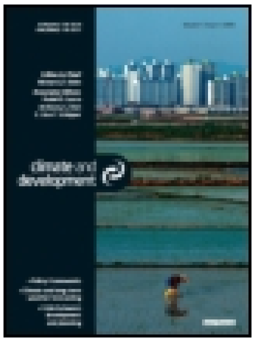
Taylor & Francis
Taylor & Francis Group



Climate and Development

ISSN: 1756-5529 (Print) 1756-5537 (Online) Journal homepage: https://www.tandfonline.com/loi/tcld20

Technology transfer and adoption for smallholder climate change adaptation: opportunities and challenges

Laura Kuhl

To cite this article: Laura Kuhl (2019): Technology transfer and adoption for smallholder climate change adaptation: opportunities and challenges, Climate and Development

To link to this article: https://doi.org/10.1080/17565529.2019.1630349

CLIMATE AND DEVELOPMENT
https://doi.org/10.1080/17565529.2019.1630349

Technology transfer and adoption for smallholder climate change adaptation: opportunities and challenges

Laura Kuhl

School of Public Policy and Urban Affairs and International Affairs Program, Northeastern University, Boston, USA

ABSTRACT
Technologies help build farmer resilience to climate change, but the relationships among technology transfer, adoption, vulnerability, and resilience are not well-understood. This paper empirically examines the technology transfer process for smallholder farmers in Honduras from an adaptation perspective. It addresses two questions: (1) How does technology transfer contribute to pathways to resilience for smallholder farmers? (2) What challenges do these efforts face in meeting diverse farmer needs and overcoming barriers to technology adoption by the most vulnerable to climate change? These questions are analysed in the context of United States government's Feed the Future initiative. Interviews with smallholder farmers were conducted regarding experiences with technology transfer, adoption choices, and perceptions of climate change. The study found that while adoption rates were high overall, the pace of adoption was still slow, demonstrating a tension between the urgency of climate change and the pace of smallholder adoption. The study found that many technologies increase resilience but may not always be adaptive in the long-term, and that significant resources are needed to successfully transfer technologies to smallholder farmers. This study provides evidence of ways agricultural technology projects contribute to pathways to resilience and demonstrates barriers to their success.

ARTICLE HISTORY
Received 23 February 2018
Accepted 5 June 2019

KEYWORDS
Climate adaptation; resilience; Honduras; technology adoption; technology transfer; agriculture

1. Introduction

Adoption of new technologies is a critical component of agricultural adaptation (Christiansen, Olhoff, & Traerup, 2011; Holt-Giménez & Altieri, 2013; Porter et al., 2014). Farmers have utilized appropriate technologies to adapt to drought and other climatic changes historically (Bryan, Deressa, Gbetibou, & Ringler, 2009; Deressa, Hassan, Ringler, Alemu, & Yesuf, 2009; Lybbert & Sumner, 2012; Mortimore & Adams, 2001; Smit & Skinner, 2002; Tambo & Abdoulaye, 2012), but there is growing recognition that past coping strategies may be insufficient. Farmers will need to adopt new technologies, particularly as climate change increases the speed and scale of change, some of which may need to be introduced to them through technology transfer (Howden et al., 2007; Lipper et al., 2014; Steenwerth et al., 2014; Wheeler & von Braun, 2013).

Despite the growing literature on technologies for agricultural adaptation that has identified the utility of various technologies for addressing climate impacts, the process of *technology transfer and adoption* for adaptation remains poorly understood. What is known, based on studies looking at technologies transferred through United Nations Development Programme (UNDP) and Global Environment Facility (GEF) projects, is that there is an emphasis on diffusion of domestic 'low-tech' solutions, and a reliance on a wide diversity of technologies, which is a sharp contrast to the majority of climate technology transfer examples found in the literature, which tend to focus on 'high' technologies from foreign sources, and single technological solutions (Biagini, Kuhl, Gallagher, & Ortiz, 2014; Tessa & Kurukulasuriya, 2010), suggesting that technology transfer for adaptation displays different characteristics than mitigation-focused technology transfer and is worthy of additional study.

A particular challenge for technology adoption for adaptation is how to balance the pace of adoption necessitated by the urgency of climate change (IPCC, 2018) and the risk aversion associated with technology adoption for smallholder farmers. This tradeoff leads to potentially complex dynamics between technology adoption, vulnerability (both climate-specific and broader social and economic vulnerability), and climate resilience. Understanding the relationships among vulnerability, resilience and technology adoption is essential for technology transfer for adaptation.

This paper examines the process of technology transfer and adoption for smallholder farmers from an adaptation perspective, specifically focusing on this potential tension between urgency and risk aversion. Based on an analysis of farmer interviews in Honduras, this paper seeks to contribute to the scholarly debates on two questions: 1) How does technology transfer contribute to pathways to resilience for smallholder farmers? 2) What challenges do technology transfer for adaptation efforts face in meeting diverse farmer needs and overcoming barriers to technology adoption by the most vulnerable to climate change?

The remainder of the paper is organized as follows: Section 2 presents the conceptual framework, followed by the methodology, results, and a discussion of the implications for the relationships among technology adoption, vulnerability and

CONTACT Laura Kuhl ✉ l.kuhl@northeastern.edu

resilience. The paper concludes with lessons learned for technology transfer for adaptation.

2. Conceptual framework

2.1. The role of technology in supporting adaptation and resilience

Farmers can increase their climate resilience through multiple pathways. Resilience can be conceptualized in many ways, but is frequently described as a set of capacities allowing individuals and communities to withstand both short-term shocks and long-term stressors (Béné, Headey, Haddad, & von Grebmer, 2016). Resilience in agricultural systems depends on resilience at multiple scales: from the scale of an individual plant, to the farm, to the household, as well as landscape and societal scales (Altieri, Nicholls, Henao, & Lana, 2015; Bailey & Buck, 2016; Cohn et al., 2017). Many agricultural technologies are designed to reduce climate risk, either by reducing sensitivity or exposure to climate impacts (Biagini et al., 2014; Eichberger & Guerdjikova, 2012; Zilberman, Zhao, & Heiman, 2012). The agricultural sector is vulnerable to multiple climate impacts, including increased heat, droughts, increased salinization, and more extreme events, as well as broader system-level impacts such as disruptions to agricultural supply chains caused by extreme events (Cohn et al., 2017; Field, Barros, Stocker, & Dahe, 2012, 2018). Technologies, such as crop varieties with heat tolerance, salinity tolerance, drought resistance or fast-maturation, as well as water technologies including irrigation, water conservation and storage technologies can all help to mitigate these impacts (Cohn et al., 2017; Vermeulen et al., 2012). Management techniques, which can also be introduced through technology transfer efforts, including planting practices, soil and water management and changes in planting timing can all be used to manage climate risks as well.

In addition to increasing resilience at the plant level, resilience at the farm level can be built through crop diversification strategies. Much of the literature on technology for adaptation focuses on specific technologies, such as drip irrigation or drought-resistant seeds (Christiansen et al., 2011; Goldstein, 2015; Sharma & Moehner, 2011; Tambo & Abdoulaye, 2012; Trærup & Stephan, 2015). However, it is increasingly recognized that resilience requires redundancy and flexibility, and therefore a focus on a suite of technologies may be more consistent with reducing climate vulnerability than transfers of individual technologies (Fleischer, Mendelsohn, & Dinar, 2011; Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013; Low, Ostrom, Simon, & Wilson, 2003; Sayer & Cassman, 2013). Technologies need to be carefully chosen to ensure that technology transfer efforts do not increase vulnerability rather than reduce it (Chambers, Pacey, & Thrupp, 1989; Dewulf, 2013; Snapp, Blackie, & Donovan, 2003).

Increasing the diversity in agricultural systems can build ecological resilience. It can also spread farmer risk in case of a particular crop failure. Farmers can also increase their economic resilience by intensifying their productivity, switching to higher-value production and diversifying into new markets (Kuhl, 2018). These strategies provide households with greater income, less reliance on single sources of income, and can also directly improve their food security. Finally, households can engage in off-farm strategies to increase resilience. Livelihood diversification is a common risk management strategy, although evidence suggests that smallholders have fewer opportunities to engage in livelihood diversification strategies compared to larger landholders (Cohn et al., 2017). While much of the research on farmer resilience has utilized either physical or economic indicators as described above, social factors such as social networks and perceptions of ability to manage shocks and stresses are also critical (Barrett & Constas, 2014; Béné et al., 2016).

Most research on adaptation in the agricultural sector to-date has focused on incremental adaptation strategies that reduce sensitivity or exposure to climate risks at the plant or farm scale, but transformational adaptation at larger scales may also be needed (Park et al., 2012; Wise et al., 2014; Fazey et al. 2015). Incremental adaptation is often conceptualized as ‘extensions of actions and behaviours that already reduce the losses or enhance the benefits of natural variations in climate and extreme events’ (Kates, Travis, & Wilbanks, 2012), while transformational adaptation is envisioned as longer-term, large-scale, rapid change, including a directional shift in practices and a significant deviation of the status quo (Béné, Cornelius, & Howland, 2018; Few, Morchain, Spear, Mensah, & Bendapudi, 2017; Wise et al., 2014). Adaptation strategies such as income diversification, off-farm employment, and migration represent more transformational strategies. While technologies are likely able to address many incremental adaptation approaches, it is less clear how (and if) technological solutions support transformational strategies.

Each of the strategies described above, from strategies to improve ecological resilience on-farm, to strategies to decrease farmer risk and diversify livelihood strategies, contribute to the pathways through which farmers can build their adaptive capacity and resilience. Technologies play an important role in building these pathways, but technologies alone are insufficient to achieve these pathways to resilience. See Figure 2 for an example of how the technologies in the case study contribute to pathways to resilience.

2.2. The technology transfer process for adaptation

Technology transfer is the process of sharing information and resources, in this case with the aim of helping farmers adapt to climate change. According to the IPCC, technology transfer is defined as encompassing ‘the broad set of processes that cover the flows of knowledge, experience, and equipment for mitigating and adapting to climate change among different stakeholders’ (Metz et al., 2000). Technology includes both ‘hardware’ and ‘software,’ or knowledge and techniques needed to make, use, and understand the hardware, placing knowledge, and absorptive capacity, or the ability to use external knowledge, at the centre of technology transfer (Abramovitz, 1986; Bozeman, 2000; Brooks, 1995; Cohen & Levinthal, 1990; Ockwell & Mallett, 2012; Grubler, 1998; Bell & Pavitt, 1993). The history of technology transfer, particularly in the agricultural sector, is rich with examples of failed attempts to transfer technology, ultimately because of a poor alignment between the technology being introduced and the needs or desires of the intended users of the technology, as Douthwaite eloquently chronicles in his book *Enabling Innovation* (Douthwaite, 2002). Building on the lessons of these past experiences will be critical to the success of technology transfer for adaptation.

