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Title

Relating farmer's perceptions of climate change risk to adaptation behaviour in Hungary

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Abstract

Understanding how farmers perceive climate change risks and how this affects their willingness to adopt adaptation practices is critical for developing effective climate change response strategies for the agricultural sector. This study examines (i) the perceptual relationships between farmers' awareness of climate change phenomena, beliefs in climate change risks and actual adaptation behaviour, and (ii) how these relationships may be modified by farm-level antecedents related to human, social, financial capitals and farm characteristics. An extensive household survey was designed to investigate the current pattern of adaptation strategies and collect data on these perceptual variables and their potential antecedents from private landowners in Veszprém and Tolna counties, Hungary. Path analysis was used to explore the causal connections between variables. We found that belief in the risk of climate change was heightened by an increased awareness of directly observable climate change phenomena (i.e. water shortages and extreme weather events). The awareness of extreme weather events was a significant driver of adaptation behaviour. Farmers' actual adaptation behaviour was primarily driven by financial motives and managerial considerations (i.e. the aim of improving profit and product sales; gaining farm ownership and the amount of land managed; and, the existence of a successor), and stimulated by an innovative personality and the availability of information from socio-agricultural networks. These results enrich the empirical evidence in support of improving understanding of farmer decision-making processes, which is critical in developing well-targeted adaptation policies.

Keywords

Adaptation, climate change, Hungary, path analysis, perception

1 Introduction

Agriculture is one of the most vulnerable sectors to climate change and associated extreme weather events (Pachauri et al., 2014). Shifts in precipitation, temperature and other weather patterns may change the suitability of crop varieties to their present agro-ecosystems, change the need for pest and disease management, and increase the turnover of soil organic matter and the associated risk of nutrient loss (Olesen et al., 2011). Extreme weather events (e.g. floods, storms and droughts) may also lead to reductions in areas suitable for agriculture, damage to infrastructure and higher yield variability (Olesen and Bindi, 2002). These negative consequences from climate change pose a direct threat to the success of agriculture and farmers' welfare at local and global scales. However, quantifying the full array of potential impacts and their effects on farmers' welfare is highly complex and uncertain (Gornall et al., 2010). The vulnerability of farmer welfare (Metzger et al., 2006) depends on the nature and severity of the climate signal, non-climate related stressors and the ability of farmers to cope or adapt in any given technological and regulatory environment. An increasing number of studies emphasise the importance of focusing on adaptation to climate change within the agriculture sector, in particular improving understanding of farm-level decision-making processes to advance the estimation of economic impacts and develop well-targeted policy

responses e.g. Below et al. (2012, 2014), Comoé and Siegrist (2015), Howden et al. (2007), Menapace et al. (2015), Reid et al. (2007), Reidsma et al. (2010), and Wheeler et al. (2013).

It has been hypothesized that farmers who have observed, or have knowledge about, phenomena related to climate change are more likely to believe in the potential of future risks, including risks associated with high-end climate changes, and consequently are more likely to adopt adaptation practices (Akerlof et al., 2013; Menapace et al., 2015). Existing studies on climate change risk perception have focused on associations between personal experience and belief in climate change risks by the general public (Bain et al., 2012; Brulle et al., 2012; Myers et al., 2013; Spence et al., 2011). While research investigating farmers' perceptions of climate change risks is growing (c.f. Menapace et al. (2015), and reference therein), most of these studies are descriptive in nature. The causal links between climate change risk perception and adaptation have rarely been examined and quantified. One of the few examples that have attempted to examine these perceptual links is the study by Wheeler et al. (2013), which stems from the theory of planned behaviour (Ajzen, 1991) and explores the role that climate change beliefs play in influencing planned and actual farm adaptation strategies in three Southern Basin states of Australia. A further study by Menapace et al. (2015) uses the exchangeability method (Baillon, 2008) and identifies that climate change beliefs and past experiences with crop losses are critical to farmers' agricultural risk perceptions in northern Italy. 'Risk' is often considered as a generic term, without distinguishing its determinants, i.e. the hazard and its probability of occurrence (Cardona et al., 2012). A risk-based approach could help to shed light on the underlying perceptual links and causalities between farmers' awareness of climate change-related phenomena, their beliefs in future climate change and actual adaptation behaviour. This insight could contribute to more effective future communication and response strategies for agricultural climate change adaptation.

In addition to climate change risk perception, actual farm adaptation behaviour may be determined by adaptive capacity, which is further associated with personal and non-climate related environmental factors concerning human, financial and social capitals, and farm characteristics (Deressa et al., 2009; Yohe and Tol, 2002). Existing adaptation literature, as reviewed in Wheeler et al. (2013), focuses on the biophysical responses and economic valuation of crop yield, whilst assessment of adaptation behaviour at the farm level is less developed and perception is often treated as one of many endogenous variables. For example, Below et al. (2012) developed an activity-based adaptation index for farmers as a regressive function of perception of weather-related problems, characteristics of the household and farm, institutional framework conditions and infrastructure. Esham and Garforth (2013) found that farmers' perceptions of climate change risk significantly affect actual agricultural adaptation actions in Sri Lanka. Personal and non-climate environmental factors that may cause changes in not only farmers' climate change perception, but also the relationships between perception and adaptation behaviour, remain little understood. Such factors could provide useful guidance to policy-makers in identifying individuals and social groups who are more likely to be concerned about the situation and engage in adaptation and help spread good adaptation practice within local agricultural networks.

