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Analysis of perceived robustness, adaptability and transformability of Spanish extensive livestock farms under alternative challenging scenarios

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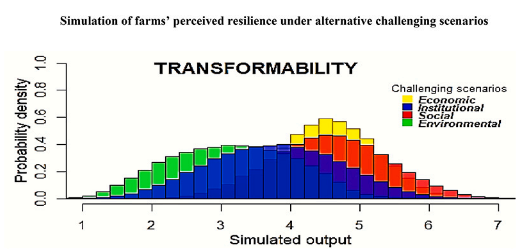
HIGHLIGHTS

- The capacity of robustness, adaptability and transformability to deal with different types of challenges is investigated.
- 120 surveys of sheep and cattle farmers are analyzed through Partial Least Square regressions and Monte Carlo simulations.
- Challenges' perception is variable, but institutional and policy-related challenges are the main threats to resilience.
- Robustness is perceived lower than other capacities, but is more effective against economic and environmental challenges.
- Adaptability and transformability are strongly correlated, and more effective under socio-economic long-term pressures".

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Extensive livestock farms in the EU operate in a context of increasing market liberalization and competition, changing consumer patterns and decreasing meat consumption, and increasing climate change-related risks. In turn, EU policy calls for better supporting extensive systems due to their numerous socio-ecological benefits and aims to improve the resilience of extensive livestock farms.
OBJECTIVE: The research question underlying this paper is: which resilience capacities may help livestock farmers deal with different types of challenges? The specific research objectives are: 1) to quantify the resilience capacities of robustness, adaptability and transformability and the challenges as perceived by farmers; 2) to identify the main challenges affecting the perceived resilience capacities; and 3) to evaluate how perceived resilience capacities perform under alternative scenarios.
METHODS: The paper relies on the use of data from a survey of 120 cattle and sheep farmers in Spain to study the latent property of resilience through farmers' perception. The methodology consists of mixed statistical methods to address the three specific objectives. First, descriptive statistics to quantify the perceived resilience capacities and challenges threatening farming systems; second, fitting Partial Least Square regressions to identify the main challenges affecting robustness, adaptability and transformability; and third, stochastically simulate challenging scenarios to predict the behavior of the three resilience capacities under different types of challenges.

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RESULTS AND CONCLUSIONS: Resilience capacities perform in different manners when dealing with challenges. Adaptability and transformability seem to be more effective under socio-economic long-term pressures. Robustness performs poorly under challenges either in the short- or long-run and appears to be more effective against economic and environmental challenges. Institutional challenges are the main threats to resilience, especially when it comes to reduced subsidies, restricted access to land, and subsidies-induced competition.

SIGNIFICANCE: The paper's contribution consists of the empirical advances in understanding the resilience capacities and their ability to deal with different types of challenges, about which the literature offers little guidance. To this end, the paper proposes a quantitative methodological solution that is relevant considering the need for methodological progress towards resilience quantifications. Lastly, the paper may inform policymaking by bringing new evidence into the debate on the future of extensive livestock in the EU based on the case of Spanish cattle and sheep farms.

1. Introduction

European extensive livestock farming is undergoing several challenges (Dubeuf et al., 2016; Morris, 2017; Komarek et al., 2020; Ruiz et al., 2020), which are particularly evident in the Mediterranean regions of Southern EU where agriculture is affected by more evident socio-economic depletion (Zagata and Sutherland, 2015). Extensive livestock farms in the EU operate in a context of increasing market liberalization and competition (Ramírez-López et al., 2020), changing consumer patterns and decreasing meat consumption (Peyraud and MacLeod, 2020), and increasing climate change-related risks (Salmoral et al., 2020). Future scenarios towards 2030 drawn by the European Commission (2019) confirm negative consumption trends and indicate downward price adjustments, while climate change impact on livestock is likely to increase (EEA Report No 04/2019).

This is also the case of extensive livestock farms in Spain and, particularly, the cattle farms of Sierra de Guadarrama (Community of Madrid) and the sheep farms of Huesca (Aragón), which are the subject of this research. These systems have been experiencing a decline in the number of farms and reared heads over the last two decades (Fau, 2016; INE, 2020), which are due to several challenging factors. For instance, in the last 20 years, these farms have suffered from a reduction in meat consumption on the one hand (Alcalde et al., 2013), and a contextual reduction of CAP subsidies on the other hand (EU Farm Economics Overview, 2018). These systems suffer a weak generational renewal, aggravated by the marginality of the regions in which the farms operate and low quality of life (Bertolozzi-Caredio et al., 2020), whereas these farms' profitability is strongly affected by variable selling prices and increasing costs of production (Bertolozzi-Caredio et al., 2021b).

EU policy gives great importance to the role of extensive farming in light of the environmental and climate ambitions reflected into the Green Deal and the new CAP 2023–2027 and, to this end, aims at promoting the resilience of such systems (EC, 2020; Reg. 2021/2115; Roche Ramo, 2021). Extensive livestock farms, in fact, provide several socio-ecological functions and public-private goods and services including, among others, the maintenance of rural population, barriers against land abandonment, protection of biodiversity and soil quality (Rossi, 2017; Rodríguez-Ortega et al., 2018). Often, these farms are located in mountainous or marginal areas, where other agricultural activities are unfeasible and extensive livestock is the only provider of such services (de Rancourt et al., 2006).

The resilience of extensive livestock systems has been investigated in previous studies including, for example, the study of resilience in a pasture management system in Central Asia (Haider et al., 2012), the resilience of small ruminant farms in Turkey (Ashkenazy et al., 2018), the resilience of mountainous dairy sheep farms in Norway (Daugstad, 2019), and of dairy cattle farms in France (Perrin et al., 2020). Reidsma (2019), Bertolozzi-Caredio et al. (2021a) and Paas et al. (2021) analyze the resilience capacities, attributes and future pathways of livestock farming systems in Spain.

Following Meuwissen et al. (2019), in this paper we define resilience as the capacity of a system to keep delivering its essential functions despite challenges and, accordingly, we distinguish between three resilience capacities: robustness, adaptability and transformability. Robustness is the capacity to withstand challenges without changes in farms' organization and functions, whereas adaptability is the capacity to pursue marginal changes in response to challenges, while conserving the existing functions, and transformability is the capacity to significantly change the internal structure in response to untenable challenges, which implies a transition to a new configuration. Crucial in understanding resilience is the study of challenges to deal with, which is traditionally enclosed into the 'resilience to what' concept (Carpenter et al., 2001). The identification of challenges to deal with is essential to understand whether and to what extent a system is resilient, which is a good practice applied in resilience assessments (e.g., Reidsma, 2019; Bertolozzi-Caredio et al., 2021a).

Due to the increasing complexity and diversity of issues threatening the survival of extensive livestock in the EU and Spain, understanding how extensive livestock farms can successfully deal with different challenges is critical starting point. Much of resilience research in agriculture attempts to determine pathways and strategies to increase resilience generally or specifically to deal with certain challenges. However, to our knowledge, no studies have attempted to understand whether certain resilience capacities are more effective in dealing with specific types of challenges. Exploring this aspect may both contribute to the theoretical understanding of resilience and provide indications to support extensive livestock systems.

The research question inspiring this article is: which resilience capacities may help dealing with different types of challenges? In order to answer this question, the following specific objectives were pursued: 1) to quantify the resilience capacities of robustness, adaptability and transformability and the challenges as perceived by farmers; 2) to identify the main challenges affecting the perceived resilience capacities; and 3) to evaluate how the perceived resilience capacities perform under alternative, hypothesized challenging scenarios.

To achieve these objectives, the perception of resilience capacities and challenges was elicited through a survey of 120 livestock farmers in Spain. Our research, hence, relies on the elicitation of farmers' perception of resilience to study this latent property. Descriptive statistics were used to quantify the perceived resilience and perceived challenges, whereas three Partial Least Square (PLS) regressions (one per resilience capacity) were fitted to estimate challenges' coefficients and identify main challenges affecting resilience. Then, six challenging scenarios were created using stochastic simulations based on the challenges' typologies proposed by Meuwissen et al. (2019): economic, social, institutional, environmental, shocks, and pressures. The fitted PLS regression models with estimated coefficients were used to predict the performance of each resilience capacity under the hypothesized challenging scenarios.

The paper's contribution consists of the empirical advances in understanding the resilience capacities and their ability to deal with different types of challenges, about which the literature offers little guidance. To this end, the paper proposes a methodological solution based on mixed quantitative methods that are innovative in resilience assessments, and seem relevant considering that there is a need for methodological progress towards resilience quantifications (Peterson et al., 2018). Lastly, the paper may inform policymaking by bringing new evidence into the debate on the future of extensive livestock in the EU (Peyraud and MacLeod, 2020) based on the case of Spanish cattle and sheep farms.

2. Methodological approach

2.1. Theoretical underpinning

Following Meuwissen et al. (2019), in this paper we define the resilience of farming systems as their capability to ensure the provision of functions in the face of increasingly complex and accumulating economic, social, environmental and institutional challenges, through capacities of robustness, adaptability and transformability.

