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Linking perceptions of climate change impacts with adaptation: Insights from landowners in Southern Chile

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ABSTRACT

Adaptation is recognized as the outcome of a complex mix of individual and institutional factors that shape how society responds to climate change. Adaptation results from a joint decision-making process, where actors simultaneously evaluate the risks associated with climate change into whether or not they should adapt. We develop a model of this joint decision-making process that incorporates risk tolerance to identify what factors influence landowners' perception and adaptation to climate change in southern Chile. The results are based on 86 in-person interviews, involving the collection of socioeconomic data, risk aversion tests, and semi-structured interviews. We found that while most landowners perceived climate change impacts as a threat, only 60 % had taken any action. Two underlying factors applied to both perception and adaptation: risk tolerance and off-farm incomes. Higher risk tolerance and greater reliance on off-farm incomes reduced people's perception and adaptation to climate change. The presence of climate change-induced impacts positively influenced the implementation of adaptation, while schooling and gender were relevant only in shaping climate change perceptions. Following these results, we suggest developing programs to communicate the real magnitude of climate risks so that landowners better understand the opportunity costs of climate change adaptation, and in that way, avoid/anticipate the need to see impacts on the land in order to act. Along these lines, further investigation of the role off-farm incomes play in adaptation is warranted, where it is simultaneously both a factor in the adaptation process but can also be an adaptation action as well.

1. Introduction

Climate change is currently one of the world's greatest challenges and increasingly the concern is how well society may be able to adapt to those impacts (IPCC 2021). Of particular concern are the environmental impacts on the goods and services these ecosystems provide and the people and communities dependent upon them, such as farmers and landowners (Deressa et al., 2010; Sousa-Silva et al., 2016; Fernández and Vásquez-lavín, 2019). The inherent uncertainties surrounding these nature-based systems have become accentuated by climate change, which has detrimental, direct and indirect ecological and economic impacts (van Gameren and Zaccai, 2015; Sousa-Silva et al., 2016; Roco et al., 2017) [1]. The more dependent people are on a natural resource, the more sensitive they are to the impacts on that resource and hence more vulnerable (Marshall and Stokes, 2014).

The Intergovernmental Panel on Climate Change (IPCC) has defined adaptation as "the process of adjustment to actual or expected climate and its effects" (IPCC, 2014). In agroforestry systems, such adaptation may include the implementation of different strategic or operational actions (e.g. implementation of new technologies; changes in infrastructure such as irrigation systems; change in species planted; change in farming practices, and contracting insurance against drought, among others) by landowners (Heltorp et al., 2018; Mortreux et al., 2020). However, not all landowners will implement adaptation actions, where the decisions to undertake these actions depends on the complex set of socioeconomic and demographic factors in those systems that interact with decision makers' characteristics (i.e., risk tolerance) as to whether they perceive climate change as a risk and if they do, whether or not they

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[1] Climate variability is producing and will continue to produce increases in pests and diseases; changes in forests (e.g. phenological changes and extensions of the vegetative growth periods to structural changes in forests, migrations of species and extinction of others); and reductions in productivity in systems like crops and livestock among other impacts (Promis, 2010; Roco et al., 2017).

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will act.

Several studies have analyzed the factors influencing landowners' perceptions and adaptation to climate change, but they have either focused only either perceptions or adaptation, or have incorporated perceptions directly into the adaptation decision. Furthermore, these studies typically analyze only socioeconomic and demographic aspects without considering more fundamental characteristics such as individuals' attitudes towards risk. Addressing this research gap is the main contribution of this research where we investigate the relationship between landowners' perceptions and adaptation to climate change, and explicitly incorporate attitudes towards risk in the adaptation process. We do so by building a model that reflects this process in which landowners' are making a joint decision around the perceptions of climate change impacts and the need for adaptation, while also incorporating their individual attitudes towards risk into this joint decision. Our contribution is therefore to present a unified framework that explicitly recognizes the interaction between these variables to gain insight into this complex process. We then apply this framework to analyze adaptation in a novel socioeconomic and cultural context.

2. Literature review

Several studies (Deressa et al., 2010; Legesse et al., 2013; Khan et al., 2020; Fahad and Wang, 2020; Thomas et al., 2021) have indicated that adaptation by farmers and landowners is highly influenced by individual characteristics such as the decision makers' age, gender, education, wealth, off-farm incomes and attitudes towards risk, that might facilitate or hinder the adaptation process (Table 1). At the same time, landowners' perception of climate change impacts has also been shown to influence adaptation and action (Blennow, 2012; Vulturius et al., 2018; Hengst-Ehrhart, 2019; Mortreux et al., 2020). In Pakistan, Fahad and Wang (2020) identify farmers implementing changes in crops and farm diversification as they adapt to climate change, although their perception of climate change is treated as one of the explanatory factors. In another study, Fahad and Jing (2018) show that farmers' willingness to pay for agricultural insurances, as an adaptation measure, is highly dependent on plot size and farmers' income.

