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How do farm and farmer attributes explain perceived resilience?

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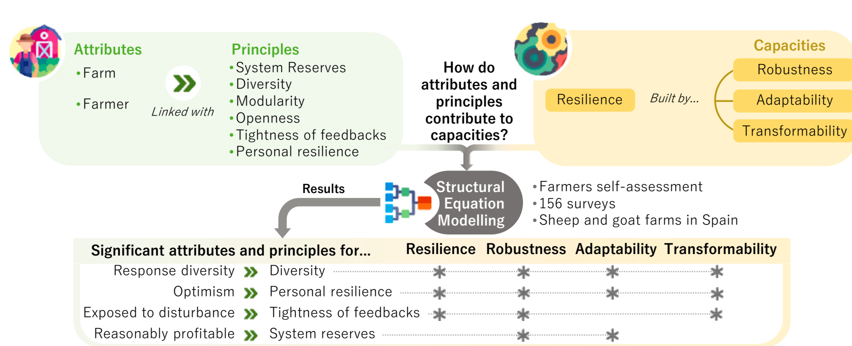
HIGHLIGHTS

- Farm(er) attributes explain farmerś perceived robustness, adaptability and transformability.
- Farmerś perceived resilience can be quantified with attributes and principles by Structural Equation Modelling.
- Personal resilience, diversity and tightness of feedbacks explain farmerś perceived resilience.
- Optimistic farmers with diverse alternatives to face challenges perceive farms as more resilient.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Uncertainty surrounds farming systems across Europe and strengthening their resilience lies at the centre of the European policy agenda. Although farming systemś resilience has been widely conceptualised, no consensus has been reached about assessing the contribution of farm and farmer attributes to farmerś perceived resilience by quantitative approaches.

OBJECTIVE: The aim of this study was to understand what farm(er) attributes and principles contribute to explain farmerśperceived resilience. Our specific objectives are to: i) develop a conceptual framework composed of attributes, principles and capacities to assess farms' resilience, including farmer personal resilience as a

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Resilience indicators
Structural equation modelling
Small ruminants

resilience principle; ii) quantify links between farm attributes and resilience principles with farmers' perceived resilience capacities.
METHODS: We developed a framework that includes different farm and farmer attributes grouped into resilience principles. We designed and conducted a structured survey to allow small ruminant farmers in Spain to self-assess their resilience attributes and capacities. We used structural equation modelling to assess to what extent resilience attributes and principles explain perceived robustness, adaptability, transformability capacities and overall resilience.
RESULTS AND CONCLUSIONS: Farmers' perceived resilience can be explained by several resilience attributes and principles, including farmers' personal resilience. Some attributes contribute similarly to robustness, adaptability and transformability, while others contribute particularly to each capacity.
Farm diversity, tightness of feedbacks and farmers' personal resilience were key for explaining farmers' perceived resilience for small ruminant farming systems in Spain. In particular, farmer optimism, and farms' ability to respond in different ways to challenges and to overcome difficulties in the past, were the attributes that most influenced resilience perceptions. Our results highlight the importance of farmer personality, in addition to farm characteristics, for understanding farmers' resilience perceptions.
SIGNIFICANCE: This study contributes to the development of quantitative farm resilience assessments by considering multiple farm attributes and also several farmers' psychological attributes. Our framework provides a list of attributes and principles that can be applied to different farming systems. We provide a specific approach to identify the most relevant attributes and principles that drive perceived resilience in a large set of them that could guide farm and stakeholders' decision making.

1. Introduction

Agricultural systems face numerous economic, social, environmental and political challenges that affect their dynamics in the short and long terms. In recent years, shocks like the COVID-19 pandemic or the Russian Invasion of Ukraine have threatened agricultural systems around the world by showing their vulnerability to unexpected events (Abay et al., 2023; Meuwissen et al., 2021; Rivera-Ferre et al., 2021). Other factors, such as climate change (Arora, 2019) or lack of farm succession in Europe (Pitson et al., 2020; Zagata and Sutherland, 2015), highlight the need to rethink agricultural production to ensure the continuity of farming systems. In this context, resilience theory stands out as an appropriate framework to take farming systems to the next era because resilience considers uncertainty and change as part of the future (Darnhofer, 2014). Indeed, improving resilience has become a main target of political agendas. For example, the first objective of the 2021-2025 European Common Agricultural Policy reform is "to strengthen the resilience of agrifood systems".

The resilience of a farming system is often defined as "its ability to ensure the provision of the system functions in the face of increasingly complex and accumulating economic, social, environmental and institutional shocks and stresses" (Meuwissen et al., 2019). Two types of resilience are distinguished (Folke et al., 2010): *general resilience,* which refers to the capacity to cope with all types of challenges, including completely new ones; *specific resilience,* which refers to the capacity to cope with a particular challenge (e.g., climate change).

Resilience is usually seen as a latent property that emerges in farming systems when challenges arise (Meuwissen et al., 2021). It enables them to cope with difficulties through three capacities: robustness, adaptability and transformability (Darnhofer, 2014; Folke et al., 2010; Meuwissen et al., 2019). Robustness is understood as the ability to withstand challenges without changing the structure of the system. Adaptability is the ability to readjust the system's structure whenever necessary. Transformability is the ability to completely change the system's structure to meet challenges. Thus, resilience thinking moves away from a stability perspective to integrate the ability to change as a requirement for farming systems' persistence (Darnhofer, 2014).

Five characteristics of farming systems are usually identified as the conditions that enable general resilience (Meuwissen et al., 2019; Resilience Alliance, 2010): system reserves, diversity, modularity, tightness of feedbacks and openness (see Table 1 for definitions). They are referred to as *resilience principles* (Paas et al., 2021a; Reidsma et al., 2020). These principles comprise more specific system characteristics, referred to as *resilience attributes* (Paas et al., 2021a; Reidsma et al.,

Table 1
Resilience principles included in the study. Definition and logic of their impact on farm resilience.

