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Researching farmer behaviour in climate change adaptation and sustainable agriculture: Lessons learned from five case studies

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A R T I C L E I N F O

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A B S T R A C T

Understanding farmer behaviour is needed for local agricultural systems to produce food sustainably while facing multiple pressures. We synthesize existing literature to identify three fundamental questions that correspond to three distinct areas of knowledge necessary to understand farmer behaviour: 1) decision-making model; 2) cross-scale and cross-level pressures; and 3) temporal dynamics. We use this framework to compare five interdisciplinary case studies of agricultural systems in distinct geographical contexts across the globe. We find that these three areas of knowledge are important to understanding farmer behaviour, and can be used to guide the interdisciplinary design and interpretation of studies in the future. Most importantly, we find that these three areas need to be addressed simultaneously in order to understand farmer behaviour. We also identify three methodological challenges hindering this understanding: the suitability of theoretical frameworks, the trade-offs among methods and the limited timeframe of typical research projects. We propose that a triangulation research strategy that makes use of mixed methods, or collaborations between researchers across mixed disciplines, can be used to successfully address all three areas simultaneously and show how this strategy has been achieved in the case studies. The framework facilitates interdisciplinary research on farmer behaviour by opening up spaces of structured dialogue on assumptions, research questions and methods employed in investigation.

1. Introduction

This paper examines the challenge of researching the complexity of farmer behaviour in the face of increasing and simultaneous ecological, economic, and social pressures, and in the dynamic frame of their institutional context, biophysical environment, power relations, and social networks. We are concerned with identifying what to investigate regarding farmer behaviour, and how to do it, to generate the knowledge needed to inform adaptation to global environmental change and transitions to sustainable agriculture. With this aim, we identify three areas of knowledge that are necessary to understand farmer behaviour, examine the utility of an integrated and interdisciplinary approach, and discuss related methodological challenges by applying it to five case studies.

Agriculture is exposed to multiple, simultaneous and interconnected ecological, economic and social pressures (O'Brien and Leichenko, 2000). Increased economic interconnections in a globalized world create unpredictable dynamics and conditions of price volatility, which can affect agricultural incomes and livelihoods (Fader et al., 2013). Moreover, pressures on agricultural systems include the competition between different land uses (Smith et al., 2010) and different uses for agricultural land (Cassidy et al., 2013), the global shift in consumption patterns towards a more dairy and meat-based diet (Popkin, 2001), and the diversification of rural livelihoods in the South (Reardon et al., 2007). Adaptation in agricultural systems to these multiple pressures is therefore an urgent need.

On the other hand, agricultural activities are themselves major contributors to a range of environmental issues, including

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greenhouse gas emissions, biodiversity loss, deforestation, water and soil pollution, and soil erosion (Foley et al., 2011; IPCC, 2013). In the face of a greater challenge of producing food while preserving the environment, a sustainable and fair global food system will require a new approach to food production, distribution, and consumption (Ingram et al., 2010; Horlings and Marsden, 2011).

Understanding farmer behaviour[1] is central to enhancing adaptive capacity and promoting sustainable agriculture. Farmers are the agents undertaking adaptation and sustainability policies and programs, so their behaviour influences how and with what success these programs are realized on the ground (e.g., Home et al., 2014; Moon and Cocklin, 2011). Understanding farmer actions in their social-ecological context is essential to identify cases where intervention is needed, and the type of policies that can effectively promote socio-technical change and innovation. This can inform the design and implementation of measures such as incentives (e.g., Home et al., 2014), regulations (e.g., Bartel and Barclay, 2011), or institutional reforms (e.g., Ziervogel and Ericksen, 2010). Furthermore, a systematic understanding of farmers' adaptive behaviour can provide a basis for drawing the boundaries of policies or external aid, that is, to identify when *not* to intervene. This will avoid wasting resources on planned adaptation policies where bottom-up, autonomous adaptation (i.e., adaptation undertaken "as a regular part of on-going management" and not "consciously and specifically planned in light of a climate-related risks" (Smit and Skinner, 2002, p.93)) is already imminent or effective (Mortimore and Adams, 2001).

However, while farmer behaviour is a key determinant of agricultural systems' adaptability, too often research relies on theories and methods that do not capture the complexity of farmer behaviour. This then translates into ineffective adaptation or sustainability policies (Vanclay, 2004; Barnes et al., 2013). Furthermore, understanding farmer behaviour is plagued by the common difficulty in communicating and conducting collaborative research on sustainability and global change across disciplines and paradigms (Feola and Binder, 2010a; Podestá et al., 2013). Finally, the role of on-the-ground decision-making by individual farmers is often studied in individual cases to determine its environmental, economic, and social effects. There have been few efforts to link across studies in a way that provides opportunities to better understand empirical farmer behaviour, design effective adaptation and sustainable agriculture policies, and be able to aggregate from case studies to a broader level.

As an author team, we realized some of these shortcomings when we came together as part of a meeting of Coupled Human and Natural System (CHANS) Fellows,[2] an event designed to encourage synthesis in research on coupled human and natural systems. We were encouraged by this focus on synthesis to take the case-level empirical material from our recent fieldwork on farmer behaviour and develop an integrated way of looking at it more rigorously and in a broader context.

In this paper, we first develop a framework comprising three areas of knowledge on farmer behaviour that we have identified as critical based on previous literature: decision-making model, cross-scale and cross-level pressures, and temporal dynamics. By developing this framework we do not aim to propose a new theory of farmer behaviour, but use the framework to compare five previously conducted case studies to illustrate how these areas of knowledge can be investigated in different geographical areas, agricultural systems, and from different disciplinary perspectives to understand farmer behaviour. Finally, we compare and discuss the five case studies to draw general lessons and identify avenues for future research. The framework and the lessons learned from this analysis can facilitate interdisciplinary research on farmer behaviour by opening up spaces of structured dialogue on assumptions, research questions and methods employed in investigation.