Further adding to the complexity of adaptation is that the interaction between these socioeconomic and behavioral (cognitive) factors varies in different settings and how that interaction then affects adaptation (Deressa et al., 2010; Legesse et al., 2013; Sousa-Silva et al., 2016). According to André et al. (2017) there is a need to focus on the local context in which adaptation decisions are made, since "these broad indicators of adaptive capacity alone cannot predict behavioral change at the organizational to individual level." While income and farm size were positive predictors of adaptation by famers in Ethiopia and France (Legesse et al., 2013; Thomas et al., 2021) the importance of these characteristics varies: Khan et al. (2020) in their analysis of adaptation strategies by famers in Pakistan found that while larger farm size and higher education were important predictors of certain adaptation choices in some cases, in others they were not important.

How actors perceive impacts and whether or not they see them as a threat has an effect as to whether they may take action. Khan et al. (2020) did find that in most cases perceived impacts were important predictors of adaptation strategies. In Ghana, about 90 % of farmers perceived significant changes in temperature and precipitation (Fosu-Mensah, Vlek, and MacCarthy, 2012), similar to that observed in Sub-Sahara Africa (Juana, Kahaka and Okurutm, 2013), Europe (Sousa-Silva et al., 2016), and other places, and this was related to a higher likely to adapt. Yet perceptions of impacts may also be influenced by other cognitive beliefs. In the Southern United States, Khanal et al. (2016) found that only 35 % of farmers perceive climate change as something relevant, with the remaining 65 % either neutral or taking a skeptical position. In the Pacific Northwest of United States, skepticism was also common among smallholders, due to their belief that climate change is highly biased by politics, money, or ideology, and most of them did not expect to change their farm management strategies (Grotta et al., 2013). Forestry also brings in a different perspective that may affect perceptions of impacts, as "the nature of the resources and the way they are handled, time horizons considered, planning and operational processes, and environmental impacts" differ from those producing agricultural crops (Weintraub and Romero, 2006).

Table 1
Socioeconomic and behavioral variables and their impact on adaptation.

Variable	Influence over adaptation	Explanation
Education	Positive	The higher the education level, the more likely the landowners is to access information, perceive and adapt to climate change (Deressa et al., 2010; Khan et al., 2020; Thomas et al., 2021).
Farm size	Positive	Larger farms are usually associated with higher incomes and greater resources for implementing adaptation (Deressa et al., 2010; Thomas et al., 2021).
Farm income	Positive	Higher incomes provides landowners with more resources to resort to, for instance, in acquiring new technologies to cope with climate change (Deressa et al., 2010; Khan et al., 2020; Thomas et al., 2021).
Gender	Mixed	Gender could influence adaptation, although some studies indicate that male heads of household are more likely to adapt, while others point to women as more likely to (Nhemachena and Hassan, 2007; Deressa et al., 2010; Legesse et al., 2013; Thomas et al., 2021).
Off-farm incomes	Mixed	Off-farm incomes can either act as a positive driver for adaptation as more the resources that this supposes to support new actions (Tessema et al., 2013) although their studies state that non-farm incomes might hinder the motivation to adapt since this reduces the reliance on-farm activities (Legesse et al., 2013).
Age	Negative	Younger farmers would be more likely to implement changes since they have initiative, are more active and take more risks (Roco et al., 2014).
Risk-aversion	Mixed	Some authors have found that a higher level of risk aversion leads to a lower probability to adapt where the risk of any change to business-as-usual outcomes for farmers is higher than the expected risk of climate change impact (Tessema et al., 2013; Brunette et al., 2020). However, others have found higher risk-aversion leading to a higher perception of climate change risks and greater willingness to take adaptive actions (Villacis et al., 2021).

One of the limitations to many of these studies is that they analyze climate change perception and adaptation separately (see, for example, Vulturius et al., 2018), which makes it difficult to ascertain the overall effect of the different factors on the adaptation process (and may explain why in some cases the results are mixed).

Another limitation is that most studies typically omit attitudes towards risk when studying landowners' willingness to engage in adaptation (Villacis et al., 2021). Whether actors perceive those impacts pose a threat and will then take action depends on actor's attitudes towards risk. Generally speaking, many studies conflate perceptions of risk with those of climate change impacts such that the greater the impact the greater the risk and that this will lead to adaptation (see, for example, Vulturius et al., 2018, examining landowners in Sweden). However, risk aversion enters not only in the assessment of the potential threat but also the decisions around whether to act. In one of the few studies explicitly measure attitudes towards risk, Brunette et al. (2020), investigating professional foresters' attitudes towards adaptation in Central Europe, found the more risk averse foresters were the less likely to change business-as-usual practices and adapt; while Villacis et al. (2021) found the opposite: smallholders in Ecuador perceived not adapting as riskier than adapting.

The case of Chile is noteworthy to study landowners' perceptions and adaptations to climate change, as there are many small and medium landholders utilizing agroforestry systems that are an important part of their livelihoods. In southern Chile, forests play an important role in the landowners' productive scheme (non-industrial private landowners). According to the National Adaptation Plan to Climate Change 2017–2022, developed by the Ministry of Agriculture of Chile (Gobierno de Chile, 2017), one of the areas most affected by climate change within the Country will be the agroforestry sector. Despite this, few studies have investigated whether these systems are being impacted, and there is no reported information on whether farmers are taking action, and more importantly, what factors are influencing this adaptation process. What limited research that has been conducted in the country has mainly focused on northern and central Chile, where there is evidence of adaptation (Roco et al., 2017). However, that adaptation is taking place on farms where there has been a history of severe and frequent droughts, and forests do not play an important role in the production system.