Although technology itself is critical, the technology transfer process is ultimately about relationships between the holders of knowledge of a technology and the intended users of the technology. Depending on the symmetry of information, some technology transfer efforts are better described as technology cooperation. This term is preferred in some cases because of the lack of agency embedded in the concept of the technology transfer, in which the end users are passive 'recipients.' Because the relationship between those introducing technology and those adopting it is so key to the technology transfer process, technology does not need to be new at the global level; the novelty to adopters is the critical aspect (Brooks, 1995; Rogers, 1995). This is particularly true for adaptation, where many of the technologies being introduced are relatively 'low-tech' but are still novel to intended users.

Technology transfer is widely acknowledged as a critical component of sociotechnical change, and a significant body of research has examined the process of technology transfer in the context of climate change. However, most of that literature has focused on mitigation, which may display different patterns compared to adaptation particularly in developing country contexts. One challenge is that the private sector is typically the most important actor in technology transfer (Gallagher, Grubler, Kuhl, Nemet, & Wilson, 2012; Lorentzen, 2009), but is often weak in developing countries. Because incentives for private sector engagement are still poorly understood for adaptation, other actors are more likely to play key roles in technology transfer for adaptation (Biagini & Miller, 2013; Pauw & Pegels, 2013; Tompkins & Eakin, 2012). In some countries, this role may be filled by government, through structures such as state-owned enterprises, but many governments are also weak, particularly in less-developed countries. In these contexts, NGOs and international organizations may provide functions typically envisioned for firms, such as providing goods and services, developing new technologies and testing new processes, and investing capital (Thomas & Slater, 2006; Williams and Woodson 2012). Relatedly, markets often do not function well, resources are more constrained, poor infrastructure acts as a barrier, indigenous capabilities to develop technologies are not as advanced, project execution skills are lacking, and the ability to mobilize finance is limited, all essential enabling factors for technology transfer (Hayami & Ruttan, 1985; Amsden 2001; Clark 2002; Arocena and Sutz 2005; Lorentzen, 2009; Williams and Woodson 2012; Ockwell, Sagar, & de Coninck, 2014; Ockwell and Byrne 2016). These factors make it more challenging to implement technology transfer efforts, because an enabling environment for such transfers is weak.

Another challenge is that adaptation strategies rarely rely on single technologies. Agricultural production is more unstable and location-specific than industrial production because it takes place in biological systems that are constantly evolving, necessitating significant local adaptation (Biggs and Clay 1981; Clark 2002; PCAST 2012). Rather than efforts that focus on interactions between one firm and another, technology transfer for adaptation is more diffuse because agricultural systems in developing countries are characterized by a large number of farmers and decentralized producers (Biggs and Clay 1981). As such, technology transfer efforts must focus on the transfer of a whole suite of technologies, which must be modified to meet the individual needs of diverse farmers. Although technologies frequently need to be adapted to local circumstances, this is particularly true in agriculture because smallholder production occurs in many different ecological niches (Cohn et al., 2017; Vermeulen et al., 2012). At the same time, characteristics of agriculture also facilitate technology transfer and adoption. For example, annual crops provide frequent adoption opportunities compared to long-term technologies, such as infrastructure.

2.3. *Linking technology transfer and adoption*

The ultimate goal of technology transfer efforts is technology adoption. Adoption can be defined as 'a change in practice or technology used by economic agents or a community' (Zilberman et al., 2012). Many factors across scales contribute to successful technology adoption. Stability of markets for agricultural products, supply systems for inputs, market information, infrastructure, and risk reduction mechanisms such as insurance can all help to reduce the risk of adopting new technologies (Aker, 2011; Thomas & Slater, 2006). Extension services tailored to the individual needs of farmers, attention to the social dynamics of technology diffusion, and a focus on the enabling conditions needed to build missing markets, supply chains, and linkages between farmers and markets help increase the adoption of technology (Foster & Rosenzweig, 2010; Feder, Just, & Zilberman, 1985; Feder & Umali, 1993; Rogers, 1995; Ruttan, 1996; Zilberman et al., 2012).

Individual level factors also influence technology adoption. Many factors, including risk tolerance, education, income, and social networks contribute to producer management decisions (Foster & Rosenzweig, 2010; Feder et al., 1985; Hayami & Ruttan, 1985; Rogers, 1995). These factors suggest that economically or socially vulnerable individuals are less likely to adopt new technologies compared to more advantaged farmers (Gershon Feder & Umali, 1993; Foster & Rosenzweig, 2010; Rogers, 1995; Smit & Skinner, 2002; Zilberman et al., 2012). However, to support adaptation, technologies need to be adopted by those who are vulnerable to climate change. From the literature on adaptation, we know that there is a strong correlation between those that are economically and socially vulnerable, and those that are more exposed to climate risks, often described as 'double exposure' (Burnham & Ma, 2016; Feola, Agudelo Vanegas, & Contesse Bamón, 2015; O'Brien & Leichenko, 2000). This suggests that adoption of technologies to support climate resilience will be more challenging for those most vulnerable to climate change. Climate change itself may exacerbate this challenge. Climate change introduces additional uncertainty (in terms of unknown climate impacts and unknown responses) on top of the risk and uncertainty inherent in technology adoption. For risk-averse farmers, this additional uncertainty may pose an additional barrier to technology adoption.

Technology adoption is important step in the technology transfer process, but it does not imply that the technology transfer process is complete. Diffusion of the technologies beyond the original recipients, as well as modification and adaptation of the technologies to better meet local contexts are all critical components of the technology transfer process (Rogers, 1995). It is also important to look at disadoption, which refers to an initial decision to adopt a new technology and subsequent decision to abandon this technology. Disadoption is different from non-adoption, because an individual originally chose to adopt the technology. Examining patterns of disadoption provides insights into the reasons users may be dissatisfied with a technology or it may not have met their needs.

The three components discussed above are summarized in a conceptual model of successful technology transfer for adaptation, articulating how the technologies included in the case study contribute to pathways to adaptive capacity and resilience (Figure 1). This conceptual model forms the basis of analysis for the empirical study.

3. Methodology

The analysis is based on interviews and field visits with smallholder farmers that participated in the United States Agency for International Development (USAID) project called ACCESO (named because ACCESSO means *access* in Spanish) in Western Honduras between 2010 and 2014.

3.1. Case selection

USAID-ACCESO was selected as a case study for several reasons: 1) it introduced a wide range of technologies and crops to farmers, 2) it targeted the most vulnerable farmers living in a region that is highly vulnerable to climate change, and 3) it operated at a fairly large scale (targeting 30,000 households) with an intensive model of technology transfer (consisting of weekly technician visits). USAID is the largest development partner in Honduras, and this project represented the largest-scale agricultural development project in the country. While USAID-ACCESO was not a climate change project, climate-smart agriculture was a cross-cutting theme and resilience was one of the key objectives of the project. Although explicit climate adaptation projects represent one mechanism through which to transfer adaptation technologies, the amount of climate finance available is insufficient to address adaptation goals. As such, it is important to understand the potential, as well as the limitations, of other mechanisms for transferring adaptation technologies, including development projects like USAID-ACCESO.

3.2. Regional selection

Two of the six regions in which USAID-ACCESO was active were selected. The department of Lempira was selected because it has very high poverty rates, limited access to markets, mountainous terrain and high vulnerability to droughts, all of which present constraints to the pathways to resilience envisioned through the ACCESO project (see Figure 2). An analysis conducted by the International Food Policy Research Institute (IFPRI) found that it can take more than 7 h for farmers in Lempira to reach the nearest market of more than 25,000 inhabitants (Ifpri, 2013). The department of Santa Bárbara was selected because it has a variety of microclimates, including lowland areas with extreme heat, various crop opportunities and significantly higher access to markets, due to both its geographic proximity to major cities and transportation infrastructure.

3.3. Respondent selection

Interviews were conducted in November and December 2013 with 100 smallholder farmers in the departments of Lempira (50) and Santa Bárbara (50) in Western Honduras. Respondents were selected from registered project participants, with a sampling strategy designed to capture geographic and altitudinal variation across the two departments. To meet this goal, villages were selected across the departments that had at least five registered participants in the project. Within selected villages, interview participants were randomly selected from among registered project participants in order to minimize bias in the sample (i.e. to ensure that the technicians did not select the most successful participants or the ones they knew the best for inclusion in the study). Best efforts were made to locate the selected participant. When it was not possible to locate the participant, a replacement was chosen from the same village by identifying the next participant on the list. It is important to note that not all registered participants were actively engaged in the project. By selecting randomly from the list of registered participants, it ensured that the study included participants who originally registered but had since chosen not to continue with the project. It was important to select villages with at

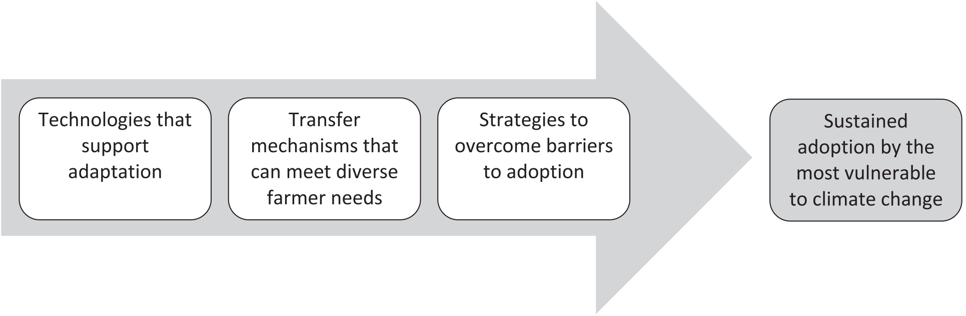


Figure 1. Conceptual Model of Technology Transfer for Adaptation.

Notes. Successful technology transfer is conceptualized as requiring three components: 1) technologies that support adaptation, 2) transfer mechanisms that can meet diverse farmer needs, and 3) strategies to overcome barriers to adoption. Only when these components are in place, are the conditions right for sustained adoption of adaptation technologies by the most vulnerable.