2. Conceptual framework

In this section, we briefly review the recent literature and recognize three areas of knowledge that we identify as a conceptual model to understand the complexity of farmer behaviour, namely: 1) decision-making model; 2) cross-scale and cross-level pressures; and 3) temporal dynamics (Fig. 1). While these areas overlap in practice, they are constructs that can be useful in examining farmer behaviour analytically from three complementary perspectives. They correspond to three distinct broad research questions, as shown in Fig. 1. In this brief review, we also highlight some of the most common disciplinary differences in each of the three areas, demonstrating that they are traditionally approached from different disciplines and rarely integrated. In fact, each of these areas of knowledge is addressed in the literature by a range of different theories, albeit with limited dialogue across disciplines and paradigms.

A caveat is in order. Due to obvious space limits, we cannot comprehensively review the existing literature and its achievements. Instead we focus here on a subset of studies within the three areas of knowledge that have been identified for future research. The framework does not represent a new theory on farmer behaviour or decision-making, but rather informs the critical analysis of the case studies to identify best practices, limitations and open issues involved in studying farmer behaviour, and lessons learned that may inform future research on farmer behaviour.

2.1. Decision-making model

Different research approaches on farmer behaviour (e.g., innovation studies, conservation agriculture, rural studies) and disciplines (e.g. sociology, social psychology, economics, cultural studies, political science) have contributed to identifying the intrinsic and extrinsic factors that may influence farmer behaviour in different contexts, including agronomic, cultural, social, psychological, and economic factors (e.g. Burton, 2004; Edwards-Jones, 2006; Siebert et al., 2006; Ilbery et al., 2013).

However, it has been argued that existing research too often relies on theoretical models that do not capture the complexity of farmer behaviour (Edwards-Jones, 2006; Galt, 2008; Feola and Binder, 2010a; Wolf, 2011). Early concerns regarding the oversimplified representation of farmer behaviour and lack of solid theoretical basis (e.g., Schneider et al., 2000; Risbey et al., 1999; Krandilkar and Risbey, 2000) do not seem to have been addressed fully (e.g., Edwards-Jones, 2006; Galt, 2013). First, studies of farmer behaviour rooted in specific disciplines often fail to integrate different types of factors and focus on a particular set of factors (e.g., biophysical, economic, or psychological) (Feola and Binder, 2010a; Jain et al., 2015). Second, studies often assume models of 'rational action' drawn from economic theory, where

[1] In this paper, the term "behaviour" refers to an action or a series of actions. An "action", or "social action", refers to a series of acts enacted by a social actor, selected among possible alternatives, on the basis of a plan which can evolve in the course of the action itself. The social action aims at a goal, given a situation or context shared also by other actors who can react to it. The situation within which the social action takes place is also shaped by norms, values, means, and physical objects, which the actor considers, to the extent he/she disposes of information and knowledge (adapted from Gallino, 1993). Based on this definition, in this paper we refer to the same term "behaviour" to indicate actions enacted in order to pursue either adaptation to climate change or sustainable agriculture.

[2] The meeting of fellows was held in December 2012, organized by the International Network of Research on Coupled Human and Natural Systems (CHANS-Net).

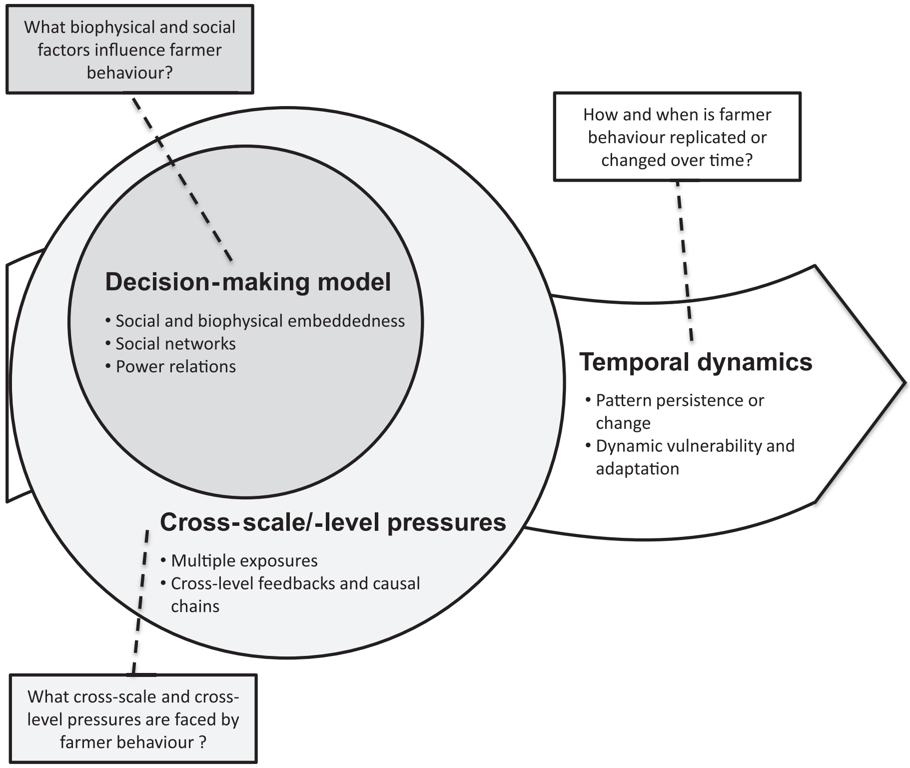

Fig. 1. The conceptual framework developed in this paper for the comparison of the five case studies, showing the three areas of knowledge (inside figure) and their corresponding research questions (in boxes). Traditionally, these areas are approached from a range of different disciplines. Here we suggest that integrating these three areas provides a tool for promoting rigorous interdisciplinary research design and communication.

farmers make the most economically rational decisions. Rational action models may be useful for simulating biophysical system outputs. However, they are not appropriate in accounting for the diverse rationalities that different types of decision-makers employ in real life, as several studies in the social sciences have shown (Krandilkar and Risbey, 2000; Jager et al., 2000; Darnhofer et al., 2010; Kaine and Cowan, 2011; Bacon et al., 2012; Kopainsky et al., 2012; Rasmussen and Reenberg, 2012; Ceddia et al., 2013; Galt, 2013). When translated into policy, such simplified models tend to result in a 'technical-fix' approach (Krandilkar and Risbey, 2000; Giddings et al., 2002; Ribeiro and Shand, 2008; Galt, 2013; Home et al., 2014). This approach defines adaptation to climate change or sustainable agriculture as problems of a technical nature, or ones that can be solved by intervening through instrumental measures (informational, technological, or economic).