Robustness is the farming system's capacity to withstand challenges without structural changes in farms' organization and functions. Adaptability is the capacity to pursue marginal changes limited to the farm structure (e.g., composition of inputs, production, marketing) in response to challenges, while conserving the existing functions and goals. Transformability is the capacity to significantly change the internal structure and qualitative nature of the farming system in response to untenable challenges, which implies a transition to a new configuration (Olsson et al., 2004; Cumming et al., 2005; Darnhofer, 2014; Daugstad, 2019; Meuwissen et al., 2019). The three capacities concur simultaneously (though not necessarily equally) to build resilience, and should not be considered as isolated objects.

The importance of studying these capacities rather than the overall resilience lays in the different strategies shaping each of them, and their implications on the farm organization that, in the long period, determine the development trajectory (Bertolozzi-Caredio et al., 2021a). For instance, the use of buffers in anticipation to price drops, or the option for an off-farm job contribute to enhance robustness, whereas introducing new technologies or management practices can lead to adaptability. More radical changes in market or production orientation, such as a shift from cattle farming to ecotourism, can determine the transformability of a system (Cumming et al., 2005; Ashkenazy et al., 2018; Daugstad, 2019).

Meuwissen et al. (2019) emphasize the need to consider all types of challenges that might affect a farming system. These challenges can be known or unknown, expected or unexpected, and cover different economic, social, institutional and environmental dimensions. Importantly, the challenges can be divided in sudden shocks impacting a system in the short-term, or pressures stressing the system in the long-run. This distinction is important as it entails different effects on a system, and diverse capacities through which farming systems respond to challenges. For example, different implications and responses emerge when considering price drops or changes in consumer habits and preferences. Likewise, droughts and climate change differ, though they are related, the first being susceptible to become more extreme and severe as result of the latter.

Consequently, when it comes to assessing resilience, it is of interest to understand how different capacities can deal with different challenges, because different attributes and decisions are behind those capacities. Based on this theoretical framing, this paper develops upon the concepts of robustness, adaptability and transformability, and the distinction between economic, social, institutional, and environmental, shocks and pressures.

2.2. The case studies

This research focuses on the extensive livestock production in Spain, focusing on two exemplary livestock systems, namely the extensive sheep farms of Huesca (Aragón), and the extensive cattle farms of Sierra de Guadarrama (Community of Madrid), North-eastern and Central Spain respectively. The map in Fig. 1 shows the location of the farming systems.

The sheep farming system is mainly characterized by (semi-) extensive, mixed farms oriented to lamb meat production, but typically diversified to cereals, almonds and olive orchards productions. In 2016, about 50% of farms had a herd size of between 200 and 1000 heads (Fau, 2016). The cattle farming systems includes (semi-)extensive farms, typically with >70 heads.

The reason behind the choice of these systems was the decline affecting these sectors over the last decades that, in turn, threatened the relevant socio-ecological contribution of extensive livestock farming in these marginal areas (Spiegel, 2019; Becking et al., 2019). For example, the sheep system in Huesca has seen a drop in the total number of heads and the number of farms by 50% over the last 20 years and 60% over the last 25 years, respectively (Fau, 2016). Likewise, the number of cattle heads and the number of cattle farms in the Community of Madrid have decreased respectively by 15% and 12% over the last 15 years (INE, 2020). These trends reflect the overall dynamics of extensive livestock in the EU, especially in the less favoured areas of the Mediterranean regions (Zagata and Sutherland, 2015; ESPON, 2018).

A number of investigations attempted to identify the main factors explaining such decline. Much importance is assigned to economic factors, such as the combination of declining and unstable selling prices, increasing feeding costs and low productive efficiency in a context of growing (domestic and international) market competition and sharp reduction of consumption, which also explain the higher dependence of livestock farms on subsidies (Soriano et al., 2018; MAPA, 2019; Bertolozzi-Caredio et al., 2021b).

However, more challenges seem to contribute to the declining trends. Among others, for example, raising extensive livestock is very time demanding and contributes to lower the quality of life of farmers and, consequently, impedes the generational renewal in the sector (Bertolozzi-Caredio et al., 2020). Moreover, tendering the sheep herds stands in conflict with the wild fauna (e.g. wolves and bears) which aggravates the limited accessibility to mountainous pastures, while cattle farms are particularly affected by regulatory constraints limiting the access to grassland (Paas et al., 2021). Overall, grassland-based farming seems affected by the increasing severity of droughts (Salmoral et al., 2020). All these types of challenges put to test the resilience of cattle and sheep farms and, consequently, constrain the capacity of extensive livestock systems to keep delivering the socio-ecological functions, ecosystem services and public goods characterizing cattle and sheep farming in marginal areas.

2.3. Data collection

Data were collected through 120 surveys of farmers, of which 60 were surveyed in Sierra de Guadarrama, Central Spain (cattle system), and 60 in Huesca, Northeast Spain (sheep system). The same survey was

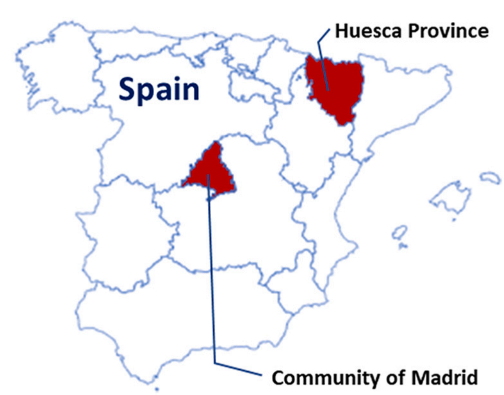

Fig. 1. Location of the case studies. Own elaboration.

administered in 2018 in the two farming systems. The surveyed farmers were selected randomly within five veterinaries' client portfolios, and the surveys were conducted by the five veterinaries themselves, previously trained by the authors. Three veterinaries delivered 20 surveys each in Huesca, whereas two veterinaries delivered 30 surveys each in Guadarrama. The survey was developed within the framework of the SURE-Farm project,[1] as part of a resilience and risk management assessment across EU countries. In this paper, the specific information used was the measurement of the perceived resilience capacities and challenges. The characteristics of the farms and farmers of the sample are reported in Table 1.

Resilience is a latent property, which becomes evident only once a system responds to shocks and pressures. Therefore, it is complex to assess resilience beforehand. Resilience capacities comes to help, because they reflect actual processes of farms' persistence, marginal changes, and/or transition to new configurations in response to challenges. Our strategy was to infer resilience capacities through the farmers' perception of their own capabilities to persist, adapt and transform on their own farms. To increase the reliability of this exercise, farmers were asked multiple questions for each capacity, as to ensure coherence in their responses and increased reliability of measurement. The farmers' perceived resilience was captured by means of nine statements scored on a 7-point Likert scale, seven indicating the highest perceived resilience. Out of these statements, three aimed at measuring robustness, three adaptability, and three transformability. Table 2 shows the nine statements and the corresponding resilience capacities. Indicators of robustness, adaptability, and transformability were measured as the average of the three corresponding statements. An ordinal version of the Cronbach's alpha test based on polychoric matrices (Zumbo et al., 2007) was computed to confirm the adequacy of statements to measure their respective indicators (Gadermann et al., 2012). In all cases the alpha values are higher than the acceptability limit of 0.7, thus high enough to guarantee sample adequacy (0.83 for robustness, 0.81 for adaptability, and 0.82 for transformability).

Furthermore, the farmers were asked to indicate, based on their perception, the extent to which different challenges were likely to affect them. To this end, 30 challenges were scored by farmers on a 7-point Likert scale, seven indicating the highest impact. Table 3 reports the 30 challenges. The 30 challenges were categorized into six types in accordance with their nature (economic, social, environmental, and institutional) and the time scale of their impact (short or long-term pressures). This categorization was made according to the examples given by Meuwissen et al. (2019) and Spiegel (2019).

Table 1
Characteristics of the sample. Own elaboration on sample data. Note: UAA stands for Utilised Agricultural Area; AWU stands for Annual Work Unit.

		Huesca	Sierra de Guadarrama
	No. of surveys	*60*	*60*
Farm	Sheep (average no.)	*643*	–
	Suckler cows (average no.)	–	*58*
	UAA (average ha)	*80.8*	*47.4*
	Owned (% average UAA)	*31.6%*	*28.8%*
	Familial AWU	*0.60*	*0.71*
	Hired AWU	*0.42*	*0.40*
Farmer	Age (average no.)	*51.2*	*50.5*
	Gender (% female)	*3.3%*	*6.7%*
	High Education (% having graduation)	*5.0%*	*26.7%*

[1] https://www.surefarmproject.eu/

Table 2
The nine statements elicited in the farmers' survey and used to measure the perception of robustness, adaptability and transformability.