Principles	Definition	Impact on farm resilience
System reserves[1]	Natural, economic and social capital that the farm can access (Reidsma et al., 2020)	Farm reserves (i.e., natural, human, social, infrastructure, economic capital) can both buffer and compensate for losses due to disturbances and to invest for changes needed in systems to adapt or transform during and after disturbance
Diversity[1]	The degree of farm variation. This may include functional diversity, i.e., the degree of the variations of the components that maintain similar functions; or response diversity, i.e., the degree of the variations of components representing different responses to disturbances (Kharrazi et al., 2020)	Diverse farms are more flexible because they can follow a wide range of ways to face disturbances
Modularity[1]	Property of a system whose components can be separated or integrated without any change in their properties or in those of the rest of the system (Kharrazi et al., 2020).	Farms with high modularity can isolate a module and limit the spread of shocks across other system components so they can limit the potential of cascading damages
Openness[1]	Connectivity on the farm and with other systems beyond (Reidsma et al., 2020)	Connection with the stakeholders outside the farm, inside or outside the agricultural sector, helps to create the enabling environment for innovations to maintain or improve farms' functioning and to timely introduce changes
Tightness of feedbacks[1]	The degree to which the farm and its (natural and social) subcomponents and processes can create signals and interact in reaction to internal and external signals from other overarching systems. This includes signals from slow variables and feedbacks (Reidsma et al., 2020)	Feedbacks within and between the natural and social components of farms allow them to respond quickly to disturbances, which enables farmers to avoid dangerous thresholds
Personal resilience	Farmers' ability to successfully adapt to adversity, stressful life events, significant threats, or trauma (Feder et al., 2019)	Farmers are at the forefront of farm management and their psychosocial factors influence their responses to challenges (Béné et al., 2019; Darnhofer, 2014)

[1] *Principles included in the resilience framework proposed by the* Resilience Alliance (2010).

2020). Based on this, farming systems' resilience is usually conceptualised with a sequential structure, from specific characteristics (i.e., resilience attributes hereafter) to more general characteristics (i.e., resilience principles hereafter) that enable resilience capacities (i.e., robustness, adaptability and transformability) (Meuwissen et al., 2019; Reidsma et al., 2020). Previous research has focused on the relation between resilience attributes and resilience capacities (Nera et al., 2020; Paas et al., 2021a; Reidsma et al., 2020). However, the full sequential structure, including resilience principles, has not been used to operationalise resilience assessments. This paper addresses the question of how this sequential structure can help to operationalise resilience assessments, and to quantify the links among resilience attributes, principles and capacities.

Some authors note that resilience implies not only system characteristics, but also farmers' capacity to face challenges (Darnhofer, 2014; Soriano et al., 2023). In the humanitarian aid and food security field, personal attitudes like risk perception and self-efficacy have influenced crises management strategies by highlighting that psychological aspects can act as drivers of household resilience (Béné et al., 2019). In psychology, optimism, self-efficacy or positive emotions have been linked with personal resilience, which is defined as the ability to adapt successfully to adversity, stressful life events, significant threats or trauma (Feder et al., 2019). Finally in agriculture, some studies have found that farmers' views, psychological characteristics and attitudes (i.e., risk perception, optimism and job satisfaction) influence their perceived resilience (Nicholas-Davies et al., 2021; Perrin and Martin, 2021; Spiegel et al., 2021). However, no study has included personal resilience in quantitative resilience assessments in agriculture as an additional principle for building resilience.

A farming system can be defined as a collection of farms with common characteristics that may differ in terms of resource base, business patterns, household livelihoods and constraints (Giller, 2013). Farms are the operation units on which farmers make decisions, which lead to diverse outcomes that determine farm resilience. For example, the decision of involving children in farming activities can improve the farm succession potential and, therefore, farm resilience (Bertolozzi-Caredio et al., 2020). Consequently, responses to different challenges vary across the individual farms that belong to a particular farming system (Nicholas-Davies et al., 2021). In a broad sense, a farming system's resilience relies on that of individual farms because they provide specific farming system functions (i.e. private and public goods) (Meuwissen et al., 2022). In addition, both the number of stakeholders, and the diversity of skills and capabilities that define their management capacities, are fundamental determinants of social-ecological systems' resilience to global change (Grêt-Regamey et al., 2019). Thus, farm resilience analysis helps to upscale the factors (farmer and farm) that determine the dynamics of farming systems (Darnhofer, 2014). We also need to consider that the attributes which contribute to resilience can vary depending on both the scale (i.e. farm or farming system) and context being studied (Feindt et al., 2022). Previous research has focused on studying resilience on the farming systems scale, but not on farms as functional units that determine the operations of farming systems (Boahen et al., 2023).

As implied by the various above-discussed aspects, assessing farm resilience is challenging given its multidimensional and latent nature (Cumming et al., 2005). Typically, resilience assessments rely on two approaches: i) an objective approach based on farm characteristics that are measured independently of people's judgements; ii) a subjective approach based on participatory methods like surveys or interviews that reflect people's perceptions of their own resilience (Jones, 2018). Subjective and objective approaches are not mutually exclusive, but form a continuum in which different gradients of objectivity and subjectivity are usually found, and both approaches can complement one another (Jones, 2018). The so-called objective approaches usually allow fixed quantitative results to be obtained, which derive from specific farm characteristics. However, they fail to account for contextual and personal factors. A comparison of different farming systems and socio-economic contexts using objective indicators is often unreliable because not all farm characteristics can be measured equally in all cases (Jones, 2019). The so-called subjective approaches allow the intangible aspects of resilience to be captured (Jones, 2019) and a comparison of farms in different socio-economic contexts to be done (Clare et al., 2017). Subjective approaches offer advantages for studying resilience in agriculture. This is because: firstly, farming systems are complex social-ecological systems and it is, therefore, difficult to capture the multiple dimensions of resilience using objective approaches (Clare et al., 2017); secondly, farmers respond to challenges based on their perceptions (Spiegel et al., 2021). Subjective assessments of farm resilience place a high value on farmers' cognitive ability to assess the current state of their farms and the potential for implementing changes (Perrin and Martin, 2021). Thus, subjective assessments may help to understand what resilience means to different people and what aspects should be addressed to improve farm resilience (Jones and Tanner, 2017).

