys as well as focus groups, interviews, and historical coffee-sector documents. Specifically, we document the smallholders' low coffee yields as a manifest of an outcome of vulnerability. We then provide evidence of a dynamic hazard context that continually exposes farmers to multiple and recurring social and environmental shocks and stresses. We further show how low resource endowments are affected by a political economy that shapes market relations, policies on coffee varieties, and institutional resources available to smallholders in ways that feedback on the sensitivity and capacity to manage these persistent challenges. In totality, we show that the vulnerability of coffee farmers in the BMs is multifaceted, intricate, and changing in form.

Given this complexity, we argue that smallholder vulnerability in the BMs can be seen as a Gordian Knot. Vulnerability is knot-like in that it is composed of many individual inter-tangled components and Gordian in that it is intractable and resists solution. The entwined components appear to create ever more difficult challenges for the smallholder farmer. Whereas the Gordian Knot was ultimately undone by a strike of Alexander the Great's sword, we argue that there is no simple solution for reshaping a more viable smallholder coffee system. Rather, the vulnerability described requires sustained interventions across a variety of strategies and scales. Jamaica's case exemplifies a need for coffee development and policy to work across individual, community, and state and international institutional dimensions.

We structure this analysis by providing a brief overview of the vulnerability literature, coffee farming in the BMs, and our methods of analysis in sections 2, 3, and 4, respectively. We then characterize in section 5 the overall vulnerability of these small-scale farmers which they experience as low yields and widespread sensitivity to hazards. In section 6 we discuss what best explains these conditions, elaborating on the multiple and overlapping stressors, farmer-level resources, and the political economy that characterizes the coffee system as a whole. Finally, in the discussion and conclusion, we analyze this highly complex environment as a type of Gordian Knot and offer thoughts on ways to loosen the knot and perhaps even cut it.

2. Vulnerability in the framework of a social ecological system

We interpret the BM coffee sector as a social ecological system (SES). The concept of a social ecological system incorporates the entangled complexities that are central to our argument. Following Ostrom (2009), the SES is presented as an integrated bio-geo-physical unit that includes a resource system (in our case, a coffee farming zone), resource units (coffee), actors (farmers), and a system of regulations (marketing board). The interactions of these components generate feedbacks that produce outcomes at different scales in space and time, and it is necessary to treat these multiple interactions holistically as a system (Gallopín, 2006). The use of SES to explain human-environment relations has become increasingly important in global environmental change and sustainability research (Brown, 2014; Xu, Marinova, & Guo, 2015).

The concept of vulnerability provides an approach to describing change in social ecological systems. Our analysis uses the common framework and definition of vulnerability that is used by the Intergovernmental Panel on Climate Change. In the IPCC's Fourth Assessment Report, vulnerability is defined as the "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system" (IPCC, 2007, p. 6). Our article operationalizes vulnerability as consisting of three interrelated dimensions: exposure, sensitivity and adaptive capacity (Gallopín, 2006; Turner et al., 2003; Adger, 2006). Within this framework, vulnerability is not simply a matter of the system being exposed or sensitive to a hazard: there must also be limited capacity for the system to adapt to the hazard (IPCC, 2007; Polsky, Neff, & Yarnal, 2007; Tonmoy, El-Zein, & Hinkel, 2014). A system's *exposure* consists of hazards that threaten people or things people value (Polsky et al., 2007). These threatening hazards take the form of perturbations – acute events beyond typical system variability, such as hurricanes (Luers, 2005)—and stresses—continuous or slow events, such as soil degradation (Turner et al., 2003). The result of a system's exposure to a hazard is an impact, which is shaped by the system's sensitivity as well as its exposure to a hazard (IPCC, 2014). The system's *sensitivity* consists of the characteristics that condition the impacts (Weis et al., 2016). *Adaptive capacity* determines the longer term ability of an individual or system to preempt, respond, and adjust to a dynamic world either in the short term by coping with the consequences, or through longer-term reorganizations to lessen vulnerability by reducing exposure and/or sensitivity (Costa & Kropp, 2013; IPCC, 2007). Adaptive capacity is often considered to be determined by the level of endowments pertaining to human, physical, social, financial, and natural capitals (H. Eakin, 2005; Scoones, 1998). Adaptive capacity concerns both the access to capital endowments and the ways they are marshaled.

Our analysis conceptualizes vulnerability as being manifest within a dynamic socio-political and economic context that conditions both sensitivity and adaptive capacity. O'Brien et al. contrast this *contextual vulnerability* approach to an *outcome vulnerability* that rather emphasizes biophysical hazards and the ways they lead to losses (Ford et al., 2010; O'Brien, Eriksen, Nygaard, & Schjolden, 2007). Our contextual vulnerability approach treats farmer resources and the wider political economy as both a forcing and feedback on exposure. And, rather than calculating a level of vulnerability for individual households, we submit that the small-scale farmers in our sample are vulnerable, broadly speaking, as they all experience a set of conditions that constrain their coffee livelihoods. We therefore use the concept of vulnerability as a framework to identify the multiple forms of stresses and shocks affecting the system, farmer responses to these dynamics, and the underlying structural elements that further shape and drive vulnerability.

The use of contextual vulnerability follows recent analytical treatments of vulnerability in the Jamaican agricultural sector, largely in the context of climate change. These studies show how the country's legacy of colonialism has shaped social conditions, including the dependence on overseas markets and the unequal distribution of land, which have led to widespread and differential impacts from a multitude of hazards in the forms of droughts, hurricanes, bush fires, rising temperatures, and pests and diseases (Birthwright, 2016; Rhiney, 2015). The small-scale farmers in Jamaica also bear a disproportionate impact of the hazards, particularly when they occur in succession (McGregor, Barker, & Campbell, 2009). For example, in 2004–2005 many farmers in the breadbasket parish of St. Elizabeth experienced multiple hurricanes and a seven-month drought. More than half of the farmers who were subjected to these hazards did not recover their pre-impact yields for at least six months, while another third required more than a year to recover (Barker, 2012). Jamaican farmers of all kinds are vulnerable to climate-related hazards. Farmers cultivating crops such as tomatoes, melons, and carrots have been repeatedly devastated by hydrometeorological events (Campbell, Barker, & McGregor, 2011; Campbell & Beckford, 2009), while cocoa producers have been experiencing declining crop yields due to a more arid dry season and shifting rainfall patterns (Rhiney, Eitzinger, & Farrell, 2016). Coffee too has been the subject of biophysical and social hazards. Climate variability and a fluctuating and unpredictable market for non-BM coffee have also led to large declines in coffee area grown outside of the BMs (Birthwright, 2016; Birthwright & Barker, 2015). Whereas coffee was once cultivated near island-wide, it has now been largely relegated to the BMs.

3. Coffee Farming in Jamaica: A Brief History

Coffee was introduced to Jamaica in the 1720s from Haiti or Martinique (Mighty, 2016). By 1790, coffee had become a significant economic activity in Jamaica, largely through the exploitation of slave labor on large estates (Talbot, 2015). For a brief period in the early 1800s, Jamaica was the world's largest coffee producer (Talbot, 2015). The abolition of slavery in 1834 initiated a gradual conversion to smaller scale production as increased labor costs and a reduced world demand forced many large landlords to rent or sell their land. By the middle of the twentieth century, around 88% of the coffee-growing farms were less than 10 acres and 13% were less than one acre (Thomas, 1964). This smallholder pattern holds true today. Approximately 80% of BM farms are less than five acres (personal communication, Jamaica Coffee

Industry Board). The conversion to smaller-scale production was also accompanied by an overall reduction in crop quality (Thomas, 1964). By the 1940s, foreign buyers had ceased purchasing Jamaican coffee and Jamaica suspended all exports (Mighty, 2016).

To resuscitate the industry, the Jamaican government established the Coffee Industry Board (CIB) under the Coffee Industry Regulation Act in 1950 (Thomas, 1964). The CIB oversaw processing, quality control, marketing, and exports (CIB, 2014). While the CIB restructured into the broader Jamaica Agricultural Commodities Regulatory Authority in 2018, we use "CIB" throughout this article. The creation of CIB, among other changes, ultimately helped rehabilitate production, and exports began anew, primarily to Great Britain and then later nearly exclusively to Japan.