The study presented here aims to bridge these knowledge gaps by (i) examining the possible perceptual relationships between the awareness of climate change phenomena and belief in risks that underlie farmers' adaptation behaviour, and (ii) identifying human, financial, social and farm-level antecedents of actual adaptation and these perceptual relationships. An extensive household survey was designed for this study in collaboration with the Central Statistical Office of Hungary (KSH) to investigate the current pattern of adaptation strategies and to collect data on the potential antecedents of future adaptation from private landowners in Veszprém and Tolna counties of Hungary. The survey data were analysed using path analysis since this approach provides unique insights into the causal connections between variables (Loehlin, 2004). The analysis focused on (i) the significance and magnitude of hypothetical perceptual relationships between farmer's awareness of climate change related phenomena, their belief in climate change risks and the need for adaptation and (ii) how factors associated with human, financial and social capitals, and farm characteristics may affect adaptation and modify the significant perceptual relationships identified.

2 Conceptual framework

Failure to incorporate meaningful hypotheses within a model of structured decision making may result in uncertainty being incorrectly or insufficiently represented leading to management strategies that are less useful and informative (Williams, 2011). In this study, a conceptual framework was developed based on current climate change and adaptive management literature. It covers a comprehensive set of hypotheses representing the possible sources of uncertainties in the decision making processes of farmers, each of which was then tested with path models for its importance.

2.1 Basic perception model: climate change awareness, belief and adaptation

Farmers may be aware of climate change based on personal experience or via professional and social communications. We hypothesize that such awareness will increase farmers' belief in climate change risk and motivate actions for "adaptation" (H0a-c).

In the basic theoretical model, three sets of climate change-related phenomena relevant to the two Hungarian counties are considered: water stress, extreme events and climate warming. Agriculture depends heavily on water availability, especially annual and seasonal totals. Farmers monitor the growth of plants and measure water demand and, hence, are more likely to be concerned about phenomena related to water shortage, such as decreases in precipitation or the frequency or severity of drought (H0a). Extreme weather events (e.g. flooding, heatwaves or storms) generally have a small frequency of occurrence. However, when they do occur, they often cause severe damage and significantly influence decision making on adaptation (H0b) (Weber, 2010). By contrast, climate change related warming unfolds over longer time scales, and can be difficult to detect based on personal experience (H0c) (Akerlof et al., 2013). The three sets of phenomena (water stress, extreme events and climate warming) can coexist. Taking note of one set may indicate that a farmer has gained some climate change-related awareness and knowledge and, from the same source of knowledge (personal experience or professional/social communications), he/she is more likely to be aware of other climate change-related phenomena. Hence, the awareness of any of the three sets is hypothesised to be positively associated with awareness of the other sets (H0d-f).

In a recent special report by the IPCC (Cardona et al., 2012), three determinants of risk are defined: "*hazard*" refers to the possible occurrence of unfavourable events, "*exposure*" refers to the inventory of elements in an area where hazard events may exist and "*vulnerability*" refers to the susceptibility of exposed elements being adversely impacted by hazard events. Following this approach, three components of farmers' belief in climate change risk were identified: beliefs in climate change hazards, exposure of local agriculture to climate variability and individual farmer vulnerability. As increased hazards may have increased adverse effects on exposed and vulnerable elements, the belief in climate change hazard is hypothesised to increase the belief in both agricultural exposure (H0g) and individual vulnerability (H0h). Exposure of local agriculture to climate hazards does not mean all individual farmers in the area are vulnerable. However, to be individually vulnerable to hazard events, it is necessary to also be individually exposed. Therefore, higher agricultural exposure is assumed to lead to higher individual vulnerability, and not vice versa (H0i).

Awareness of the three sets of phenomena may heighten farmers' belief in climate change risks leading to recognition of their exposure and vulnerability to hazards. Awareness alone may also directly cause concern and stimulate adaptation actions. However, existing evidence is limited for establishing a set of specific hypotheses on relating climate change awareness and belief to adaptation. Rather, we are interested in establishing and testing the occurrence, significance and magnitude of potential causal relationships (i) between the awareness of each set of phenomena (as cause) and the belief in risk at all three levels (as effect) (H0j-r), and (ii) between each of the awareness (H0a-c) and belief-related elements (as cause) and actual adaptation (as effect) (H0s-u).

As reviewed in Arbuckle et al. (2015), individual's beliefs and risk perceptions have been central to many behavioural models, such as the expectancy-value model, the theory of planned behaviour, and the values-beliefs-norms theory. All suggest that these perceptual elements provide the foundation to form "*attitudes towards action*" which can be highly predictive of actual behaviours. Examination of the basic conceptual model and associated hypotheses proposed in this study facilitates improved understanding of the relative importance of different perceptual elements, and the causal relationships between these elements and actual adaptation behaviour. Such insights into farmer's current knowledge about climate change may support the development and prioritisation of alternative strategies for promoting and managing actual and planned adaptations.

2.2 Antecedents of perception and adaptation: human, social and financial capitals and farm characteristics

Farmers adjust land use and land management to adapt to a changing and uncertain future environment. A significant body of literature focuses on how human, social and financial capital and farm characteristics impact on farmers' adaptive capacity and how this capacity can be translated into actual behaviour (Below et al., 2012; Burch and Robinson, 2007; Frank et al., 2011; Wheeler et al., 2013; Yohe and Tol, 2002). Based on these existing studies, we identify a list of variables that may cause changes in farmers' land use and land management decision making and explore how they affect the causal relationships between climate change perception and adaptation.