In contrast to such a technical-fix approach, several authors stressed the need to move away from reductionist behavioural models by providing an understanding of farmer behaviour as embedded in specific agricultural systems (e.g., Vanclay, 2004; Edwards-Jones, 2006; Darnhofer et al., 2010; Feola and Binder, 2010a; Brown and Westaway, 2011; Cowan et al., 2013; Galt, 2013). This concern resonates with a broader effort that has recently been made to improve the human representation of agents in models of coupled social-ecological systems (e.g., Karali et al., 2011; Rounsevell and Arneth, 2011; An, 2012; Schlüter et al., 2012; Millington et al., 2013).

This literature has increasingly stressed the importance of looking at both the biophysical and the social 'embeddedness' of farmer behaviour. Crane et al. (2011), for example, showed the importance of understanding "adaptation as a dynamic process that is socially embedded" (p. 179) in order to identify the factors to be addressed by policy (see also Röling et al., 2012). This cultural approach acknowledges that the agricultural performance and the technical decisions may in fact entail several layers of institutional, moral and symbolic meaning (e.g., compliance with traditional and/or religious systems of values, or socially recognised and accepted role models) (see also Vanclay, 2004; Crane, 2010; Head et al., 2011). In fact, social identity can play a significant role in motivating farming decisions (e.g. farming practices reproducing the roles, values, and identity of rural communities, such as through subsistence food production) (Frank et al., 2011, see also Nielsen and Reenberg, 2010; Wolf, 2011; Lerner et al., 2013).

Furthermore, it is essential to recognise that, in the same way they are embedded in biophysical landscapes, farmer decisions are enacted in a social landscape bounded by other actors, which include extension agents, rural development agents, local authorities or agri-business (Barnes et al., 2013; Bernard et al., 2014). That is, not only other actors might influence farmers directly (e.g., social pressure) as captured by the social factors, but they can do this indirectly, by voluntarily or involuntarily creating physical (e.g., land appropriation and enclosure) or social structures (e.g., norms) that constrain, or enlarge, farmers' opportunity space (e.g., Scoones, 2009; Bacon et al., 2012; Ilbery et al., 2013; Bernard et al., 2014).

This draws the attention to the importance of addressing power relations in understanding farmer behaviour. Social, economic, and political power is unevenly distributed and therefore the boundaries of farmer behaviour may be restricted when there is a large difference between the perceived power of farmers and other actors. As discussed by Shove (2010) with reference to behaviour change policies, by overlooking such imbalances, there is the risk of implying that it is only the farmers' responsibility to take action to adapt or innovate, and not a responsibility shared with other, possibly more powerful and influential actors. This position ignores the power and social relations that underpin situations of intrinsic vulnerability in many rural areas worldwide and in the global South in particular (Scoones, 2009). Implicit in this critique is the shift of focus from adaptation (or sustainability) *solutions*, to the analysis of the *causes* of vulnerability (e.g., Ribot, 2011, 2014) as a necessary prerequisite to identify and develop durable behaviour change towards sustainability.

2.2. Cross-scale and cross-level pressures

Farmers consider the perceived effects of multiple and simultaneous pressures, such as environmental change and economic liberalization, in their farming decisions (O'Brien and Leichenko, 2000; Mortimore and Adams, 2001; Leichenko and O'Brien, 2002; Morton, 2007; Mertz et al., 2009). Several cases of interactions of multiple pressures have been analysed in the literature, in cases as diverse as shrimp farming in Mexico (Luers et al., 2003), dryland farming in West Africa (Mertz et al., 2009), and smallholding in Mozambique (Silva et al., 2010) (see also Leichenko and O'Brien, 2002; Morton, 2007).

In analysing agricultural systems, it is necessary to link spatial and temporal scales and levels within scales (e.g., micro- or macro-spatial scale, short- or long term temporal scale) (Scoones, 2009). Multiple pressures often cut across scales and levels (Leichenko and O'Brien, 2002; Rasmussen and Reenberg, 2012) and the connections of local and global processes influence the thresholds, delays, time lags and 'surprises' that characterise complex social-ecological systems (Liu et al., 2007, 2013). Such cross-level and cross-scale connections have been the object of intense study in integrative research on global environmental change (Gibson et al., 2000) and research informed by complex system approaches, which have significantly moved beyond the individual, household or community focus traditionally taken by particular disciplines such as psychology, economics or social studies (Liu et al., 2007; Brown and Westaway, 2011).

Including such interactions in the analysis entail at least two important implications. Firstly, causal chains in cross-scale and cross-level interactions are arguably more difficult to be perceived by actors at one level, and therefore considered in the decision-making process. Secondly, the pressures that farmers perceive might be out of the control of farmers' influence, because of constraints at a higher societal level (Galt, 2008, see also Stern, 2000). It is known that perceived behavioural control (i.e., the perception of the capacity to influence a certain phenomenon) is an important driver of social action (Ajzen, 2002). For example, despite international and national agrarian policy shifts in Mexico, and price spikes for basic commodities such as maize, many smallholding, traditional maize farmers tend to persist in low-input agriculture (Sweeney et al., 2013).