Some studies have used farmers' perceptions to explore how some farm(er) attributes may individually enhance resilience capacities (Ashkenazy et al., 2018; Bertolozzi-Caredio et al., 2021; Slijper et al., 2022b; Spiegel et al., 2021). Other studies have explored the quantitative relations between attributes and capacities by following participatory assessments (Nera et al., 2020; Paas et al., 2021a; Reidsma et al., 2020). However, the contribution of a large number of farm(er) resilience attributes and principles to resilience capacities is still ambiguous and difficult to assess (Paas et al., 2021a). As far as we know, no study has quantified the relations among resilience attributes, principles and capacities to study farmers' perceived resilience.

The aim of this study was to understand what farm(er) attributes and principles contribute to explain farmers' perceived resilience. To do so, we pursued two objectives to: i) develop a conceptual framework composed of attributes, principles and capacities to assess farm resilience, including farmers' personal resilience as a resilience principle additionally to those proposed in the farming systems literature; ii) quantify the links between attributes and principles with farmers' perceived resilience capacities to identify which ones more significantly explain these perceptions. To operationalise these objectives, we implemented the study on small ruminant farms in Spain.

2. Conceptual framework

Our approach considers resilience as a latent property of farms expressed by three resilience capacities: robustness, adaptability and transformability (Meuwissen et al., 2019). Farms' resilience capacities are enabled by resilience principles (i.e., general characteristics) that are, in turn, composed of resilience attributes (i.e., specific farm characteristics) that contribute to overall farming resilience. In this study, resilience is framed within a sequential structure in which a set of farm attributes is grouped into the corresponding principles, and principles collectively contribute to resilience capacities (Fig. 1).

The principles used in this study were those proposed by the Resilience Alliance (2010), and the set of farm attributes was adapted to farms from Cabel and Oelofse (2012) for socio-ecological systems. As a novelty, we included farmers' personal resilience as an additional principle, which is called *Personal resilience* hereafter. *Personal resilience* accounts for a farmer's different psychological aspects that may contribute to farm resilience. Table 1 includes the definitions of principles and the logic of their impact on resilience. Principles are expressed as specific farm attributes based on previous research (Darnhofer, 2021; Paas et al., 2021a), and also on the expertise of the researchers and farmers associations that participated in the study (see Acknowledgements). Generically, *Personal resilience* consists of farmers' attributes related to their ability to cope with personal challenges.

The full list of attributes included in the framework and their assignment to each principle are shown in Fig. 2. Supplementary

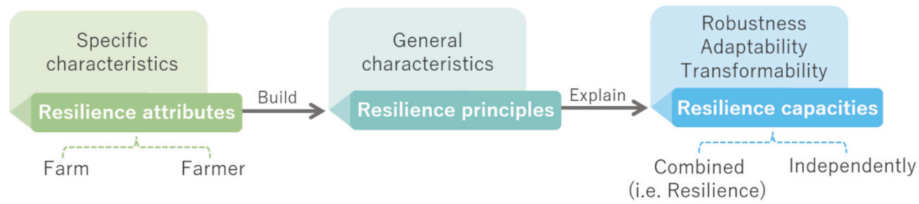

Fig. 1. Rationale of the theoretical framework.

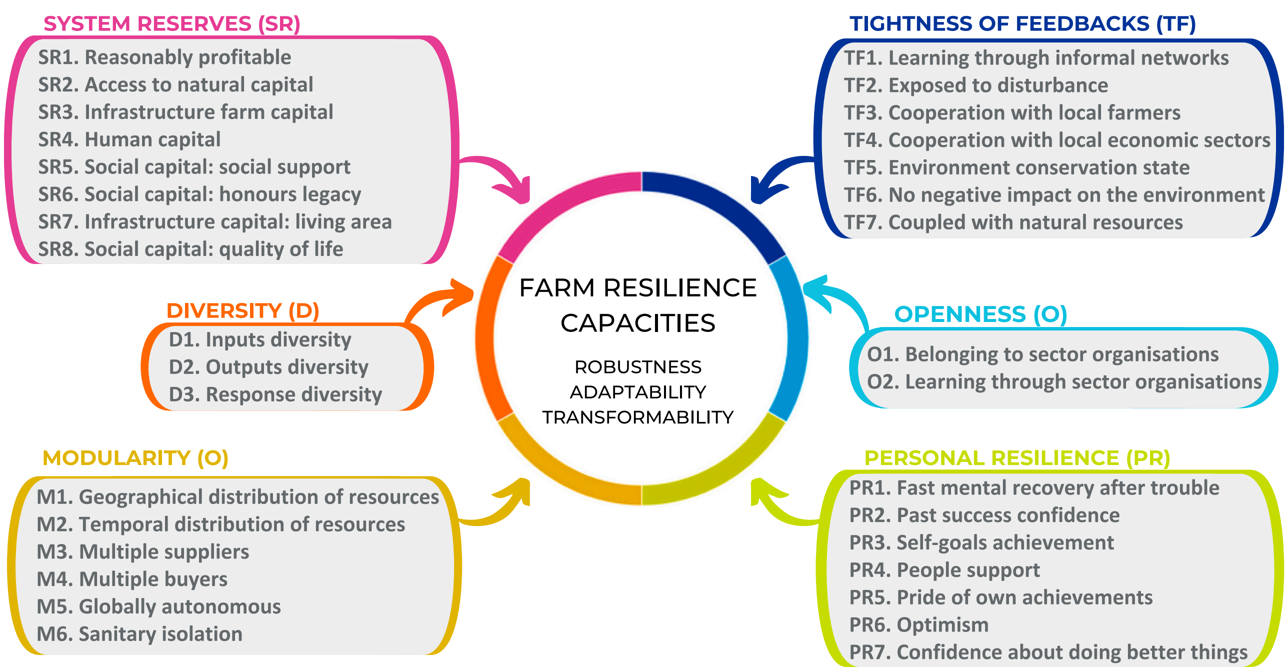

Fig. 2. Graphical representation of the conceptual framework. Resilience principles are System reserves (SR), Diversity (D), Modularity (M), Openness (O), Tightness of feedbacks (TF) and Personal resilience (PR). The attributes classified in each principle are coded with the principle's abbreviation and a serial number in grey boxes. Attributes are assigned to each principle based on Paas et al. (2021a), Darnhofer (2021) and the authors' expertise.

information about the definition of attributes can be found in Appendix I.