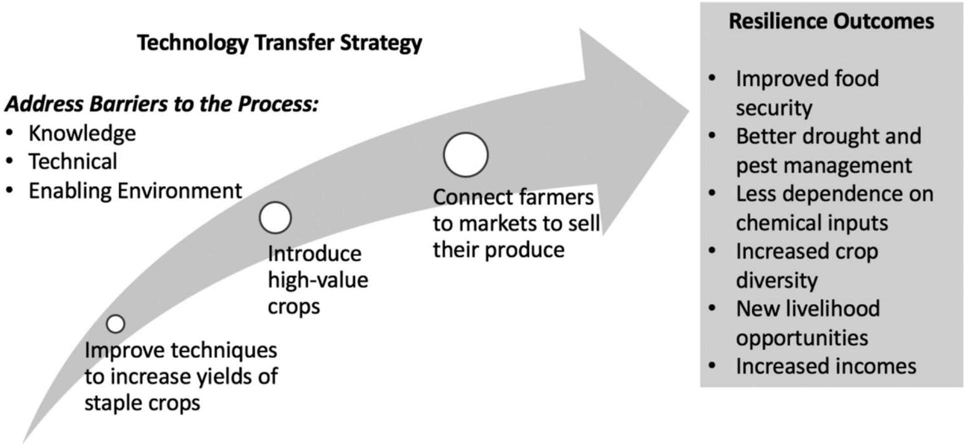


Figure 2. Pathways to Resilience in USAID-ACCESO.

Notes. Technology transfer strategy of USAID-ACCESO and how it contributed to pathways to resilience.

least 5 registered participants because of the group model of technology transfer (See Section 4.2) and the social nature of technology adoption.

3.4. Interviews

Semi-structured interviews with farmers were conducted by the author in Spanish. After initial questions regarding the crops grown and area under cultivation, farmers were asked to describe each step in the production process from soil preparation and planting to harvesting. Follow-up questions were asked to identify the use of techniques and technologies that USAID-ACCESO introduced. When these techniques were identified, participants were asked when they started using them, how they learned them, what purpose they served, how they compared to previous techniques, and whether they planned to continue using them. This open-ended format was used to help minimize bias that could have been introduced by farmers thinking that they were supposed to be using certain technologies. After determining usage patterns, questions explored farmer knowledge and awareness of new techniques. Interviews addressed whether the adoption of new techniques had led to changes in the farmers' lives, including impacts on income, costs and purchasing decisions, as well as non-monetary changes, such as changes in time, motivation, etc. These questions were intended to contribute to the understanding of the contributions of technology adoption to the resilience pathways for farmers. Interviews also addressed experience with climate change. Farmers were asked whether they had observed differences in climate between now and the past, and what the impacts of these changes had been on their production. Frames such as 'when they were a child' or 'before Hurricane Mitch (1998)' were used to clarify the difference between long-term trends and weather fluctuations. Interviews continued with a discussion of whether any of the new techniques could help address these observed impacts, or if there were any other strategies that they knew of to manage these impacts. Finally, interviews addressed farmer plans for the future and if/how they plan to use the information.

Whenever possible, results were triangulated to ensure the validity of responses. Interviews concluded with a tour of the farmer's plot, allowing for confirmation of the use of techniques, as well as identification of additional crops that the farmer had omitted during the interview. Follow-up and clarifying questions as well as personal observation during field visits were used to supplement data collected during interviews.

In addition to the farmer interviews, key informant interviews with stakeholders engaged in the project as well as participant observation were conducted to better understand the perspective of both sides of the technology transfer process. As discussed in Section 2, technology transfer is about the relationships between the originators and the recipients of the technology, and as such, it was important to gain insights into the strategies used by the project to transfer technologies, the sources of the technologies, factors they considered important for the technology transfer, and the barriers that they identified in the transfer process. Twenty-eight interviews with stakeholders involved in USAID-ACCESO in various capacities were conducted (5 with government officials and other donors, 6 with USAID staff, 5 with senior managers/directors of the project implementer, and 12 with field staff). Interviews discussed the following themes: their role with the project, the challenges the project faced, barriers to technology adoption, opinions on the technology transfer model, and perspectives on resilience. The stakeholder interviews informed the analysis of the farmer interviews but were not formally analyzed themselves.

3.5. Analysis

The primary analysis is based on a qualitative content analysis of farmer interviews, and consisted of identification of technology and crop adoption rates and patterns among different groups of farmers, assessment of barriers and motivations for adoption, impacts of adoption, perceptions of climate change, and relationships among climate perception, adaptation options, and resilience. With the permission of participants, all farmer interviews were recorded and transcribed. Ninety-six of the 100 farmer interviews were analyzed. The remaining four interviews were excluded because of technical issues that prohibited transcription.

Interviews were coded using the qualitative data analysis software NVivo. Interviews were coded based on demographic variables identified in the literature as relevant to technology adoption, including gender, age, and geographic location. Because of the path-dependent nature of technology adoption, each farmer was categorized as a staple crop, coffee, or horticulture grower based on the crops grown before the project started and as non-adopters, basic adopters, or advanced adopters in order to analyze adoption patterns for different groups of farmers. Basic adopters were defined as those who adopted at least one production technique for staple crops. Advanced adopters included those who had adopted at least one new crop or new technique associated with horticulture. Dis-adoption (an initial decision to adopt, and then subsequent decision to stop using the new technique or crop) and future adoption plans were also coded.

Technology adoption choices were coded according to the following themes: favourite techniques, least favourite techniques, most challenging techniques to learn, and additional techniques they were interested in learning. Experience with the technology transfer model were coded using the following themes: how they learned of the new techniques, awareness of USAID-ACCESO and any positive or negative comments regarding the project and/or its technicians, and comparative experiences with other projects. Interviews were coded with the following themes related to climate change: climate observations, impacts on production, and strategies to address climate change.

Adoption percentages were calculated for different types of technologies and crops and disaggregated based on farmer characteristics. Based on farmer responses, motivations and barriers for adoption were also analyzed qualitatively, with special attention paid to differences across groups. Farmer perceptions of climate change, its impacts on production, and adaptation strategies were analyzed to identify key climate impacts of concern for farmers and the extent to which the technologies they were adopting addressed these concerns. Strengths and weaknesses of patterns were determined based on the consistency of farmer responses and analysis of the text of the interview responses. Based on these empirical results, implications for technology transfer to address vulnerability and build resilience and the limits or barriers to its success were explored. The analysis was structured based on the conceptual framework identified in Section 2 (Figure 1) of the process of successful technology transfer for adaptation.

3.5. Limitations

While the qualitative nature of the interviews provided rich insights into farmers' experience, the relatively small sample size precluded statistical analysis. Additionally, the data were collected at a single point in time. It would be illuminating to compare results at different points in time, allowing for greater analysis of the pace and sequencing of adoption. While interviews at a single point in time can capture some of the resilience implications of technology adoption, this approach did not allow for the empirical measurement of changes in resilience.

More broadly, technology adoption was measured by farmer self-reporting, which could introduce bias. Bias could also have been introduced because research was conducted in collaboration with USAID. This collaboration provided essential access to the farmers that were participating in the project and increased the legitimacy of the study. However, there are clearly tradeoffs between the access and legitimacy afforded by collaborating with USAID and the potential for bias this introduced. Several techniques were employed to attempt to limit this bias: 1) random sampling was used to ensure that technicians were not selecting participants that they felt would provide positive perspectives, 2) I was transparent with participants about my role as an independent researcher and not an employee of USAID or its contractors, 3) after an initial introduction by the USAID technicians, staff left the site of the interview and allowed the interview to be conducted privately, 4) I explained that USAID was interested in feedback and improving the programme. Because the project was only partway through, and because a follow-up project targeting the same population was already being planned, this was a significant motivator.

The analysis was conducted in a single country. Thus, the findings may not be generalizable to other contexts. Similarly, the process of technology adoption is highly dependent on the technology transfer mechanism (in this case the USAID-ACCESO project and its approach). Technology adoption patterns, and the relationships between adoption, vulnerability and resilience, may be different with other technology transfer models. Finally, while climate change was a component of the USAID-ACCESO project, it was not the primary objective of the project. Technology transfer and adoption patterns would likely look different in a project focusing on adaptation and resilience.

Despite these limitations, this analysis provides important insights into factors that influence technology adoption and the relationships among technology transfer, vulnerability, and resilience for smallholder farmers in a tropical, developing country context. This analysis should be viewed as a theory-building study, and the findings further tested and validated using other case studies and quantitative approaches.

4. Context

4.1. The dry corridor of honduras

Honduras is the second poorest country in the Western Hemisphere, second only to Haiti. Nationally, the poverty rate in 2011, when the project began, was approximately 66%, and the extreme poverty rate was 45% (USAID, 2011). Much of this poverty is concentrated in the Western region, where USAID-ACCESO operated. Chronic undernutrition rates are also very high, at 50% for the region, compared to a national average of 25% (USAID, 2011). Western Honduras is part of the Dry Corridor of Central America, named for frequent droughts associated with the El Niño phenomenon. The mountainous terrain includes varied microclimates, and is known for coffee production, with over 100,000 coffee producers, more than 90% of whom are smallholder farmers (IHCAFE, 2015). In addition to coffee, most households produce maize and beans. Yields are low, with average maize production of 223 kilograms and bean production of 529 kilograms (IFPRI, 2013). Horticulture production is increasing, driven by demand in urban centres and the emergence of supermarkets (Bloom, 2015; Key & Runsten, 1999), although very few participants in USAID-ACCESO (6%) sold horticulture prior to the project, demonstrating that poor farmers were not participating in these opportunities (IFPRI, 2013). Since 1994, with the passage of the Law of Agricultural Modernization, Honduras has had very little public agricultural extension, and technical assistance to farmers, particularly in the Western region, has been provided primarily through NGO projects or private sector input providers. Recently, the vulnerability of the Dry Corridor of Central America has been placed in the spotlight due to the 'migrant caravan' of immigrants to the United States.

4.2. The USAID-ACCESO project

USAID-ACCESO was a project implemented in Honduras as part of the United States' global food security and nutrition initiative, Feed the Future. The goal of the project was to raise household incomes above $1.25 per person per day. The project was based on a sustainable intensification strategy and emphasized high-value horticulture production. Sustainable intensification approaches seek to increase productivity while decreasing negative impacts of agriculture (Campbell, Thornton, Zougmoré, Van Asten, & Lipper, 2014; Garnett et al., 2013; Lin, Perfecto, & Vandermeer, 2008). As part of its strategy to improve agricultural production and reduce poverty, USAID-ACCESO facilitated the transfer of technologies to farmers. These included: 1) new production techniques, 2) new crops, particularly horticulture, and 3) new business, processing, and marketing techniques (See Table 1). As previously described, USAID-ACCESO was not explicitly an adaptation project, although climate-smart agriculture was a cross-cutting theme, and increasing household resilience was an objective.