Currently, Jamaican coffee is grown island-wide but is concentrated in the BM where approximately 80% of the island's coffee is cultivated (Mighty, 2015). The original coffee variety planted in Jamaica was Typica, a *Coffea arabica* variety known for its exceptional quality. Typica, relative to other varieties, thrives with a medium amount of agricultural inputs, has a lower yield potential, and is highly susceptible to coffee leaf rust (CLR), characteristics that can make Typica challenging for households with limited financial capacity (World Coffee Research, 2018). Nonetheless, Typica is a dominant cultivar in Jamaica and worldwide. International markets, particularly in Japan, have come to associate the BM coffee brand with Typica's distinct flavor profile. Through a combination of factors that includes the region's reputation for producing high quality cherries and niche marketing, BM coffee is a differentiated product that fetches some of the highest farmgate prices worldwide.

Currently, coffee is one of Jamaica's most important sources of foreign exchange and its largest agricultural export; in 2016 exports were valued at approximately US$27.6 million (Statistical Institute of Jamaica, 2018). During the last coffee farmer census in 2004, there were approximately 7,032 registered farmers in the BM (CIB, 2014); CIB believes the number of registered farmers is currently about half that number. This represents a relatively small fraction of the 230,000 estimated farmers in Jamaica (as of 2015; Rhiney, Eitzinger, Farrell, & Prager, 2018). Nonetheless, coffee supports employment of around 80,000 Jamaicans who participate in different facets of the coffee supply chain (personal communication, CIB), or approximately 16% of the total agricultural workforce there (World Bank, 2019). Despite being an important source of livelihood, coffee production in Jamaica has been gradually declining in recent decades (Montagnon & Pierre Charmetant, 2014), especially outside the BM where coffee prices are much lower and farmers are largely replacing coffee with other crops like sugar cane, cocoa, and bananas (Birthwright & Barker, 2015).

4. Data and Methods of Analysis

We employ a mixed methods approach to capture the diverse aspects of the coffee farming system. We conducted 12 focus group discussions (FGDs) in the summer of 2015 (see Guido et al., 2018 for details), followed by 434 household surveys and interviews with more than 26 coffee industry stakeholders between January and April of 2016. We provide topic outlines of these data instruments as supplementary material (see Appendix A). We also conducted archival research of all CIB annual reports dating back to 1953. Figure 1 shows the study site and location of the FGDs and surveys. We collected this primary data during a period of multiple stressors, including a severe drought and soon after the first severe outbreak of coffee leaf rust (CLR) on the island in 2012–2013. This research was part of a larger project on climate adaptation and services (Guido et al., 2018; Guido, Knudson, Campbell, & Tomlinson, 2019; Knudson & Guido, 2019).

[Figure 1 around here]

4.1. Focus Group Discussion, Interview, and Household Survey Methods

We conducted the FGDs in 12 communities, four in each of the three BM coffee-producing parishes of St. Thomas, St. Andrew, and Portland. Because elevation significantly affects the lifecycle of coffee through its moderation of temperature, the timing of crop management practices and the quality of the coffee differ by community (Bertrand et al., 2012; Camargo, 2010; de Souza Silveira et al., 2016). We therefore held FGDs in communities with elevations between 230 m and 1270 m, which spanned nearly the full elevation range of the BMs and included some of the highest elevations at which coffee is grown in Jamaica (Figure 1).

The research team visited all 12 communities and identified local farmers in each community to organize the FGDs. The farmers recruited a diverse group of participants, including male and female farmers with a range of ages and experiences. FGD attendance ranged between 6 and 19 people. A total of approximately 143 farmers participated of which 67% were men. The FGDs lasted 1–2 hours on average. The discussions followed a topic guide and were facilitated, at times, in local patois. Topics included farming history, management practices, challenges, and coping strategies (Appendix A). Two note takers recorded the content in all but one FGD where only one note taker was present.

In addition, we conducted 26 semi-structured key informant interviews with members of the CIB, agricultural extension, coffee buyers, large farmers, and other actors in the coffee supply chain. CIB and the Inter-American Institute for Cooperation on Agriculture (IICA) helped identify initial interviewees. We expanded the number through snowball sampling. The interviews followed a topic outline similar to that used with the FGDs (Appendix A). These interviews were supplemented with additional formal interviews and unstructured conversations between the author team and members of CIB, coffee buyers, and larger-scale farmers.

We conducted the household survey in 20 communities covering every BM community with a population of at least 100 households and where coffee was the main livelihood. We identified these communities in collaboration with CIB and IICA. The communities were distributed roughly equally across the three parishes in the BMs and also spanned nearly the full BM elevation gradient (Figure 1). In each community, we implemented a random sampling protocol that targeted 15% of the households. To the best of our knowledge, lists of households in each community did not exist. Therefore, we used recent Google Earth imagery to identify all structures within a reasonable distance of the community center. We then randomly selected 15% of those building and had an enumerator team from the University of West Indies survey each of them. If the structure was a residence but unoccupied, we would return at least several times. If the structure was not a residence, was abandoned, or if the residents did not grow coffee, we would interview the nearest residence. We tested the accuracy of our approach by mapping in detail one community. In this community we visited every structure and compared with those we identified on the image. The accuracy was high. On the image we identified 77 of the 79 structures visually mapped (97%).

In total, we completed 434 surveys with a response rate of 84%. Of those, we omitted 10 households that cultivated coffee on plots larger than a combined 20 acres. The average farm size for the omitted households was 41.0 acres while that of households included in the sample was 3.5 acres.

We surveyed the primary farmer of each household. Many questions required the farmer to recall their activities over the most recently completed harvest year. Questions were based in part on a sustainable livelihoods approach (Scoones, 1998), focusing on household characteristics, livelihood activities, farm practices, social interactions, and perceptions of risks and impacts, and coffee production outcomes (Appendix A). Approximately 77% of our sampled population was male farmers. The mean age was 53 years, while the average and median farm size was about 3.5 and 2.5 acres, respectively. Approximately 84% of the respondents stated that at least half their household income was generated from coffee. In Section 6.2, we present a more thorough description of the sample population.

4.2. Qualitative and Quantitative Analysis

For the qualitative analysis, we transcribed interviews and performed content analysis on the FGD notes. We analyzed both in terms of key themes of vulnerability. From the historical CIB documents, we identified all the hazards that were referenced in the documents to have impacted production, while also building a database of the BM coffee production. We presented this information in Section 6.

From the survey we compile descriptive statistics of key household variables and explore associations between coffee production in an Ordinary Least Squares (OLS) linear regression model. The dependent variable in the OLS is the number of boxes they harvested during the 2014–2015 agricultural year. A box is the standard unit of measurement in Jamaica and holds roughly 27 kg of ripe coffee cherries (Davis, Rice, Rockwood, Wood, & Marra, 2019; Johnson, Kellermann, & Stercho, 2010). We log transformation this variable, first adding a positive constant, *1*, to all observations prior to the transformation because many farmers did not harvest any coffee. We present the coefficient and the standard error. We also present the exponentiated coefficient, or expB, to facilitate interpretation. The interpretation of the expB coefficient for continuous variables is an incident rate ratio where the dependent variable changes at a factor equal to the expB. In the case of binary variables, subtracting one from the expB and multiplying it by 100 represents the percent change in the dependent variable when the binary variable increases from 0 to 1.

The omitted cases leave a sample size in the OLS of 254. We therefore tested using a Chi Square and an Independent Sample T-Test each variable in the analysis for differences between the group included in the analysis and those omitted. There was as significant difference ($p = <0.10$) in only two of the 13 variables: hired labor and elevation. Therefore, we believe the results to be largely representative of the full sample.

5. Outcomes of Coffee Farmer Vulnerability

[Figure 2 around here]

During the 2014–2015 agricultural year, the average total coffee production for about 80% of the smallholder farms was 50 boxes or less. The median yield was around 10 boxes per acre (Figure 2). In contrast, the CIB considers 80–100 boxes per acre to be an attainable output following recommended agronomic practices which include high input use, sufficient tree spacing, and routine pruning. This level of yield is reached by many of the larger farms in the BMs.

The low coffee production and yields in 2014–15 were affected by multiple hazards (Guido et al., 2018). In 2014–15, the aggregate precipitation deficit in the BMs during the August–July period was 68% of the 1981–2015 average, the highest it had been since at least 1981 (Guido et al., 2018). Farmers perceived this drought to be the most impactful, with many farmers during the FGDs reporting the drought to be one of the worst in their memories (Guido et al., 2018). Also 61% of the farmers surveyed stated that CLR affected their coffee in 2014-2015. These stresses have also been present over several years. Nearly 80% of the farmers stated that the biggest challenge they had faced in the past three years (between 2014-2016) was related to climate, plant disease, or personal finances.