3. Methodology

3.1. Study area

The study was conducted in the Los Lagos region, Chile, located between the 40°13 'and 44°03′ S latitude and 74°49′ and 71°34′ W longitude. This region was selected since it counts for 20.3 % of the native forest in Chile and is representative of the typical pattern of landownership where landowners have ties to agriculture and cultivated farmland alongside their forests (multifunctional landscapes). The climate of this territory is temperate-wet. Monthly average temperatures fluctuate between 10 °C in winter and 20–25 °C during summer. Rainfall increases from the sea eastwards to the mountain ranges, between 1600 mm/year to 2500 mm/year depending on the area, with precipitation almost all year round (GORE Los Lagos, 2020).

The primary activities within the region vary from dairy production, cattle raising and forage planting in the Northeast, to forest plantations in the Northwest, to fishing, aquaculture, and associated industrial processes, in the South. Landowners within the region then draw their incomes from on and off-farm activities, where forests, crops and livestock coexist as part of their on-farm income sources.

3.2. Data collection

To assess perception and adaptation to climate change in landowners, in-person interviews were undertaken on a one-to-one basis. For this purpose, a questionnaire adapted from FAO (FAO et al., 2016) was applied which included:

a) The evaluation of climatic variations by interviewees (e.g., looking at changes in levels and variability for precipitation, droughts and temperature), and the impacts on their production systems (i.e., forests, crops, cattle, and others);
b) The perception of climate change as a threat ("In your opinion, do you think the changes in climate that you have perceived will threaten the well-being of your household in the future?"); and
c) The actions that they have adopted to cope with climatic changes. The questions were open-ended to facilitate the discussion but linked to the impacts reported earlier by the interviewees.

Additionally, landowners were characterized by a series of socioeconomic and demographic variables, which included questions about decision makers and their farms in terms of age and schooling, farm size and land use, along with a complete description of their production systems (on-farm and off-farm activities for people's livelihoods).

The farms were randomly selected through a systematic grid of 100 points, based on the National Forest Inventory of Chile, from properties that counted native forest within their boundaries. A total of 86 of the 100 points were visited once, in early 2021 (Fig. 1). The remaining 14 points could not be reached due to accessibility problems or the absence of the decision-maker at the time of the interview.

3.3. Risk-aversion test

Landowners' risk-aversion (attitude toward taking risks) was also assessed through the application of a game described in Eckel & Grossman (2008) and Menapace et al. (2013). This was based on the gamble-choice task. Subjects were presented with five coins with different values ($CLP) on each side. To account for heterogeneities in landowners' income, three different levels were defined. This was made using the socioeconomic information previously collected by the National Forest Inventory (socioeconomic component). Thus, depending on the income level of each participant, the values on each coin changed, leading to three sets of five coins each. For example, for the median income level, the values were: Coin 1: $8000/$8000; Coin 2: $12,000/$6000; Coin 3: $16,000/$4000; Coin 4: $20,000/$2000 and Coin 5: $24,000/$0 (Table 2). The lower and higher levels used half and twice the payoffs of the middle level, respectively.

The game consisted of asking the interviewee to select a coin to throw, by using real money (in-cash payments), keeping in mind that the value shown will be the one to gain. The gambles were designed to maintain a linear relationship between the expected value of the gamble and its risk, measured as the standard deviation of payoffs. Thus, for those that chose for instance the first coin (CLP$8000/$8000) the risk calculated was equal to zero. In the case of those that selected the last coin ($24,000/$0), the associated risk was equal to 12,000. We used the value of risk as an index of risk preference, and as an indicator of risk aversion. Thus, the lower the risk taken, the higher the risk aversion; conversely, the greater the degree of risk-seeking the lower the risk aversion.

3.4. Data processing and statistical analysis

After the data was collected, descriptive statistics were calculated to summarize the characteristics of the respondents. To characterize climate change's impacts on landowners' production systems, a categorization regarding the nature of the effects perceived was used. Since each landowner could select more than one option, a frequency analysis was conducted to assess the occurrence of each effect among the respondent farms. For analyzing adaptation, only actions related to climate impacts were considered. Thus, a dummy variable was applied when any action was adopted (i.e., a score of 1 was assigned when one or more actions related to climate effects were implemented). From this, the actions were grouped according to their nature to understand the characteristics of adaptation.