Project technicians met with farmers in groups of 5–10 approximately every 10 days to transfer the tacit knowledge needed to select, utilize, and modify the technologies, crops, and techniques. Technicians were all Honduran nationals, most of whom had been trained as agronomists. A total of 122 production technicians were employed by the project (USAID, 2015). Unlike many technology transfer projects that select a specific technology and measure success by rates of adoption of that technology (See (Douthwaite, 2002) for a good example of failed technology transfer in agricultural development), the project did not have a preselected technology. Rather, technicians worked with farmers to identify a suite of techniques and new crops that each farmer was interested in adopting. Analysis conducted by the project found that if farmers only adopted techniques for staple crops, the average household would need 5 hectares to achieve the project targets while the average landholding was less than 0.5 hectares. They concluded that only through the adoption of multiple technologies, including new crops, could households move out of poverty (USAID, 2015) (Table 1). The project focused on addressing knowledge barriers, technical barriers, and facilitating the enabling environment for participation in agricultural markets, all with the goal of helping farmers improve their yields, incomes, and livelihoods (See Figure 2). Although the design of the project was not participatory, the implementation of the project at the household level did leave significant room for individual farmer preferences.

The average income of project participants at the beginning of the project was $0.89 per person per day. Of the 34,031 participating households, 89% were below the poverty line. 27,857 were below the national extreme poverty line ($1.81 per person per day), and an additional 2,526 were below the national poverty line ($2.42 per person per day) (USAID, 2015). Participants had an average landholding of less than half a hectare, and limited education (49% of participants had a less than 3rd grade level) (USAID, 2015). Compared to the population of the region as a whole, which had a poverty rate of 45%, participants in the project were significantly poorer, which was to be expected, given that the project targeted those making below $1.25 per day.

Table 1. Agricultural production technologies introduced through USAID-ACCESO.

Technology Category	Description	Examples
Basic agricultural practices	These basic techniques represented the core 'technology package' introduced to producers. They were appropriate for maize and beans, but also for other crops.	• Soil preparation • Density planting (also for coffee) • Lime application • Appropriate fertilizer use • Crop rotation • Seed selection
New crops and advanced agricultural practices	Horticulture crops were introduced, along with associated techniques. These techniques required higher investments (in terms of capital, labour or knowledge) compared to the basic practices.	• New crops • Irrigation • Raised beds • Mulching and live barriers • Integrated pest management (also for coffee) • Improved seeds • Contouring and terraces • Transplanting (also for coffee) • Soil, water and pest sampling (also for coffee)
Coffee management practices	These techniques were specific to coffee production. Because coffee is a perennial, opportunities to use some of these techniques only arose at key moments.	• Pruning • Shade coffee • Soil driers
Processing and marketing techniques	In addition to agronomic techniques, producers were introduced to a wide range of business, marketing and processing techniques designed to improve their investments.	• Business plan development • Post-harvest processing and value addition • Access to financial services • Organization/ legalization of cooperatives • Classification of production

The different crops, techniques and technologies introduced by the USAID-ACCESO project are described here, along with examples in each category.

4.3. Interview participants

Study participants were compared to the overall population of participants in USAID-ACCESO (Table 2). The distribution across initial crops of interviewed farmers was similar to the overall population. Thirty-four percent grew only maize and beans. Fifty-five percent produced coffee, almost all of whom (92%) also grew maize and beans. There was wide variation among coffee producers; for some coffee served as their primary livelihood, while others had limited production. Eight percent of the sample grew vegetables for sale before USAID-ACCESO started.

The share of females in the sample is smaller than the share in the project overall. This discrepancy is not surprising, as the project included participants in both production and microenterprises. In Honduras, most women do not consider themselves to be farmers, even if they are involved in farming activities, and therefore more commonly self-selected into the micro-enterprise components of the project. Because the sample for this study was drawn only from production clients, there was a higher share of males. Household size was also an important characteristic for USAID-ACCESO because household poverty was calculated based on the per-capita income of the household. Since land was a significant constraint on production, larger households required more efficient production to achieve the same per-capita income as smaller households.

5. Results and discussion

5.1. Technologies that support adaptation

The first part of this analysis considers the technologies being introduced and how they support climate adaptation. Premised on the understanding that technologies for adaptation must address climate impacts, the analysis begins with a discussion of climate observations and projections in the region, followed by an analysis of farmer perceptions regarding climate change and the role of technology in addressing it. It concludes with a conceptual model of the contributions of technology transfer to farmer pathways to resilience.

5.1.1. Climate observations and projections

Western Honduras has a wet and a dry season, and is strongly influenced by the El Niño Southern Oscillation (ENSO) phenomenon, a global variation in wind and sea surface temperatures that affects the climate of much of the tropics. ENSO leads to large variations in temperature and rainfall, with years experiencing an El Niño event causing warm and wet weather, and the alternative pattern, La Niña, being associated with periods of cooling and drought. As such, in Western Honduras, inter-annual temperature anomalies (1.5 C) are larger than the observed warming trend (0.9 C), suggesting that variability is currently the dominant pattern (Parker et al., 2014). Temperatures are projected to increase between 1.0 and 2.5 C by 2050, with significant impacts on water resource availability. Since 2007, rainfall patterns have been characterized by a very unstable climate, with rapid alternation of excessive wetness (over 10 anomalies) and dryness events (over 4 anomalies) (Parker et al., 2014). Although recently the region has experienced above-average rainfall (due to ENSO patterns), long-term projections suggest a 10–20% decrease in precipitation by 2050. While overall precipitation has increased, this has occurred in a smaller number of rainfall events, a pattern projected to intensify with time (Magrin et al., 2014; Parker et al., 2014). Consistent with observed changes, climate models project a shift in the peak in maximum temperatures from late March to late April and a delay in the onset of the rainy season, with implications for agricultural production (Parker et al., 2014). These patterns suggest that while climatic changes may be observable, they are likely due to a combination of factors including ENSO, climate change, and local land-use change.

Table 2. Comparison of study participants to all participants in USAID-ACCESO.

	Study Sample	USAID-ACCESO participants
Initial Crops Grown		
Maize and beans only	34%	38%
Coffee	55%	56%
Other (including horticulture)	10%	6%
Female	14%	20%
Average household size	5.3	5.4
Total	**96**	**34,031**

This table compares the study participants with the overall population of participants in the USAID-ACCESO project. Data for the USAID-ACCESO participants is drawn from the project baseline survey and final report (IFPRI, 2013; USAID, 2015).

5.1.2. Farmer perceptions

One hundred percent of respondents had observed changes in the climate in the past 2–3 years compared to the past (Table 3). The most commonly-used phrase was that the weather was ‘completely crazy’ now. Sixty-three percent described the climate as hotter, and only 3% as colder; each of those who observed a colder climate cited local reforestation efforts. Forty-five percent of respondents said that the climate has gotten drier, while only 5% said that it has gotten wetter. The remaining 50% did not describe changes overall, although several commented that it has become wetter in winter and drier in summer.

Thirty-one percent of respondents described the rain as more intense, and an additional 12% described it as more variable in its intensity. Whereas farmers characterized rainfall in the past as ‘soft, gentle, and even’ they described today’s rainfall as ‘intense, unpredictable, and harsh.’ Participants remarked that it would rain as much in the span of a day or two as would normally fall over a whole month. Over 75% of respondents said that rainfall was less predictable, and 54% commented on a shift in the timing of the rainy season. They described how in the past, the first rain would always begin in the last week of May, and they could be assured of planting at that time. Now, rainfall patterns are more sporadic and it is difficult

Table 3. Farmer Perceptions of Climate Change and Alignment with Scientific Records.

Qualities of weather	Farmer perceptions	Alignment with scientific records
Temperature	Hotter: 63% Colder: 3%	Hotter
Predictability of rainfall	Less predictable: 75% Shift in timing: 54%	Less predictable as well as a shift in timing
Amount of rainfall	Drier: 45% Wetter: 5%	Recent period wetter than average, but predicted to become drier

Farmers have observed many changes in today’s climate compared to the past, with negative impacts on their production. These observations are in alignment with the scientific observational records.

to know when the rains will arrive and whether they will be consistent enough for a successful growing season. These changes made it challenging for farmers to identify clear trends. Although the observational record indicates a period of above-average rainfall recently, it is not surprising that many farmers describe conditions as drier, as the available water for production may have declined despite absolute rainfall increases. These observations are consistent with what is described in the climate literature as non-stationarity, which means that events do not follow predictable patterns and don't display the same statistical properties as expected historically (Milly et al., 2008).

Almost all farmers believe that climatic changes have had a negative impact on their production. Only three producers identified positive outcomes related to opportunities to plant crops that previously only grew at lower elevations. The most commonly-identified problem was lack of rain and rainfall predictability (27 respondents). Predictability of rainfall was deemed critical for labour coordination so as not miss the window of opportunity for planting. Sixteen respondents described how excessive or intense rain has negatively impacted their production, particularly for coffee. Nineteen producers expressed concern that increased temperatures and rain led to higher pest and disease incidence, such as potato blight. Four farmers identified increased heat as a negative impact. Farmers expressed concern that if temperatures increased, high-elevation coffee might decrease in quality and lose the premium price it currently receives. Farmers also observed that lower-elevation coffee is more susceptible to disease, and speculated that the coffee rust epidemic could be related to climate change, a link supported by the academic literature (Avelino et al., 2015; Gay, Estrada, Conde, Eakin, & Villers, 2006; Laderach et al., 2011). From this analysis, it is clear that farmers in Honduras are in need of adaptation technologies to help them manage the increasing climate shocks and stresses they are already experiencing and which are projected in the future.

5.1.3. Technologies and pathways to resilience

While farmers were aware of climate impacts, very few could identify ways to adapt to these changes. The most common response was that nothing could be done other than pray for rain. Of identified adaptation options, the most frequently (almost universally) cited was irrigation. Those with irrigation described the ways that it allowed them to plant and harvest without dependence on rainfall, and attributed much of their success to its use. Drip irrigation was viewed as a prerequisite for horticulture adoption. Drip irrigation can be a very effective adaptation strategy because it allows for highly controlled, efficient water use, and can help increase the resilience of smallholder farmers, but is only an appropriate adaptation strategy for some farmers, depending on the resources they have available. Investing in irrigation is frequently not an individual-level adaptation decision because it requires a community-level system to transport water from the source to the field (Hanif, 2015). Access to irrigation also decreased farmer anxiety, because they knew that they had an option if they needed it. Those without irrigation expressed fatality regarding their ability to adapt. These perspectives highlight that irrigation may contribute to resilience more broadly than just through its impact on production by also impacting emotional well-being and sense of self-efficacy.

While USAID-ACCESO did introduce drip irrigation, a technology that farmers clearly identified as addressing an adaptation need, this was not the only technology transferred through the project with the potential to build climate resilience. Techniques introduced to increase yields of staple crops (many of which are also applied to the high-value crops) directly address climate impacts. For example, techniques to conserve soil and water will help during droughts. Some of the other technologies transferred through the project focused more on building the capacity of households to withstand shocks and stresses associated with climate change. For example, connecting farmers to markets helped farmers increase their incomes and build savings which they could use during bad seasons. Figure 2 demonstrates the technology transfer strategy of USAID-ACCESO and its various contributions to pathways to resilience.