Resilience capacities	Statement
Robustness	1. Personally I find it easy to get back to normal after a set back
	2. After something challenging has happened, it is easy for my farm to bounce back to its current profitability
	3. A big shock will not heavily affect me, as I have enough options to deal with this shock on my farm
Adaptability	1. In times of change, I am good at adapting myself and facing up to agricultural challenges
	2. As a farmer, I can easily adapt myself to challenging situations
	3. If needed, my farm can adopt new activities, varieties, or technologies in response to challenging situations
Transformability	1. For me, it is easy to make decisions that result in a transformation
	2. After facing a challenging period on my farm, I still have the ability to radically reorganise my farm
	3. If needed, I can easily make major changes that would transform my farm

2.4. Data analysis

The analysis relies on a mixed statistical methodology addressing the three specific objectives. The scheme in Fig. 2 shows the three methodological steps, each addressing an objective. The 120 surveys of farmers provide data on 30 challenges and three resilience capacities. The first objective was to quantify the resilience capacities as perceived by farmers, and was addressed through descriptive statistics, notably means values. The second objective was to identify the main challenges affecting resilience capacities, and was pursued by fitting three PLS regressions (one per resilience capacity), and analyzing the variables through circle plots. The third objective was to assess the resilience capacities under alternative challenging scenarios through the stochastic simulation of 6 scenarios (one per type of challenge (Table 3)) and the prediction of resilience capacities by scenario using the coefficients estimated through the three fitted PLS regression models. The three methodological steps are described below in dedicated sub-sections.

2.4.1. Step 1: Descriptive statistics

The 120 surveys of farmers provided data on 30 perceived challenges and three resilience capacities. The former derived from structured questions about the perception of 30 challenges, each scored by farmers on a 1–7 Likert scale. The latter derived from nine resilience statements (three statement per resilience capacity) reported as a 1–7 Likert scale. Resilience capacities are measured as the average of the three corresponding statements. We used mean values to quantify the perception of the 30 challenges and the three resilience capacities. Moreover, for what regard resilience, we also analyzed the values' distribution and the correlation between the three capacities. Results are displayed and observed through bar charts, histograms and correlation matrix.

2.4.2. Step 2: Fitting Partial Least Square regressions and Correlation Circle Plot

PLS regression is a method for constructing predictive models, an extension of multiple regression analysis that reduces the predictors (the challenges in our case) to a smaller set of latent factors (or components) in order to predict the response variable (the capacities in our case). In practice, PLS establishes a few latent factors accounting for most of the variation in the response (Carrascal et al., 2009; Boongaling et al., 2018). PLS is widely applied when the number of predictors is high, the ratio observations/predictors is relatively low, and there is multicollinearity between them (Carrascal et al., 2009; Boongaling et al., 2018). Due to the collinearity in our sample, we opted for using a PLS regression. Appendix A reports the Spearman rank correlation matrix of the 30 challenges, their Eigen values and Kappa ratio describing the

Table 3
The 30 challenges elicited in the farmers' surveys categorized among six types.

Type	Impact time scale	Challenge	Challenge ID
Economic	Short	*High input prices* (e.g. *fertiliser, feed, seed)*	high_costs
	Short	*Input price fluctuations* (e.g. *fertiliser, feed, seed)*	costs_fluct
	Short	*Low market prices*	low_prices
	Short	*Market price fluctuations*	price_fluct
	Long	*Low bargaining power towards processors and retailers*	sell_bargain.power
	Long	*Low bargaining power towards input suppliers* (e.g. *fertiliser, feed suppliers)*	buy_bargain.power
	Long	*Limited access to loans from banks*	credit_access
	Long	*Late payments from buyers*	late_cashout
	Long	*Implementation of new technology in the production process*	production_tech
	Long	*Implementation of new technologies in marketing and trade process*	trade_tech
Institutional	Long	*Access to information system*	info_access
	Long	*Strict regulations* (e.g. *environmental, animal welfare, or competition)*	strict_regulation
	Long	*Reduction in direct payments of the Common Agricultural Policy (CAP)*	cap_reduction
	Long	*Increasing competition of more intensive or CAP-supported sectors*	competition
	Long	*New measures limiting land access*	restricted_land.access
	Long	*Increasing limitation for sheep farm close to urban areas or natural parks*	urban_limit
Social	Long	*Limited availability of skilled farm workers*	lack_of_workers
	Short	*Limited ability to work due to illness, divorce or other personal circumstances*	inability_to_work
	Long	*Public distrust in agriculture*	public_distrust
	Long	*Low societal acceptance of agriculture*	social_acceptance
	Long	*Intense work commitments and effort*	work_commitments
	Long	*Depopulation and loss of public services*	depopulation
	Long	*Spread of alarming news relative to food in social networks and media*	media_comunication
	Long	*Reduction of meat consumption*	reduced_consumption
Environmental	Short	*Extreme weather events* (e.g. *floods, droughts, frost)*	extreme_weather
	Short	*Pest, weed, or disease outbreaks*	pests
	Long	*Low soil quality*	soil_quality
	Long	*Reduction of pastures*	pasture_availability
	Long	*Land abandonment*	land_abandonment
	Short	*Wild fauna attacks*	wildfauna

collinearity characteristics of the sample.

The analysis was carried out through the R packages 'plsRglm' (Bertrand et al., 2014) and 'mixOmics' (Lê Cao et al., 2011). Firstly, three PLS regressions were fitted to estimate the coefficients explaining the relationship between challenges and robustness, adaptability and transformability. Transposing the PLS regression into a linear form, the fitted regression can be formulated as follows

$$Y_i = \widehat{\beta}_0 + \widehat{\beta}_1 X_1 + \widehat{\beta}_2 X_2 + \ldots + \widehat{\beta}_{30} X_{30} + \varepsilon_i \quad (1)$$

Where Y is the observed value of the perceived resilience capacity i (either robustness, adaptability or transformability), $\widehat{\beta}_0$ is the intercept, $\widehat{\beta}_1^{30}$ are the estimated coefficients, and X_1^{30} are the 30 perceived challenges (observed variables). The disturbance is assumed white noise.

For each regression, the number of latent factors was identified based on the Q^2 criterion (Bertrand et al., 2014). This criterion is a means for assessing the model's predictive relevance, measured through a sample re-use technique: the smaller the difference between predicted and original values the greater the Q^2 and the model predictive accuracy. Specifically, a Q^2 larger than zero indicates the predictive relevance of the model (Hair et al., 2014; Sarstedt et al., 2014), whereas Pérez-Enciso and Tenenhaus (2003) set this value at 0.05. To test the predictive capacity of the model, a leave-one-out cross validation technique was applied following the example by Bertrand et al. (2014). Research shows that Q2-leave-one-out component selection methods gives more reliable results than other methods (Quan, 1988; Nengsih et al., 2018). Appendix B reports the selection parameters for the three regressions, whereas appendix C reports the bootstrapped PLS regression coefficients.

Secondly, the fitted PLS model was used to analyze the relation between the challenges and the resilience capacities. The model treats the variables by implementing Lasso penalization (Lê Cao et al., 2008; Perrin et al., 2020). Following González et al. (2012), we observed the relationships between the challenges and the resilience capacities through correlation circle plots. In correlation circle plots, the coordinates of the variables are obtained by calculating the correlation between each original variable and their associated component: the correlation between each variable and a component is simply the projection of the variable on the axis defined by the component. Thus, the plot is useful to synthetize the nature and strength of relationships between predictors and response variables.

2.4.3. Step 3: Monte Carlo simulations and predictions

All challenges were used for prediction under challenging scenarios, for two reasons. The first is that removing predictors does not contribute relevantly to improve the model (Mehmood et al., 2020). The second reason is that, to study the different challenging scenarios, we are interested in considering all challenges.

The three fitted regressions provided estimates of the challenges' coefficients necessary to predict robustness, adaptability and transformability. At this step, the values of each resilience capacity were predicted under six challenging scenarios, yielding 18 predicted outputs. Building upon formulation (1), the prediction model can be formulated as follows:

$$\widetilde{Y}_i = \widehat{\beta}_0 + \widehat{\beta}_1 \widetilde{X}_{1,s} + \widehat{\beta}_2 \widetilde{X}_{2,s} + \ldots \widehat{\beta}_{30} \widetilde{X}_{30,s} \quad (2)$$

Where $\widetilde{Y}_i$ is the probability distribution of the i resilience capacity (either robustness, adaptability or transformability), $\widehat{\beta}_s$ are the coefficients estimated in (1), and $\widetilde{X}_{30,s}$are the 30 challenges stochastically simulated under the s challenging scenario (either economic, social, institutional, environmental, shocks, or pressures). The outputs of (2) were analyzed by means of probability distributions and corresponding statistics, including the mean value, median, standard deviation, variance, skewness and kurtosis.

The construction of the six challenging scenarios obeys to the following approach. Each of the 30 challenges is classified as either economic, environmental, social and institutional. Moreover, challenges can belong to the category of shocks or, alternatively, long-term pressures. A scenario consists of stochastic simulations of the 30 challenges under certain assumptions. The assumptions are that, in a given scenario, one type of challenges is perceived very high, while the remaining challenges perform according to the observed values in the sample (Table 4).