We applied a bivariate probit model to identify the relationships between the variables affecting the perception of climate change and adaptation since it reflects a joint decision-making process (Nhemachena and Hassan, 2007; Blennow, 2012; Lenart and Jones, 2014), where landowners are "perceiving that the climate is changing and responding to those changes with actions." (Deressa et al., 2010). The power in estimating these relationships jointly is that it identifies what role different factors play in each stage and their overall effect on the adaptation process. A similar approach has been used to model joint decision-making in regard to perceptions of wildfire risk and subsequent likelihood of evacuation (Mozumber et al., 2008) and in evaluating wildfire risk and then willingness to pay for wildfire risk mitigation measures (Fried and Stewart, 2001). The benefit of such an approach is that it explicitly treats perception of threats and adaptation separately, while recognizing they are part of a joint process. By doing so, rather than combining perception into the adaptation decision directly, the

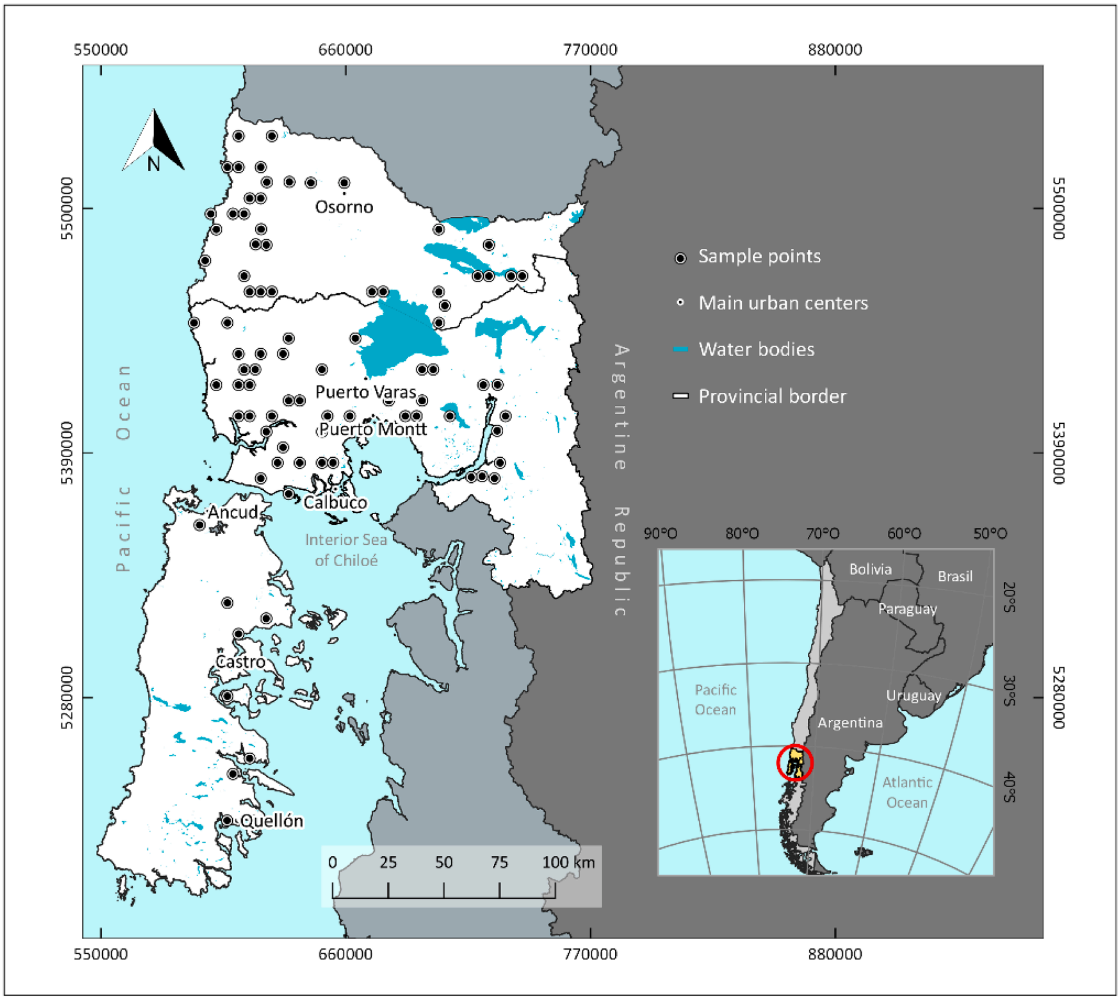

Fig. 1. Sample points in the los Lagos region, Chile ($n = 86$) .

Table 2
Gambling choices, expected payoffs, and associated risks for the median income level.

Choice	Prob	Payoff		Expected payoff	Risk
		A	B		
1	50/50	$8000	$8000	$8000	0
2	50/50	$12,000	$6000	$9000	3000
3	50/50	$16,000	$4000	$10,000	6000
4	50/50	$20,000	$2000	$11,000	9000
5	50/50	$24,000	$0	$12,000	12,000

model provides a way to determine what underlying factors influence the perception of threats as well as the adaptation decision. By separating perception from adaptation, one can then assess what role different factors play in the two parts of this joint process, especially attitudes towards risks.

The bivariate probit model estimates two equations for the two binary dependent variables, where the independent and identically distributed errors in each equation are correlated (Mozumder et al., 2008; Joshi et al., 2015). The bivariate system can be described as follows:

$$y_1^* = x_1^{'}\beta_1 + \epsilon_1$$
$$y_2^* = x_2^{'}\beta_2 + \epsilon_2 \quad (1)$$

Where y_1^* and y_2^* are the unobserved latent variables, β_1 and β_2 are vectors of parameter coefficients and $x_1^{'}$ and $x_2^{'}$ are the matrix of independent variables (i.e. the variables affecting perception and adaptation to climate change). It is assumed that ϵ_1 and ϵ_2 are drawn from a bivariate normal distribution with mean=0 (Joshi et al., 2015).