Although the technologies introduced can improve resilience, there are limits to the extent they can address adaptation challenges (Adger et al., 2009; Dow et al., 2013). For some farmers, the risks associated with climate change may be too large to overcome through the types of adaptation technologies introduced through USAID-ACCESO. For example, lack of access to water emerged as a fundamental constraint to the potential for irrigation technology to contribute to resilience. Among producers that did not have irrigation (81%), 29% said that they did not have access to water. Even when a water source was available, producers needed to purchase drip irrigation. Even for 1 tarea, or 1/16 of a hectare, this represented a significant investment of $48 (for context, the average household income at the beginning of the project was $0.89 per person per day) (Hanif, 2015). As drought risk increases in the region due to climate change, water may become more of an absolute limit to production. Production may become more constrained, and in extreme cases, agriculture may become untenable as a livelihood strategy. More radical strategies and alternative adaptation pathways, such as a transition out of agriculture, may become necessary.

Other strategies may be currently feasible but may not be appropriate in the long-term. While horticulture may increase resilience by rapidly raising household income and diversifying livelihood options, the long-term feasibility of this adaptation strategy may decline over time as water resources become more stressed. Most horticulture is very water-intensive, making it a risky investment unless water is available. Identification of high-value crops that are less vulnerable to water stress, particularly intermittent water availability, may be necessary. Selecting more drought-resistant varieties of crops could also help to expand adaptation limits. Perennial crops such as avocados or other fruit trees may be more strategic (Parker et al., 2014).

When technology transfer occurs in isolation and not as part of a holistic approach to building resilience pathways, adaptation technologies may not achieve their goals. For example, although it may be possible to achieve short-term gains without investing in land preparation and soil and water conservation practices, long-term adaptive pathways will likely require such investments. Only through transformations of social structures like land tenure arrangements can barriers to adoption of these approaches be overcome (Feola, 2015; O'Brien & Selboe, 2015; Pelling, O'Brien, & Matyas, 2014).

5.2. Transfer mechanisms that can meet diverse farmer needs and strategies to overcome barriers to adoption

As discussed in Section 2, identifying technologies to support adaptation is not enough. The next step in successful technology transfer for adaptation is to identify and employ transfer mechanisms that address diverse farmer needs and utilize appropriate strategies to overcome barriers to adoption. This section analyzes the technology transfer mechanisms in USAID-ACCESO and how this influenced farmers' adoption of the technologies, paying attention to differences across farmers.

The model of technology transfer used by the USAID-ACCESO project differed from traditional firm-to-firm models of technology transfers in ways that are consistent with expectations of what technology transfer for adaptation would look like. USAID-ACCESO's model of technology transfer facilitated technology adoption but did not provide technologies directly. This model was initially poorly received by farmers, who were familiar with other organizations (primarily NGOs and faith-based organizations) in the region that donated seeds or provided other tangible inputs. Without tangible incentives for participation, it took longer to demonstrate the value of the technical assistance offered. This was particularly true for the poorest farmers, for whom the lack of donations represented a more significant barrier to technology adoption compared to farmers who had more personal resources available for investment.

This model, however, led to more sustained adoption by increasing the likelihood that farmers were making adoption decisions because they saw the value and were willing to make the investments needed to maintain use. Many farmers began to appreciate the value of the tacit knowledge being offered in this model of technology transfer. Once farmers were engaged in the programme, their concerns shifted to the frequency with which they received technical assistance, or interest in training on additional crops, indicating an engagement with the approach. The sustainability of the technology transfer model was important to farmers, and this approach left them confident in their ability to continue to use the new techniques after the project finished. By supporting farmers to improve their production and engage in new livelihood opportunities such as horticulture production for markets, this model of technology transfer increased resilience to specific climate impacts, through the introduction of agronomic techniques, but also contributed to farmer resilience more broadly, by empowering farmers. Because farmers were not given any inputs they gained confidence that the successes they observed would continue to be achievable long after the end of the project. This confidence then translated to increasing ambition and a feeling of empowerment as to their future and their own control of that future. Ultimately, this empowerment may contribute more to the resilience of farmers than any specific technical skill gained through the project.

Although the technology transfer methodology was flexible and could be tailored to the needs and desires of individual farmers and their land, the project followed a fairly linear model overall. The project began by introducing techniques for staple crops (maize and beans) and progressed to higher-value horticulture crops while also working with coffee producers. The complexity of technologies increased across this gradient, as did the level of investment and the risk associated with adoption, but the payoffs also increased. Processing and marketing techniques were introduced alongside agronomic techniques, mostly for horticulture.

The introduction of new production techniques for maize and beans was often the entry point for technology transfer. Almost every farmer grew staple crops (94% grew maize and 78% grew beans) and many of the poorest farmers and those on the most marginal land only grew maize and beans; thus technology transfer of these techniques was critical for reaching the most marginal farmers. These techniques formed the technical foundation for more advanced techniques, and did not require large (or any) financial investment. Relatively basic technical changes, including planting density, proper fertilizer use, and minimum tillage, can dramatically improve yields. The national average yield is 116 kilograms per acre. Based on demonstration plots, the basic techniques introduced by USAID-ACCESO could increase yields to 348 kilograms per acre, and the complete package of techniques could produce 1163 kilograms per acre (Lardizábal, 2013). Farmers observed significant yield increases after adopting basic practices and techniques, estimating that yields doubled. In addition, farmers were reluctant to reduce production for home consumption, so improving efficiency of staple crop production was the only way to create space for horticulture for land-constrained farmers.

Although there was a strong logic for the order in which technologies were introduced, it did have some drawbacks. The sequencing of technology introduction also played an important role in the pace at which technologies were adopted. Soil preparation techniques, including weeding, minimum tillage, contouring, and raised beds were consistently identified as the most difficult techniques to adopt. Because they required more labour than spraying with herbicides, many farmers viewed them as a costly investment. Soil preparation also required advance planning. Farmers explained that they were interested in adoption, but had missed a narrow planting window (particularly if they did not have access to irrigation). Because soil preparation was the first step in the technology transfer process, it served as a barrier to overall adoption. An advantage of starting with soil preparation, however, was that it required no financial commitment, which was important for limiting farmer risk exposure, as it allowed time for the farmer and the technician to develop a relationship and commitment to change before making expensive financial investments. In the long term, starting with the most committed farmers may prove to be very effective for widespread diffusion of the technology. Social networks are critical for the diffusion of technologies, and early adopters play an important demonstration role (Rogers, 1995; Strang & Soule, 1998). Farmers who face more barriers can learn from the experiences of early adopters, thus increasing their own chances of success and perpetuating a positive diffusion process.

Another barrier to technology adoption identified by producers and technicians was land ownership, which is widely acknowledged to be a barrier to agricultural technology adoption (Gershon Feder & Umali, 1993; Gebremedhin & Swinton, 2003; Place & Swallow, 2000; Rogers, 1995). Renters worried that they might lose access to their land the following year, creating a barrier for techniques requiring large upfront investments of labour, such as proper soil preparation, raised beds, and terraces. They also expressed concern that landlords might raise rents if they improved the land, creating a perverse incentive to adopt any techniques that would increase productivity. Most of the literature on land ownership and technology adoption has focused on longer-term investments, such as terracing, rather than seasonal land preparation like minimal tillage (Nowak, 1987; Place & Swallow, 2000). Although USAID-ACCESO promoted terracing and other long-term investments in soil and water conservation, there was minimal adoption among either renters or landowners, suggesting that renting was not, in fact, the primary barrier to adoption. Additional research on the barriers to adoption of soil and water conservation techniques would be helpful, as these are likely to play an important role in adaptation. On the other hand, because renters paid to rent the land on which they grew maize for household consumption, they were particularly interested in yield-increasing techniques. For example, one farmer reduced the land he rented by half by increasing his yields, saving 500 lempiras (approximately $25) per season, which he invested in coffee and horticulture production. For these producers, adoption of new techniques led to lower input costs and the cost savings opened opportunities to invest in more lucrative activities.

5.3. Sustained adoption by the most vulnerable to climate change

If technology transfer is to support smallholder adaptation, producers need to adopt the technologies. In this section, rates of technology adoption, as well as patterns of adoption are analyzed. Particular attention is paid to who has adopted different technologies and what they chose to adopt.

Seventy-six percent of interviewees had adopted at least one technology or crop promoted by the project, and an additional 5% expressed plans for future adoption (Table 4). Considering the barriers smallholders face for technology adoption and their risk aversion, the decision to adopt new technologies or crops is not made lightly.

A key way of distinguishing farmers is by their initial production: staple crops, coffee, or already engaged in horticulture (Table 4). These groups had different rates of adoption and also made different choices as to what to adopt.

Farmers growing only staple crops, unsurprisingly, most commonly adopted techniques associated with maize and beans. Despite the fact that the techniques for maize and beans were the easiest to implement, approximately 40% of producers had not adopted them. Some producers had strongly-held beliefs about the process of growing traditional crops and were resistant to expert advice. Farmers offered 'because this is how we have always done it' to explain their continued use of traditional practices. These relatively low rates of adoption indicate the high barriers to technology adoption facing smallholder farmers.

A significant percentage of farmers engaged in coffee production (55%). Coffee producers were less likely to adopt techniques for staple crops, but more likely to adopt horticulture. Some coffee farmers were the most reluctant adopters. Many coffee producers were accustomed to minimal investments (including labour), which made annuals like vegetables less appealing. The behavioural change required to produce vegetables was more difficult, particularly for older coffee producers. During the study period, a coffee rust epidemic hit Central America, damaging harvests and killing many plants. Coffee rust is a fungal disease, and its frequency and severity are projected to increase with climate change (Avelino et al., 2015; Gay et al., 2006; Laderach et al., 2011). Many farmers had invested all their savings (and some had taken loans) to purchase new rust-resistant varieties. They also invested significant time growing seedlings and planting them. The coffee rust epidemic played a dominant role in the adoption of new production techniques and crops, serving both as a barrier and an enabler of adoption. Due to the lost income and investments rebuilding their plantations, many coffee producers believed they were not in a position to adopt new technologies or crops, and did not imagine they would be able to do so before the new plants produced a harvest. This suggests that as climate change worsens and events like the coffee rust epidemic become more frequent, farmers may be less inclined, or less capable, of adopting resilient technologies. At the same time, the epidemic also served as a motivation for technology adoption.

Despite the significant hardship and increased vulnerability caused by the coffee rust epidemic, it opened a window of opportunity. Many producers were re-planting their plantations from scratch, providing an opportunity to adopt more sustainable planting techniques, such as proper plant spacing and appropriate fertilization. Mature coffee plants only need to be replanted every four to five years, so opportunities to change behaviour on a large scale are rare. Producers were interested in learning better management techniques to ensure that they don't

Table 4. Adoption of technologies based on initial crops grown.