3. Materials and methods

3.1. Questionnaire design

A structured questionnaire was designed to collect information on each farm(er) attributes and resilience capacities included in our framework. On one hand, farm attributes and resilience capacities were translated into statements that could be assessed by farmers. These are short affirmative sentences formulated in broad terms to encompass the multiple aspects related to each attribute and capacity, but specific enough to be interpreted by farmers. Wording of statements was based on recommendations from the literature (Jones and Tanner, 2015). On the other hand, the statements used to assess *Personal resilience,* were selected and adapted from the items included in tested psychometric scales of personal resilience: the Brief Resilience Scale (BRS; Smith et al., 2008), the Connor Davidson Resilience Scale (CD-RISC; Connor and Davidson, 2003), the Life Orientation Test (LOT-R; Scheier et al., 1994; Scheier and Carver, 1985) and the Posttraumaic Growth Inventory-short form (PTGI-SF; Cann et al., 2010). Therefore, these items referred to as attributes hereafter were selected to assess the personal resilience principle in this study. Then the first questionnaire version was tested in two steps. It was firstly discussed with technicians of the farmers associations that participated in the study. It was secondly tested on eight farmers to check the wording and understanding of statements. The questionnaire was then amended by reformulating some questions and shortening its length.

The final questionnaire version consisted of three sections that allowed farmers to independently self-assess farm attributes, resilience capacities and personal resilience attributes. Statements were rated by farmers with a 7-point Likert scale, where 1 corresponded to "I strongly disagree" and 7 to "I strongly agree". A "Don't know/Don't answer" option was included. In the first section, farmers rated farm attributes using 27 statements (Appendix II). These statements were related to the farm and working as a farmer. For example: "My farm is profitable enough to earn a living". In the second section, farmers assessed the robustness, adaptability and transformability of their farms in the event of unexpected challenges with three statements (Appendix III). To avoid comprehension problems, an explicit description of robustness, adaptability and transformability implications on farms was included (Appendix IV). Finally, the third section included seven statements to assess the personal resilience attributes (Appendix V). Unlike the previous statements, these were written without referring to the farm or working as a farmer, but referred to strictly personal characteristics. For example, "I'm able to do better things with my life". The rates assigned to each statement served as proxy indicators for the attributes and capacities used in the data analysis.

3.2. Case study

We applied our framework to study small ruminant farms in Spain based on local breeds. Small ruminant farming systems, especially those that focus on meat production and those located in areas of high natural value, have dramatically declined in recent decades in Spain, with the number of sheep and goats having dropped by around 41% and 13%, respectively, since 2000 (MAPA, 2022). Presently, these systems are one of the most vulnerable livestock sectors in Europe. They are facing many challenges related to economic factors, such as low farm income or strongly depending on EU Common Agricultural Policy payments, and also to social challenges, such as little generational renewal (Belanche et al., 2021; Dubeuf et al., 2016). The decline of these systems based on local breeds will reduce important economic activity in disadvantaged areas, which will lead to irreversible loss of cultural values, traditional ecological knowledge and public goods, such as forest fire prevention production of quality products and biodiversity conservation (Bernués et al., 2005, 2016; Oteros-Rozas et al., 2014). Studying their resilience is, therefore, key to implement new management strategies and to prevent their decline. To obtain a comprehensive farms sample, we surveyed farmers from four regions in Spain, namely i) Aragón, ii) Andalusia, iii) the Basque Country and Navarre and iv) Extremadura (Fig. 3).

The sample covered meat sheep, dairy sheep and dairy goat farms. Feed management strategies ranged from extensive grazing systems to intensified systems with varying dependence on external feed inputs and grazing practices. A brief description of the sampled farms is provided in Table 2.

3.3. Data collection

Between June 2022 and February 2023, 160 farmers were surveyed face-to-face. They were selected by a quota sampling method to ensure the representativeness of the variety of farms in each region. The structural variables considered in sampling were farm orientation, use of grazing resources on farms, farm's geographical location in the region and farmer's age. Farmers' contacts were facilitated by the farmers associations that participated in the study and veterinary services. Surveys were conducted by researchers and associations ́staff, who had received specific training to minimise surveyor bias.

Before the survey, farmers were asked for their consent. The research protocol, questionnaire content and all the methods were carried out according to the guidelines and approval of the Ethics Committee of the Agrifood Research and Technology Centre of Aragón, Spain (No. CESIH_2022_4).

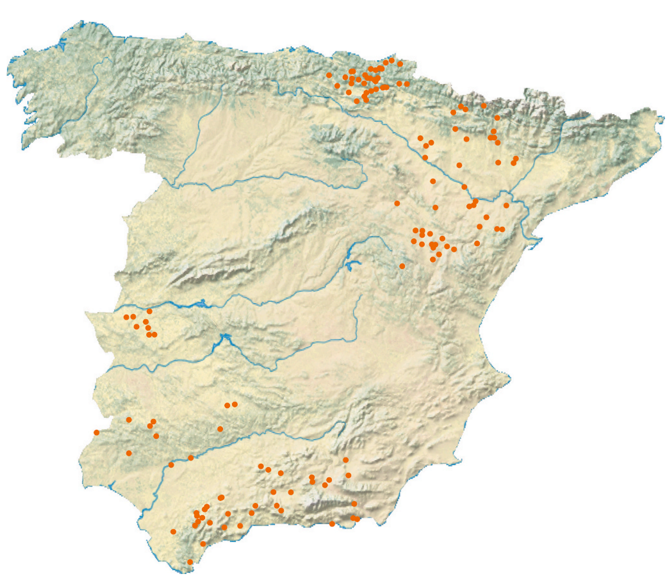

Fig. 3. Map of Spain with sampled farms represented by dots.

Table 2
Description of the sampled farms.