From this, the bivariate probit model specifies the outcomes as:

$$y_1 = \begin{cases} 1 \ if \ y_1^* > 0 \\ 0 \ otherwise \end{cases}$$
$$y_2 = \begin{cases} 1 \ if \ y_2^* > 0 \\ 0 \ otherwise \end{cases} \quad (2)$$

These outcomes may be correlated, with correlation ρ. A ρ estimate different than 0 means y_1^* and y_2^* are not independent and that the choice of estimating a joint model is correct. Otherwise, it is better to estimate β_1 and β_2 by two separated probit models (Katchova, 2013).

The variables in the specification of the model were chosen based on the literature (Neumayer and Plümper, 2007; Deressa et al., 2010; Legesse et al., 2013; Tessema et al., 2013; Jara-Rojas et al., 2020; Khan et al., 2020) and the context for this study (where the nature of the regional economy provides opportunities for off-farm income and forests make up a significant portion of land use). The dependent variables were perception of climate change as a threat (*perception*) and the implementation of adaptation actions on the farm by landowners (*adaptation*). The independent variables included the decision maker's age, education and gender, farm size, off-farm incomes (share of the total income), climate change impact, risk aversion and forest cover. A robust correction was applied for heteroscedasticity. All the statistical analyses were made through the statistical software, STATA/IC 15.0.

4. Results

Based on the National Forest Inventory 2015–2023 (n = 250), a subsample of 86 landowners were identified and successfully visited in the Los Lagos region. They averaged 59 years old, and 80 % were men. Most of them had completed primary education and some secondary school, with a mean of 9.8 years of formal schooling. These and other characteristics are summarized in Table 3. Just over three-quarters of landowners in the subsample saw climate change as a threat (76 %), but fewer had responded in taking action (60 %). The subsample was representative of the entire group of landowners included in the National Forest Inventory dataset, as no statistically significant differences were detected between both groups after performing Welch's t-test for landowners' schooling, gender, importance of off-farm incomes, and forest cover (Table 3). However, farms considered in the subsample tend to be slightly smaller than in the entire dataset.

4.1. Climate change perception

There was a consensus among landowners regarding weather variations (Table 3). Most of them had perceived an increase in temperatures (81.4 %; N = 70) and a decrease in water availability (rivers, streams and springs) (89.5 %; N = 77). These variations have become more evident during summer (i.e., between December and February). Landowners also perceive longer seasons: "*summer used to be shorter before, now in March [almost autumn in the southern hemisphere] we still have high temperatures*" (Farmer #17); longer periods without rainfall: "*before it was 15 good days in summer and then it rained. Now it goes up to a month and a half without rain*" (Farmer #56); and events such as frost in midsummer that make harder to predict seasons: "*Now temperatures can no longer be forecast, they are more uncertain. Before you knew when the seasons began and when they ended*" (Farmer #21). These observations of higher temperatures and lower water availability coincide with meteorological data and climate projections for the region (Araya-Osses et al., 2020).

There was less consensus around precipitation patterns. A smaller majority perceived a decrease in rainfall (60.5 %, N = 52) while a few (9.3 %, N = 8) noticed a change in the rainfall pattern, describing fewer rain events but more concentrated: "*it rains harder, more intense*" (Farmer #07). One of them, for instance, mentioned an event of "*100 mm in one day*" (Farmer #48).

Regardless of the intensity of these events, these climatic variations have broadly affected landowners. Thus, 75 % of the interviewees reported at least one impact on their household or production systems. Most (62.5 %) mentioned impacts were related to a decrease in crop yields, such as barley, wheat, and ryegrass, arguing that "*with a week of heat and no rain, the entire pastures die*" (Farmer #31). This was followed by a decrease in water availability for domestic consumption (41.3 %), and a loss or decrease in animal production (31.8 %), as droughts reduce fodder and water availability for livestock. Concerning native forests, only 5 out of 84 respondents reported impacts to these natural ecosystems. Most reported that their native forests were in good shape, stating that they have resisted weeks with unprecedented high temperatures while also providing shelter for livestock and protection of streams and watercourses (illustrating the resilience of these natural forests).

It is worth mentioning that at least seven interviewees ascribe the problem of water availability to external causes such as the building of a dam upstream, or the presence of industrial tree plantations (mainly Eucalyptus), and salmon processing factories. According to them, these are consuming the resources that before were available to the community. Other causes, like urban expansion, were also mentioned by the interviewees. These landscape-level changes would affect the availability of water, as more people lead to greater demand for water in the watershed.

The nature of the impacts also influenced landowners' perception, as when they were asked about climate change as a threat in the future, the largest proportion (76.3 %) pointed out their worries about the impacts on water availability: "*If we see impacts in water availability now, I cannot imagine how is it going to be in the future*" (Farmer #26). Landowners that did not see climate change as a threat in the future tended to obtain a higher proportion of their income from off-farm sources. "*I don't see climate change as a risk, because I don't live from the forest or the farm, so I don't have that concern*" (Farmer #15). Other respondents pointed out that these climatic variations might be an opportunity to sow crops that were not previously cultivated in the area.