To quantify the impacts, we asked farmers to compare their 2014–2015 harvests to the amount they had expected to harvest that year. About 63% stated they harvested less coffee than expected with approximately 40% reporting harvesting less than half of what they expected (Figure 2). We recognize that this is an imperfect measure of impact. However, more precise data are not available. Since neither CIB nor most farmers keep detailed records of their production, it is difficult to quantitatively compare yields from one year to another.

All else being equal, both low coffee yields and total production translate into less income for household expenditures and investments in farming operations. Lower income is part of a feedback that makes the farming situation more precarious to adverse future conditions. While we have captured only a snapshot in time, the FGDs and interviews document low production as a persistent challenge. In fact, increasing production has been a long-held policy objective by the farmer support services in Jamaica (Edwards, 1954; Montagnon & Pierre Charmetant, 2014). In the sections that follow, we advance explanations for the BMs coffee system's low productivity and high sensitivity to environmental impacts.

6. Explanations of Blue Mountain Coffee Vulnerability

The literature suggests that vulnerability is produced by complicated interactions across scales and actors. Our analysis reveals this to be true in the BMs. Both the individual farmer and the broader coffee production system are caught within a web of constraints where each strand contributes to farmer vulnerability. In this section we define the nature of these constraints as the exposure context, the inadequacy of farmer resources to respond, and the structural elements that govern coffee production. We describe each in turn but do not assess their relative importance.

6.1. The Hazard Context: Recurring and Interrelated Shocks and Stresses

Coffee farmers in the BMs experience recurring, interrelated, and overlapping hazards. Nearly every year coffee farmers are exposed to either severe storms, droughts, pests and diseases, or market volatilities in some overlapping combination. Figure 3 displays the frequency of episodes that have affected coffee production as noted both by CIB annual reports and the FGDs.

[Figure 3 around here]

At least eight hurricanes and tropical storms have assailed coffee farmers since 1985 (Figure 3). Such severe storms damage coffee in three principal ways. First, coffee cherries mature during the hurricane season in many communities in the BMs, particularly those at lower elevations. The strong winds and rain can therefore strip the trees of the ripening cherries. CIB estimated that damage from Hurricane Ivan in September 2004 contributed to a decline of 250,000 boxes during that harvest year (CIB, 2004).

Secondly, rain causes land slippage and landslides that damage roads, thus hindering the movement of coffee and cash crops to markets. Finally, both the strong winds and land upheaval can destroy and uproot trees, thereby reducing production for years to come.

Like severe storms, droughts have been common and harmful in the region. At least six droughts have occurred since 1985 (Figure 3). Because smallholder farming is principally rainfed, coffee production is particularly susceptible to dry periods. Insufficient rain causes cherries to be less dense and, consequently, of inferior quality, while causing fewer and smaller cherries. A lack of rain generally stresses coffee plants, making them more susceptible to pests and diseases. In extreme cases coffee trees may die, extending the impact into future years. Droughts have also affected the production of other crops that provide supplementary income to farmers and influenced other hazards, such as wildland fires. In fact, several studies on Jamaica's agriculture sector have identified impacts caused by increases in aridity and temperature, including a reduction in plant-available moisture due to increased rates of evapotranspiration, an increased spread of some pests and diseases, and a decline in crop yields (Eitzinger et al., 2015; McGregor et al., 2009).

Pests and diseases have also affected coffee production in the BMs at least nine times since 1985, spanning six distinct periods (Figure 3). The most prominent have been the impacts from the coffee berry borer pest and, more recently, CLR. CLR is caused by a fungus that thrives in wet conditions and whose severity and prevalence is affected by farm management practices (Avelino et al., 2015). CLR was first observed in Jamaica in 1986 but was largely confined to lower elevations. This changed in 2012–2013 when CLR affected Jamaican farms across the full elevation range of the BMs. During this event CIB estimated that about 25–30% of coffee producing land in the BMs was affected and the income of farmers fell by approximately 25% (Bank of Jamaica, 2015; ICO, 2013). Some farmers reported that CLR was severe and widespread throughout 2015—despite a noted presence of drought conditions—with high levels of tree mortality that extended the duration of the economic hardship. The presence of CLR in 2015 during dry conditions could in part be explained by a lack of active CLR management or by wet spells within an overall drought period. CLR and other pests and diseases are influenced both by prevailing climate conditions and coffee management practices in complex ways (Avelino et al., 2015).

The fourth main shock farmers in the BMs experience is related to periodic market changes. The CIB and farmers identified five separate occasions of economic stress during four periods since 1983 (Figure 3). Farmers singled out the global economic recession around 2008 as particularly severe and a time when the price farmers received for their coffee cherries ultimately plummeted to the lowest levels in their collective memory. This shock is perhaps matched by a recent farmgate price collapse where from 2016 to 2018 the farmgate price per box fell by 75% to J$3,000, or approximately US$22 (Jamaica Observer, 2018). Such price declines have been exacerbated by rising costs of fertilizers and chemicals, as well as the devaluation of the Jamaican currency which has made inputs more expensive.

While these stresses occur at a specific time and in a specific place, they are neither short-lived nor independent of each other. Stresses that reduce household income, such as a drought or market decline, affect coffee management practices which, at a later point in time, make the trees more susceptible to disease. An example that many farmers recounted during the FGDs was the global recession in 2008, which generated a decline in farmgate prices and returned less coffee income to farmers for their reinvestment in their farms. In response, many farmers curtailed their use of inputs like fertilizers. In some extreme cases, farmers abandoned coffee farming altogether. The inability to care for the coffee trees led to weakened plants, thereby likely worsening the impacts of the 2012–13 CLR outbreak and the subsequent drought (e.g. Avelino et al., 2006). Paradoxically, while these interrelated shocks and stresses reduce production at a point in time, the last three decades have also experienced periods of growth in total coffee production in the BMs. It is therefore clear that both shocks and stresses capture only part of the vulnerability context.

6.2. The Farmer

Since the household resource base is the set of asset packages that enable farmers to cope with and adjust to external changes (Adger, 2006; Parry & Canziani, 2007), an analysis of these endowments offers a second part of the explanation for low coffee production throughout the BMs. Table 1 summarizes the statistical distribution of variables that characterize human, social, physical, and economic resources at the household level.

[Table 1 around here]

The coffee farming population is largely composed of middle-aged to elderly individuals. The mean age of the household's primary coffee farmer is 53, with one standard deviation of the population falling between the ages of 39 and 77. A large fraction of the coffee farmers that were surveyed have not attended formal school above the 9th grade, and nearly a third of the sample completed, at most, primary school. With few younger farmers showing an interest in farming, many FGD participants were not optimistic about the future. Moreover, coffee farming is physically difficult even for young farmers. The steep terrain in the BMs creates extra challenges for mobility for older farmers, particularly during the rainy and harvest seasons.

Many farmers also possess low stocks of physical and economic resources. About 81% of the small-scale farmers cultivate plots of five acres or less. This small size of farms is common across many coffee growing regions (Waller, Bigger, & Hillocks, 2007). On these plots, most farmers in 2014–15 cultivated a several varieties including Typica, Geisha, and other varieties named in colloquial terms. The predominant variety was Typica which has been heavily promoted by the CIB and coffee buyers to meet Japanese market specifications of quality. Coffee in the BM is also cultivated by many farmers within an agroforestry system that provides both shade for the coffee and additional income. As 90% of the farmers stated they have shade trees (n = 326), fruit from banana or citrus trees provided additional revenue for 62% and 14.4% (n = 422 and 423, respectively) of the farmers, respectively. Other research in the BM has shown that fruit trees can account for as much as 15% of a coffee farming households income (Davis et al., 2019). Vegetables were also sold by 32.3% (n = 424) of the coffee farming households.

The utilization of inputs was also low in this sample. Farmers applied fewer than the recommended number of four fertilizer applications per year. Additionally, 62% of the farmers did not apply any fungicides in 2014–15 despite 61% of the farmers reporting at least some coffee losses as a result of CLR. Fungicides are the principal method to treat CLR in Jamaica. Of those who did spray fungicides, the majority own hand-held sprayers that are less effective than mechanical sprayers at coating the undersides of leaves where CLR thrives. In fact, only 15% of farmers owned a mechanical sprayer which is more expensive than the handheld variety. There were also very few farmers who obtained loans from banks, family or friends, or coffee buyers.

Finally, information and knowledge networks were found to be weak. More than half the farmers (54%) did not receive any technical help from extension services such as the CIB, the Jamaican government's Rural Agricultural Development Authority (RADA), or coffee buyers. Additionally, more than half of the farmers did not participate in any form of informational group activities, including attending farmer-led group training sessions. For those who did participate, they attended very few meetings over a 12-month period with the most attended group being hosted by RADA which focuses on cash crops other than coffee.