2.3. Temporal dynamics

As shown by the resilience and socio-ecological literature scholarship, agricultural activities entail many decisions that are recursive (i.e., cyclically repeated over time) and made at least partly in response to changes and pressures that are the result of previous behaviours and their consequences in the agricultural system. Such cycles can reinforce or change biophysical and long-standing social structures (Feola and Binder, 2010a; An, 2012; Schlüter et al., 2012; Millington et al., 2013). Several studies show that policies and interventions aimed at a transition towards sustainable agricultural practices often fail to achieve a structural, durable, self-sustaining change of practices among farmers. Research in various disciplines from economics to social psychology has shown that the adoption rate of a new practice (e.g., integrated pest management) increases during the intervention timespan, but the system bounces back to the initial state as soon as the active interventions stop (Hellin and Schrader, 2003; Orr and Ritchie, 2004; Ospina et al., 2009, see also Steg and Vlek, 2009). Regarding vulnerability and adaptation to climate change, several authors have discussed the notions of 'dynamic vulnerability' and 'dynamic adaptation' (Belliveau et al., 2006; Meza and Silva, 2009; Westerhoff and Smit, 2009). They point firstly to the changing nature of the pressures farmers are facing, and secondly to the dynamic nature of the adaptation process as based on the observation of continuous feedbacks between adaptation actions and consequences in the social and biophysical system domains (Kaine and Cowan, 2011; Schiere et al., 2012).

For durable, self-sustaining behavioural change to occur, the process of how behavioural patterns change over time must be captured, and this has been mostly a focus of system-oriented approaches (e.g., Schiere et al., 2012). A shift of focus is in order, "from the explanation of one-off decisions to the understanding of how and why social and biophysical structures and patterns of social actions persist or change over time" (Feola, 2013, p. 324). That is, a shift is needed from static to dynamic models of decision-making and agricultural systems. Firstly, this shift entails asking why some farmers enact certain behaviours and others do not, seeking to explain observed variation of behavioural patterns (Feola, 2013). Secondly it entails asking why, and through what temporal dynamics of behaviour (such as social learning, adaptive or maladaptive and sustainable or unsustainable behaviour) persist over time or are dropped, when it is reproduced or new ones emerge, and how these co-evolve with the system's social and biophysical structures (Scheffer and Westley, 2007; An, 2012; Schiere et al., 2012).

3. Case studies

In this section we use the framework (Fig. 1) to compare and reflect upon five previously conducted case studies that span a range of agricultural systems in distinct geographical contexts across the globe (Table 1). None of the cases was originally informed by the framework, which is used here to reflect upon the studies *post hoc*. All cases were conducted as interdisciplinary research projects in fields ranging from Geography to Biology to Environmental Policy, and adopted a range of methodological approaches.

3.1. Background of the case studies

3.1.1. Peri-urban maize farming in central Mexico

This study focused on peri-urban maize production in the Toluca Metropolitan Area west of Mexico City. The goal of the study was to uncover the processes affecting farmers' decisions to continue or abandon maize production in an expanding urban area and in a country that has experienced significant policy changes and climatic stress since agrarian reform distributed land to formerly landless peasants throughout the twentieth century (Lerner and Appendini, 2011). The issue of maize in Mexico is tied to household and national food security, as well as tradition and cuisine, which makes a potential agrarian transition complex. Despite a production system that is increasingly industrialized to produce grain for the urban consumers of Mexico, small-scale production persists throughout the country using low inputs and heirloom seeds (Sweeney et al., 2013). A livelihoods framework (Ellis, 2000) was used to examine the factors that could affect farmer decisions, and cause farmers to abandon or maintain their maize production (Lerner et al., 2013).

Table 1
Overview of the five case studies.

	Mexico	Colombia	California	India	The Philippines
Location	Toluca Metropolitan area	Boyacá Region	Napa and Sonoma Valleys	Gujarat	Palawan
Crop	Maize	Potato	Wine grapes	Cotton and castor	Rice, sweet potato, cassava and maize
Farm units	Smallhold	Smallhold	Smallhold and private corporations	Smallhold	Smallhold
Theoretical framework	Sustainable livelihoods	Integrative agent-centred framework	Vulnerability scoping diagram	Drivers of adaptive capacity	Politicized Institutional Analysis and Development
Data collection	Semi-structured interviews and farmer household surveys	Household survey and participatory simulation modelling	Semi-structured interviews and ranking exercises	Remote sensing and household surveys	Household survey and ethnography
Data analysis	Interview coding, regression and cluster analysis	Statistical and simulation modelling	Interview coding and descriptive statistics of rankings	Multi-variate statistics	Discourse and statistical analysis
Participants	146 farmers, 20 officials	197 farmers, 9 local experts	20 farmers	750 farmers	529 farmers
Level	3 communities	4 communities	1 district	15 villages	9 communities
Farming decisions investigated	Persistence of maize growing	Persistence of risky pesticide use practices	Farming decisions under environmental stresses	Adaptive cropping strategies	Participation in jatropha, oil palm, or rubber plantations
Problem focus	Adaptation to climate change	Sustainable agriculture	Adaptation to climate change	Adaptation to climate change	Sustainable agriculture
Interdisciplinarity within project	Yes, cultural ecology, political ecology, livelihoods analysis, economics, urban planning	Yes, social psychology, sociology, economics	Yes, anthropology, ecology, biochemistry	Yes, psychology, economics, environmental sciences, anthropology	Yes, political ecology, new institutional analysis, environmental anthropology, economics.
Interdisciplinarity across projects	Yes, part of a large project integrating climatic, economic, and household data	Yes, part of a larger interand transdisciplinary project	No, independent project (but led to further interdisciplinary collaborations)	No, this study was a standalone project	No, but further studies will be part of a larger interdisciplinary project
Disciplinary basis (degree program)	Geography	Geography	Interdisciplinary Program in Environment and Resources	Ecology, Evolutionary, and Environmental Biology	Environmental and Natural Resources Policy
References	Lerner and Appendini (2011) and Lerner et al. (2013)	Feola and Binder (2010a) and Feola et al. (2012)	Nicholas and Durham (2012)	Jain et al. (2015)	Montefrio (2013) and Montefrio and Sonnenfeld (2013)

3.1.2. *Potato farming in the Colombian Andes*

In the Region of Boyacá in the Colombian Andes, smallholders apply pesticide by means of a lever-operated knapsack sprayer without wearing adequate personal protective equipment (PPE), and they often also over-use pesticides. This is associated with high health and environmental risk levels (e.g., Cardenas et al., 2005; Ospina et al., 2008), and high production costs (MADR, 2006). Interventions often failed to achieve a durable change of such PPE and pesticide mis-use (e.g., Ospina et al., 2009), because the understanding of why farmers adopt certain pesticide use practices is incomplete. This study aimed to uncover the behavioural dynamics of unsustainable PPE and pesticide use practices, and to provide policy recommendations for a transition towards more sustainable practices. The study developed and adopted the integrative agent-centred (IAC) framework (Feola and Binder, 2010a) and alternative policies were identified, simulated and discussed in workshops with local experts and policy-makers (Feola and Binder, 2010b,c; Feola et al., 2012).