The most important investments in human capital include education, training and medical care to improve expertise, health and livelihoods. Developing human capital thus helps enrich farmers' knowledge and improves their capability of accessing and making use of information and adopting new technologies. The current literature reports mostly positive, while partly contradictory, results on how human capital-related factors may impact climate change perception and adaptation. The education of farmers has been frequently introduced as a positive indicator of perception and adaptation (H1a), for example in Below et al. (2012), Deressa et al. (2009), and Menapace et al. (2015). Farm succession can have a direct influence on farm persistence and adaptation in changing economic and biophysical environments (Inwood and Sharp, 2012). Farmers with lower uncertainty about succession may have greater growth intentions and a higher willingness to adjust land management practices with existing fixed input factors (H1b) (Huber et al., 2015). Innovative farmers willing to try new management plans are more open to experimenting with new technologies (Ang et al., 2007) and hence are assumed to be more likely to increase adaptive behaviours (H1c). Farming experience, sometimes captured by the age of the farmer, may be associated with either an increased or decreased probability of adopting improved practices, such as soil conservation (H1d) (Deressa et al., 2009; Shiferaw and Holden, 1998). Similarly, the effects of gender on climate change concerns and adoption of new technology (Fosu-Mensah et al., 2012; McCright, 2010) has been found to be context-specific and different between studies (H1e) (Bryan et al., 2009).

Individual climate change adaptation often involves the adoption of new farming technologies, which is, in the innovation literature, often regarded as being profoundly influenced by the structure and quality of social networks (Greenhalgh et al., 2004). Furthermore, risk perception may be amplified by information gained through a social network (Scherer and Cho, 2003) and expected benefits derived from social networks can incentivise farmers' adaptation to climate change (Pelling and High, 2005). To account for different types of networks, four social capital-related factors are included here: direct social networks (membership of the survey participants in agricultural social groups), indirect social networks (family member in agricultural social groups), government-led educational networks (access to extension services) and geographical networks (number of neighbouring farmers). We assume that the four factors can all potentially increase climate change perception and adaptation (H2a-d).

Utility maximisation is an important consideration in farmers' land use decisions. To respond to environmental changes, sufficient financial capital is a fundamental requirement. As reviewed by Knowler and Bradshaw (2007), studies indicate that farmers with higher income are more likely to adopt new technologies (H3a). The diversification of income source by creating off-farm income or adding novel business activities to traditional farming activities may help reduce farm business risk that might result from climatic or market events (H3b) (Bradshaw et al., 2004). Moreover, the sale of farm products (as a percent of total agricultural production) is used to capture how much of the farm is business-oriented. A "business-oriented" farm may show a high commitment to farm continuation and place a high value on personal experience and information sources (Karali et al., 2013), thereby having a greater chance of being aware of climate change-related phenomena and the risks (H3c). This is also confirmed by Darnhofer (2010), who found trade-offs between farmers' activities driven by short-term profitability and management solutions that support longer-term adaptation and resilience due to economic costs, implying that having adequate resources makes handling these trade-offs easier. Conversely, subsistence farmers are often regarded as particularly vulnerable to climate change, owing to limited resources and capacity (H3d) (Harvey et al., 2014).

Farm characteristics, as a collective set of variables related to natural and physical capital, are thought to impact on climate change perception and adaptation (Reidsma et al., 2010). It is hypothesised in this study that a larger farm size indicates a greater management capacity, which in principle enables farmers to access more information to improve knowledge about climate change adaptation (H4a). However, it is uncertain whether such a consequent motivation could directly lead to the adoption of adaptation strategies, which are often new and more risky (Bradshaw et al., 2004). Soil quality is a main driver of food production and has a strong inter-dependency with climate (Lal, 2004). Poor soil exposed to a greater risk of erosion can be linked to greater vulnerability (Paavola, 2008), which may heighten farmers' risk perception (H4b). Farm type, e.g. arable, livestock and viticulture, which reflects land use and its intensity, and farm location, which reflects the regional settings of agroecosystems, may affect how the impacts of climate change and variability are manifested, and influence management decisions and actual adaptation (Reidsma et al., 2007). In this study, we test whether and how farm type (H4c) and location (H4d) influence perception of, and adaptation to, climate change. Land ownership indicates whether the land is legally held or rented by the farmer. When farming rented land, farmers may not be the only decision-maker as the landholders can be equally important (Primdahl, 1999). Decision-making may even be further decentralised in the case of cooperatives, where ownership of the land and related assets can be distributed among a large number of actors. It is hypothesised that direct ownership of land whether in individual or cooperative form both

creates incentives and institutional capabilities in the form of access to information, technology, finance and networks that facilitate adaptive management (H4e).

Operationally, adapting agriculture to climate change requires multidisciplinary and transdisciplinary solutions that focus on strengthening the interface between science, policy and practice (Howden et al., 2007). As agricultural policies often affect multiple sectors, it is important to take account of cross-sectoral interactions in order to avoid unintentional maladaptation and ensure the robustness of planned adaptive actions (Harrison et al., 2016). Investigating the antecedents of climate change perception and adaptation supports the development of a more comprehensive and integrated risk management framework which can help to connect plans for managing climate risk with those for human, social and financial capitals, and land use so as to minimise trade-offs and the potential for maladaptation.