Table 3
Summary of individual characteristics and selected interview responses.

Variable	Description	Dataset (n = 250)		Subsample (n = 86)	
		Mean	S.E.	Mean	S.E.
Gender	Dummy variable = 1 if male, 0 otherwise	0.8	0.0	0.8	0.0
Age	landowner's age in years (continuous)	59.6	0.8	59.2	1.5
Education	Years of formal schooling (continuous)	9.6	0.3	9.8	0.6
Farm size	Farm area in hectares (continuous)	495.5	64.6	334.3	139.9
Off-farm incomes	Share of off-farm incomes (continuous)	0.5	0.0	0.5	0.0
Forest cover	Proportion of the farm that is covered by native forests (continuous)	0.6	0.0	0.5	0.0
Risk	Standard deviation of expected payoff (continuous)	n.m.	n. m.	9.6	8.6
Climate change impact	Dummy variable = 1, if landowner perceives any impact in his production system, 0 otherwise	n.m.	n. m.	0.8	0.0
Perception	Dummy variable = 1, if landowner perceives climate change as a threat in the future, 0 otherwise	n.m.	n. m.	0.8	0.0
Adaptation	Dummy variable = 1, if landowner has taken any adaptation action in the farm, 0 otherwise	n.m.	n. m.	0.6	0.1

Note: "n.m." means "not measured".

4.2. Climate change adaptation

Out of 86 interviewees, 52 (60.5 %) have taken at least one adaptation measure. Most of them were looking for new water sources for livestock (27.7 %, N = 18), which may generate new impacts: "*Due to drought, cows have to be taken elsewhere to drink water, causing also erosion by their walking to further places*" (Farmer #25). Along the same lines, the search for other water sources for domestic consumption has increased (21.3 %, N = 13) as well as the implementation of water accumulation systems (18.2 %, N = 12).

Another adaptation measure has been anticipating changes in forage availability (20 %, N = 12). Due to the impact on crops and pastures, users have had to deliver forage and supplements to livestock earlier during summer, which means increased (and at times unplanned) expenses and work, and a higher pressure on the fodder supply chain, and in forests (where cattle usually get fodder when this is not available in other way).

4.3. The relationship between landowners' perceptions and adaptation

Our results show that the implementation of adaptation actions is endogenously related to the individual's perception of climate change as a risk. The log-likelihood ratio test (LR) in the biprobit model showed that the correlation coefficient of errors in the two probit models was significant ($p < 0.05$) (Table 4). The model results also show two individual characteristics that are common across both perception and action: the share of off-farm incomes and risk tolerance.

In addition to those two common factors, two others were associated with the perception of climate change: schooling and gender. In this first stage, lower levels of schooling and if the decision—maker was a woman led to an increased likelihood of seeing climate change as a risk for the future. In this stage, where a higher share of the total income came from off-farm sources, the likelihood of perceiving climate change as a threat to the future was lower, as did higher degrees of risk tolerance (higher risk preference).

In the next stage of adaptation, the impacts perceived in the production systems were significant in explaining action. The likelihood of landowners taking adaptation actions increased when they saw the impacts associated with climate change as a threat to their production systems. However, this was moderated by the two other common factors which affected perception as well: the importance of off-farm incomes and the attitude toward risk. In both cases they acted in a similar fashion: the higher the proportion of off-farm incomes, the less likely landowners were to adapt; and a higher risk tolerance also reduced their propensity to adapt. We discuss the implications of these findings further in the next section.

Mean number of gambles was 2.6 (from 1 to 5), which means that the majority of landowners are risk averse (choice number 1 had risk=0) [2].

5. Discussion

5.1. Climate change perception and adaptation acting jointly

Our results confirm that the perception of climate change as a future threat and the implementation of adaptation actions act jointly, supporting the argument of Sousa-Silva et al. (2016) that: "*people's strength of belief in local effects of climate change is strongly correlated with their willingness to undertake adaptation practices*". This is especially relevant in cases like Chile, where most land (including forests, pastures, and different land qualities) is privately owned, and people's livelihoods depends on multiple activities (multifunctional landscapes) (Reyes et al., 2021). At the local level, people's perceptions about climate change and their adaptation strategies are mediated by socioeconomic, cultural and environmental factors that, in this case, were strongly related to people's economic dependency on the farm (as a higher proportion of off-farm income reduced that dependency) and attitudes towards risks.