Farm and farmer descriptors	Value
Number of surveys	160
Farmer's gender (% female)	18.7%
Farmer's age (Mean ± SD[2])	47.6 ± 10.9
Herd size[1] (Mean ± SD)	653.5 ± 581.2
Farm type	
Meat sheep (% farms)	35.6%
Dairy sheep (% farms)	31.3%
Dairy goat (% farms)	33.1%
Mixed crop-livestock system (% farms)	43.3%
Number of grazing months[3] (Mean ± SD)	8.8 ± 4.3

[1] *Herd size corresponds to the number of adult females per farm.*
[2] *SD = standard deviation.*
[3] *Number of months per year in which livestock graze.*

3.4. Data analysis

3.4.1. Structural equation modelling (SEM)

We took resilience as a latent property that cannot be directly measured. Accordingly, we processed it statistically as a latent variable that is inferred from some measured variables (Clare et al., 2017; Food and Agriculture Organisation of the United Nations, 2016). To deal with the latent variables, structural equation modelling (SEM) is a useful analytical approach that simultaneously examines the relations between the measured variables and the latent variables, as well as among the latent variables (Clare et al., 2017; Gefen et al., 2000; Hair et al., 2014). We applied SEM to simultaneously quantify the links among the resilience attributes, principles and capacities following the sequential structure presented in the conceptual framework (Section 2). We used the measures of attributes obtained in the questionnaire (Section 3.1.) as formative indicators of the resilience principles, which were considered to be latent variables. Principles were linked with resilience capacities, which were also considered latent variables and were measured by the indicators obtained in the questionnaire (Section 3.1.).

In SEM, latent variables are called constructs. Indicators are the proxy variables that contain raw data. The hypothesised relations between variables are represented in path models, i.e., visual diagrams in which indicators are linked with arrows to the latent constructs they measure, and latent constructs are linked with one another according to their relations. The models consist of two distinct parts: (i) measurement submodel/s and (ii) the structural submodel (Hair et al., 2014). (i) Measurement submodel/s include the unidirectional relations between latent constructs and their observed indicators; in our case, the attributes and capacities measured during the survey. Latent constructs can be formative or reflective depending on their relation with the indicators used to measure them. For formative constructs, the arrows in the visual diagram point from indicators to constructs, and the associated coefficients are called weights (w). For reflective constructs, arrows point from constructs to indicators, and the associated coefficients are called loadings (l). (ii) The structural submodel includes the relations or paths (β) between latent constructs, which can be exogenous or endogenous. In our case, paths are links from principles to resilience capacities. Principles are exogenous constructs and resilience capacities are endogenous constructs.

Of all the other SEM methods, we used Partial Least Squares Structural Equation Modelling (PLS-SEM) because it can easily handle reflective and formative measurement models, as well as single-item constructs (Hair et al., 2014). The PLS-SEM algorithm focuses on finding linear combinations of data that maximise the explained variance of the latent variables included in a structural model (Gefen et al., 2000; Hair et al., 2011). Indeed PLS-SEM enabled us to find the attributes and principles that significantly contributed to explain farmers' perceptions of robustness, adaptability and transformability based on different models.

3.4.2. Structural models

We built four different PLS-SEM models to explore the relation among farm(er) attributes, principles and capacities (Fig. 4). In Model 1, also called the Resilience model, the endogenous latent construct *Resilience* was measured reflectively using robustness, adaptability and transformability indicators. Models 2, 3 and 4, also respectively called the Robustness model, the Adaptability model and the Transformability model, refer separately to robustness, adaptability and transformability capacities. In these models, the endogenous latent constructs *Robustness, Adaptability* and *Transformability* are measured as single-item latent constructs based on the indicators used to separately assess the three capacities. The Resilience model allows the attributes and principles that contribute to all the three resilience capacities to be explored. The Robustness, Adaptability and Transformability models aim to dig more deeply in the results of the combined model (Resilience model) by exploring how attributes and principles contribute specifically to each capacity.

All the models share a measurement submodel in which resilience attributes are the indicators of six formative exogenous constructs that represent resilience principles (the measurement submodel in the box on the left of Fig. 4). The four models share the structural part, i.e., the six resilience principles point to an endogenous latent construct (the structural submodel in the middle box of Fig. 4). The difference between models is the latent construct, which refers to *Resilience*, *Robustness*, *Adaptability* and *Transformability* (the measurement submodels in the box on the right of Fig. 4).

PLS-SEM analyses were performed using the SmartPLS statistical software package (version 4.0.9.5). The PLS-SEM algorithm firstly calculates the scores of latent constructs, and then the paths, weights and loading coefficients (Hair et al., 2011). The obtained results refer to the coefficients calculated to explain the relations between attributes and principles, and also those between principles and capacities. The original models extracted from the SmartPLS software, which include the visual diagrams of models, can be found in Appendix VI.

Following literature recommendations (Hair et al., 2014), the results are evaluated in two steps: a) evaluating the measurement submodel/s; b) evaluating the structural submodel.

a) In the measurement models, we checked the indicators for collinearity issues using the variance inflation factor; values under 5 are normally considered non-problematic (Hair et al., 2014). For formative indicators (i.e. the attribute indicators building resilience principles), we then applied a bootstrapping procedure to assess the significance of the weights assigned to each indicator by considering indicators with a *p*-value $\leq$0.05 to be significant and those with a p-value $\leq$0.10 to indicate trends worth discussing. For the reflective indicators (i.e. resilience capacities indicators in the Resilience model), we ran several tests to check if indicators could be simultaneously explained by *Resilience*. We firstly evaluated variation in the resilience capacities indicators explained by *Resilience* using