3 Material and methods

3.1 Study area

The area covered by this study includes Tolna and Veszprém counties in the Transdanubian region of Hungary (Fig. 1a). According to the data published by the Hungarian Central Statistical Office (KSH), both counties are predominantly rural, with total populations of ca. 230 thousand and just over 350 thousand, respectively (KSH, 2011). From the global perspective Hungary can be considered a country moderately vulnerable to the impacts of climate change (Kreft et al., 2014). However, longer-term analyses indicate significant increases in climate risk. Inter-annual temperature and precipitation variability is expected to grow, accompanied by seasonality effects, most prominently significant warming during the summer months. Annual total precipitation may remain unchanged or slightly decrease, but there will be an increasing frequency of negative precipitation anomalies during the summer and slight increases during the winter months (Bartholy et al., 2007; Government of Hungary, 2013). While this indicates a growing risk of drought during the summer, seasonal flooding, waterlogging and erosion due to the increasing frequency of extreme events can also become a more common problem (Fábián et al., 2006; Faragó et al., 2010; Várallyay, 2006).



(b) Area of land cultivated by different actors in Tolna and Veszprém Counties (Source: KSH)

Type of farming entity	Tolna County (ha)	Veszprém County (ha)
Individual farmer, own land	96,248	54,249
Individual farmer, rented land	23,237	21,533
Corporate entity	135,631	219,898

Fig. 1 Location (a) and farmland statistics (b) of the two research areas: Tolna and Veszpreim.

Fig. 1b shows the area of farmland cultivated in the two counties among different actors in 2010. Farms under corporate control are typically larger and include both cooperatives and a few state farms carried over in transformed form from the pre-1989 socialist era and farms held by corporations. In 2013 the national average for the size of private farms was 5.4 ha, while for corporate farms was 308 ha. Since the turn of the century the number of both corporate and family farms has been dropping, in the case of family farms to almost half. It is typically the elderly, women and those with no agricultural qualifications who give up farming (KSH, 2014).

Due to the significance of agriculture for Hungary's and the selected two counties' economy and agriculture's sensitivity and exposure to anomalies in agroclimatic conditions, these projected and to some degree already observable changes represent a significantly changing risk environment for the sector. In the broader European context, the agricultural sector of the countries of the Pannonian zone (Hungary, Serbia, Romania and Bulgaria) were found to be the most at risk to the impact of climate change (Olesen et al., 2011).

3.2 Data collection

An agricultural household survey was conducted to collect the data required in collaboration with the KSH. For this study, a questionnaire was designed using expert knowledge on local agriculture and climate (for a list of climate change adaptation actions that are most commonly practised in the case areas), and the practical and translation assistance from the KSH. In the questionnaire, survey participants were asked (i) to provide information related to human, social, financial capitals and farm characteristics; (ii) to specify details of changes in land cover and land use related to their farms; and (iii) to express their views on climate change and adaptive strategies, including their observation of specific climate change phenomena, the scale of the climate change

problem in general and more specifically for their farms, and their adoption of specific adaptation practices. The questions and measurements in the questionnaire were initially designed following approaches used in previous survey studies on European farmer's attitudes and perceptions (Guillem et al., 2012; Karali et al., 2013). Experts from the KSH then helped modify the questionnaire based on their local knowledge and practical experience. Variables collected are described and summarised in the Supplemental descriptive analysis of variables (and Fig S1 and Tables S1 and S2), Electronic supplementary materials. The in-person household survey was conducted jointly with the KSH's regular agricultural survey between June and August 2015 by trained and experienced KSH surveyors. The KSH determined the survey participants in this study by randomly selecting 110 farmers (owners and tenants of private holdings) from their annual sampling pools for each research area. The KSH's annual agricultural sampling pools in 2015, which contain 687 farmers (out of 13,529) in Veszprém county and 1,253 farmers (out of 18,092) in Tolna county, were determined by their internal experts to adequately reflect the local distribution of farm size and farming objective.

3.3 Path analysis

Path analysis was used to examine causality, a relationship that is more than correlational and sometimes referred to as structural (Loehlin, 2004; Shipley, 2002). It is a special form of multivariate analysis that examines the roles the inter-relationships of multiple variables play in determining a particular outcome. The proposed causal relationships are represented in a path model, illustrated using a path diagram, and analysed for the standardised partial regression coefficients (the path coefficients), which can be interpreted as the magnitude of direct causal influence. In this study, path analysis was performed using IBM SPSS AMOS version 22 (Arbuckle, 2013; Blunch, 2008). We first built the "perception – adaptation" path model (M0) for the hypothetical causal relationships between farmers' awareness of climate change related phenomena, beliefs in climate change risks, and their actual adaptation behaviour, based on the theoretical expectations explained in section 2. Then, different sets of individual and environmental factors were included in M0, respectively, yielding four extended path models for the influence of human capital (M1), social capital (M2), financial capital (M3) and farm characteristics (M4) on adaptation. A feasible path model should both satisfy the theoretical expectations and meet the adequate, or ideally the recommended, level of goodness-of-fit (GOF) measures. The refinement of the model, by adding/removing paths, was performed in order to keep the GOF measures at least at their adequate levels. Existing literature on causal and structural relationships uses various measures of GOF (Doloi et al., 2011; Molenaar et al., 2000; Ong and Musa, 2012; Xiong et al., 2014), among which some of the most widely used ones were included in this study (see GOF measures included in Table S4, Electronic supplementary materials).