(a) Coping with Recent Hazards

Despite the limited resources, farmers largely rely on their own capacities to deal with major challenges. According to the household survey, 98% of farmers coped with the recent drought, CLR outbreak, and recent price shocks by applying fewer inputs, drawing down their savings, selling assets, or deciding to cultivate other crops. Figure 4 shows the coping strategies deployed for the three main stresses farmers experienced. Farmers overwhelmingly relied on strategies classified as self-reliant, while strategies drawing on community and external resources were used far less. Abandoning plots represents an extreme case that occurred with some farmers after the 2008 economic crisis and again more recently in 2017 as a result of a steep decline in farmgate prices.

[Figure 4 around here]

The high dependence on self-reliant strategies is in part reflective of a broader system that offers limited support. Only 10% of farmers received help from others in their community, and only 3% received support from the government, non-governmental organizations, or banks. While there have been recent government programs that distribute resources after major disaster events—such as seedlings after a large bush fire in 2015—these efforts reach only some individuals and are generally seen by farmers as insufficient.

(b) Relationship between farmer resources and vulnerability outcomes

In order to understand how the characteristics of farmers and the resources available to them affect vulnerability outcomes, we investigate the associations between farmers' resources and harvest amounts using an OLS regression analysis. We omit some variables described above due to low variability in the data. Loans, for example, could enable farmers to purchase fungicides when trees experience severe CLR incidences. However, because less than 1% of the farmers secured loans, this variable will bear little effect in the analysis.

[Table 2 around here]

We report results in Table 2. The noteworthy variables that show significant relationships are the age of the household primary decision maker, elevation, and four different measures of farm investment—hired labor, the number of productive agricultural assets, and fungicide and fertilizer use. The signs of these explanatory variables are as expected. Coffee production negatively scales with age, likely due to the physical demands of coffee farming in the rugged BMs. Pruning, picking cherries, and applying inputs can be difficult on steep terrain, and older farmers may not be as efficient and effective at these activities. This also relates to the significance of hired labor, which not only can help with the physical demands but also can limit waste from the quickly ripening cherries. Moreover, cherries ripen unevenly among trees, and this requires more frequent harvesting that can be burdensome for a family to undertake alone. Additionally, and not surprisingly, the possession of agricultural tools appears as significant in both specifications. Tools enable farmers to be effective across a range of management practices. Mechanical sprayers, for example, more thoroughly coat the undersides of leaves with fungicides where CLR resides than do handheld sprayers.

Perhaps the two most insightful correlations are between production and elevation and the use of agricultural inputs. The results suggest that the elevation at which coffee is grown has a large effect. The coefficient, for example, could a 0.1% increase in boxes per meter increase in elevation, equating to nearly a tripling of yields over a 1000 m rise, holding all other variables constant. Omitted variables in the model, however, prevent this interpretation from being conclusive. Nonetheless, it is widely known that higher elevations with their cooler temperatures and more rainfall are favorable for growing coffee (Bertrand et al., 2012; Camargo, 2010; de Souza Silveira et al., 2016). Land, however, is in limited supply and financially inaccessible for many of these farmers. Smallholder farmer mobility is largely restricted, and most farmers cultivate land either in or close to the communities wherein they reside. Elevation is therefore an endowment that has a relative benefit for some more than others. In this sense, there is a vulnerability of place that is inherited.

In addition, the use of fertilizer and fungicides appears to have large effects on the amount of coffee harvested. As stated, an additional fertilizer application and the use of at least one fungicide application are associated with increases in production. Despite these benefits, only 41% of the farmers applied fungicides and about 30% of the farmers applied fertilizers at least once. These results emphasize the importance of being able to purchase inputs; yet, at the same time they highlight how limited financial resources have a positive feedback.

6.3. Political Economy

The farmer attributes and exposures combined are still inadequate explanations for our manifestations of vulnerability because resource endowments are shaped by the history of the broader coffee system (Turner et al., 2003). In this section we discuss elements related to institutions, principally the CIB which regulates the industry and provides some support; market relations, including those between the smallholder farmers and the local processors and overseas buyers; and the coffee plant itself. We show how the coffee system in the BMs has become less cohesive through time. We draw mostly from the expert interviews and archival research of the CIB annual reports.

(a) Institutions

The CIB was established in 1950 to encourage the development of the coffee industry and to promote the welfare of the people engaged in it. The CIB became the principal purchaser of coffee, setting a price that all farmers received. Concurrent with the CIB's early activities, the Jamaica Agricultural Society began to organize nearly all coffee farmers into Cooperative Societies. These Societies divided up the coffee-growing regions so that farmers would be members of, and sell their cherries to, their local co-ops, which were in turn bought and exported by the CIB. Over the first three decades, this arrangement allowed the coffee industry to expand its production nearly twentyfold and return most of the export price to the growers (CIB, 1954, 1980). The benefits of membership also included dividends, access to loans, extension support, and employment. However, the global recession of the late 1970s and early 1980s caused the coffee industry to struggle economically. The country's high unemployment, interest rates and inflation, along with its massive debt and declining GDP, led the Jamaican government to accept loans from the International Monetary Fund that were conditioned on structural adjustment policy reform

(Schipke, 2001). As part of a broader restructuring of its export commodities market to maximize foreign exchange earnings, Jamaica instituted the Coffee Industry Deregulation Policy in 1983. Under new rules, approved growers and processors could circumvent the co-op system and buy directly from the growers (CIB, 1983).

From the 1980s through the early 2000s, the CIB gradually reduced the financial and administrative support to the co-operatives. The cooperatives also began to experience management problems that by the 1990s became severe enough to compel many farmers to sell their coffee directly to the CIB's processing factories (CIB, 1996). The BMs last two cooperatives, Silver Hill and Moy Hall, ceased operations in 1996 and 2011, respectively. The closure of Moy Hall was particularly acrimonious and damaging for the member farmers who lost invested shares, jobs in the factory, access to guaranteed extension support, and a supply of credit from a trusted source. The demise of cooperatives is one reason why coffee farmers in the BM display low levels of associativism and social capital.

A modern form of the farmer co-op, the Jamaica Coffee Growers' Association (JCGA), has emerged to preserve one element of the old system: the ability of farmers to receive a higher share of the export price through value-added processing. However, the JCGA currently is only a small part of the BMs coffee system; only 9% of the surveyed farmers interacted with it. Moreover, without banding together with other farmers, as those in the JCGA do, smallholders are excluded from value-added processing because recent regulations require processors to have a minimum annual production of 6,000 boxes of coffee—production that none of the farmers we sampled attains—and a license fee of JM$200,000. Although a senior CIB official has argued that a main way that smallholders can reduce their vulnerability is through collective action like the JCGA's, the CIB cannot actively enable such a transformation in the industry without jeopardizing their neutrality as a regulatory authority.

While the role of CIB has evolved, the share of the national budget allotted to agriculture was around one percent between 2003–2011, three-quarters of which was provided by donors (Del Mar Polo et al., 2014). This fraction was one of the lowest among Latin American countries, and in 2007 was about a quarter of the world average (Del Mar Polo et al., 2014). Not only was state expenditure low but also donor support for the sector declined over this same period. As one consequence, extension services are inadequate. The CIB has only three extension officers for the entire BMs while RADA has about one officer for every 2000 farmers.

(b). Markets Relations

CIB's role as near-exclusive buyer and exporter of the entire island's coffee crop for three decades ended with deregulation, which ushered in the large processing companies that resulted in more volatile farmgate prices and a smaller farmer share of the profits. Through the 1960s and 1970s, farmers typically received more than 50% of the price realized from export sales (CIB, 1964, 1976). This value peaked in 1964 at 77%, fell to about 50% in the early 1970s, and then rose again to 72% in 1976 as part of an "aggressive pricing policy in an effort to back the expansion drive [begun in 1969] in a very meaningful way" (CIB, 1976, p. 4). Cooperative factories also received a small share of the export price from which the farmers received benefits as well. In 1964, for example, CIB paid the cooperative factories 4% of the export price (CIB, 1964, p. 8). By giving the farmers the majority of the export price, the CIB tried to ensure that smallholder farmers had the resources to improve both their yields and the quality of an increasingly sought after premium coffee. A report by the FAO calculated that between 2006 and 2010 Jamaican farmers were receiving less than 5% of the coffee revenue generated across the supply chain (Del Mar Polo et al., 2014). Not surprisingly, most of the farmers we surveyed were unable to invest the required amounts of inputs needed to increase yields.