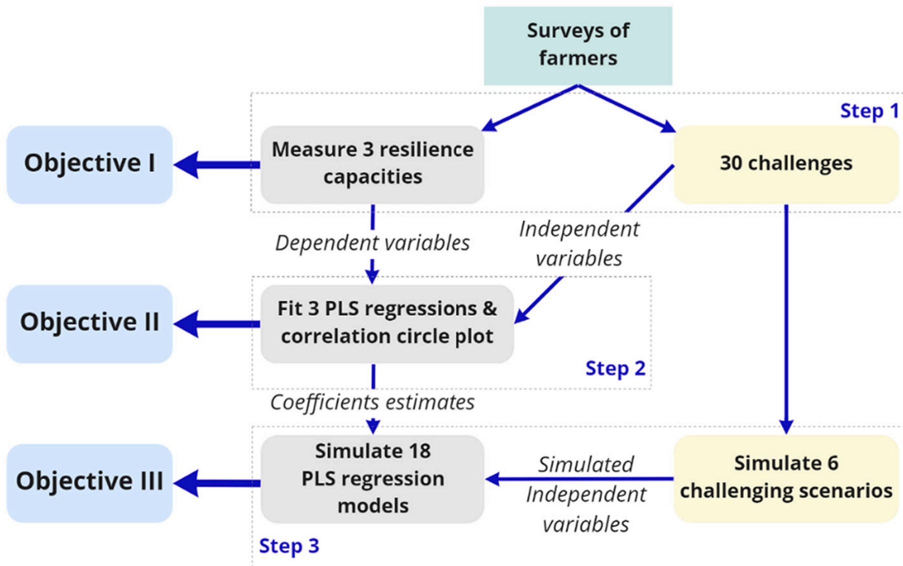

Fig. 2. Methodological steps to address the three specific objectives.

Table 4
Challenges simulated with high values across the six scenarios. ✓ means that corresponding challenges have been set as perceived very high.

Challenges	Challenging scenarios					
	Economic	Social	Institutional	Environmental	Shocks	Pressures
high_costs	✓				✓	
costs_fluct	✓				✓	
low_prices	✓				✓	
price_fluct	✓				✓	
sell_bargain.power	✓					✓
buy_bargain.power	✓					✓
credit_access	✓					✓
late_cashout	✓					✓
production_tech	✓					✓
trade_tech	✓					✓
info_access	✓					✓
strict_regulation			✓			✓
cap_reduction			✓			✓
competition			✓			✓
restricted_land.access			✓			✓
urban_limit			✓			✓
lack_of_workers		✓				✓
inability_to_work		✓			✓	
public_distrust		✓				✓
social_acceptance		✓				✓
work_commitments		✓				✓
depopulation		✓				✓
media_comunication		✓				✓
reduced_consumption		✓				✓
extreme_weather				✓	✓	
pests				✓	✓	
soil_quality				✓		✓
pasture_availability				✓		✓
land_abandonment				✓		
wildfauna				✓		

In the first place, we selected the best fitting distributions for each challenge. Since challenges were measured on a Likert scale, only discrete distributions were considered, namely: *Binomial*, *Uniform*, *Hypergeo*, *Poisson*, *Geomet*. The selection was done based on the Akaike Information Criterion (AIC): the lower the AIC, the better the fitting. All challenges' data fitted into either *Binomial* or *Uniform* discrete distributions.

Secondly, to simulate hypothesized high values for a type of challenges, we used *Binomial* distributions with minimum value 1, maximum 7, median 7 and mean value equal to 6.5, which on average yields 60% of simulated values equal to 7, about 30% equal to 6, and <10% equal to 5 or below. For example, to simulate the economic scenario (where economic challenges are particularly high), the challenges classified as economic were assigned with the hypothesized binomial discrete distributions (median 7 and mean 6.5). At the same time, the simulation of social, institutional and environmental challenges was performed based on the best fitting distributions and corresponding parameters. Same procedure was applied for shocks and pressures scenarios.

Monte Carlo simulations up to 10.000 iterations were applied, and the correlation matrix between the 30 challenges was used to take into account the interdependencies between challenges. As a result, we obtained six datasets of 10.000 observations each, corresponding to the six challenging scenarios, namely: economic, social, institutional, environmental, shocks, and pressures. Each scenario contains the $\widetilde{X}_1^{30}$ simulated challenges to be used in model (2) along with the coefficients estimated in (1). The analysis was carried out by using @Risk Palisade software, following the methods applied by Zinnanti et al. (2019) and Bertolozzi-Caredio et al. (2021b).

3. Results

3.1. Perceived challenges and resilience

Fig. 3 shows the farmers' perception of challenges grouped by type and farming system, whereas overall results from the joint sample are reported in appendix D. The breakdown by farming system reveals that there are variable differences in the perception of challenges, with this difference being most significant in some cases such as *depopulation*, *restricted_land.access*, *land-abandonment*, and *urban_limit*. Most importantly, almost all challenges are perceived higher in the sheep farming system of Huesca (though with variable differences). In overall term, the economic challenges perceived the highest by farmers are *low prices*, *production technologies* and *high costs*, while *access to credit* and *late cash out* are perceived less challenging. Regarding the social challenges, farmers seem more concerned about *media communication* and *public distrust*. ThWhen it comes to institutional challenges, the *reduction of CAP subsidies*, *strict regulations* (including the administrative burden), and high *competition* induced by the policy framework are the most challenging issues, whereas the constraints posed by the proximity to urban areas and corresponding regulations are perceived as less challenging. The *reduction of CAP subsidies* scores the highest overall. Lastly, the main environmental challenges affecting farmers are the conflicts with *wild fauna* and the increasing severity of *extreme weather* events. On the other hand, *soil quality* scores the lowest.

Fig. 4 shows the distribution of robustness, adaptability and transformability, their mean values, and the correlation between them. As described in section 2.3, starting from the nine statements of resilience collected through the surveys, indicators of robustness, adaptability, and transformability were measured as the average of the three corresponding statements. As shown by average scores and value distributions in Fig. 4, all three perceived resilience capacities score relatively low, considering that their mean values approach the centre of the 1–7 Likert scale. Transformability and adaptability are scored similarly, and perceived higher than robustness. Moreover, all three capacities are positively and significantly correlated with one another, but adaptability and transformability show a stronger correlation.

Significance level: *** p.value <0.001.

3.2. Main challenges affecting resilience

Fig. 5 shows the challenges based on their loading values on the PLS components, and their correlation with robustness, adaptability and transformability. To interpret the correlation plot (please, find more details in González et al., 2012), an angle with vertex on the center can describe the relation between the predicted value (ROBUS, ADAPT or TRANS) and the predictor (the challenges from 1 to 30). When the angle between a challenge (the predictor) and the capacity (predicted value) is sharp (<90°), relation is positive, if obtuse (>90°) otherwise. The longer the distance between the predicted value and the predictor (summing up the length of the axes of the defined vertex), the strongest the relation. For example, the challenge *reduced_consumption* (Carpenter et al., 2001) has a positive and strong correlation with all three capacities, whereas *pasture_availability* (Fau, 2016) has a strong, negative correlation with the three capacities.

The three challenges *access to information (*Bertrand et al., *2014)*, *reduction of consumption* (Carpenter et al., 2001) and *trade technologies (*Bertolozzi-Caredio et al., *2021c)* have strong positive correlation with the resilience capacities. This relationship could indicate that farmers highly perceiving these challenges also perceive themselves as highly resilient. Most of the challenges, however, show negative correlation with the resilience capacities, and mainly with robustness and transformability. Regarding institutional challenges, the *reduction of CAP subsidies (*EEA, *2019)*, *strict regulations* (EC, 2020) and *restricted land access* (ESPON, 2018) show the strongest negative correlation with the three capacities, and mainly with adaptability and transformability. The challenge of *competition* (EC, 2019) induced by the policy framework