4 Results and discussion

4.1 Farmers' adaptation strategies in Veszprém and Tolna counties

In total, 110 farmers (out of 219) reported having adopted climate change adaptation practices (Fig. 2), including 65 (out of 109) from Tolna county and 45 (out of 110) from Veszprém county. The most commonly practised strategies in the two counties were "water preserving soil tillage" (29.7%), "new crop varieties" (28.8%), "soil conversion/fertilisation" (27.4%), and "changed planting date" (26.9%). Adopting "novel crop production" technologies was found to be common in Tolna (23.6%) while only being practised by 7.3 % of survey participants in Veszprém. The other two strategies mentioned, namely, "increased use of cover crops" and "new crop rotations", both have the lowest adoption rate of 11.9%. In Tolna, where the rate of actual adaptation was higher, survey participants were more involved in social groups and extension services, selling more products, receiving higher income, and managing larger farms with better soil quality (see the Spearman's rho correlation matrix for all variables; Fig. S1, Electronic supplementary materials). In contrast, Veszprém County has generally lower agro-ecological and agro-economic potential due to topography, microclimate and soil quality, and agriculture is a less important sector of the local economy in comparison with other sectors, such as forestry or tourism (KSH, 2012).

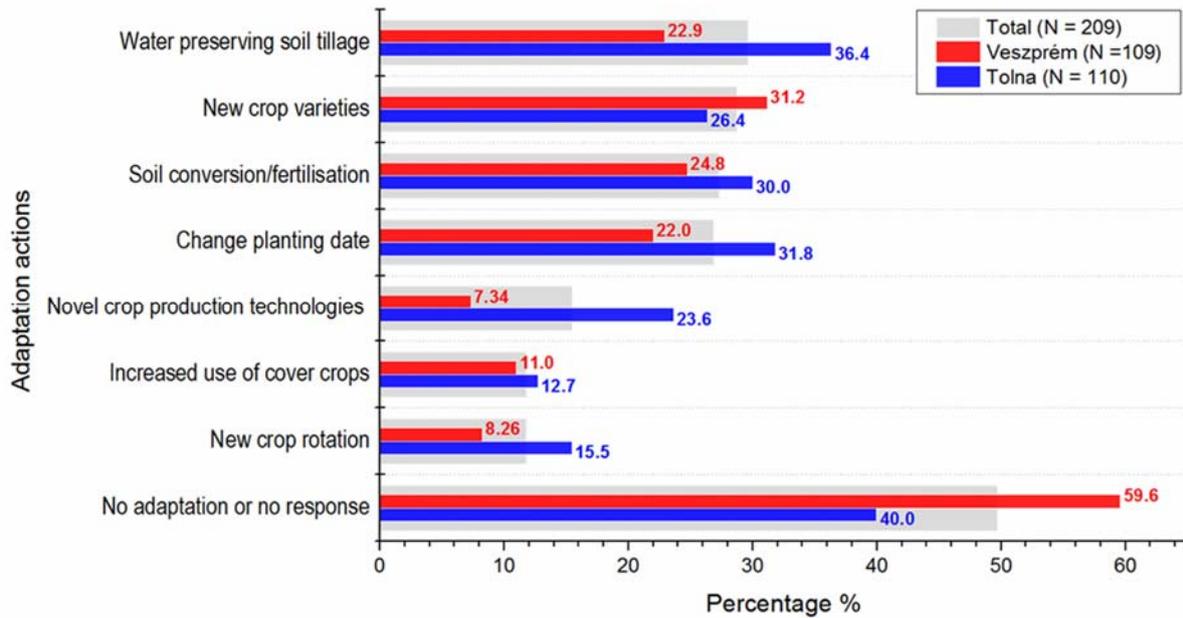


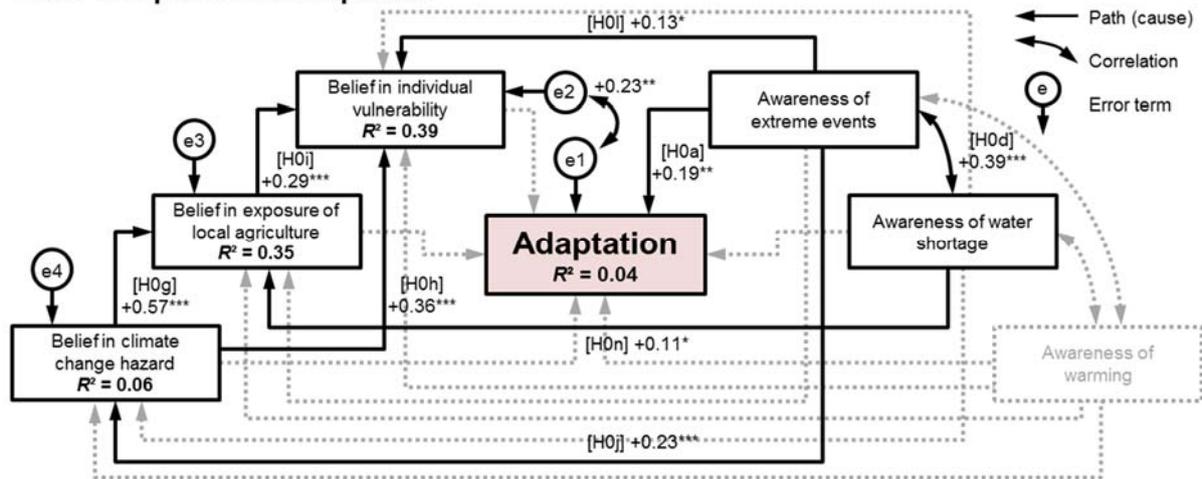
Fig. 2 Percentages of participants adopting specific types of adaptation actions.