External market relationships have also changed since the CIB's founding. Jamaica began increasingly exporting to Japan. In the 1960, Japan received approximately 10% of the Jamaica coffee exports (CIB, 1960), but by the late 1970s, Jamaica was shipping nearly 100% of its exportable coffee to the Japanese market (CIB, 1976). By the mid-2000s that number was only slightly lower, at around 90% (CIB, 2008). The Japanese market prized the quality of Jamaica's Typica variety and helped develop the iconic BM brand.

The reliance on the Japanese market has tradeoffs, however. On the one hand, BM coffee earns some the highest consumer prices of all coffee growing countries, which tends to buoy the prices farmers received. On the other hand, BM coffee prices are highly volatile, a result in part caused by inconsistent and falling demand from Japan (ICO, 2015). Since at least 2015, according to a BM coffee buyer, Jamaican exporters have been unable to negotiate contracts with Japanese buyers, which has contributed to interannual farmgate price volatility. In addition, the Japanese market's preference for the flavors of the Typica variety and high dependence on that export market limits Jamaica's ability to cultivate other varieties without jeopardizing its primary market. While the high price does benefit growers, Typica is "very highly susceptible" to CLR (World Coffee Research, 2018). It also requires medium amounts of inputs and has a relatively lower yield potential (World Coffee Research, 2018) compared to other varieties. These characteristics make it a variety not well-suited for smallholders, and, in fact, Typica has gradually been replaced across much of the Americas (World Coffee Research, 2018).

7. Discussion

We chose the metaphor of the Gordian Knot to depict the vulnerability of the smallholder coffee sector in Jamaica's BMs because from the perspective of the farmer this problem appears deeply enrooted, entangled, and intractable. It is a problem that seemingly defies a ready solution.

The presence of one strand of the knot arises out of environmental conditions. Hurricanes and droughts, have been a regular feature of farming while CLR has become a new shock in recent years. The impacts of these events, however, are produced by the characteristics of the farmers and the farming system that stewards them. The ability to prepare, respond, and recover from the impacts is often beyond the capacity of BM farm households. This manifests in chronically low levels of production which are further reduced by these events. The loss of income from likes of drought or CLR undermines the financial ability to mitigate the impacts, thus increasing exposure to the next event. The lost income prevents many farmers from purchasing fertilizers and chemicals to support the input-needy Typica variety. This feedback is present across the BMs but it is accentuated at lower elevations where the yields are lower.

Another strand of the knot comes from the volatility of the market which farmers see as uncontrollable and externally sourced. Initially, the emergence of smallholder coffee in the BMs after emancipation enjoyed a certain level of protection from market forces. The construction of an export-driven coffee industry, which began on large estates under slavery, modernized in the mid-20th century when the CIB was created to organize, oversee, and aid the small-scale farmers. During its first few decades, the CIB engaged policies that successfully expanded production, returned a high percentage of the export value to the growers, and deployed a large research and development staff. This was a time of expansion and success for coffee farming in the BMs. However, by the early 1980s structural adjustment had removed the price protections of the state, and the sector was turned over to private buyers. In the following decades, the farmgate price both fell as a share of the export price and became more volatile as exporters focused almost exclusively on Japan. Moreover, external institutional support through rural credit sources and access to technical assistance has been low, and farmers feel isolated from public services of all sorts. These developments have contributed to a smallholder farmer reality characterized by low resource base and a production cycle which itself is constantly hampered by multiple shocks and stresses. Consequently, these smallholder farmers cannot cut the Gordian Knot with their own resources, and thus the intractable nature of the problem.

The dynamics that produce the vulnerability of smallholder coffee do not portend well for a viable, let alone a thriving, smallholder system. An increase in coffee production and of farm size is constrained by the intrinsic limits of BM farmland and the difficulty in farming it. Global climate change seems also likely to reduce the land suitable for coffee in Jamaica and/or lower the quality of coffee produced there (e.g. Bunn et al., 2015; Rhiney et al., 2018). At the same time, climate change may also acerbate the severity of droughts (Herrera & Ault, 2017) and affect CLR through changing temperature, humidity, and precipitation. Even absent of climate changes, CLR has shown itself to be difficult to control without farm-level and sector-wide investment. And yet investment in Jamaica's coffee sector in ways that reach the small-scale farmer is lacking, a consequence related in part to government and donor expenditures in agriculture that not only rank as one of the lowest in Latin America but are also in decline (Del Mar Polo et al., 2014). This constrained financial environment is further accentuated by the closure of cooperative societies, thereby reducing resource pooling and the advocacy power of more organized groups. Finally, these changes are occurring alongside rising production costs and inflation. Between 2009 and 2015, for example, chemical and fertilizer costs rose locally by about 15%, and since 2000 the Jamaican dollar has declined in value against the US dollar by about 65% (Bank of Jamaica, 2016; MICAF, 2018).

The intractable nature of vulnerability also arises from its entangled character and the tradeoffs created when one source is addressed in isolation. The heavy reliance on the Typica coffee variety demonstrates tradeoffs. On the one hand, the taste profile of Typica is integral to the high farmgate prices of BM coffee. On the other hand, Typica is costly in its input requirements, is a low producing variety, and is highly susceptible to CLR (World Coffee Research, 2018). While the benefits have helped smallholders in the BMs persist, ameliorating the CLR risks with new a variety—a strategy used in other growing regions (Avelino et al., 2006)—is not viable. Access to the Typica-preferred Japanese market would be jeopardized.

The volatile coffee market generates another conundrum. The prices for BM coffee historically are one of the most variable compared to coffee prices in all other producing nations (ICO, 2018). A high dependence on one market contributes to these temporal fluctuations. Even if farmers had the resources to purchase the recommended inputs, the volatility limits their willingness to invest in their farm. For example, precipitous price drops in 2008 and in 2017 rendered coffee cultivation unprofitable and untenable for many smallholders (Jamaica Observer, 2018). Some of these farmers opted not to harvest at all and consequently did not invest much, if any, in their farms.

The complexity of this Gordian Knot requires an equally complex response. One activity alone is likely insufficient to reduce smallholder vulnerability. There are at least five areas where improvements to small-scale farming in the BMs can be made (Table 3). Studies across a diversity of coffee and smallholder contexts show these deficits and discontinuities to be common (Jacques Avelino et al., 2015; C. Bacon, 2005; Barjolle, Quiñones-Ruiz, Bagal, & Comoé, 2017; Gay, Estrada, Conde, Eakin, & Villers, 2006; McCook & Vandermeer, 2015; Sachs et al., 2019; Shiferaw et al., 2013; Talbot, 2004; Tucker, Eakin, & Castellanos, 2010).

One of the strategies would be to make more available and accessible financing in order to help farmers obtain needed capital. In the BMs, farmers do not use credit and loans either because they do not exist, their low assets preclude securing loans, or fractures in relationships between farmers and lenders have made each wary of the other. Many BM farmers, for example, perceive the loans for inputs offered by coffee buyers in the past as exploitive, while coffee buyers for their part stated that the frequency of past default was too high.

Insurance schemes could also be offered as risk management tools. However, many small-scale farmers cannot afford insurance premiums even if suitable products were available. In many cases, the most appropriate form is to enable local and/or subsidized forms of financing (Gugerty, Biscaye, & Leigh Anderson, 2019). Given the importance of inputs on coffee yields, enabling farmers to invest in their farms, even during price drops, is paramount. While finance surely plays a role, alone it is no panacea.

Moderating price volatility is a second strategy. Among agricultural products, swings in coffee prices are high (Gilbert & Morgan, 2010), and are particularly high in Jamaica where yearly price variability is among the highest of all coffee growing countries (ICO, 2018). Price volatility is a main source of financial stress for smallholder coffee farmers. It limits farmers' ability to plan and, during low prices, to invest (ICO, 2014). Strategies to address price volatility can take on forms of price support at the farmgate level such as price floors and loan platforms. However, both have been somewhat ineffective and have been criticized for providing more benefit to largescale producers than smallholders (Sachs et al., 2019). Nonetheless, there is potential for them to be effective with proper design and management (Sachs et al., 2019). At a global level, international trade agreements have placed quotas on producing countries that helped raise and stabilize prices. However, the global coffee trade agreement dissolved in 1989 (Talbot, 2004) and a predecessor still seems unlikely in the near term (Gilbert, 1996).