3.1.3. *Winegrowing in Northern California*

Winegrowing in California is economically important, contributing $61.5 billion to the state's economy (Wine Institute, 2012) and producing over 90% of wine in the US, the world's fourth-largest wine producer (Heien and Martin, 2003). Wine also contributes cultural services and values, including tourism and identity (Viers et al., 2013). Wine grapes are a climatically sensitive crop and are increasingly used as a model for climate adaptation studies (Diffenbaugh et al., 2011). The objectives were to examine farm-scale adaptive responses to environmental stresses, to understand the views and motivations of agricultural managers, and to explore adaptive capacity in practice (Nicholas and Durham, 2012).

3.1.4. *Short-term adaptation strategies of smallholder farmers in Northwest India*

This study examined how cropping decisions in Gujarat, India were influenced by a variety of social, demographic, economic, and biophysical factors (Jain et al., 2015). This region faced high inter-annual variability in rainfall, which can be used as a proxy to understand how climate variability and change may influence farmer behaviour. The cropping decisions and possible adaptation strategies of farmers sampled across a rainfall and irrigation gradient were surveyed for three years (2011–2013). Model selection and multivariate analyses were used to understand which factors were the strongest behavioural drivers. Furthermore, by comparing self-reported yield and income data, it was assessed whether these cropping strategies were adaptive (i.e., beneficial for livelihoods) or mal-adaptive (Jain et al., 2015).

3.1.5. *Production of low carbon commodities in upland Philippines*

This study aimed to understand non-economic variables that influence indigenous farmers' decisions to continue or abandon swidden (shifting) cultivation and fallow land management amidst enticements and pressures to engage in “low carbon” commodity crops, namely oil palm, jatropha, and natural rubber production regimes (Montefrio, 2012, 2013; Josol and Montefrio, 2013; Montefrio and Sonnenfeld, 2013). The study incorporates the role of social constructions and environmental discourses in actors' decisions in an institutional setting. With reference to smallholder households in upland Philippines, the study aimed to elucidate the relative influence of each of the measured socio-demographic, economic, and institutional variables, and the social constructions of the environment.

3.2. Case studies analysis and discussion

3.2.1. Decision-making model

Looking across the five cases in light of the framework, we found that social as well as biophysical conditions influenced farmer behaviour, although the specific combination of different factors is highly context dependent. In some regions, biophysical factors served as significant constraints to the cropping decisions that farmers could make in a growing season (i.e., India, California). Furthermore, we found that economic drivers or utility maximization motives were only partly able to explain behaviour, and that the social embeddedness and the socially adaptive behaviour of farmers were of equal, or even greater importance (i.e., Mexico, Colombia, and the Philippines). This result confirms the importance of studying adaptation as a social process (Crane et al., 2011; Wolf, 2011) rather than just a technical response to external pressures. For example, integrating social and biophysical factors was essential to understand the factors affecting decisions regarding maize production and pesticide use in Mexico and Colombia, respectively, where farmer decisions were adaptive not only with respect to biophysical (climate, level of pest infestation), but also to social and cultural conditions (food culture, social norms). In addition, social factors like information networks, biophysical factors like soil type, and economic factors like assets all played a strong role in whether farmers in India altered cropping behaviours in response to weather variability.

We also identified several cases in which actors other than farmers played a predominant role in constraining farmer decisions. These cases were often connected to power relations and how they play out in access and use of physical (e.g., land) and symbolic (e.g., authority) resources. Thus, by investigating social networks and power relations, the case studies highlighted not only possible adaptation measures or more sustainable practices, but the sources of vulnerability and of persistence of unsustainable practices. For instance, social networks convey information on adaptive farming practices, although in the California case growers mostly make decisions individually and therefore social networks prove to be more difficult to mobilize for anticipatory adaptation. Social networks are often associated with power relations, whereby more powerful actors can exert influence on less powerful ones (e.g., pesticide sellers influencing farmers in Colombia), or exclude farmers physically and socially from access to resources and farming options (e.g., non-indigenous agents contributing to enclosures and land appropriation in the Philippines).

3.2.2. Cross-scale and cross-level pressures

Our analysis of the five cases suggest that farmer behaviour responds to multiple cross-scale and cross-level pressures, although often it was the most imminent pressure that elicited a behavioural response. For example, weather variability, market price variability and groundwater depletion all serve as important drivers of behaviour in India. In this region, farmers must adapt to these multiple forms of risk, yet qualitative evidence suggests that few farmers altered their cropping strategies based on all three risks simultaneously. Instead, farmers typically responded to the most immediate risk (e.g., rainfall shock, market prices), and hoped that the decisions they made would make them more resilient to other types of risk (e.g., groundwater depletion). Similarly in the California vineyards, pressures of different types elicited different responses: those that could be addressed on an individual scale were tolerated until they reached a certain impact threshold (e.g., certain pests like leafhoppers). Those that required prevention were anticipated or monitored in advance to address (e.g., frosts or heat waves). Those that required collective action because of how the stress was spread formed working groups for research and response (e.g., vine mealybug). Climate change was a potential example of a long-term stress that could be addressed by a collective, anticipatory or proactive approach. However, most anticipatory strategies have to date been short-term, in response to imminent threats.