4.2 Farmers' perception of, and adaptation to, climate change

All causal relationships kept in the refined M0 model were significant and are presented in the path diagram in Fig. 3 (detailed path coefficients in Table S3, GOF measures in Table S4, Electronic supplementary materials). The hypothetical structure of farmers' beliefs in climate change risk was found feasible: the belief in (climate change) hazard may heighten both the beliefs in (local agriculture's) exposure (H0g) and (individual) vulnerability (H0h), and the belief in exposure may further heighten the belief in vulnerability (H0i). However, amongst the elements tested, only the awareness of extreme events was found to be a significant cause of adaptation behaviour (H0a). Variance in adaptation behaviour can only be explained at a limited level ($R^2 = 0.04$). Interestingly, the belief in individual vulnerability was found not to directly influence adaptation behaviour (H0u: the hypothetical cause was removed as it was only marginally significant at $P < 0.1$ level and yielded unsatisfactory GOF measures). Our results suggest that, farmers' concern about climate change and actual adaptation behaviours could be significantly heightened and stimulated by the awareness of more observable climate change phenomena (H0a, H0j, H0n and H0l). A significant error correlation ($e1-e2$, Fig. 3) between belief in individual vulnerability and adaptation suggested the two elements were causally related, however, the covariance between them is not explained by the predictors. This suggests that some more important common causes may not have been included in the analysis, for example, the farm/farmer characteristics that determine coping capacity.

The causality between belief and adaptation behaviour seemed more complex than the direct cause-effect relationship hypothesised in section 2. Belief in climate change risks was found to be heightened by the awareness of more observable climate change phenomena (e.g. extreme weather events and water shortage), but it was not a direct cause of adaptation behaviour. Wheeler et al. (2013) found that belief in climate change risks may be heightened by implementing strategies for adaptation to current (or future) water shortage in some of their models, but not others accounting for more risky and uncertain future adaptive strategies. Menapace et al. (2015) found no evidence for belief to be reinforced by the perception of future crop loss. These results suggest that the causal link between belief and adaptation behaviour varies between contexts and may not play a key role in driving actual adaptation.

M0: Perception and Adaptation



Sig. level of coefficients: *** $P < 0.001$; ** $P < 0.01$; * $p < 0.05$

Fig. 3 Causal relationships between farmers' perception of, and adaptation to, climate change. Path coefficients are the magnitude or strength of relationships. Dotted arrows and box in grey refer to the hypothesised relationships and elements that have been excluded due to statistical insignificance or low model fit.

4.3 The role of human, social and financial capitals and farm characteristics in climate change adaptation

All four models were refined (M1-M4, path diagrams in Fig. 4; detailed path coefficients in Table S3, GOF measures in Tables S4, Electronic supplementary materials) and achieved higher R-squared values (0.17-0.37) than the basic perception model (0.04), indicating a stronger explanatory power for individual adaptation (17-37% of variance explained). These values are comparable to two related modelling studies on individual adaptation behaviour: one in Germany explaining 26-45% of the variance (Grothmann and Patt, 2005) and the other in Tanzania explaining 28% (Below et al., 2012).

4.3.1 Human capital

In M1 (Fig. 4a), 17 % of the variation in "adaptation" could be explained by including the selected human capital factors. We found no evidence to support the hypothesised direct relationship between education and adaptation, but identified "low education" as a positive cause of the "awareness of extreme events" (coefficient = 0.14) (H1a). This could possibly be due to farmers with a low educational background having reduced economic or social safety nets and thus being more acutely aware of their exposure to extreme events e.g., drought or flooding. It may also indicate that farmers with lower educational levels cultivate more marginal land and have access to poorer infrastructure that is more susceptible to extremes. Confirming the results from previous research (Huber et al., 2015; Wheeler et al., 2013), farmers' "succession intention" was found to be a direct and positive cause of "adaptation" (coefficients = 0.14) (H1b). The "willingness to try new land use plans", as a mediator variable, helped explain the indirect effect of "belief in individual vulnerability" on "adaptation" by decreasing the error correlation (e1-e2) from 0.23 (M0) to 0.16. In this mediated effect, farmers' "belief in individual vulnerability" could enhance their "willingness to try new management plans" (coefficient = 0.22), which could further cause "adaptation" (coefficients = 0.14) (H1c).

4.3.2 Social capital

In M2 (Fig. 4b), the social capital factors selected could increase M0's explanatory power for "adaptation" to 24%. The three social network factors, "membership in agricultural social groups" (direct social networks), "family member in agricultural social groups" (indirect social networks) and "access to extension service" (government educational networks) were positively correlated with each other (all coefficients > 0.3). While the first was found to heighten the "belief in individual vulnerability" (coefficient = 0.21), the latter two were found to directly cause "adaptation" (coefficients = 0.29 and 0.24) (H2a and H2b). The inclusion of these factors marginalised M0's error correlation (e1-e2) to insignificant, highlighting the importance of social capital as a common cause of "adaptation" and "belief in individual vulnerability". A growing literature has proven the importance of agricultural extension services to farmers' adaptation (Below et al., 2012; Deressa et al., 2009). Our results add new empirical evidence in support of this and further highlight the potential contribution of social networks.