A third strategy would help increase the bargaining power of smallholders. This is particularly important as coffee profits have increasingly become concentrated at the end of the coffee supply chain. Cooperatives offer one mechanism to increase representation and power in shaping market relations, although they are not always successful. Cooperatives also create opportunities to pool resources and share information. In the BMs, collective management has wanted and recreating the original cooperative system may be too difficult given the changes to the coffee industry. Nonetheless, fostering a greater associativism would allow farmers to collectively own an export license and sell themselves to traditional and specialty markets.

Strengthening the diffusion of information, knowledge, and technology is a fourth strategy. Each has been historically important for coffee production, but that importance takes on a greater significance with the rapid pace of changes in communication and technology. Some have argued that many of the new technologies that will become available to farmers will be information intensive and require high knowledge bases (Shiferaw et al., 2013). Because knowledge management often falls on government extension services, strengthen these bodies requires reversing trends in public funding that rarely meet costs for personnel, technical training, and services (Swanson, 2008). The CIB, for example, has only three extension officers for the entire BMs. It came as no surprise therefore that many farmers we surveyed had limited understanding of effective ways of treating emergent risks like CLR.

Finally, increasing farmer resilience to social and environmental hazards would allow for better planning. The price collapse in 2017–18 in Jamaica offers a recent example. Many farmers were not expecting prices to fall and were unaware of how low the price would ultimately drop. Improvements in the availability of information and access to price forecasts, for example, could also be accompanied with early warnings for drought and CLR outbreaks. The latter would require improved environmental observations, such as from weather stations, and more spatially and temporally active CLR reconnaissance. Better monitoring, information exchange, and transparency would have the added advantage of creating stronger relationships across the supply chain.

8. Concluding Remarks

This analysis documents that vulnerability in smallholder coffee farmers in the BMs is produced by factors at the household level that are entwined with environmental shocks and stresses and institutional realities that arise beyond the farmgate. This analysis supports the need to analyze vulnerability comprehensively. A piecemeal analysis will not only fail to show how the determinant of vulnerability interact, but also fail to generate a suite of strategies that address the intensity of the problem.

In summary, the small-scale BM farming system became viable in the mid-1950s in large part through the creation of the CIB to mend production challenges. Over time, however, changes across social, economic, political, and environmental dimensions have led to the reduction of support for farmers while aspects of the environment have also changed in ways that produce greater stresses and shocks. However, as new forms of vulnerability have emerged, old ones have not gone away.

Currently, the outcomes from farmer vulnerability manifest as system-wide low coffee production and a sensitivity to environmental hazards that, during our sampling period, produced crippling impacts from a combination of drought, CLR, and market volatility. Even under normal conditions, the small-scale coffee farmers in the BMs struggle to make investments in their farm, and in times of stress and shock farmers are even further constrained. Because farm investment is a principal control for production, the inability to invest in the farm not only has immediate impacts but also consequences that extend into the future.

In our identification of the complex factors that produce vulnerability, we have also discussed areas where reductions in vulnerability could be made. We argue that the smallholder farmer now faces an intractable situation that requires more support across a variety of dimensions able match the complexity of the vulnerability problem. While external support to help smallholder coffee farmers deal with systemic challenges has been argued elsewhere (e.g. Eakin, 2005), what makes this situation more urgent is that the factors that produce vulnerability appear to be on the rise. We thus discussed invigorating support across dimensions of financing, economic certainty, smallholders bargaining power, knowledge systems, and resilience to hazards. Indeed, a piecemeal, limited approach seems insufficient to cut the knot.

Figure Captions

Figure 1. The approximate locations of communities in which we conducted household surveys and focus group discussion within the BM coffee farming zone. The number of surveys, along with approximate elevation of community, are also shown.

Figure 2. Coffee production and perceived coffee losses during the agricultural year of 2014-2015. Percent of farmers we surveyed reporting their coffee yields (top), total coffee production (middle), and the fraction of total coffee harvest lost in 2014-2015 relative to what they had expected to harvest (bottom).

Figure 3. Hazards that affected BM coffee production between 1985 to 2017 and total BM coffee production. Coffee production data was obtained from CIB annual reports with the exception of 1988–89, 1989–90, and 1992–93. Senior personnel at CIB provided these data. Production corresponds to the agricultural year, August 1 to July 31. Each data point corresponds to the July year (e.g. data plotted in 2017 corresponds to the period August 1, 2016 to July 31, 2017). The occurrences of the exposure events were recorded in CIB annual reports. We supplemented these episodes with additional harmful events stated by the farmers during the FGDs. With the exception of hurricanes, the specific onset and cessation dates were not obtained. Therefore, we mapped the episodes to span the entire crop year in which they were referenced.

Figure 4. Coping strategies used to respond to the three most reported hazards experienced by the farmers: drought (A), CLR (B), and price volatility (C). Sample sizes reflect farmers who stated that the hazard was experienced recently. The sample sizes are 278, 118, and 98, respectively. The strategies are distinguished by three categories (represented by colors). The self-reliant strategies are: (1) used fewer inputs; (2) used savings or sold assets; (3) worked more; (4) abandoned plots altogether; and (5) planted

other cash crops. The community-based strategies are: (6) received help from community members; (7) received help from community organizations; (8) received loans from community members; (9) received loans from community groups. The external support strategies are: (10) received support from the government; (11) received support from NGOs; and (12) obtained loans from banks and/or credit organizations.

Tables

Table 1. Descriptive statistics of study population. The total sample size is 424 with most individual variables containing some non-responses. Data pertains to the 2014–2015 agricultural year for each household. SD is standard deviation. The 11 productive tools are: owned land, a hand sprayer for chemicals, a mechanical sprayer for chemicals, a pruning saw, pruning scissors, a tractor, a truck, a car, a tree nursery, a coffee pulping machine, and an irrigation system.

Variable	**Resource Capital Classes**	**Description**	**n**	**Mean (SD)**	**%**
Age	Human	Age of the primary coffee farmer	412	53.0 (14.2)	
Highest Education	Human	• Completed primary or below • Completed between grades 6-9 • Completed grade 10 or above	417		24 49 27
Household Members	Human	Number of people identified as members of the household	421	3.5 (1.8)	
Farm elevation	Natural	Average elevation of coffee farm, in meters	424	659.6 (317.5)	
Farm size	Physical	Total acres farmed	383	3.5	
Coffee cultivation area	Physical	Total acres of coffee farmed	424	2.9 (3.0)	
Production	Natural	Total number of boxes of coffee harvested	337	34.3 (103.6)	
Yields	Natural	Number of harvested boxes of coffee per	337	11.8 (20.3)	

		acre			
Variety	Natural	Number of farmers who cultivate more than one coffee variety	342		84
Household income	Financial	• All income from agricultural activities • Half or greater from agricultural • Less than half from agricultural	364		36 47 17
Fertilizer	Physical	Number of fertilizer applications per household	382	2.1 (1.3)	
Fungicides	Physical	Percent of households who applied at least one fungicide application	424		41
Labor	Human	Percent of households who hired labor	424		52
Group participation	Social	The number of days per year a household participated in group activities like a farmer group or a financial savings group	365	7.3 (24.0)	
Technical assistance	Social	Whether a household received technical farming assistance	424		47
Savings	Financial	Percent of households who had savings	399		63
Loans	Financial	Percent of households who accessed loans	417		<1
Irrigation	Physical	Percent of households who used irrigation, at least partially	418		11
Productive tools	Physical	The number of coffee production equipment owned of 11 total tools*	407	2.9 (1.6)	

Table 2 Summary statistics for the OLS with a log transformed dependent variable. Variables correspond to the respondent's last full agricultural season. The corresponding coefficient and standard error are presented along with the exponentiated coefficient in parenthesis. Variance Inflation Factor collinearity statistics for all variables is less than 1.63.