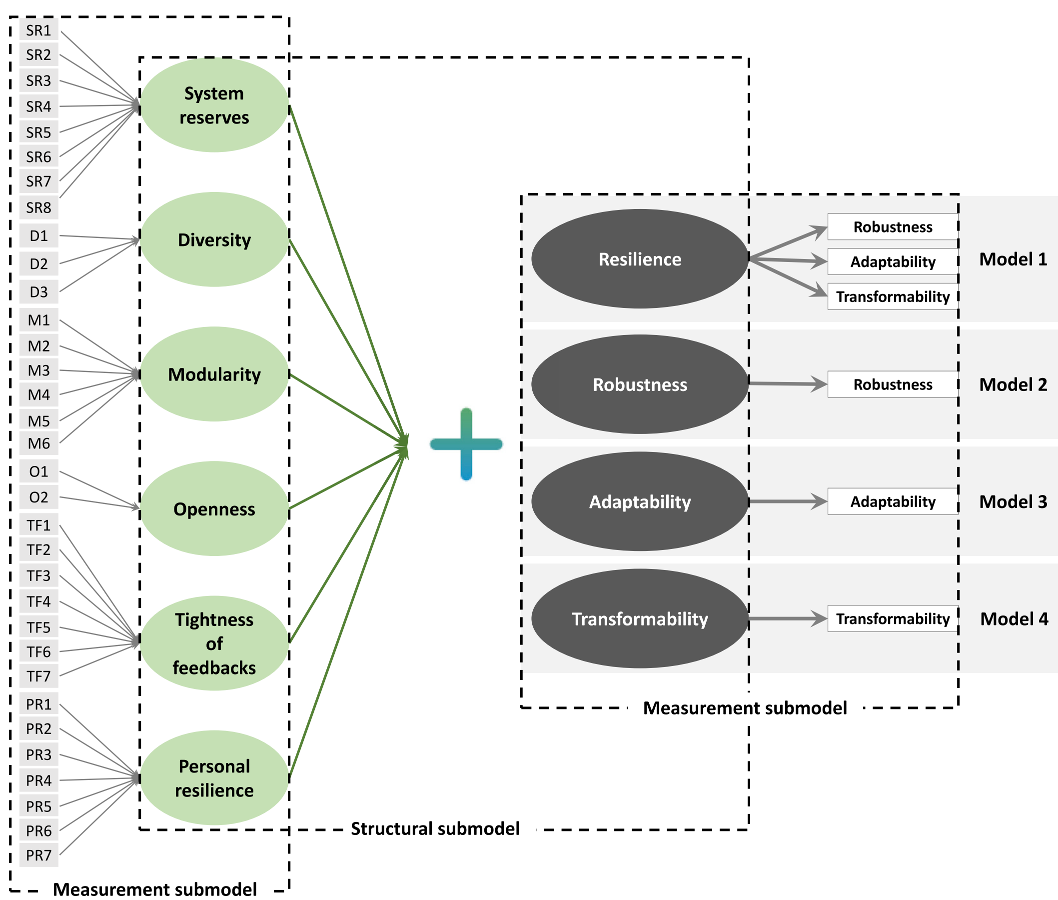

Fig. 4. Graphical representation of the four structural models implemented in the study. From left to right: the grey squared boxes to the left of the figure refer to the proxy indicators obtained through farmers' assessment of the attributes included in the framework, available in Fig. 1. *System reserves, Diversity, Modularity, Openness, Tightness of feedbacks* and *Personal resilience* are the exogenous latent variables. *Resilience*, *Robustness*, *Adaptability* and *Transformability* are the endogenous latent constructs of models. The white squared boxes to the right of the figure refer to the three proxy indicators obtained through farmers' assessment of resilience capacities.

indicators′reliability. This test should exceed 0.5 per indicator, which would correspond to 50% variance of each indicator, explained by the latent construct (Hair et al., 2014). We also tested the internal consistency of the resilience construct employing the composite reliability (rho_c) by considering that values between 0.60 and 0.70 were acceptable in exploratory research (Hair et al., 2014). We finally assessed the proportion of variance explained by *Resilience* with Average Variance Extracted (AVE), which should exceed 0.5 (Hair et al., 2014).

b) In the structural models, we checked the exogenous constructs for collinearity issues using the variance inflation factor. We assessed the variance explained by *Resilience*, *Robustness*, *Adaptability* and *Transformability* with the coefficient of determination (R^2). In general, R^2 values of 0.50 and 0.25 indicate explained moderate and weak variance, respectively (Hair et al., 2014). To assess a model's capacity to predict the endogenous constructs based on collected data, we obtained Stone-Geisser's value (Q^2) by applying a blindfolding procedure. Q^2 values above 0 indicate that models have predictive relevance (Hair et al., 2011). We also tested the significance of the path coefficients by a bootstrapping procedure and considered the paths with *p*-values below 0.05 to be significant. Finally, we assessed the change in the R^2 value of each model's endogenous construct when a principle was omitted using the effect size (f^2) of each principle. The f^2 values of 0.02, 0.15, and 0.35 respectively indicated small, medium and large effects of each principle on the variance of the endogenous construct (Hair et al., 2014).

4. Results

The models' results were presented in two separate parts: i) measurement submodel/s; ii) structural submodel. These two parts respectively showed the specific attributes that were significant to explain resilience principles and the validity of the *Resilience* construct; the principles that were significant to build *Resilience*, *Robustness*, *Adaptability* and *Transformability*. The results are graphically presented in Appendix VI.

4.1. Measurement submodels: relations between indicators and latent variables

The measurement submodels did not show any collinearity problems because the variance inflation factor of the indicators used to build the latent constructs (i.e., indicators of attributes and capacities) was <2 in all cases.

4.1.1. Formative submodels: from attributes to principles

The results of the formative submodels showed the relative contribution and the significance of the resilience attributes to build the resilience principles in each model (Table 3).

The results revealed that the contribution of attributes to principles presented similar patterns across models, but also some specific differences (Table 3). *Reasonably profitable, Response diversity, Exposed to disturbance* and *Optimism* contributed significantly to their principles in the four models. *Infrastructure farm capital* contributed significantly to *System reserves* in the Resilience, Adaptability and Transformability models. *Cooperation with local economic sectors* and *Fast mental recovery after trouble* contributed significantly to *Tightness of feedbacks* and *Personal resilience,* respectively, in the Resilience and Transformability models.

For the attributes with significant weights in only one of the models,

Table 3
Weights coefficients (w) and significance levels of the indicators used to measure the formative constructs (i.e. resilience principles) in models. Latent variables refer to resilience principles and indicators refer to the resilience attributes used in this study.