The first of these two common factors helps to explain why, in the case of the Los Lagos region, even though more than 80 % of landowners have observed climate change impacts, not all of them have implemented adaptation measures. Our results show that the probability of perceiving climate change as a threat decreases when the proportion of off-farm income increases. Landowners obtain income from different external sources, which can be located in the same county or in other counties or regions (Reyes, 2021). These off-farm resources include salaries, remittances, subsidies, off-farm production (for instance, renting pieces of land from other people), and other revenues (businesses). In the case of Chile, remittances may come from relatives working in other regions of Chile (e.g., the mining sector in the north of the country). In the case of subsidies, the most important was the Universal Guaranteed Pension (non-contributory pension of about US$300 per month), which was created in 2008 and benefits all people over 65 years old (Reyes, 2021). The way how these off-farm resources influence landowners' perceptions about climate change coincides with what was predicted and reported by Deressa et al. (2010) and Marshall and Stokes (2014), where people with higher off-farm incomes perceived four times fewer changes in weather variability than people without that off-farm income. As observed in the interviews, the less directly people are economically dependent on the farm, the less concerned they may be about climate impacts, including paying attention to climate variability.

In terms of perception, our results did show a gender difference: women were much more likely to perceive climate change as a threat ($p < 0.05$). This is consistent with what was reported by Gustafson (1998), where female-head of households were more prone to be aware of the environment. Education worked in a different direction than is usually observed, as landowners with higher levels of education were less likely to see climate change as a threat for the future. However, this could be explained because schooling creates other income opportunities (networks) and thereby reduces landowners' economic dependency from the land and their perception of economic vulnerability (Reyes et al., 2021). These socio-demographic factors were not significant concerning adaptation, as were the other socioeconomic factors considered in the analysis (age, income, farm size, etc.).

Although observed impacts were not a significant individual factor in explaining whether climate change was perceived as a threat, the perception of climate-related impacts was a primary motivator for adaptation, whether it was building or finding new water sources or modifying when landowners provide fodder to their livestock. This coincides with what Thomas et al. (2021) found where impacts on there forests led to French landowners adapting their management. Similar behavior has been observed further north in Chile, where farmers in the Central Valley usually waited until the fluctuations in climate and their effects happened before implementing measures (Engler et al. 2021). Given too the importance of water for both productive systems and personal use, we observe that most of the perceived effects were focused on water issues and the implications for crops (e.g., shortage of drinkable water, lack of water for cattle, and decrease in crop yield) with the most common types of adaptation measures tied to those impacts (34.3 % and 31.4 % of landowners adopted actions related to water in production systems and for personal consumption, respectively). This is also similar to what Aldunce et al. (2017) found in Central Chile, concluding

Table 4
Bivariate probit model for dependent variables, perception and adaptation.

Variable	Coef.	Std. Error	P value
Perception of climate change as a threat			
age	−0.022	0.014	0.119
education	−0.082	0.041	0.048**
farm_size	0.000	0.000	0.529
off_farm_incomes	−1.952	0.714	0.006***
female	−1.353	0.607	0.026**
forest_cover	0.304	0.752	0.686
impact	0.297	0.473	0.530
risk	−0.032	0.019	0.090*
_cons	5.103	1.587	0.001
Adaptation measures			
age	−0.008	0.012	0.484
education	−0.010	0.034	0.781
farm_size	0.000	0.000	0.746
off_farm_incomes	−1.133	0.530	0.033**
female	−0.054	0.391	0.890
forest_cover	0.837	0.592	0.158
impact	1.159	0.398	0.004***
risk	−0.034	0.020	0.086*
_cons	0.546	1.130	0.629

Wald test of rho=0: chi2(1) = 5.75359 Prob > chi2=0.0165.
Note: ***, **, * imply significance at 0.01, 0.05, and 0.1 levels respectively.
Note 2: None of the explanatory variables used in the model suffered from multicollinearity.
Note 3: Here the variable "risk" refers to the measure of risk taken in the test performed. The higher the risk taken, the lower the risk aversion.

[2] The gamble number is a reasonable parametric summary index of risk preference (Eckel & Grossman, 2008).

that people who perceive drought as a potential risk are more likely to incorporate adaptation strategies than those who do not. Since farmers acted from perceived impacts, the employed actions might be cataloged as reactive rather than proactive, which is common when adaptations occur at an individual level (Berrang-Ford et al., 2011; Fischer, 2019). Consequently, most of the adjustments adopted were those faster to implement, with the benefits realized sooner and that were also lower cost. For instance, landowners used water accumulation systems instead of creating or accessing a long-term provision method of supply. For grazing, they provided bales earlier instead of installing irrigation systems or using more resistant species. This finding is consistent with Roco et al. (2014) who reported that in the case of water conservation techniques in farmers of central Chile, the most frequently adopted are those that require the lowest investment. Similarly, McGee et al. (2009) and Eriksson (2014) posited that in response to different hazards, landowners tend to make only minor adjustments that are easier and less costly.

This leads us to the second factor that explains why not everyone who perceives climate change as a threat adapts. Higher risk tolerance (risk-prone decision makers) has a significant and positive effect on the lack of willingness to adapt. This is consistent with the findings of Villacis et al. (2021), who studied farmers in Ecuador, where they found that those with lower risk tolerance (risk averse decision makers) who saw climate change as a risk also saw greater risk in maintaining the business-as-usual scenario, thereby making them more likely to adapt. We see similar decision-making here too, where climate change leads to lower risk-tolerant farmers being more willing to take adaptive actions. This is associated with "a positive and significant relationship between a farmer's level of risk tolerance and his subjective belief in the probability of crop losses" (Menapace et al., 2013). This may also explain why age, which typically is important in explaining adaptation among farmers, is not significant here. It has been suggested that more experienced or older farmers lag behind in adaptation decisions because they tend to be risk-averse (Tessema et al., 2013; Khan et al. 2020). However, those studies did not assess attitudes towards risk directly– nor how farmers may view different adaptation strategies (including doing nothing). Our results here suggest that these underlying factors may be more important than age, which in these other studies served as an imperfect proxy for risk tolerance.