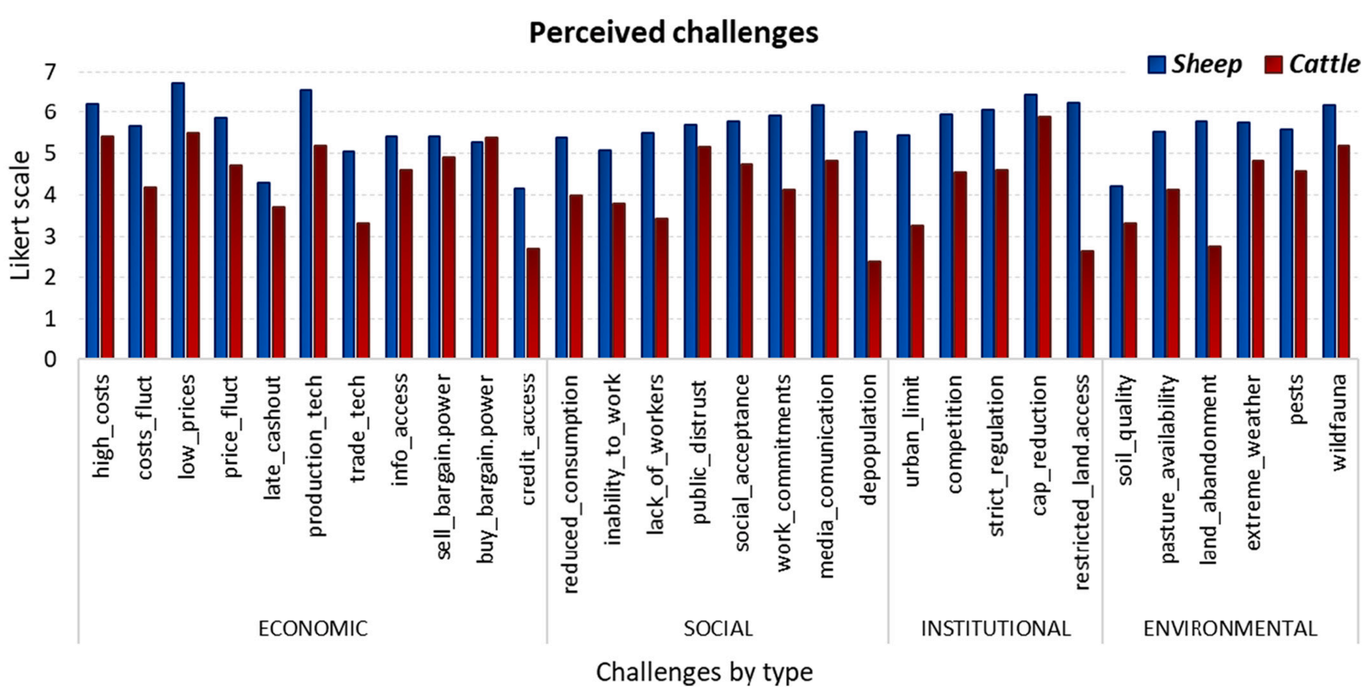

Fig. 3. The farmers' perception of future challenges by type and farming system.

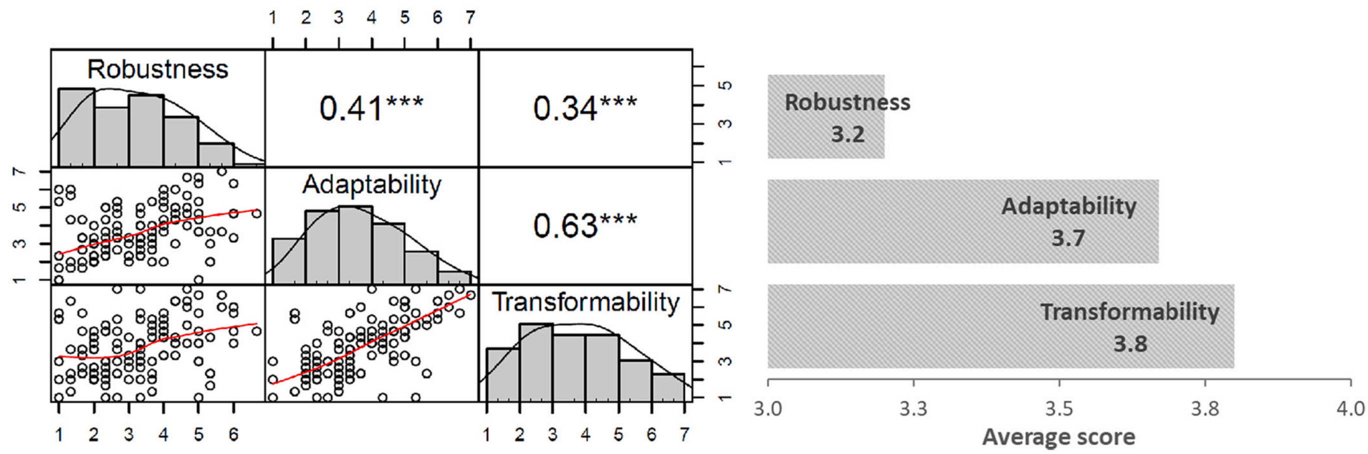

Fig. 4. On the left, the distribution of values of the three perceived resilience capacities and their correlation; on the right, the average score corresponding to the perceived resilience capacities.

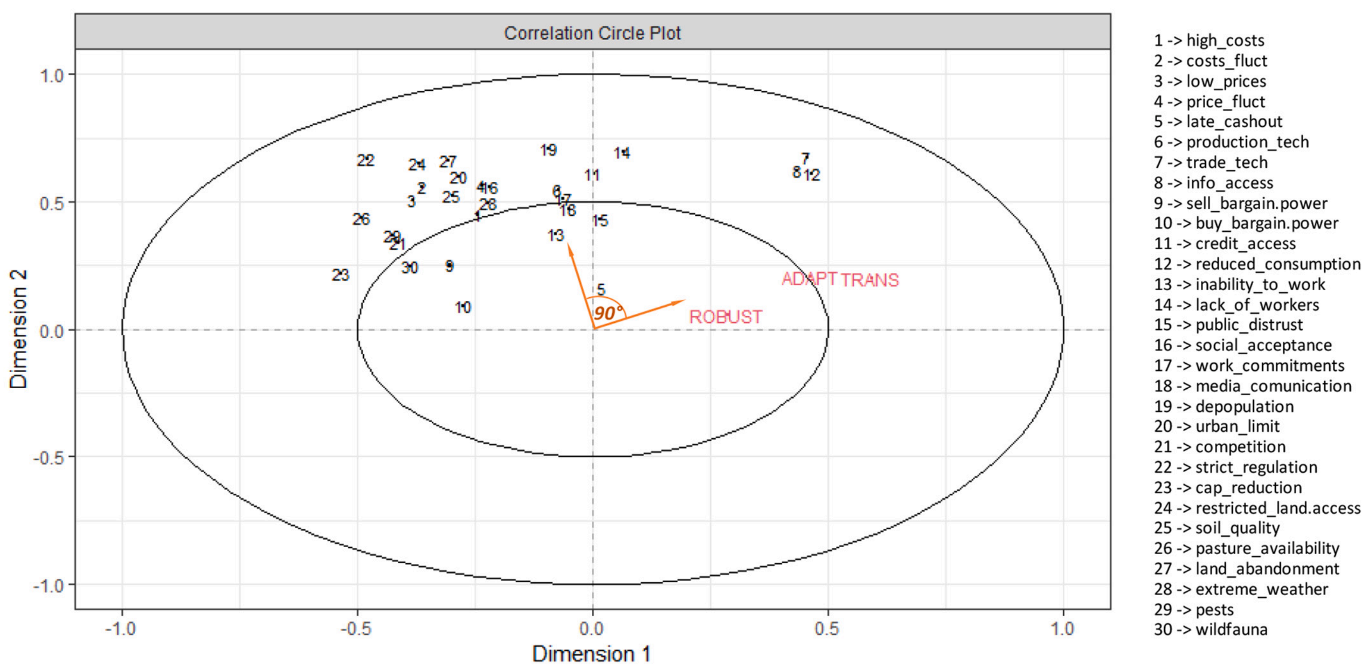

Fig. 5. Correlation plot showing the correlation between the challenges (numbered from 1 to 30) and the three resilience capacities of Robustness (ROBUS), Adaptability (ADAPT) and Transformability (TRANS). On the right, the legend with the 30 challenges.

have strong, negative correlation as well. Likewise, observing the environmental challenges, the *availability of pastures (*Fau, *2016)*, *land abandonment* (Folke et al., 2010) and the risk of (animal) *pests* (González et al., 2012) show strong negative correlation, again, stronger with adaptability and transformability. These results, therefore, suggest that adaptability and transformability might perform worse under environmental and institutional scenarios. Also, the economic challenges due to *low selling prices* (Becking et al., 2019) and the *fluctuation of production costs* (Bertolozzi-Caredio et al., 2020) have negative correlation with the resilience capacities, though weaker than for the other challenges. Among the social challenges, only *social acceptance* (Darnhofer et al., 2010) and the *inability to work* (Carrascal et al., 2009) show a clear negative correlation.

3.3. Resilience capacities under challenging scenarios

Fig. 6 shows the probability distributions (PDs) of the resilience capacities under economic, social, institutional, environmental, shocks and pressures challenging scenarios, based on the output of the PLS regression predictions. The PDs help identify significant differences in the resilience performance based on the range of potential outputs obtained under specific scenarios. Besides, Table 5 reports the statistics and results of the performed simulations for the three resilience capacities under the six challenging scenarios.

Robustness's mean values are always lower than adaptability' and transformability's ones, except under the environmental scenario. Accordingly, robustness is also the least scored based on farmers' perception (see Fig. 4 in previous section). However, robustness performs best under the environmental challenging scenario; that is to say, robustness might be less affected by environmental challenges or, by other interpretation, more effective against this type of challenges.