4.3.3 Financial capital

In M3 (Fig. 4c), by extending M0 with factors on farmers' financial capital, the variation in "adaptation" could be explained by 37%, which is the largest of the four extended models. Farmers' "farm income" (absolute amount of subsidies and income by selling products and services) and "production sale" (% production sale on the market) were positively correlated (coefficient = 0.56). Higher "farm income" was found to directly cause "adaptation" (coefficient = 0.22) (H3a) and greater "production sale" to enhance "belief in individual vulnerability" (coefficient = 0.56). By removing their error correlation (e1-e2), the two factors were found to be important common causes of "adaptation" and "belief in individual vulnerability". Interestingly, the model identified two opposite causes to farmers' "awareness of water shortage": higher "farm income" was found to lower this awareness (coefficient = -0.26), while greater "production sale" increased it (coefficient = 0.22) (H3c). A high farm income could drive investments in water infrastructure which reduces the risk of experiencing water shortage. Our results indicate that smallholders, who sell a larger proportion of their production, but earn less money, are more likely to experience, and be concerned about, water shortage.

4.3.4 Farm characteristics

In M4 (Fig. 4d), the farm characteristics increased the variation explained for "adaptation" to 28%. The "farm size" and "purchased farm land" (gain in farm ownership) factors were positively correlated with one another (coefficient = 0.54) and both negatively correlated with "farm ownership" (coefficients = -0.44 and -0.34). Farmers managing larger farms were more likely to have a deeper "belief in climate change" (coefficient = 0.14) (H4a), a shallower "belief in local agricultural exposure" (coefficient = -0.12), and greater "awareness of water shortages" (coefficient = 0.56). Farmers having "purchased farmland" in the last five years had a deeper "belief in individual vulnerability" (coefficient = 0.17) and were more likely to adopt "adaptation" strategies (coefficient = 0.38). This common cause reduced the error correlation (e1-e2) from 0.23 (M0) to 0.14. Finally, "farm ownership" was found to impede "adaptation" (coefficient = -0.23). Our results suggest that farms managed by their owners (not tenants) were typically smaller (Fig. S1, Electronic supplementary materials). The owners of these small farms were more likely to sell their land and less likely to take part in climate change adaptation. This is supported by the general farm consolidation trend in Hungary, which has resulted in a steady decline in the number of small farms. In contrast, tenants who sought to achieve farm ownership were more willing to adopt adaptive strategies (H4e). This is partly in line with the finding of Wheeler et al. (2013) that larger farming businesses (with more employees and a higher proportion of irrigated area) were more likely to plan further adaptive strategies.