One limitation of our study was that we did not ask farmers to assess or quantify how severe was the threat. As was mentioned above, adaptation seems to be a function of experiencing extreme events and their intensity (Mortreux et al., 2020). According to Vulturius et al. (2018), the sense of urgency to adapt comes when impacts are threatening something important or highly valued for farmers. It may be the case that landowners who detected impacts on their systems and perceived them as a threat but did not adapt either did not perceive them as costly enough to warrant action or did not yet see a benefit from investing in adaptation. This may be similar to what Fried and Stewart (2001) found, where there may need to be a certain threshold of risk that is exceeded before landowners begin to pay attention to the risk.

Finally, we note the role of native forests. In these interviews, landowners offered that they saw either little or no impact on their native forests related to climate change (indeed, we found the proportion of native forest to be insignificant when it came to perceptions of climate change, as seen in Table 4). However, in conversations with landowners, it did seem to offer an adaptive strategy in the way they used these forests to protect livestock and water and food sources that some recognized but not others. While not significant, the greater the amount of native forest as a proportion of land use did show up as a positive factor in explaining adaptation by landowners (Table 4).

6. Conclusions and policy implications

We found that while most landowners are currently perceiving climate change and seeing impacts on their farms, only slightly more than half are engaging in adaptation actions. This was explained by the joint nature of the adaptation process, in which decision makers simultaneously consider the impacts of climate change and the relative threat they pose (how they are perceived) for their livelihood. We found that for adaptation to occur, farmers had to perceive that there were climate change-related impacts on their farms and that they posed a significant threat for their livelihoods. The perceptions of those threats and the consecuent adaptation actions were moderated by two common factors in both stages of this two-part assessment: first, landowners' risk tolerance; and second, the importance of off-farm incomes (as a proportion of the total income). While individual characteristics such as decision makers' gender and schooling were important in perceiving climate change as a threat, neither factor carried over into whether or not adaptation took place.

The results of this study shed light on aspects that can guide the formulation of programs to promote climate change adaptation. The analysis showed that a higher importance of off-farm incomes and being more risk prone reduce the likelihood of taking adaptation action. Given the anticipated impacts of climate change in the region, and the importance of these resource-based systems in underpinning people's livelihoods and the regional economy, further exploration of both the vulnerabilities in the region and how and where individual action may need to be supplemented with larger-scale actions (for example in water infrastructure) is warranted. Doing this will allow the government and other entities in charge of these processes to channel efforts and resources, considering that they are limited. These results also point to the need for further research as to why women are more likely to perceive climate change as a threat, and whether this reflects they are in a more vulnerable position to begin with.

The analysis showed that the actions adopted were reactive, driven by the impacts perceived in the land. However, the longer-term ability of landowners to adapt depends on building adaptive capacity in the system in order to take a more proactive approach. Our results here show that the perception of climate change as a threat proved to be key in the implementation of adaptive measures. Here, educating and training farmers in understanding the risk that climate change poses and actions they can take, in order to ensure landowners are correctly perceiving both the costs and benefits of adaptation measures, could prompt more proactive approaches, without waiting to incur all those costs before taking action. An important part of this will be understanding how risk attitudes affect whether or not landowners may take action and how people deal with uncertainty. Climate change can not only lead to potential impacts on the farm (crop yields, water availability, etc.), which increase uncertainty about on-farm production (required inputs, manpower, the seasonality of income, etc.), but may also create new uncertainties concerning off-farm incomes. Given the varied and different sources of off-farm incomes, government has a role to play in helping landowners also understand the more systemic risk in the system (e.g., increased wildfire may reduce adaptation strategies centered around agroforestry production), so landowners are properly informed when making choices around adaptation strategies.

Additional attention could also be paid to other joint-effects that can either increase or reduce landowners' vulnerability and whether or not these might create differential risks across the landscape. This could be the case when smaller plots are combined with higher off-farm incomes, which can create a scenario of very high economic dependency and less adaptation and land and forest degradation is more likely. The negative impacts of climate change (less water, lower fodder availability) could lead to increased pressure on native forests for grazing, as landowners in these circumstances are less likely to invest in adaptation strategies (as they have fewer resources and options). This potentially leads to further degradation, further increasing landowner's vulnerability, while also reducing their ability to develop effective adaptation strategies in the future. Targeted interventions may be necessary here to break what could otherwise become a negative degradation loop, to prevent declining resource availability leading to even more pressure on the system and further degradation.

CRediT authorship contribution statement

Amanda Martinez: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rene Reyes:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Funding acquisition, Conceptualization. **Harry Nelson:** Writing – review & editing, Supervision, Resources, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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