The PDs of adaptability and transformability show lower performance under environmental and institutional scenarios, as opposite to social and economic scenarios, where adaptability and transformability

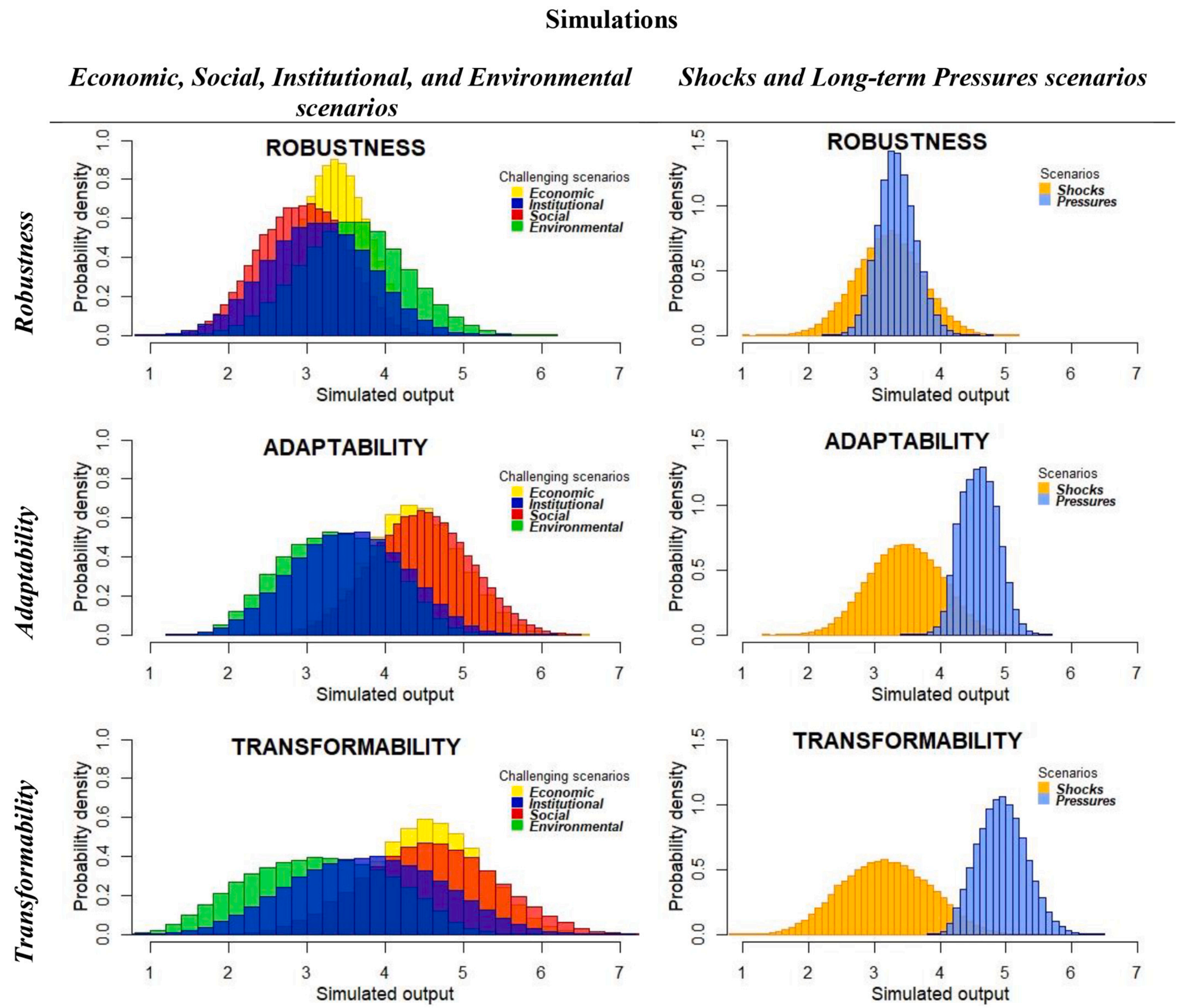

Fig. 6. Probability distributions of the predicted resilience capacities under four challenging scenarios, by farming system.

perform better. Adaptability reaches on average the values of 3.5 and 3.4 for institutional and environmental challenges, much lower than the mean values under the economic and social scenarios (4.4 and 4.5. respectively). Likewise, transformability performs the worse under environmental challenges (3.1) followed by institutional challenges (3.8), while it reaches the average value of 4.6 for economic and social challenges. Consequently, adaptability and transformability appear adequate to deal with socio-economic issues, but less to face environmental and institutional challenges. In particular, transformability seems less effective to environmental challenges. The strong negative correlation of institutional and environmental challenges such as *cap reduction*, *competition*, *pasture availability*, *land abandonment* and *restricted land access* (as detected in the correlation plot in the previous section), therefore, contribute to explain why adaptability and transformability perform worse under environmental and institutional scenarios.

On the other hand, robustness shows the worst outputs under social and institutional scenarios, achieving mean values of 2.9 and 3.2, respectively (against values of 3.4 and 3.6 for economic and environmental challenges). Robustness, therefore, performs better under economic and environmental scenarios, which might suggest better efficacy of this capacity to deal with these challenges.

The three capacities perform better under pressures scenario than under shocks scenario, achieving mean values of 3.3 (robustness), 4.6 (adaptability), 4.9 (transformability). However, the difference with shocks scenario is very marked for adaptability (4.6 against 3.5) and transformability (4.9 against 3.2), but not relevant for robustness (3.3 against 3.2). Summing up, the more we move from robustness to adaptability and transformability, the highest the impact of shock scenarios. This might indicate that adaptability and transformability have better effect on pressures in the long-term (unlike robustness), but are less effective in coping with sudden shocks in the short-term.

4. Discussion

4.1. Perceived challenges and resilience capacities

The picture drawn by the analysis of challenges perceived by the farmers reflects the main threats affecting extensive livestock systems across Spain and the EU. Farmers perceive the reduction of CAP subsidies as a crucial challenge, which fits into the European context. In fact, livestock farms are strongly dependent on subsidies (EU Farm

Table 5
Statistics of the performed simulations for robustness, adaptability and transformability under economic, social, institutional, environmental, shocks and long-term pressures challenging scenarios.

		CHALLENGING SCENARIOS					
CAPACITIES		ECONOMIC	SOCIAL	INSTITUTIONAL	ENVIRONMENTAL	SHOCKS	PRESSURES
Robustness	mean	3.4	2.9	3.2	3.6	3.2	3.3
	median	3.4	2.9	3.2	3.6	3.2	3.3
	std.dev.	0.4	0.5	0.7	0.7	0.5	0.3
	variance	0.2	0.3	0.4	0.4	0.3	0.1
	skewness	0.0	−0.1	0.0	0.0	0.0	0.2
	kurtosis	−0.1	−0.4	−0.2	−0.2	−0.1	0.1
Adaptability	mean	4.4	4.5	3.5	3.4	3.5	4.6
	median	4.4	4.5	3.5	3.4	3.5	4.6
	std.dev.	0.6	0.6	0.7	0.7	0.5	0.3
	variance	0.3	0.4	0.5	0.4	0.3	0.1
	skewness	0.0	0.0	0.0	0.0	0.0	0.1
	kurtosis	−0.2	−0.3	−0.4	−0.6	−0.3	−0.4
Transformability	mean	4.6	4.6	3.8	3.1	3.2	4.9
	median	4.6	4.6	3.8	3.2	3.2	4.9
	std.dev.	0.7	0.8	0.9	0.9	0.7	0.4
	variance	0.4	0.7	0.9	0.8	0.4	0.1
	skewness	0.01	0.01	0.01	−0.01	0.02	0.2
	kurtosis	−0.26	−0.27	−0.42	−0.67	−0.4	−0.24

Economics Overview, 2018), which implies high vulnerability to policy changes (de Rancourt et al., 2006; Soriano et al., 2018). Farmers are also concerned about social acceptance, public distrust, and media communication, which are related to the changing consumer habits and preferences, resulting in the reduction of meat consumption (Henchion et al., 2014). As shown in previous research (Boogaard et al., 2011; Clark et al., 2016), livestock systems, particularly, suffer from a negative or undervalued public perception. Besides, in line with previous research in the case study areas (Bertolozzi-Caredio et al., 2021b; San Martìn et al., 2020), farmers stress the issues related to low prices and high costs, and highlight the conflicts with wild fauna and increasing vulnerability to extreme weather events.

Livestock farms can rely on different resilience capacities to keep providing private and public goods/services despite challenges. There are differences, however, in how these capacities are perceived by farmers. In fact, robustness is perceived weaker than adaptability and transformability that, in turn, are perceived similar to one another and strongly correlated. That is to say, under current conditions, farmers perceive themselves more capable to adapt or transform than to persist in the same configuration. The sector is undergoing important transformations affecting a wide range of livestock farms, which are reorienting to more diversified, intensive or, simply, different productions (Pardos et al., 2008; Becking et al., 2019; Bertolozzi-Caredio et al., 2021a). This context might contribute to explain the farmers' perception, as they could identify themselves locked into an on-going dynamic of change.