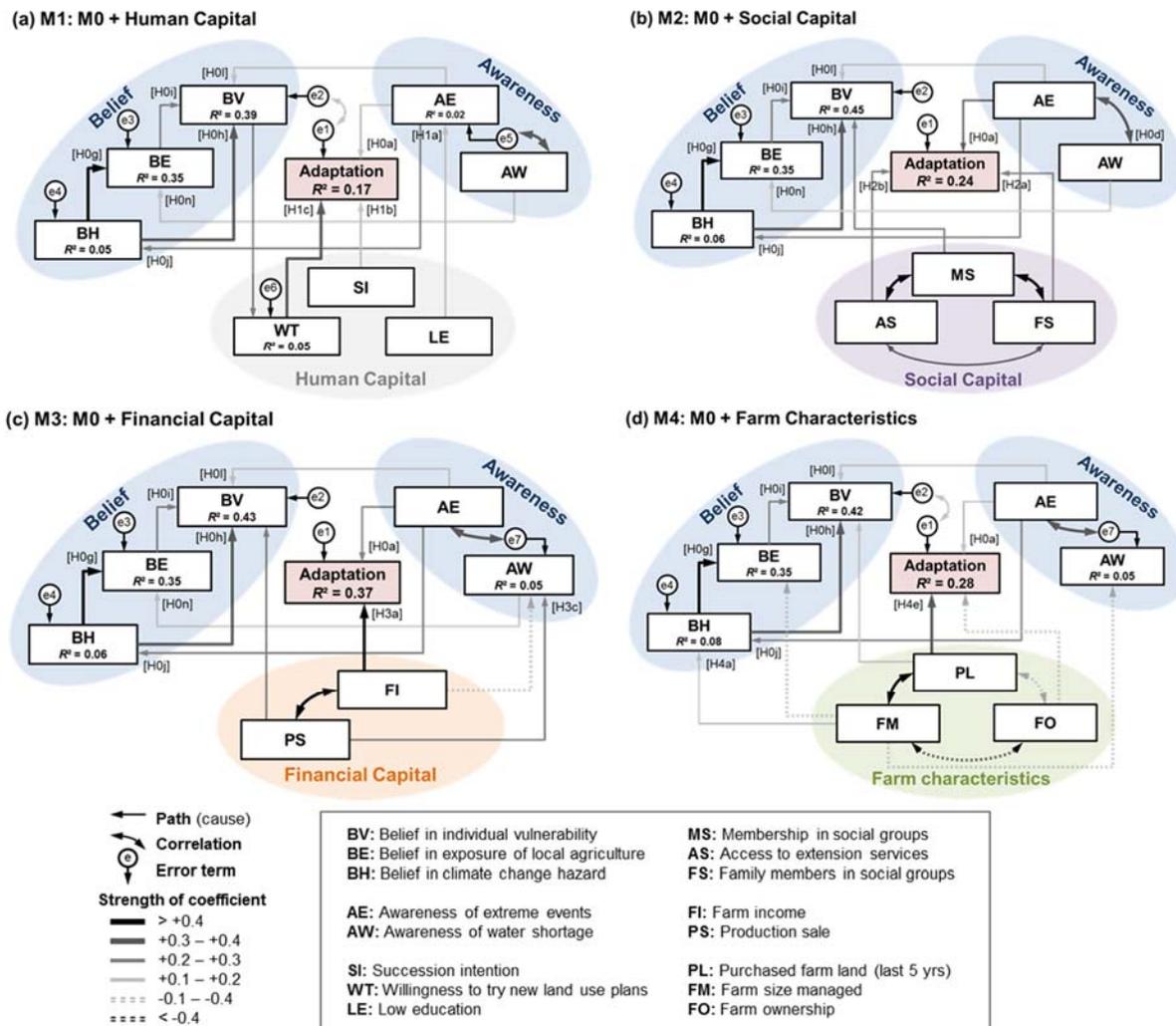


Fig. 4 The role of human capital (A), social capital (B), financial capital (C) and farm characteristics (D) in the causal relationships between farmers’ climate change perception and adaptation. Relationships without H notations are those not hypothesised in the theoretical framework but which were found to be significant.

5 Conclusions, implications and recommendations

This study contributes to the growing body of literature on the factors affecting farmers’ actual adaptive behaviour to climate change. By distinguishing the factors that may affect climate change perceptions, both conceptually and empirically, this study provides insights into their interrelationships and distinct roles in farmers’ actual adaptation behaviours.

The paper first explored the complex relationships between farmers’ climate change perception and actual adaptation behaviour using a risk-based approach (M0, Fig. 3). We analysed a set of hypothesised causal relationships among farmers’ awareness of different phenomena (i.e., water shortage, extreme weather events and climate warming), beliefs in different risk components (i.e., climate change hazard, exposure of local agriculture and individual vulnerability), and whether any actual adaptation strategies had been adopted. We found that only awareness of extreme events was a significant cause of adaptation behaviour. Central to this paper and the definitions of perceptual terms used, we found no consistent evidence that beliefs in climate change risks can lead to, or be caused by, actual adaptation behaviour. A heightened belief in climate change risk was found to be caused by increased awareness of extreme weather events and water shortage. Actual adaptation behaviour was explained only to a limited extent by perceptual factors alone (4% of variance explained).

These results have several implications for policy. Policies which prioritise ways to reinforce farmers’ *general* belief in climate change risks may not be the most effective means of promoting adaptation strategies. Instead, policies that put greater emphasis on the severe consequences of directly observable weather phenomena (e.g.,

extreme events and water shortages), rather than being too general and only linked to long-term climate change (e.g., climate warming), may be more successful in promoting farmer's engagement in adaptation. Furthermore, without acknowledging the contextual factors of the target populations, climate change adaptation policies focused solely on improving farmers' risk perception may be ineffective and unable to achieve their desired outcomes.

To identify the criteria of target populations that could make policy intervention more effective, we further tested the influence of individual and environmental variables on farmers' perception of, and actual adaptation to, climate change. Four sets of variables were selected to represent human capital, social capital, financial capital and farm characteristics, respectively (M1-M4, Fig. 4a-d). Including any set of these variables could greatly improve the perceptual model's explanatory power (to 17-37%). This indicates that farmers who have an innovative personality and intention to pass on the farming business to the next generation (M1, Fig. 4a), who are more actively engaged in socio-agricultural networks and extension services (M2, Fig. 4b), who earn greater farm income (M3, Fig. 4c) or who have been seeking to gain farm ownership (M4, Fig. 4d) are a potential target for the promotion of adaptation actions. These results shed more light on further options for promoting agricultural adaptation strategies. Policies to promote adaptation may benefit from providing information on the projected improvement in profitability and advice on better land use and business management techniques. Encouraging the communication of adaptation-related information through agricultural extension services and farmer social networks helps enhance farmers' beliefs and stimulate actual adaptation to climate change. Moreover, our results indicate that farmers who are engaged in socio-agricultural networks and seek to expand their farming businesses by producing more sales and buying more land to manage, were found to have a deeper belief in the risks of climate change. As the only perceptual direct driver of actual adaptation identified in this study, the awareness of extreme events was found to be greater for farmers with a lower educational background. Farmers that have greater awareness of water shortages are those who manage small farms and earn less farm income, albeit they sell a greater proportion of their production. These farmers, however, were found to be less likely to engage in actual adaptation. Future empirical studies are needed to explore the barriers that prevent them from doing so.

Based on the results of this study, several directions for future research can be suggested. *First*, future empirical studies may explore the patterns and factors of planned adaptation. Planned adaptation refers to the intention to undertake adaptation behaviour, though this plan may not eventually be executed due to various constraints (Ajzen, 1991) such as low farm income, farm debt and reduced productivity (Wheeler et al., 2013). Understanding the gaps between planned and actual behaviour could help gain more insight into farmers' decision-making mechanisms. *Second*, land use modellers may make use of these results in the modelling of individual adaptation behaviours. For example, in an agent-based modelling framework, Alexander et al. (2013) assessed the spatial pattern and speed of diffusion of certain adaptation strategies among farmers. *Third*, future investigations can benefit from a standard protocol or ontology to define the perceptual variables that are commonly used in the context of climate change adaptation, such as awareness, beliefs, attitudes and perceived risks. In this study we tried to frame the concept of "beliefs" within a risk-based framework. It is unfortunate that such a standardised protocol is missing from the current literature, making the approach and results of relevant studies less comparable, even though similar terminology is used. Finally, although the empirical findings strongly support the hypothetical models, it should be recognised that alternative causal models are possible. Future studies are encouraged to explore and compare these alternative conceptual models for a better understanding of farmers' decision-making mechanisms and ways to integrate them in exploiting adaptation options for policy-makers.

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