Initial crop	Adopted basic practices (staple crops)	Adopted coffee practices	Adopted horticulture and associated practices	No adoption	No adoption but planning to	Number of participants
Maize and beans only*	21 (64%)	N/A	17 (52%)	9 (27%)	0	33
Coffee	25** (51%)	20 (38%)	35 (66%)	12 (23%)	5 (9%)	53
Horticulture	7 (88%)	N/A	8 (100%)	0	0	8
Other***	N/A	N/A	0	2 (100%)	0	2
Total (of eligible)	**53 (59%)**	**20 (38%)**	**59 (61%)**	**23 (24%)**	**5 (5%)**	**96**

This table identifies adoption rates for different types of technologies (including new crops for horticulture) based on the initial crops farmers grew.

*Production in a home garden for household consumption was not counted.

**Four coffee growers did not produce maize or beans, and were not included when calculating adoption percentages.

***Participants received technical assistance for non-agricultural income-generating activities.

experience similar crises in the future. The rust epidemic also provided an opportunity to diversify beyond coffee. Sixty-six percent of coffee producers began growing horticulture for market production. Younger producers were particularly interested because they did not see a future in coffee due to the low prices in the global market and the coffee rust epidemic. These producers were investing in horticulture at a larger scale than farmers growing only staple crops. Because of their experience with coffee, they were familiar with producing for a market, and accustomed to taking risks and investing in their production.

Farmers already growing horticulture crops had the highest adoption rates of any group, with 100% adopting either a new horticulture crop or new techniques associated with horticulture, and all but one also adopting new techniques for staple crops. Because horticulture production is highly correlated with improved incomes (this was the whole basis for the project), it can be assumed that those farmers already growing horticulture were less poor than those only growing staple crops (although interviews did not formally collect household income data).

Although the highest risk and the highest barriers to entry, horticulture crops and associated techniques were the most commonly adopted, with 63% of farmers planting at least one new crop (Table 5). Despite the higher barriers to adoption, the pace of adoption for horticulture was faster, as farmers could observe results within a few months. The impact in terms of income gains was also most dramatic. Horticulture production was also novel so news travelled quickly throughout a community. If the early adopters continue to be successful, it is likely that many other farmers will follow in their path. The primary explanation offered by farmers for adoption was that horticulture was 'new' and 'exciting.' This suggest that under the right conditions, even farmers that face significant barriers are willing to engage with technology transfer efforts. Peppers, passionfruit, carrots, squash, and tomatoes were the most commonly adopted crops, but in total, 29 different new crops were adopted (Table 5). Many farmers experimented with a wide range of new crops. It was not uncommon to adopt three or four, or even more new crops. Peppers and tomatoes were popular with 28% and 22% of horticulture adopters adopting each respectively (adoption rates were similar irrespective of the initial crops grown). These are central to the Honduran diet, which meant that they were familiar to farmers and had local market demand. While they required larger investments and were more vulnerable to pests and disease, they were also higher-value crops, and it was possible to generate significant income.

Table 5. Horticulture adoption.

	Initial Crop				
	Maize and beans	Coffee	Horticulture	Other	Total
*Adopted new crops**	17 (52%)	35 (66%)	8 (100%)	0	60 (63%)
Pepper	24%	29%	38%		28%
Passionfruit	18%	31%	0%		23%
Carrots	18%	29%	0%		22%
Squash	12%	14%	75%		22%
Tomato	18%	20%	38%		22%
Cabbage	12%	26%	13%		20%
Radish	12%	23%	0%		17%
Banana/ Plantain	29%	6%	13%		13%
Cucumber	12%	14%	13%		13%
Green Bean	6%	20%	0%		13%
Yucca	12%	11%	25%		13%
Avocado	24%	6%	0%		10%
Mustard	0%	14%	0%		8%
Watermelon	0%	0%	63%		8%
Eggplant	18%	3%	0%		7%
Onion	12%	3%	0%		5%
Non-adopter	16 (48%)	18(34%)	0	2 (100%)	34 (35%)
Plan to adopt	3 (9%)	5 (9%)	0	0	8 (8%)
*Dis-adoption***	3 (9%)	8 (15%)	0	0	11 (11%)

This table identifies which horticulture crops were adopted by farmers based on what they originally grew. It distinguishes between adopters, non-adopters, those that had not yet adopted, but had plans to adopt horticulture in the future, and disadoption.

*Percent of horticulture adopters.

**Percentages do not total to 100% because all disadopters were still active adopters of other crops.

Horticulture production was particularly interesting to women. Home gardens could play a role in exposing farmers to new techniques, crops, and measures to improve their productivity, which could later pave the way to production for the market. Because there were fewer expectations regarding their prior farming knowledge, female farmers were particularly open to the technical assistance offered by the project. In households with little or no adoption, women often expressed more interest than their husbands in the new techniques, suggesting that women could serve as an entry point for technology transfer.

Staple crop producers were more likely to adopt avocadoes and bananas and plantains (29% compared to 6% for coffee growers and 13% for horticulture producers) because these crops did not require irrigation and these farmers were the least likely to have access to irrigation or the ability to invest in it. Among coffee growers that adopted horticulture, 41% adopted fruit trees, with passionfruit particularly high with 11 adopters. In contrast, only 16% of non-coffee-producing horticulture adopters adopted fruit trees, and only 3 adopted passionfruit. Passionfruit was heavily promoted by the project because of strong market opportunities, something that coffee producers were particularly well-prepared to engage with. Coffee producers also expressed preferences for perennial crops like fruit tress because of the similarities in maintenance to coffee.

While many farmers had adopted at least one new technique or crop (76%), the decision to adopt a new technology did not immediately translate to significant improvements in wellbeing or other indicators of increased resilience to climate change. Once farmers decided to adopt new technologies and/or crops, most still required multiple years to adopt it on their full landholding, and many adoption decisions were made sequentially, necessitating multiple growing seasons. Several factors contributed to the slow pace of adoption. Frequently farmers, particularly those without irrigation, only had one planting cycle annually. They had a limited window in which to adopt new techniques, and there was a significant delay between adoption and observable results, which slowed the diffusion process. Many farmers were knowledgeable about various techniques and convinced of their utility, but had learned about them after planting, and therefore had to wait until the following year to adopt them. Some farmers had only adopted one or two technologies, while a whole suite are necessary to achieve significant gains in productivity. Others had adopted a range of technologies but only on a small fraction of their field. Historically, many agricultural technologies with promising laboratory results failed to live up to expectations under the suboptimal conditions of most smallholder plots, suggesting that farmer skepticism is warranted (Chambers et al., 1989; Snapp et al., 2003). For farmers, incremental adoption served as a means of determining if technologies that were successful elsewhere would be successful in their own case. Only once incremental adoption decisions are scaled up will adoption have a significant impact on resilience.

6. Conclusion

This study looked at the process of technology transfer and adoption among smallholder farmers in Honduras to gain insights into technology transfer and adoption for adaptation. Through a case study, it sought to provide insights to two questions: 1) How does technology transfer contribute to pathways to resilience for smallholder farmers? 2) What challenges do technology transfer for adaptation efforts face in meeting diverse farmer needs and overcoming barriers to technology adoption by the most vulnerable to climate change? This analysis was conducted by looking at three components of the technology transfer and adoption process: 1) Technologies that support adaptation, 2) Transfer mechanisms that can meet diverse farmer needs and strategies to overcome barriers to adoption and 3) Sustained adoption by the most vulnerable to climate change.

The study found that many technologies increase resilience in general, by, for example, increasing farmer incomes in the short term, but may not respond to climate impacts or be adaptive in the long-term. Climate information is important at both the farmer and programme levels. Explicit climate considerations may lead to better selection of technologies in programmes. Discussions with farmers of climate change and adaptation benefits are also necessary to promote informed decision-making, particularly when technology adoption involves trade-offs between short-term gains and long-term risks.

Another finding was that significant resources are needed to successfully transfer technologies to smallholder farmers, especially when targeting the most vulnerable as will frequently be the case for adaptation. Despite a considerable investment, namely $40 million, and a full-time staff of over 200, technology adoption rates were not sufficient to bring the project target of 12,500 households above $1.25 per person per day by the end of the project period. As discussed, raising household incomes is only one measure of increased resilience, which alone does not capture the full range of potential resilience impacts of technology transfer for adaptation, but income is strongly correlated with other measures of resilience, and thus this indicates the substantial effort required to transfer adaptation technologies to this population. The diversity of farmer circumstances and need for individualized training increased the amount of effort and limited the rapid scale-up of technology transfer efforts. While providing options met individual farmers' needs, this diversity added to the challenge of transferring technologies (Feder et al., 1985; Kassie et al., 2013; Zilberman et al., 2012). This challenge is likely to be common for many adaptation technology transfer efforts, as diversification is a key adaptation strategy and smallholder farmers occupy a wide range of agro-ecological niches. Diversity also led to challenges of scalability. For certain strategies to be successful (i.e. production for a market), a certain economy of scale is required, potentially putting farmer resilience strategies and system resilience strategies in tension (Kuhl, 2018).

The 'hardware' costs of technologies transferred were not high, but the 'software' costs, particularly in the form of capacity-building and training, were very high. In the international discourse, a strong emphasis remains on the hardware aspects of technology transfer, but this case study suggests that the software components need to play a much larger role, particularly for vulnerable populations like the smallholder farmers in this case. Most of the technology transfer discussions in the United Nations Framework Convention on Climate Change (UNFCCC) context have focused on larger, more expensive technologies, or technologies for which there are intellectual property concerns, such as patented seed technologies (Ockwell, Haum, Mallett, & Watson, 2010; Technology Executive Committee, 2014; UNFCCC, 2006). This research demonstrates that even in the absence of the constraints of international technology transfer, significant domestic technology transfer efforts are needed to encourage adoption of climate-resilient strategies.

Finally, in terms of adoption, a high percentage (76%) of Honduran farmers adopted at least one new technology, indicating that technology transfer efforts were reaching farmers, and the technologies met perceived farmer needs. However, there were important differences in adoption patterns across groups of producers. In line with existing literature (Foster & Rosenzweig, 2010; Rogers, 1995; Ruttan, 2001), there was evidence that renters, producers hit by coffee rust, and maize producers with very few resources, all of whom can be considered particularly vulnerable populations, had lower rates of adoption compared to farmers with more resources.

While certain farmers faced more barriers to adoption and needed more time to adopt technologies than others, the relationship between vulnerability and adoption was not unidirectional. There was evidence of specific motivations that drove adoption for particular groups, which could be used to encourage adoption among these populations. They suggest that different transfer mechanisms and incentives drive technology adoption for these groups, and strategies need to target them explicitly. Transforming vulnerabilities into opportunities for technology transfer will require a critical examination of the underlying causes of those vulnerabilities and whether technology transfer mechanisms support or address these structures (Dewulf, 2013). Doing so is likely to form an essential component of technology transfer efforts for adaptation, because unless specific care is taken to ensure that technologies meet the needs of the most vulnerable, technologies can reinforce existing inequalities and structural vulnerabilities.