The similarity of results between adaptability and transformability may induce one to argue that these two capacities are extremes of a gradient of modification, i.e., they reflect different degrees of change occurring on the farm. By theoretical definition (Meuwissen et al., 2019), in fact, the two capacities are about marginal or significant changes in response to challenges (as opposite to robustness), which difference is basically the preservation or not of the system's identity. Besides the definitions, the relationship among these capacities may contribute to explain why these capacities come together. This interpretation is consistent with the conceptualization by Darnhofer (2014) and Daugstad (2019), according to which adaptability can be functional to bouncing forward to a new configuration (transformability), likely through a series of incremental adaptations over time (de Kraker, 2017).

Slijper et al. (2021) measured and mapped the three resilience capacities based on FADN data across the EU: in line with our findings, robustness appears weak in Aragón and the Community of Madrid, though adaptability and transformability seem to be weak as well. Instead, previous research on extensive sheep farming in Aragón demonstrates that farmers' robustness is weaker under current conditions, while transformability seems to be favoured by the policy and market environment (Bertolozzi-Caredio et al., 2021a).

4.2. *Perceived resilience capacities under economic, social, institutional and environmental challenges*

Yet, according to the PLS simulations, perceived resilience capacities show diverse performance under different challenging scenarios. In fact, adaptability and transformability were higher under social and economic scenarios than under environmental and institutional, suggesting that livestock farms have a stronger capacity to adapt and transform in the face of socio-economic challenges, but weaker against institutional and environmental ones. In line with our results, a recent study on five different farming systems in the EU (Nicholas-Davies et al., 2021) reveals that mainly socio-economic drivers trigger adaptability and transformability. Our findings, in turn, warn about the current opportunity to achieve environmental goals for the EU agricultural agenda. If livestock farms are less able to adapt and transform in the face of environmental and climate challenges, policymakers should be even more concerned over livestock adaptations for the achievement of the Green Deal and CAP sustainability ambitions.

On the other hand, robustness performs better under economic and environmental challenges, but perform poorly under social and institutional challenges. Economic and environmental dimensions account for numerous shocks in our framework: by nature, robustness is the capacity to absorb shocks through reserves and buffer capacities (Walker et al., 2004), which can explain the higher performance under these challenging scenarios. Instead, with regard to the social dimension, the considered social challenges are by nature developing over relatively long periods. This aspect might contribute to explain why adaptability and transformability perform better than robustness in dealing with these social issues. In addition, social challenges consist mainly of worsening social acceptance, trust and media communication, which require changes either at marketing or production orientation level to meet social expectations and changing consumers' preference (Dumont et al., 2018).

Overall, all capacities perform poorly under institutional challenges, though transformability performs slightly better than the others, which corroborates previous studies on sheep farming in Aragón that explain how the current policy framework might favour transformability (Bertolozzi-Caredio et al., 2021a). A first reason for the poor performance could be that livestock farmers have experienced a significant decline alongside the decoupling and reduction of CAP payments, payments' asymmetries exacerbating the unfair competition, and increasing liberalization (EU Farm Economics Overview, 2018; Soriano et al., 2018; Ramírez-López et al., 2020). In this context, and based on their experiences, farmers might perceive themselves not able to cope with further policy changes. Accordingly, a policy assessment carried out in the case study regions (Soriano et al., 2018) suggests that the current policy framework constrains the three resilience capacities, as opposite to, for example, the case of extensive cattle farms in France (Léger, 2018) and arable farms in The Netherlands (Buitenhuis et al., 2020) for which robustness is enhanced. Unlikely, Manevska-Taseuska et al. (2021) find that policy adaptive processes have no significant influence on the resilience capacities of the eggs and broiler sector in Sweden. The policy effect on resilience, therefore, seems context-specific and, in our case, counteracting the current policy ambitions to improve the resilience of farming systems (EC, 2020; Roche Ramo, 2021). Policy changes, in fact, might pose challenges to extensive livestock farms and risk to undermine their resilience, which is relevant aspect in light of the forthcoming CAP reform 2023–2027.

4.3. Perceived resilience capacities under shocks and pressures

Adaptability and transformability appear more affected by shocks than by pressures. Similarly, Nicholas-Davies et al. (2021) found that few shocks can drive adaptability in different European farming systems. This evidence might suggest that farmers are more confident about their capacity to adapt and transform when challenges occur over middle-longer periods. Besides, it should be considered that livestock farms, typically, are less flexible than other productive orientations, mainly due to their reliance on fixed capital and public subsidies (EU Farm Economic Overview, 2018; Bertolozzi-Caredio et al., 2021c). These findings generally corroborate the theoretical notions for which the capacities to adapt and transform take place over relatively long periods. Transformability can be pursued through a series of incremental marginal adaptations over time, when adaptability contributes to bounce forward to another configuration of the system (Darnhofer et al., 2010; Daugstad, 2019). As pointed out by Carpenter et al. (2001), adaptive capacities might depend on the development of novelties and innovations, which require time to be learned and implemented, making adaptability and transformability adequate for dealing with challenges in the long-run.

Folke et al. (2010) describes transformability as also triggered by crisis, extreme situations suddenly pushing farmers beyond the boundaries of the status quo towards different development trajectories. In our paper, though, this dynamic is not captured and there are no clues on the effectiveness of transformability in coping with sudden shocks. This could be justified by the fact that farmers' perception can describe the capacity to transform through a deliberate process occurring over time, but cannot identify the capacity to transform in the face of sudden and unexpected disruptions. Accordingly, based on their study across EU, Nicholas-Davies et al. (2021) explain that farmers do not assign great importance to shocks in their narratives, but they accept shocks as part of expected variation or background noise. Yet, our results might simply indicate that, in the cases under study, farmers do not perceive themselves able to transform in the face of shocks, which would be consistent with the relatively low structural flexibility of livestock farms to change.

4.4. Methodological considerations

The use of a predictive model was functional to the study of resilience capacities under hypothesized scenarios, rather than to projecting probable, future scenarios. The PLS model, therefore, is not intended to generate knowledge on what will happen, since scenarios were arbitrarily drawn, but to indicate which resilience capacities may help deal with different types of challenges. Yet, farmers' perception of challenges provides indications about threats that may have a relevant impact in future. The combination of survey data, PLS regressions and stochastic simulations appears to be effective and flexible in studying resilience constructs and may be profitably replicated or improved in future research.

Resilience is a latent property, unknown until a system's reaction to challenges become evident. Hence, farmers' ability to measure their own resilience can be limited. However, the approach provides a reliable indicator based on farmers' knowledge. In fact, farmers can be assumed to be most aware about their farms' ability to persist, adapt and transform. Resilience assessments based on farmers' perception might come with cognitive bias and misunderstanding of the resilience concepts (Herrera, 2017; Perrin et al., 2020). Still, as for previous studies (Spiegel, 2019; Slijper et al., 2021), resilience capacities were derived from the use of composite indicators built upon theory-based questions ensuring higher reliability of the measurement and mitigating the bias.

Compared to farmers' surveys, multi-actor approaches may help bring together different perspectives to quantify and study resilience at wider scale, such as supply chain (e.g. Vroegindewey and Hodbod, 2018) or farming systems (e.g. Reidsma, 2019), where diverse components increase the system's complexity (Kerner and Thomas, 2014). Although multi-actor methods help foster discussion and converge to more comprehensive results, the approach is still subject to bias and potential misunderstanding of resilience concepts (e.g. resilience might be understood differently among actors) (Herrera, 2017). In our case, resilience was assessed at farm level, which explains the use of surveys to build the research from farmers' knowledge.

5. Conclusions

The paper presents a mixed quantitative methodology based on Partial Least Square model and Monte Carlo simulations to observe the resilience capacities of robustness, adaptability and transformability of Spanish extensive livestock farms under six challenging scenarios, namely economic, social, institutional, environmental, shocks and pressures. Farmers rely on different resilience capacities to keep delivering their products and services despite challenges, and perceive their transformability and adaptability higher than robustness. However, this paper shows that the effectiveness of such capacities may vary depending on the nature of the challenges to deal with.

First, the results reveal that adaptability and transformability, seem to be effective under socio-economic challenges but weaker under environmental and institutional ones. However, robustness appears to be more effective against economic and environmental challenges but less relevant dealing with social and institutional. All capacities perform poorly under institutional challenges, mainly due to the impact of reduced CAP payments and policy-induced unfair competition. Such evidence warns about the current capacity of extensive livestock farms to adapt and transform in face of growing environmental and climate threats, and casts light on their vulnerability to policy changes, which is particularly relevant in light of the forthcoming CAP reform 2023–2027.

Second, adaptability and transformability are less effective under shocks but perform better under long-term pressures, whereas robustness performs poorly under challenges either in the short- or long-run. These findings stress the long-term nature of adaptability and transformability, while no clue is revealed regarding the potential role of these capacities to cope with sudden shocks.