Variable Name	Description and scales of Variable	Dependent Variable: Log of Total Boxes of Coffee Harvested
Gender	The gender of household's primary decision maker; (binary, takes the value of 1 if *male*)	0.072 (0.709) 1.075
Age	The age of household's primary decision maker (continuous)	-0.020*** (0.007) 0.980
Education	The highest education of household's primary decision maker (1: none; 2: Primary incomplete; 3: Primary complete; 4: middle school complete; 5: Secondary incomplete; 6: Secondary complete; 7: above Secondary)	-0.124 (0.076) 0.883
Family size	The size of the family (continuous)	-0.027 (0.045) 0.973
Farm elevation	The approximate elevation of the coffee farm, in meters (continuous)	0.001** (0.000) 1.001
Cultivation Area	Total area cultivated with coffee, in acres	0.113*** (0.031)

		1.120
Frequency of fertilizer use	The number of times fertilizers were applied (continuous)	0.144** (0.068) 1.155
Fungicide Use	Whether fungicides were used or not (binary, takes the value of 1 if used)	0.436** (0.187) 1.547
Hired labor	Whether the household hired labor or not (binary, takes the value of 1 if hired labor)	0.338*** (0.170) 1.402
Agricultural equipment	The number of productive agricultural assets owned by the household out of a total of 11 (continuous)	0.164*** (0.059) 1.178
Group participation	The number of days per year the household participated in group activities, such as farmer groups or financial savings groups	-0.003 (0.003) 0.997
Technical assistance	Household that received technical farming assistance from national programs like extension or coffee buyers (binary, takes the value of 1 if yes)	0.229 (0.169) 1.257
Savings	Whether the household had a savings account (binary, takes the value of 1 if yes)	0.146 (0.183) 1.157
Observations		254
Adjusted R^2		0.306

* significant at the 0.10 level; ** significant at the 0.05 level; ***significant at the 0.01 level

Table 3. Strategies for aiding smallholder coffee production and livelihood security

Deficits and discontinuities addressed	**Strategy**	**Description of strategy**
Financing	Increase the flow of financial capital	Farmers experience episodes of capital scarcity such as when purchasing inputs or as a consequence of a shock (e.g. hurricane). This strategy makes capital more available and accessible, including through the organization of local savings groups, a national coffee bank, and credit co-ops, as well as services that offer favorable loans and subsidized insurance.
Price volatility	Moderate economic uncertainty	Price volatility is a main source of economic uncertainty and strain, disrupting farmers' planning and investments. This strategy would reduce or moderate price falls through price support tools like inoput subsidies or price floors.
Strengthen the bargaining position of small-scale farmers	Understand and take advantage of international markets and trends	Profits are increasingly concentrated at the end of the coffee supply chain. Growers can capture more of the profits by selling to specialty markets that require adhering to ethical, environmental, and/or quality standards. Also, direct sale to consumers allows farmers to capture more profits.
	Improve community-level organization	Organizing farmers (e.g. in cooperative) puts farmers on a stronger footing to own processing facilities, jointly purchase and share expensive equipment, and deal directly with buyers, giving access to both information and bargaining opportunities. Organization also

		enables farmers to coordinate their efforts to address pests and diseases and responses to disasters.
Information, Knowledge and Technology	Increase the creation and uptake of knowledge, technology, and information	This strategy would provide technical information on coffee farming best practices (e.g. input use and disease control) by investing in knowledge transfer and social network development, often through agricultural extension programs. This strategy would also improve access to reliable coffee price and weather/climate forecasts, which would require improved economic and environmental monitoring. This strategy also prioritizes R&D for the physical and social dimensions of coffee production, from coffee variety breeding programs to decision-making logics.
Resilience	Minimize vulnerability to shocks and stresses	This strategy would diversify coffee variety cultivation to reduce the farm share susceptible to plant diseases like CLR. It would also diversify livelihood activities to reduce total exposure to particular shocks or stresses. Early warning systems for plant disease and climate and weather would also enable preventative action.