For other cases, national and international policies and demands can affect smallholders' ability to remain in their traditional activities. In the Philippines, the burgeoning discourses on “low carbon” commodity production at the national and international levels have resulted in increased policies and investment activities that specifically targeted uplands and ancestral domains for biofuels and natural rubber development. The increase in demand for land contributed to a drastic increase in land prices brought about by agro-industrial development, and consequently to land appropriation, prohibiting indigenous smallholders in acquiring lands in the future. In the Mexican case, national and international policy had profound effects on smallholder producers' ability to continue selling maize through the withdrawal of guaranteed grain purchasing and several subsidy and credit programs which intended to make the maize sector more efficient. These policy shifts led periurban small and medium-scale maize producers to shift to nonfarm forms of employment, engage in other forms of agriculture like greenhouse crops, use their grain to feed livestock for meat or dairy, or grow maize for subsistence only instead of growing maize to sell on the market.

3.2.3. Temporal dynamics

In order to understand farmer behaviour, we observe in the case studies that it is essential to investigate the process of how behaviours evolve, or persist, over time. As alluded to in the previous section, behaviour reacting to stressors in the short-term are often more common than decisions made for long-term goals. For example, in the California case, shorter-term actions such as changing irrigation or pruning practices were easier to adopt, and more frequently undertaken. Several short-term adaptations may provide as much adaptive capacity as more burdensome, longer-term ones, such as replanting varieties or changing location. In India, farmers alter their decisions from year to year based on variability in early monsoon indicators and market prices, yet few farmers are adapting to longer-term changes like climate change or groundwater depletion. Thus, what seems to be a beneficial strategy (e.g., increasing irrigation during low rainfall years) may actually be a mal-adaptive strategy over longer, decadal timeframes (e.g., due to severe groundwater depletion). In the Colombian case, farmers tended to intermittently react to short-term pesticide-related adverse health effects (individual feedback), but showed only short-term memory of these effects, and disregarded personal protective equipment use as the health symptoms lost relevance with time.

At the same time, some agricultural practices tend to persist in the long-term regardless of various stressors that would threaten smallholders' ability to continue in production. In the Phillipines, the abandonment of swidden cultivation and fallow lands can be due to multiple factors, including erosion of traditional cultures and prevalence of off-farm wage labour. However, field data showed that a significant population of indigenous smallholders continue to practice swidden cultivation with fallow periods ranging from 3 to 5 years. Data thus far indicate that "low carbon" commodity production regimes have not yet induced drastic conversion of swidden and fallow lands into plantations, due to the continued reliance of smallholder farmers on subsistence agricultural production. The research conducted in peri-urban Mexico illustrated that despite climate and policy stressors, smallholders continue to grow maize for tradition and the preference for home-grown grain for tortillas. The persistence of maize producers in urbanizing Mexico could drastically change over time as younger generations opt out of agriculture, but by investigating only one period of time, farming seems to continue despite the challenges producers face.

3.2.4. Retrospective analysis

In our retrospective examination of the case studies, we realized that the three areas of knowledge discussed above need to be addressed simultaneously in order to understand farmer behaviour. Despite their interdisciplinary design, no case study fully considered all three areas of knowledge, but the need to address an area that was overlooked emerged during the case study research. In fact, the examination of the case studies through the lenses of the framework (Fig. 1) opened up a space for the contribution of other disciplines or theoretical approaches.

In the study of maize farming in central Mexico, in which the behavioural shifts over time were not addressed, it was found that it was impossible to fully understand how the macro-scale processes such as climate and urban growth will affect farmers' decisions to continue in agriculture: while maize production seems to persist in urbanizing Mexico, this could drastically change as younger generations opt out of agriculture under climate and policy shifts that make it difficult. Additionally, the analysis did not take into account economic values such as the income from maize or the value of land in the peri-urban fringe that could greatly affect decision-making processes regarding maize. Understanding the decision-making model requires the integration of several types of variables to fully understand producer behaviour. Measuring land prices over time alongside the necessary investments to plant maize would greatly enhance the analysis of farmer decision-making in peri-urban areas.

In the study of potato farming in Colombia, the presence and role of cross-scale and cross-level pressures was not investigated. However, it was found that considering the local and national processes of social marginalization of peasants would have contributed to understanding the power relations among farmers and non-farm actors, which is a historical determinant of farmers' disempowerment in the region. On account of disempowerment, smallholders generally do not challenge the decision space practically set by other actors, such as pesticide sellers or credit agencies, who are perceived as having authority. However, those farmers who are empowered tend to acquire a leadership role within the community. This not only potentially opens the decision space and alternative behavioural options for less empowered farmers, but also influences social networks, as some farmers become more influential regarding social norms such as that of personal protective equipment misuse. Moreover, in this study, pesticide use was investigated in isolation from other external pressures. In practice, however, it is likely that pesticide use behaviours were indirectly influenced by smallholder responses to different pressures, and therefore, that to understand this behaviour it is necessary to understand indirect connections to different pressures. For example, farmer responses to price variability, a common characteristic of the regional market, may have caused shifts in agricultural cycles which, in turn, exposed the crop to different pest infestation levels, to which farmers may respond by changing pesticide use behaviours.

In the study of winegrowing in California, a long-lived perennial crop like grapevines must be studied over time, and the interrelationship of social and biophysical factors shaping farmer decisions was essential. Applying the framework to the California case highlighted the need to consider more socially embedded contexts for biophysical climate adaptation choices. Indeed, climate adaptation actions may not be driven primarily by climate at all, rather by response to market forces, social trends, or other pressures. Although the farmers in the Californian case were financially well-off by comparison with the other cases, working with a luxury crop in a developed country, they still faced some of the same pressures. Through the analysis of this case, both temporal and spatial scales were found to be important. If these were explicitly studied from the beginning by following the framework, perhaps deeper insights could have been achieved.