Future research may bring theoretical advances by further exploring the relation between capacities and challenges to understand whether these relationships can be generalized. Also, further investigating the challenges posed by the policy and governance framework may benefit a more informed policymaking, above all in light of the new CAP 2023–2027. Lastly, methodological advances could be reached by assessing resilience under realistic forecasted scenarios, building resilience indicators from multiple sources to reduce bias, or by replicating this study in other cases for comparison and generalization.

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

Data will be made available on request.

Acknowledgments

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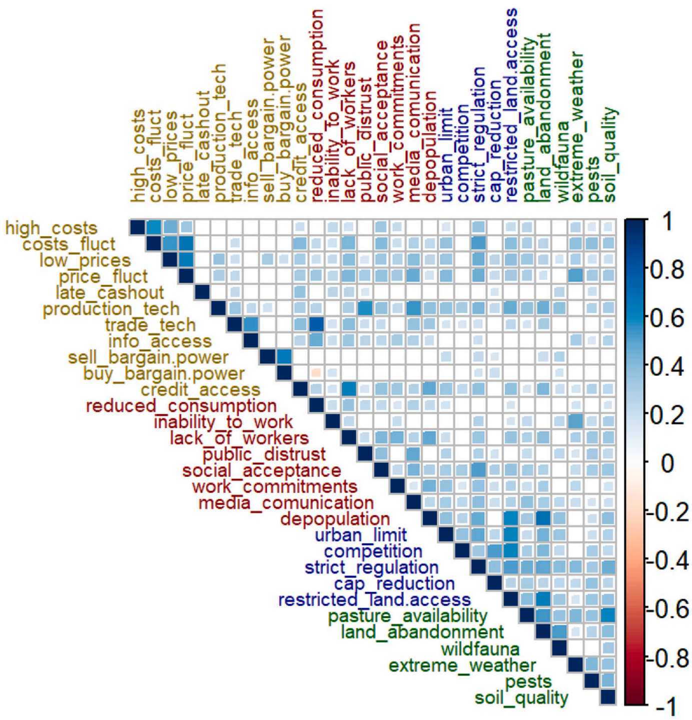
Appendix A. Challenges' collinearity

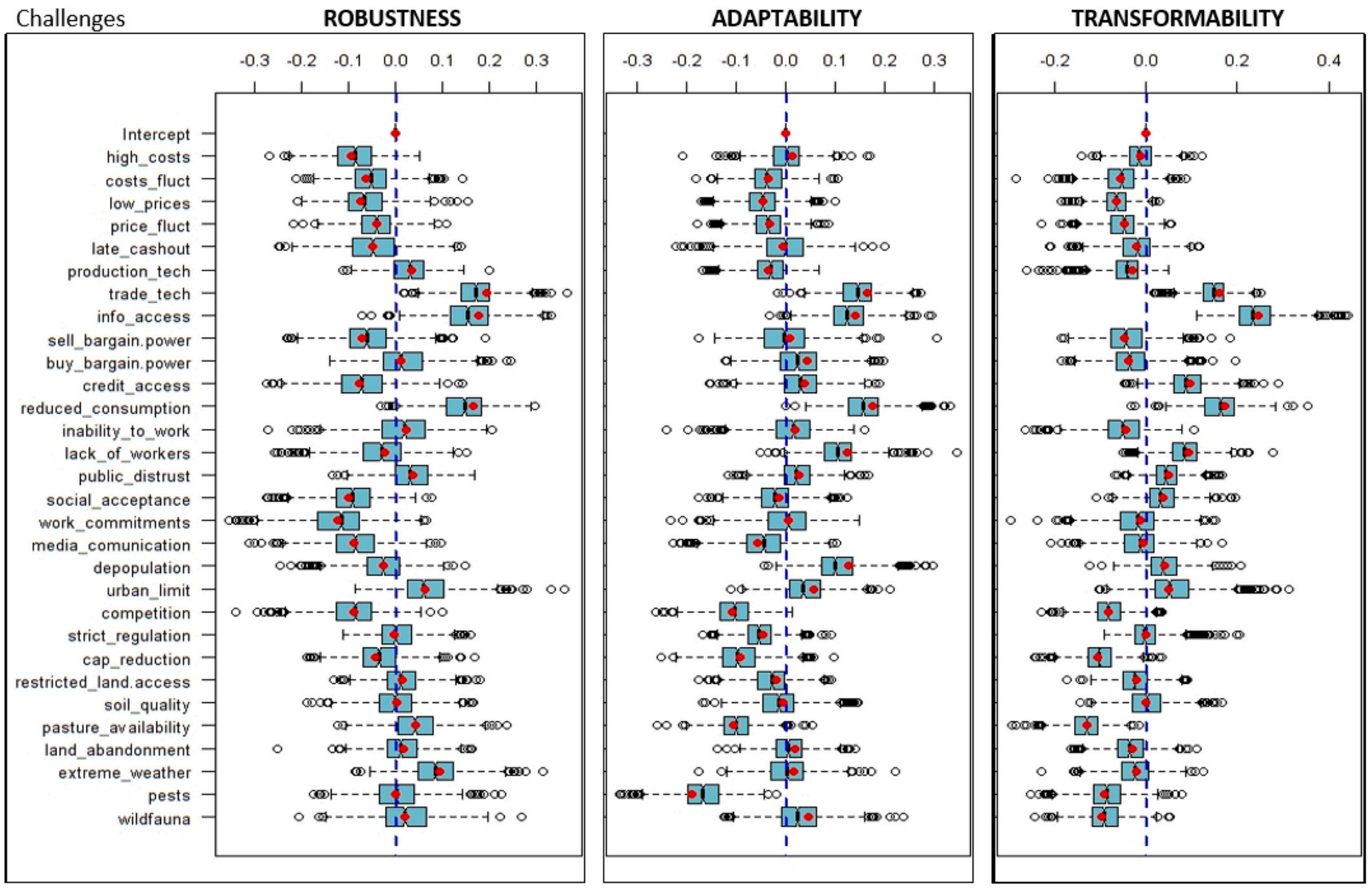


Factors	Eigen values	Ratio (kappa)
1	8.41718694	97.64285
2	2.56656210	
3	2.25676050	
4	1.72610536	
5	1.67771678	
6	1.58823248	
7	1.29940253	
8	1.12259853	
9	1.01369	
10	0.9481334	
11	0.793338	
12	0.7695086	
13	0.6188497	
14	0.5762042	
15	0.5300578	
16	0.4910602	
17	0.4674393	
18	0.4169099	
19	0.3454415	
20	0.336144	
21	0.3153298	
22	0.3018618	
23	0.2915937	
24	0.2381861	
25	0.1976604	
26	0.1817522	
27	0.1660938	
28	0.1413205	
29	0.118648	
30	0.0862038	

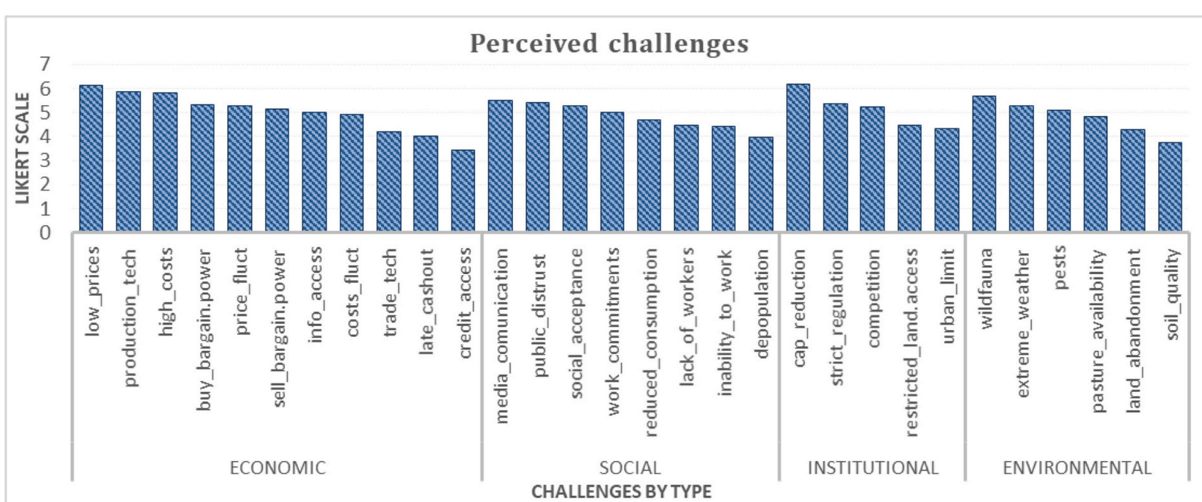
Appendix B. Partial Least Square component selections and parameters

Capacities	No. of components	Q2	Q2 cum	R2	PRESS
Robustness	*2*	*0.0404*	*0.0383*	*0.2468*	*183.18*
Adaptability	*1*	*0.0795*	*0.0795*	*0.2834*	*200.974*
Transformability	*1*	*0.2365*	*0.2365*	*0.367*	*214.66*

Appendix C. Bootstrapped partial least square regression coefficients



Appendix D. Perception of challenges in the overall sample



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