Despite overcoming numerous barriers to adoption, the potential contributions to resilience was limited by the slow pace of adoption. A significant tension exists between the urgency of adaptation and technology transfer and adoption rates, particularly for smallholder farmers. The technology transfer literature suggests that we should be cautious in our expectations of the rate at which technological innovations are adopted, with most socio-technical transitions occurring over long periods of time, such as decades (Grubler, 1998; Bell, 2012; Park et al., 2012). Evidence from this study supports this finding; adoption of adaptation technologies takes years, and the pace of adoption is slower for more vulnerable farmers due to the greater constraints they face. Concerningly, evidence from the coffee rust epidemic suggests that farmers may be less capable of adopting climate-resilient technologies in the future, and the pace of adoption may *decrease* rather than increase as climate impacts become more serious.

In conclusion, USAID-ACCESO in Honduras provides an insightful case study of the numerous ways in which agricultural technology transfer projects can contribute to pathways to resilience for smallholder farmers. It also demonstrates some of the barriers and challenges of technology transfer for adaptation, and the need to ensure that technology transfer for adaptation receives sufficient resources in order to be successful in addressing climate vulnerabilities.

Acknowledgements

I would like to thank USAID Honduras and Fintrac for facilitating the fieldwork conducted for this study, Génesis Sandres Suazo, Cinthia Henríquez Martínez, Anne Elise Stratton and Yirat Nieves for their research assistance, and all of the farmers that participated in the study. This research also benefited greatly from the insights, guidance and feedback provided by Kelly Sims Gallagher, Jenny Aker and Rosina Bierbaum.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

Funding support was provided by the NSF IGERT Water Diplomacy program (grant # 0966093); a research grant from BP to the Center for International Environment and Resource Policy; the Fletcher School; the Hitachi Center for Technology and International Affairs; and Tufts Institute for the Environment.

Notes on contributor

Laura Kuhl is an Assistant Professor in the School of Public Policy and Urban Affairs and the International Affairs Program at Northeastern University. Her research focuses on adaptation and resilience policy in developing countries. She received her PhD and a masters degree from the Fletcher School of Law and Diplomacy at Tufts University and a bachelors degree from Middlebury College.

ORCID

Laura Kuhl http://orcid.org/0000-0002-1379-9435

References

Abramovitz, M. (1986). Catching up, forging ahead, and falling behind. *The Journal of Economic History*, *46*, 385–406.

Adger, W. N., Dessai, S., Goulden, M., Hulme, M., Lorenzoni, I., Nelson, D. R., … Wreford, A. (2009). Are there social limits to adaptation to climate change? *Climatic Change*, *93*(3–4), 335–354.

Arocena, R., & Sutz, J. (2005). Evolutionary learning in underdevelopment. *Int. J. Technology and Globalisation*, *1*, 209–224.

Aker, J. C. (2011). Dial "A" for agriculture: A review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*, *42*(6), 631–647.

Altieri, M. A., Nicholls, C. I., Henao, A., & Lana, M. A. (2015). Agroecology and the design of climate change-resilient farming systems. *Agronomy for Sustainable Development*, *35*(3), 869–890.

Amsden, A. H. (2001). *The rise of "the rest": challenges to the west from late-industrializing economies*: Oxford University Press, USA.

Avelino, J., Cristancho, M., Georgiou, S., Imbach, P., Aguilar, L., Bornemann, G., … Morales, C. (2015). The coffee rust crises in Colombia and Central America (2008–2013): Impacts, plausible causes and proposed solutions. *Food Security*, *7*(2), 303–321.

Bailey, I., & Buck, L. E. (2016). Managing for resilience: A landscape framework for food and livelihood security and ecosystem services. *Food Security*, *8*(3), 477–490.

Barrett, C. B., & Constas, M. A. (2014). Toward a theory of resilience for international development applications. *Proceedings of the National Academy of Sciences*, *111*(40), 14625–14630.

Bell, M. (2012). International technology transfer, innovation capabilities and sustainable directions of development. In D. G. Ockwell & A. Mallett (Eds.), *Low-Carbon technology transfer: From Rhetoric to Realticy* (pp. 45–72). Independence, KY: Routledge.

Bell, M., & Pavitt, K. (1993). Technological accumulation and industrial growth: Contrasts between developed and developing countries. *Industrial and Corporate Change*, *2*, 157–210.

Béné, C., Al-Hassan, R. M., Amarasinghe, O., Fong, P., Ocran, J., Onumah, E., … Mills, D. J. (2016). Is resilience socially constructed? Empirical evidence from Fiji, Ghana, Sri Lanka, and Vietnam. *Global Environmental Change*, *38*, 153–170.

Béné, C., Cornelius, A., & Howland, F. (2018). Bridging humanitarian responses and long-term development through transformative changes—some initial Reflections from the World Bank's adaptive social Protection program in the Sahel. *Sustainability*, *10*(6), 1697.

Béné, C., Headey, D., Haddad, L., & von Grebmer, K. (2016). Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations. *Food Security*, *8*, 123–138.

Biagini, B., Kuhl, L., Gallagher, K. S., & Ortiz, C. (2014). Technology transfer for adaptation. *Nature Climate Change*, *4*(9), 828–834.

Biagini, B., & Miller, A. (2013). Engaging the private sector in adaptation to climate change in developing countries: Importance, status, and challenges. *Climate and Development*, *5*(3), 242–252.

Biggs, S. D., & Clay, E. J. (1981). Sources of innovation in agricultural technology. *World Development*, *9*(4), 321–336.

Bloom, J. D. (2015). Standards for development: Food safety and sustainability in Wal-mart's Honduran produce supply chains. *Rural Sociology*, *80*, 198–227.

Bozeman, B. (2000). Technology transfer and public policy: A review of research and theory. *Research Policy*, *29*, 627–655.

Brooks, H. (1995). What we know and do not know about technology transfer: Linking knowledge to need. In *Marshalling technology for development* (pp. 83–96). Washington, DC: National Academies Press.

Bryan, E., Deressa, T. T., Gbetibou, G. A., & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: Options and constraints. *Environmental Science and Policy*, *12*, 413–426.

Burnham, M., & Ma, Z. (2016). Linking smallholder farmer climate change adaptation decisions to development. *Climate and Development*, *8*(4), 289–311.

Campbell, B. M., Thornton, P., Zougmoré, R., Van Asten, P., & Lipper, L. (2014). Sustainable intensification: What is its role in climate smart agriculture? *Current Opinion in Environmental Sustainability*, *8*, 39–43.

Chambers, R., Pacey, A., & Thrupp, L. A. (1989). *Farmer first: Farmer innovation and agricultural research*. London, UK: Intermediate Technology Publications.

Christiansen, L., Olhoff, A., & Traerup, S. (2011). *Technologies for adaptation. Perspectives and practical experiences*. Roskilde: UNEP Risoe Centre on Energy, Climate and Sustainable Development.

Clark, N. (2002). Innovation systems, institutional change and the new knowledge market: Implications for third world agricultural development. *Economics of Innov. New Techn*, *11*, 353–368.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, *35*(1), 128–152.

Cohn, A. S., Newton, P., Gil, J. D., Kuhl, L., Samberg, L., Ricciardi, V., … Northrop, S. (2017). Smallholder agriculture and climate change. *Annual Review of Environment and Resources*, *42*, 347–375.

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, *19*, 248–255.

Dewulf, A. (2013). Contrasting frames in policy debates on climate change adaptation. *Wiley Interdisciplinary Reviews: Climate Change*, *4*, 321–330.

Douthwaite, B. (2002). *Enabling innovation: A practical guide to understanding and fostering technological change*. London; New York: Zed Books.

Dow, K., Berkhout, F., Preston, B. L., Klein, R. J. T., Midgley, G., & Shaw, M. R. (2013). Limits to adaptation. *Nature Climate Change*, *3*(4), 305–307.

Eichberger, J., & Guerdjikova, A. (2012). Technology adoption and adaptation to climate change- A case-based approach. *Climate Change Economics*, *3*, 1250007.

Fazey, I., Wise, R. M., Lyon, C., Câmpeanu, C., Moug, P., & Davies, T. E. (2015). Past and future adaptation pathways. *Climate and Development*, 1–19.

Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change*, *33*, 255–298.

Feder, G., & Umali, D. L. (1993). The adoption of agricultural innovations: A review. *Technological Forecasting and Social Change*, *43*(3), 215–239.

Feola, G. (2015). Societal transformation in response to global environmental change: A review of emerging concepts. *Ambio*, *44*(5), 376–390.

Feola, G., Agudelo Vanegas, L. A., & Contesse Bamón, B. P. (2015). Colombian agriculture under multiple exposures: A review and research agenda. *Climate and Development*, *7*(3), 278–292.

Few, R., Morchain, D., Spear, D., Mensah, A., & Bendapudi, R. (2017). Transformation, adaptation and development: Relating concepts to practice. *Palgrave Communications*, *3*, 17092.

Fleischer, A., Mendelsohn, R., & Dinar, A. (2011). Bundling agricultural technologies to adapt to climate change. *Technological Forecasting and Social Change*, *78*(6), 982–990. Retrieved from http://www.sciencedirect.com/science/article/pii/S0040162511000345. doi:10.1016/j.techfore.2011.02.008

Foster, A., & Rosenzweig, M. (2010). Microeconomics of technology adoption. *Annual Review of Economics*, *2*, 395–424.

Gallagher, K. S., Grubler, A., Kuhl, L., Nemet, G., & Wilson, C. (2012). The energy technology innovation system. *Annual Review of Environment & Resources*, *37*, 137–162.

Garnett, T., Appleby, M. C., Balmford, A., Bateman, I. J., Benton, T. G., Bloomer, P., … Godfray, H. C. (2013). Sustainable intensification in agriculture: Premises and policies. *Science*, *341*(6141), 33–34. doi:10.1126/science.1234485

Gay, C., Estrada, F., Conde, C., Eakin, H., & Villers, L. (2006). Potential impacts of climate change on agriculture: A case of study of coffee production in Veracruz, Mexico. *Climatic Change*, *79*(3–4), 259–288.

Gebremedhin, B., & Swinton, S. M. (2003). Investment in soil conservation in northern Ethiopia: The role of land tenure security and public programs. *Agricultural Economics*, *29*(1), 69–84.

Goldstein, D. (2015). Climate-adaptive technological change in a small region: A resource-based scenario approach. *Technological Forecasting and Social Change*, *99*, 168–180.