Latent variables	Indicators	Models			
		Resilience	Robustness	Adaptability	Transformability
System reserves	Reasonably profitable	0.69***	0.54*	0.68**	0.62*
	Access to natural capital	-0.14	0.21	-0.58**	0.18
	Infrastructure farm capital	0.38*	0.14	0.44*	0.48*
	Human capital	-0.12	0.01	-0.22	-0.09
	Social capital: social support	0.31.	0.28	0.23	0.32
	Social capital: honours legacy	0.26.	0.27	0.20	0.21
	Infrastructure capital: living area	0.17	0.42*	0.12	-0.35
	Social capital: quality of life	0.07	0.04	0.19	-0.14
Diversity	Inputs diversity	-0.14	-0.08	-0.22	-0.08
	Outputs diversity	-0.23	-0.30	-0.35.	0.13
	Response diversity	1.04***	1.03***	1.03***	0.99***
Modularity	Geographical distribution of resources	0.04	0.44	0.31	-0.05
	Temporal distribution of resources	0.50	0.52	-0.40	0.13
	Multiple suppliers	-0.29	-0.68	-0.11	-0.03
	Multiple buyers	0.27	0.43	0.33	0.81*
	Globally autonomous	0.81	0.50	-0.81	0.52
	Sanitary isolation	-0.40	-0.27	0.51	-0.02
Openness	Belonging to sector organisations	-0.39	-0.16	-0.10	-0.88
	Learning through sector organisations	1.11	1.06.	1.04	1.01
Tightness of feedbacks	Learning through informal networks	-0.15	0.05	-0.20	-0.31.
	Exposed to disturbance	0.86***	0.94***	0.87**	0.51*
	Cooperation with local farmers	0.00	0.12	-0.07	-0.06
	Cooperation with local economic sectors	0.36.	0.22	0.22	0.69**
	Environment conservation state	-0.20	-0.22	-0.32	0.05
	No negative impact on the environment	-0.06	-0.14	-0.09	0.12
	Coupled with natural resources	0.30.	0.15	0.39	0.31
Personal resilience	Fast mental recovery after trouble	0.30*	0.23	0.22	0.47*
	Past success confidence	0.10	0.18	-0.04	0.21
	Self-goals achievement	-0.07	-0.40.	0.19	-0.02
	People support	0.19	0.31	-0.01	0.32
	Pride of own achievements	0.14	0.05	0.43*	-0.31
	Optimism	0.60**	0.77***	0.41*	0.48.
	Confidence about doing better things	0.16	0.10	0.17	0.17

Significance: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$,. $p < 0.1$, $p < 1$.

for the Resilience model *Social support*, *Honours legacy* and *Coupled with natural resources* were significant. For the Robustness model, *Infrastructure capital of the living area*, *Knowledge of innovation through sector organisations* and *Self-goals achievement* were significant. For the Adaptability model, *Access to natural capital*, *Outputs diversity* and *Pride of own achievements* were significant. Finally, the Transformability model had significant weights for *Multiple buyers* and *Learning through informal networks*.

4.1.2. Reflective submodel: from Resilience to capacities

The reflective submodel results were related only to the Resilience model, where *Resilience* was an endogenous latent variable reflectively measured with three indicators: Robustness, Adaptability and Transformability. The reliability of the indicator loadings was 0.590 for Robustness, 0.714 for Adaptability and 0.426 for Transformability. Although the Transformability indicator did not exceed the lower limit of 0.5, *Resilience* had a composite reliability of 0.802 and the AVE was 0.578, which were above the minimum thresholds of 0.7 and 0.5, respectively. Therefore, our results showed that *Resilience* met the minimum criteria to be used as a latent variable embedding robustness, adaptability and transformability.

In the Robustness, Adaptability and Transformability models, the endogenous latent variable was a single-item construct and, therefore, the reflective measures were not interpretable.

4.2. Structural submodels: from principles to Robustness, Adaptability, Transformability and resilience

The structural submodels' results showed the relative contribution and the significance of the resilience principles to explain resilience capacities (Table 4). Structural models did not reveal any collinearity problems because the variance inflation factor of the exogenous latent constructs was <2 in all cases.

The path coefficients of the principles contributing to the endogenous latent construct were positive in all cases, although their relative importance varied across models. *Diversity* and *Personal resilience* had significant effects on the four models. *System reserves* was significant in the Robustness and Adaptability models, and *Tightness of feedbacks* was significant for all the models, except for Adaptability. *Openness* and *Modularity* had no significant path effect on any model.

The structural fit indices showed that the models could explain and predict resilience as a latent construct based on the measured indicators. Explained variance (R^2) was 45% for the Resilience model, 35% for the Robustness model, 40% for the Adaptability model and 23% for the Transformability model. In addition, the obtained positive Q^2 values indicated the predictive relevance of the four models (Table 4).

The effect sizes (f^2) of the principle's constructs varied from 0 to 0.12. The main principle with f^2 close to zero was *Openness,* which had no substantial effect size for any of the models.

5. Discussion

Approaches to quantitatively assess the influence of multiple attributes and principles on resilience capacities in a single analysis are lacking. To address this research gap, we propose a framework and an analytical approach that provide insights into the links between resilience attributes and principles with resilience capacities and resilience itself. Our study contributes to the development of farm resilience assessments that account for not only farm attributes, but also place a value on farmers' psychological aspects that influence their perceived resilience, which is discussed below. Our framework provides a general list of farm attributes applicable to different types of farming systems. The use of perceived resilience attributes and capacities as indicators opens up the possibility to apply the assessment to different farming systems given that farmers respond from their own farming experience (Clare et al., 2017).

Overall, the results of our study showed that some farm(er) attributes contributed similarly to farmers' perceived resilience as a combination of robustness, adaptability and transformability, and to the three capacities independently. When we looked in detail on how specific attributes contributed to resilience capacities separately, we found attributes that contributed to the three capacities and attributes that contributed differently to each capacity. These results support the consideration of robustness, adaptability and transformability capacities in both ways: as independent and complementary capacities that enable resilience, as theoretically proposed by Darnhofer (2014). Other studies have shown trade-offs among the three capacities, which highlights the importance of considering robustness, adaptability and transformability capacities separately (Slijper et al., 2022a). We argue that considering robustness, adaptability and transformability as combined resilience outcomes allows to identify attributes and principles that contribute transversally to the three capacities. At the same time, considering the three capacities independently allows to find attributes and principles that contribute to each capacity individually.