In the study of climate adaptation strategies in India, cross-scale and cross-level pressures were not directly examined, and this influenced the interpretation of farmer behaviour and decisions to adapt to weather variability in this region. First, without considering the multiple top-down shocks that farmers respond to simultaneously (market prices, groundwater depletion, rainfall variability), it is difficult to identify the extent to which farmers are adapting their cropping behaviours in response to climate variability as opposed to in response to other stressors. For example, informal discussions with farmers suggest that many changes in cropping strategies were in fact driven by changes in crop subsidies provided by the government, which were determined by cross-level government policies. Furthermore, considering the first area of the decision-making model, while this study did examine how multiple social (e.g., caste) and biophysical (e.g. soil type) factors influenced farmer behaviour, it did not explicitly consider how social embeddedness may have influenced crop choice. Yet discussions with farmers suggest that long-standing traditions and values, like planting the same crops that previous generations planted or growing traditional crop varieties used in traditional cooking, may have played a role in cropping decisions in this region.

In the study of swidden cultivation in the Philippines, power relations through environmental discourse was well documented, drawing from a "politics" oriented theoretical frame. However, the behavioural shifts over time were not measured directly. Doing so would have allowed the understanding of how various external and internal pressures contribute to indigenous farmers' decisions to either give up or retain swidden cultivation amidst burgeoning "low-carbon" agro-industrialization project in upland Philippines. Also, the influence of biophysical factors on farmer decisions was not investigated, due to the remote locations of and the innate difficulties in documenting these practices. Measuring the biophysical changes in the communities of concern would substantiate farmers' social constructions of and discourses on their natural environment. Furthermore, such measurements would provide a more holistic understanding of the factors that influence decision-making in upland Philippines. Longer field research with biophysical measurements, coupled with GIS analysis, would strengthen the analysis of how environmental change affects social constructions of environment and environmental discourses, which ultimately affects farmers' decisions.

4. Researching farmer behaviour: challenges and lessons learned

We discuss here best practices, limitations and open issues specifically involved in studying farmer behaviour in an interdisciplinary fashion, and lessons learned that may inform adaptation to climate change and sustainable agriculture across a wide variety of settings.

While individual studies should identify specific research questions and aim to select the most appropriate methods to match the research goals (Poteete et al., 2010), we suggested above that to avoid oversimplification in representing farmer behaviour, and thus inform adaptation and sustainability policy, three fundamental areas of knowledge need to be addressed (Fig. 1) in such research. The case studies then illustrated how a diversity of interdisciplinary research designs, theories and methods can be employed to investigate our conceptual framework (Table 1).

We recognize that our conceptual framework brings together different streams of literature on farmer behaviour and is therefore challenging because it requires merging different research programs and their corresponding philosophies of knowledge, theories, and research strategies with their corresponding methods (Khagram et al., 2010). On the other hand, the framework provides structure to interdisciplinary dialogue on farmer behaviour and therefore supports the critical examination of different research assumptions underpinning the study of farmer behaviour, which is essential in interdisciplinary research (Winowiecki et al., 2011). We undertook this challenging task ourselves firstly by analysing our individual case studies through the lens of the framework, and secondly by comparing the case studies. We found that the framework, while rooted in a holistic understanding of farmer behaviour based on current literature, helped raise further questions about the research we had undertaken, which opened up potential spaces for increased interdisciplinary dialogue within those case studies. Noting that no case study fully covered all three areas of knowledge acknowledges the difficulties and pitfalls of interdisciplinary research, but at the same time opens up spaces for future interdisciplinary research collaborations. Interdisciplinarity may be achieved by an individual investigator through a more comprehensive research design than what was used in any of our five case studies, either in the questions asked and data gathered. Alternatively, the framework also provides a structure for interdisciplinary research teams of investigators to address all three areas in the same study. Such structure is fundamental to support interdisciplinary collaborative research in that it helps make assumptions, questions, and methodological approaches explicit, and therefore is open for discussion (Winowiecki et al., 2011; Podestá et al., 2013). Indeed, the framework provided us with a common mental map of farmer behaviour that facilitated a structured conversation which resulted in the comparative analysis presented in this paper.

Based on our own experience and the comparison of the case studies, we propose that to provide understandings “that go beyond rather simple specifications of human decision making” (Schlüter et al., 2012, p. 220), in the contexts of complex interactions of cross-level and cross-scalar pressures, some methodological considerations are in order (Table 2).

Firstly, one common limitation that we encountered was that the methods or the theoretical frameworks adopted to address some questions did not suit others. For instance, some frameworks adopted in the case studies tend to frame behaviour into a static rather than dynamic perspective, i.e. not to recognize the recursive nature of human behaviour. This is the case of the Vulnerability Scoping Diagram (Polsky et al., 2007) used in the Californian case study, or the sustainable livelihoods framework (Ellis, 2000), adopted in the Mexican one. As recognized by Scoones (2009), for example, one of the challenges for the livelihoods perspective is that of dealing with long-term dynamics. On the other hand, the Integrative Agent-Centred framework (Feola and Binder, 2010a), adopted in the Colombian case study focuses on such dynamics, but in its focus on one specific action or farming practice may miss opportunities to uncover how that action or practice interacts with other actions enacted by the same farmer, thus poorly equipping the researcher to uncover multiple cross-scale and cross-level pressures. The Institutional Analysis and Development framework (Ostrom, 2005), adopted in the Philippine case study, allows for the examination of temporal and feedback dynamics, as well as an analysis of multiple levels and scales. However, this framework still needs further development in terms of the integration of biophysical factors and the role of discursive interactions and power relations. An open issue in this respect is, therefore, whether the theoretical frameworks that have informed research on farmer behaviour, each rooted in specific disciplines and paradigms, need to be reconsidered or synthesized in light of the advancement of understanding and the new challenges posed on farmers and different agricultural systems.

Secondly, the methods adopted for data collection and analysis also appear to entail trade-offs that affect the possibility to address all three areas of knowledge in a single study. For example, projects aiming at identifying behavioural patterns and their interactions with the social and biophysical environment at a broad level (regional), might face difficulty in uncovering the social networks and power relations at lower levels (e.g., the case study in India). This is also related to the need for large samples to cover large spatial areas (e.g., regional level), which however does not allow the deployment of qualitative methods for in-depth investigation on such large scale. Moreover, while modelling coupled social and ecological processes is recognised to be useful to unravel dynamics in social-ecological systems (An, 2012; Schlüter et al., 2012), some of the methods adopted in these case studies and some theoretical frameworks are more easily integrated with ecological modelling than others. This is because they generate quantitative rather than qualitative data (e.g., statistical modelling), or conceptualise feedbacks and interactions between social and ecological systems and the role of social actors driving or mediating these dynamics (e.g. IAC framework; Feola and Binder, 2010a).