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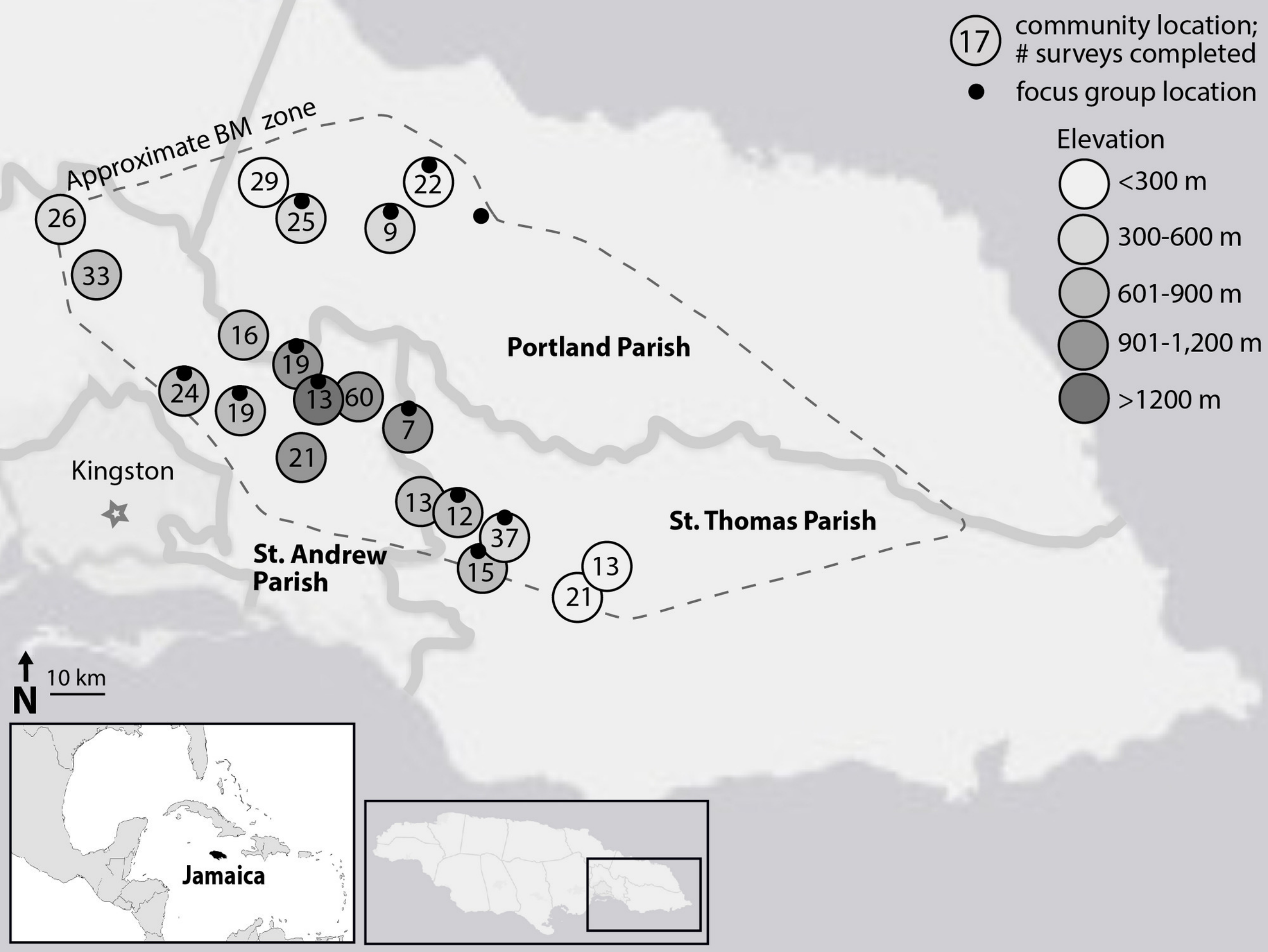
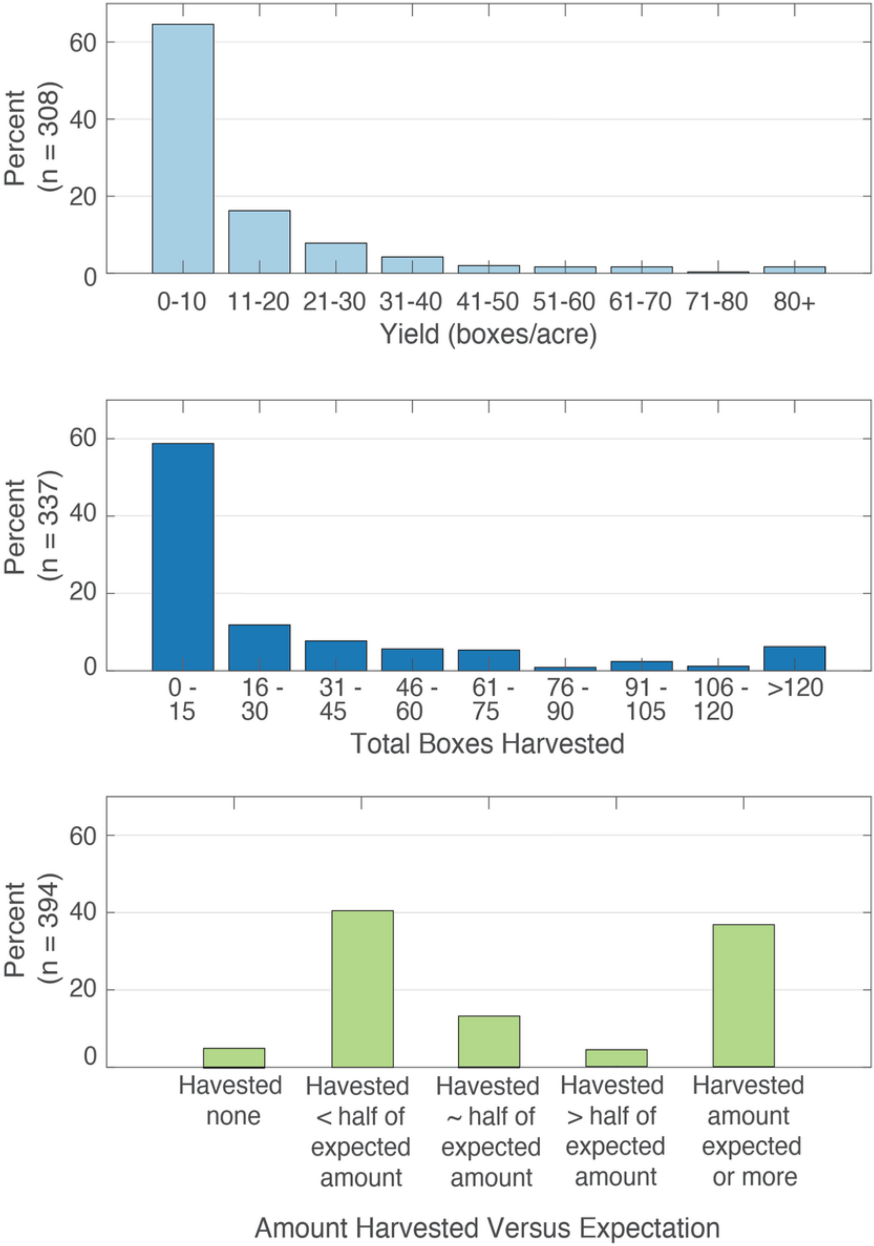
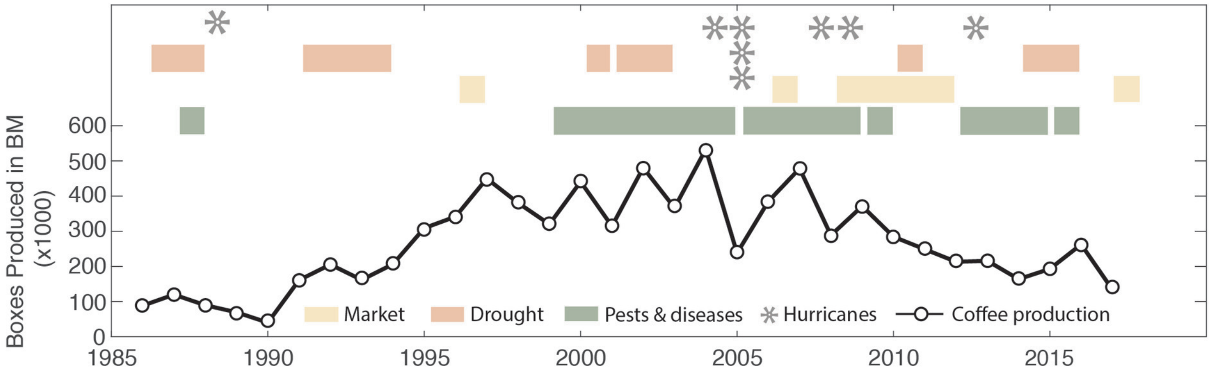
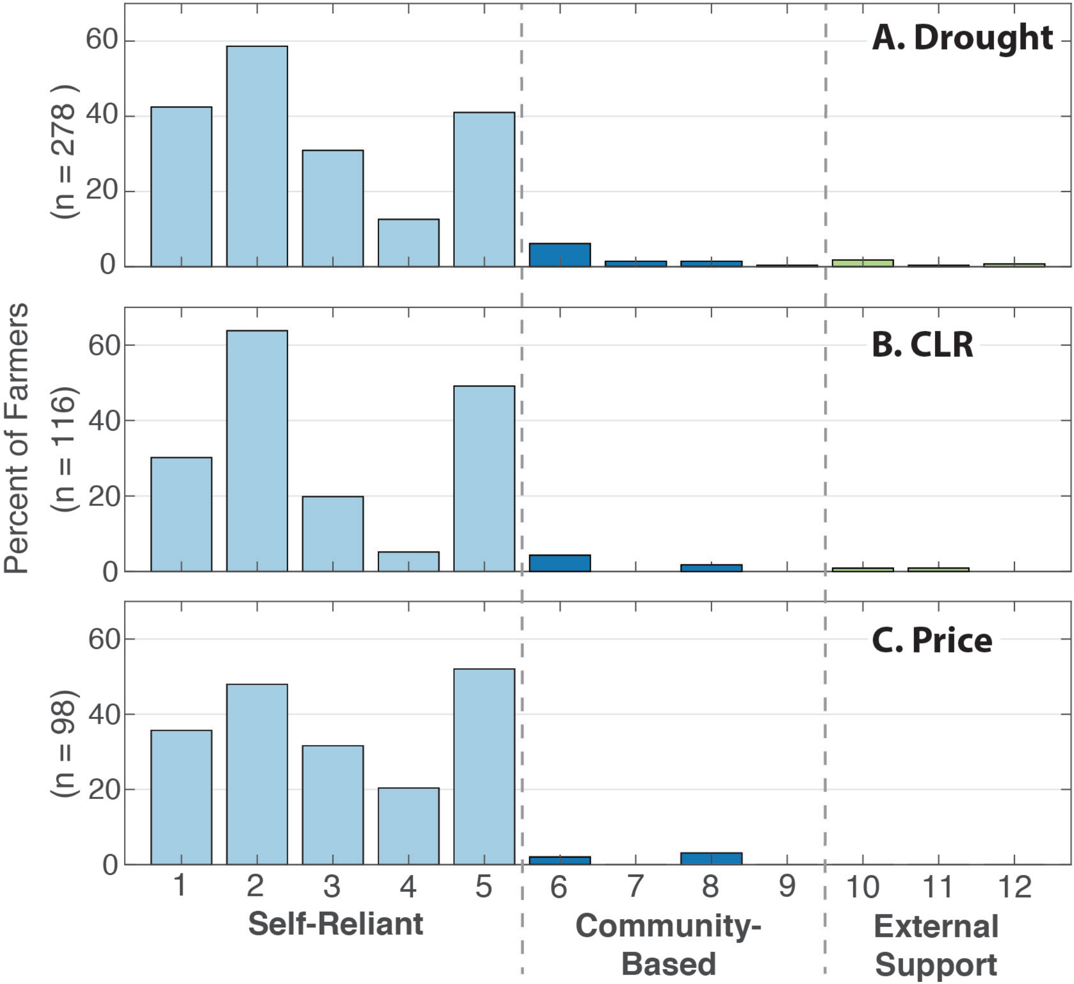


17
community location;
surveys completed
focus group location
Elevation
<300 m
300-600 m
601-900 m
901-1,200 m
>1200 m
Approximate BM zone
29
22
26
25
9
33
16
Portland Parish
19
24
13
60
19
7
21
Kingston
13
12
St. Thomas Parish
37
St. Andrew
Parish
15
13
21
10 km
N
Jamaica



Percent (n = 308)
60
40
20
0
0-10
11-20
21-30
31-40
41-50
51-60
61-70
71-80
80+
Yield (boxes/acre)
Percent (n = 337)
60
40
20
0
0 - 15
16 - 30
31 - 45
46 - 60
61 - 75
76 - 90
91 - 105
106 - 120
>120
Total Boxes Harvested
Percent (n = 394)
60
40
20
0
Havested none
Havested < half of expected amount
Havested ~ half of expected amount
Havested > half of expected amount
Harvested amount expected or more
Amount Harvested Versus Expectation


Boxes Produced in BM (x1000)
0
100
200
300
400
500
600
1985
1990
1995
2000
2005
2010
2015
Market
Drought
Pests & diseases
Hurricanes
Coffee production


A. Drought
B. CLR
C. Price
Percent of Farmers
(n = 278)
(n = 116)
(n = 98)
0
20
40
60
1
2
3
4
5
6
7
8
9
10
11
12
Self-Reliant
Community-Based
External Support