Grubler, A. (1998). *Technology and global change*. Cambridge, UK: Cambridge University Press.

Hanif, C. (2015). *Drip irrigation in Honduras: Findings and recommendations- scaling up agricultural technologies from USAID's feed the future*. Washington, DC: USAID.

Hayami, Y., & Ruttan, V. W. (1985). *Agricultural development: An international perspective*. Baltimore, MD: John Hopkins University Press.

Holt-Giménez, E., & Altieri, M. A. (2013). Agroecology, food sovereignty, and the new green revolution. *Agroecology and Sustainable Food Systems*, *37*(1), 90–102.

Howden, S. M., Soussana, J. F., Tubiello, F. N., Chhetri, N., Dunlop, M., & Meinke, H. (2007). Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences*, *104*(50), 19691–19696. doi:0701890104 [pii].

IFPRI. (2013). *Honduras feed the future zone of influence baseline report*. Washington, DC: IFPRI.

IHCAFE. (2015). [Instituto Hondureño del Café]. Web Page.

Metz, B., Davidson, O. R., Turkson, J. K., Martens, J. W., van Rooijen, S. N., & van Wie McGrory, L. (Eds.). (2000). *Methodological and technological issues in technology transfer: a special report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Field, C. B., Barros, V., Stocker, T. F., & Dahe, Q. (Eds.). (2012). *Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

IPCC. (2018). *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Future-Oriented Technology Analysis*, *80*(3), 525–540.

Kates, R. W., Travis, W. R., & Wilbanks, T. J. (2012). Transformational adaptation when incremental adaptations to climate change are insufficient. *Proceedings of the National Academy of Sciences*, *109*(19), 7156–7161. doi:10.1073/pnas.1115521109.

Key, N., & Runsten, D. (1999). Contract farming, smallholders, and rural development in Latin America: The organization of agroprocessing firms and the scale of outgrower production. *World Development*, *27*(2), 381–401.

Kuhl, L. (2018). Potential contributions of market-systems development initiatives for building climate resilience. *World Development*, *108*, 131–144.

Laderach, P., Lundy, M., Jarvis, A., Ramirez, J., Portilla, E. P., Schepp, K., & Eitzinger, A. (2011). Predicted impact of climate change on coffee supply chains. In *The economic, social and political elements of climate change* (pp. 703–723). Berlin: Springer.

Lardizábal, R. (2013). *Manual de producción de maíz bajo el manejo integrado de cultivo*. La Lima, Honduras: USAID-ACCESO.

Lin, B. B., Perfecto, I., & Vandermeer, J. (2008). Synergies between agricultural intensification and climate change could create surprising vulnerabilities for crops. *Bioscience*, *58*(9), 847–854.

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., … Henry, K. (2014). Climate-smart agriculture for food security. *Nature Climate Change*, *4*(12), 1068–1072.

Lorentzen, J. (2009). Learning and innovation. *Science, Technology and Society*, *14*, 177–205.

Low, B., Ostrom, E., Simon, C., & Wilson, J. (2008). Redundancy and diversity: Do they influence optimal management. In Berkes F., Colding J. & Folke C. (Eds.). *Navigating social-ecological systems: building resilience for complexity and change*. Cambridge University Press.

Lybbert, T. J., & Sumner, T. A. (2012). Agricultural technologies for climate change in developing countries: Policy options for Innovation and technology diffusion. *Food Policy*, *37*, 114–123.

Magrin, G. O., Marengo, J. A., Boulanger, J. P., Buckeridge, M. S., Castellanos, E., Poveda, G., … Vicuña, S. (2014). Central and South America. In V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part B: Regional aspects. Contribution of working group II to the Fifth assessment report of the Intergovernmental Panel on climate change* (pp. 1499–1566). Cambridge, UK and New York, NY: Cambridge University Press.

Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z. W., Lettenmaier, D. P., & Stouffer, R. J. (2008). Stationarity is dead: Whither water management? *Science*, *319*(5863), 573–574.

Mortimore, M. J., & Adams, W. M. (2001). Farmer adaptation, change, and 'crisis' in the Sahel. *Global Environmental Change*, *11*, 49–57.

Nowak, P. J. (1987). The adoption of agricultural conservation technologies: Economic and diffusion explanations. *Rural Sociology*, *52*(2), 208.

O'Brien, K., & Selboe, E. (2015). *The adaptive challenge of climate change*. New York, NY: Cambridge University Press.

O'Brien, K. L., & Leichenko, R. M. (2000). Double exposure: Assessing the impacts of climate change within the context of economic globalization. *Global Environmental Change*, *10*(3), 221–232.

Ockwell, D., & Byrne, R. (2016). Improving technology transfer through national systems of innovation: climate relevant innovation-system builders (CRIBs). *Climate Policy*, *16*(7), 836–854.

Ockwell, D., Haum, R., Mallett, A., & Watson, J. (2010). Intellectual property rights and low carbon technology transfer: Conflicting discourses of diffusion and development. *Global Environmental Change*, *20*, 729–738.

Ockwell, D., Sagar, A., & de Coninck, H. (2014). Collaborative research and development (R&D) for climate technology transfer and uptake in developing countries: towards a needs driven approach. *Climatic Change*, 1–15.

Ockwell, D. G., & Mallett, A. (2012). *Low-carbon technology transfer: From rhetoric to reality*. New York, NY: Routledge.

Park, S. E., Marshall, N. A., Jakku, E., Dowd, A.-M., Howden, S. M., Mendham, E., & Fleming, A. (2012). Informing adaptation responses to climate change through theories of transformation. *Global Environmental Change*, *22*(1), 115–126.

Parker, J., Miller, K., Caballero Bonilla, L. A., Escolan, R. M., Muñoz, E., del Rio, A., … Seimon, A. (2014). *Vulnerability and resilience to climate change in Western Honduras*. Brattleboro, VT: USAID and TetraTech.

Pauw, P., & Pegels, A. (2013). Private sector engagement in climate change adaptation in least developed countries: An exploration. *Climate and Development*, *5*(4), 257–267.

Pelling, M., O'Brien, K., & Matyas, D. (2014). Adaptation and transformation. *Climatic Change*, *133*, 1–15.

Place, F., & Swallow, B. (2000). *Assessing the relationship between property rights and technology adoption in smallholder agriculture: a review of issues & empirical methods*. CGIAR System-wide Program on Property Rights and Collective Action.

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., … Garrett, K. (2014). Food security and food production systems.

President's Council of Advisors on Science and Technology (PCAST) (2012). Report to the president on agricultural preparedness and the agriculture research enterprise. Executive Office of the President. Available at: https://fedbyscience.org/assets/reports/PCAST-Ag-Preparedness-Report-December-2012.pdf

Rogers, E. M. (1995). *Diffusion of innovations*. New York, NY: Free Press.

Ruttan, V. (2001). *Technology, Growth, and development: An induced innovation perspective*. Oxford, UK: Oxford University Press.

Ruttan, V. W. (1996). What happened to technology adoption-diffusion research? *Sociologia Ruralis*, *36*, 51–73.

Sayer, J., & Cassman, K. G. (2013). Agricultural innovation to protect the environment. *Proceedings of the National Academy of Sciences*, *110*(21), 8345–8348. doi:10.1073/pnas.1208054110.

Sharma, S., & Moehner, A. (2011). The evolution of 'technologies for adaptation' in the international climate change negotiations. In L. Christiansen, A. Olhoff, & S. Traerup (Eds.), *Technologies for adaptation: Perspectives and practical experiences* (pp. 3–17). Roskilde: UNEP Risoe Centre on Energy, Climate and Sustainable Development.

Smit, B., & Skinner, M. W. (2002). Adaptation options in agriculture to climate change: A typology. *Mitigation and Adaptation Strategies for Global Change*, *7*, 85–114.

Snapp, S. S., Blackie, M. J., & Donovan, C. (2003). Realigning research and extension to focus on farmers' constraints and opportunities. *Food Policy*, *28*, 349–363.

Steenwerth, K. L., Hodson, A. K., Bloom, A. J., Carter, M. R., Cattaneo, A., Chartres, C. J., … Horwath, W. R. (2014). Climate-smart agriculture global research agenda: Scientific basis for action. *Agriculture & Food Security*, *3*(1), 11.

Strang, D., & Soule, S. (1998). Diffusion in organizations and social Movements: From hybrid corn to poison pills. *Annual Review of Sociology*, *24*, 265–290.

Tambo, J. A., & Abdoulaye, T. (2012). Climate change and agricultural technology adoption: The case of drought tolerant maize in rural Nigeria. *Mitigation and Adaptation Strategies for Global Change*, *17*, 277–292.

Technology Executive Committee. (2014). Technologies for adaptation in the agricultural sector. TEC Brief #4. UNFCCC, Bonn, Germany.

Tessa, B., & Kurukulasuriya, P. (2010). Technologies for climate change adaptation: Emerging lessons from developing countries supported by UNDP. *Journal of International Affairs*, *64*, 17–31.

Thomas, G., & Slater, R. (2006). Innovation, agricultural growth and poverty reduction. *International Journal of Technology and Globalisation*, *2*, 279–288.

Tompkins, E., & Eakin, H. (2012). Managing private and public adaptation to climate change. *Global Environmental Change*, *22*, 3–11.

Trærup, S., & Stephan, J. (2015). Technologies for adaptation to climate change. Examples from the agricultural and water sectors in Lebanon. *Climatic Change*, *131*(3), 435–449.

UNFCCC. (2006). *Application of Environmentally Sound Technologies for Adaptation to Climate Change*.

USAID. (2011). *Feed the future Honduras FY 2011–2015 multi-year country strategy*. Washington, DC: United States Government.

USAID. (2015). *Final report USAID-ACCESO (April 2011-May 2015)*. Washington, DC: USAID.

Vermeulen, S. J., Aggarwal, P. K., Ainslie, A., Angelone, C., Campbell, B. M., Challinor, A. J., … Kristjanson, P. (2012). Options for support to agriculture and food security under climate change. *Environmental Science & Policy*, *15*(1), 136–144.

Wheeler, T., & von Braun, J. (2013). Climate change impacts on global food security. *Science*, *341*(6145), 508–513. doi:10.1126/science.1239402.

Williams, L. D. A., & Woodson, T. S. (2012). The Future of Innovation Studies in Less Economically Developed Countries. *Minerva*, *50*, 221–237.

Wise, R. M., Fazey, I., Smith, M. S., Park, S. E., Eakin, H. C., Van Garderen, E. R. M. A., & Campbell, B. (2014). Reconceptualising adaptation to climate change as part of pathways of change and response. *Global Environmental Change*, *28*, 325–336.

Zilberman, D., Zhao, J., & Heiman, A. (2012). Adoption versus adaptation, with emphasis on climate change. *Annual Review Resource Economics*, *4*, 27–53.