One way to overcome the trade-offs that occurred in the case studies was to use a triangulation research strategy (Khagram et al., 2010), combining multiple methods (Creswell and Clark, 2007). Triangulation research is, of course, not a novel approach. However, the case studies compared in this paper show how triangulation can be done not only in a methodologically solid manner, but also in

Table 2
Challenges encountered and lessons learned from the comparison of the five case studies.

Challenge	Lesson learned
Different methods required make it difficult to address all three spheres simultaneously	Triangulation research strategy can help overcome tradeoffs.
Theoretical frameworks may not be suitable to address all three spheres simultaneously	Open issue for future research: need for reconsidering or synthesizing existing theoretical frameworks?
The limited timeframe of typical research projects prevents the study of long-term dynamics	Possible alternative research designs: simulation modelling; use of complementary studies in the same region; use of medium time scales as proxies for longer ones; space-for-time substitution.

novel ways and specifically cutting across traditionally separate approaches and methods. For example in the Mexican case study, quantitative surveys at the household level combined with semi-structured interviews with government officials allowed for both qualitative and statistical analysis. The interviews combined with closed and open survey questions allowed for greater depth in interpreting the results of statistical models. In the Indian case study combining social survey data with environmental data (e.g., soil and water quality) helped assess how natural resource quality influences farmer behaviour, and how the cropping decisions farmers make in turn affect natural resource quality. In the Colombian case study, an action-centred approach was adopted that aimed at understanding the meaning of the action from the actor's perspective through collection of information and social investigation based on a diverse set of research tools. Survey data and statistical modelling were used to inform a dynamic simulation model which was employed as a discussion and learning platform in workshops with local experts. This allowed for the cross-validation of the results, and for exploiting the complementarity of the methods, in terms of the ability to represent cross-sectional or dynamical systems, or to assess social structures as perceived by different actors. In the California case, the interviews and ranking exercises related to social adaptive capacity were conducted to compliment a study of the sensitivity of biophysical factors (light and temperature) affecting the chemical composition of Pinot noir grapes, and thus their sensitivity to climate change (Nicholas et al., 2011). In the Philippine case study, the survey data and statistical models provided robust quantitative evidence of how social constructions determine farmers' decisions vis-à-vis other socio-economic factors. The ethnography, on the other hand, not only validated the statistical models, but also disclosed how these social constructions are produced and reproduced in discursive spaces, through formal and casual interactions of various actors.

This evidence supports the suggestions for using a triangulation research strategy with mixed methods to more fully understand complex social-ecological systems, and to dare to do that across traditionally separate approaches and methods, e.g. simulation research, ethnography, statistical modelling and indicator-based measurements (Miller et al., 2010; Moran, 2010; Poteete et al., 2010; Vaccaro et al., 2010). Our comparison of case studies suggests that designing research to address each of the three areas of knowledge in our framework will likely require using mixed methods, either by single researchers or teams of collaborators, to achieve a holistic understanding of farmer behaviour.

Finally, a key limitation we encountered, particularly regarding the study of the temporal dynamics of behaviour, is the limited timeframe of typical research project funding. While studying behaviour for multiple (e.g., 3–5) years gives some indication of possible longer-term dynamics in the system, to truly understand how farmers are being impacted by shocks to the system the same farmers should ideally be followed for decades given that many of the processes affecting these actors occur over longer time-scales (e.g., changes in climate, market volatility, natural resource degradation). On the other hand, the case studies offer three different approaches of how to resolve this limitation. In the study of potato farming in Colombia, a simulation model was used to project possible scenarios and discuss the behavioural and system processes triggered by different pesticide risk reduction interventions. In the study of swidden agriculture in the Philippines, qualitative data and ethnographic observations on the present situation were compared with existing ethnographic studies carried out in the past two decades in the study area. Finally, in the case study of India, understanding how farmers alter behaviour to inter-annual variability in rainfall can give an indication to how farmers may respond to shifts in weather over longer time scales.

5. Conclusions

We have developed and used an interdisciplinary framework that aims to facilitate interdisciplinary research on farmer behaviour by opening up spaces of structured dialogue on assumptions, research questions and methods employed in investigation. Indeed, the framework provided us with a common mental map of farmer behaviour that facilitated a structured conversation which resulted in the comparative analysis presented in this paper. It helped raise further questions about the research we had previously undertaken, thus opening up spaces for increased interdisciplinary dialogue and collaborations. We developed the framework retrospectively after conducting independent case studies and encountering some of the limitations of our own research. Therefore our goal was to have both a tool for analysing our completed investigations in a new light, as well as to help guide future research to be more interdisciplinary and integrated. Ultimately, we hope that this framework will help design research that represents farmer behaviour more realistically and therefore more effectively in devising climate change adaptation and sustainable agriculture policies.

Any framework inherently shapes what will be studied, and therefore influences to some extent what is possible to find. Therefore it is essential to ensure that the research framework selected will align with the desired research goals. One challenge in interdisciplinary research is the pressure on the researcher to coherently combine tools and methods from various backgrounds. This can also hinder collaboration and synthesis, if each interdisciplinary effort essentially represents a new "discipline of one" that is hard to link to existing scholarly conversations. We found this development and use of a shared framework a valuable exercise to promote collaboration and synthesis, and hope that it can serve the same purpose for others, especially if used in earlier research design phases.

In reflecting on this exercise, this research would not have been possible if the authors had not come together across disciplines and study systems at the CHANS networking meeting, which catalysed this collaboration. Opportunities like this one are extremely valuable to foster cross-disciplinary fertilization, and spur the type of interdisciplinary research that can lead to understanding farmer behaviour and the complexities of coupled human and natural systems more broadly.

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