Following an order of significance, we noted that for the small ruminant farms in Spain personal resilience, diversity, tightness of feedbacks and system reserves were the most relevant principles for determining farmers' perceptions of resilience. Modularity and openness, were not significant in our assessment. These results are discussed below in order of importance in the models.

5.1. Farmers' personal resilience

As hypothesised, personal resilience influenced farmers' perceptions about their farms' resilience. Specifically, farmer optimism and fast mental recovery after trouble were the key attributes. Our results support previous studies which suggest that optimistic farmers perceive their farms to be more resilient, robust, adaptable and transformable (Spiegel et al., 2021). However, the role of farmers' optimism is

Table 4
Path coefficients (β), significance levels and effect sizes (f^2) of latent variables (i.e. resilience principles), and model's explained variance (R^2) and predictive relevance (Q^2).

	Models							
	Resilience		Robustness		Adaptability		Transformability	
Latent variables	Coefficient	f^2	Coefficient	f^2	Coefficient	f^2	Coefficient	f^2
System reserves	0.115	0.017	0.204*	0.049	0.182*	0.042	0.117	0.014
Diversity	0.298**	0.120	0.202*	0.051	0.197*	0.048	0.183*	0.035
Modularity	0.094	0.015	0.134	0.026	0.197	0.053	0.091	0.010
Openness	0.038	0.002	0.005	0.000	0.001	0.000	0.079	0.008
Tightness of feedbacks	0.230**	0.074	0.202*	0.051	0.161	0.034	0.191*	0.036
Personal resilience	0.246**	0.083	0.246**	0.039	0.283**	0.105	0.149*	0.024
R^2	0.446		0.350		0.394		0.232	
Q^2	0.264		0.130		0.180		0.007	

Significance: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$,. $p < 0.1$, $p < 1$.

controversial. Some authors suggest that optimism can be seen as a driver of resilience or a bias towards positive responses in questionnaires (Jones and Tanner, 2017; Perrin and Martin, 2021). Other authors have identified optimism as a psychological mechanism related to human resilience (Feder et al., 2019), which would encourage farmers to persevere in farming and in daily life after natural disasters (Caldwell and Boyd, 2009; Shah et al., 2017). It is likely that the relation between farmer optimism and perceived farm resilience is twofold, and the influence of each fold remains unclear and difficult to assess. In any case, our results imply that farmer optimism should be considered, in addition to farm attributes, when assessing perceived resilience. Farmers' *Fast mental recovery after trouble* was also found to be relevant, especially for farm transformability. The ability to control emotions helps to change the perception of an event and its meaning (Averill et al., 2018). Thus the farmers with faster mental recovery may be better able to reassess their initial reaction and consider additional relevant information, which helps to transform their negative reactions into more positive ones (Troy and Mauss, 2011). So they may be more able to restructure their farms or start new businesses. These and other psychological aspects related to farmers' personal resilience have started to become a concern for agricultural institutions. For example, sector-wide initiatives have been established in some countries to improve farmers' well-being (e.g. the FarmStrong initiative in New Zealand). This underlines that farmers' personal attributes are central to sustain farming activities and should be improved to promote farm resilience. Hence the inclusion of psychological support programmes for farmers could benefit farming systems' resilience.

5.2. Farm diversity

We considered farm diversity as a combination of input, output and response diversity. Previous studies have shown that they are all relevant for building resilience in a variety of farming systems (Dumont et al., 2020). However, although low diversity levels limit options for coping with change, high levels of inputs and outputs diversity in farms can be complex to manage due to the inability to integrate all the upcoming processes (Biggs et al., 2012). The expected benefits of input and output diversity depend on the implementation of fine-tuned management practices in time and space terms (Dumont et al., 2020). In line with previous research, farm response diversity in our study is the main component of diversity that influenced farmers' perceived resilience. Response diversity refers to the alternatives available to farmers to cope with difficulties, which can include access to different markets or having distinct sources (Cabel and Oelofse, 2012). For the small ruminant farms in Spain, diverse management alternatives, such as extensification, conservation, re-orientation or intensification, have been found to build resilience through resilience capacities (Bertolozzi-Caredio et al., 2021). Thus like previous findings, our results support the notion that farmers' ability to manage diverse alternatives might be crucial for enhancing farm resilience.

In addition, we found that greater outputs diversity was negatively associated with farmers' perceived adaptive capacity. In general, outputs diversity is considered positive for resilience because it promotes economic diversification through the expansion of farmers' activities (Ashkenazy et al., 2018). However, an increase in delivered products is also associated with more complex farm organisation and work overload to the detriment of farmers' quality of life and farm resilience (Darnhofer and Strauss, 2014). This trade-off may explain why the farmers who produce diverse outputs also perceive their farms as less adaptable in the event of unexpected events.

5.3. Tightness of feedbacks

Having overcome difficulties in the past, i.e., *Exposed to disturbance*, was perceived as positive to increase farm resilience, as shown in previous studies (Béné et al., 2019). This falls in line with previous findings in the climate change field, where exposure to discrete and recurrent disturbances has helped small-scale agricultural producers to identify and to develop coping and adaptation strategies (Le Goff et al., 2022).

Farmers' cooperation with other economic sectors locally had a positive impact on their farms' transformative capacity. In our case study, farm transformation refers to the start of new economic activities, such as re-orientation of farms towards other livestock species or farming systems, tourism activities, catering, etc. Farmers' familiarity with economic sectors like tourism or restaurant industry can facilitate this transformation (Stotten, 2020). This finding is very significant, and it supports the importance of encouraging local collaboration within and beyond the farming sector to improve farms' resilience.

5.4. System reserves

Several studies point out that (farm) system reserves are a key driver of resilience because they allow losses due to disruptions and investment to be buffered and compensated (Reidsma et al., 2020). Indeed we found that several forms of farm capital influence perceived resilience. Particularly, farm profitability is key for the three resilience capacities of farms. As repeatedly shown across livestock species and farming systems, the general feeling is that farmers' economic satisfaction is key for farm resilience (Bertolozzi-Caredio et al., 2021; Perrin et al., 2020; Perrin and Martin, 2021), which falls in line with studies that have applied technical and economic approaches (Slijper et al., 2022a).

In addition to economic reserves, social capital was also relevant for building farm and farming systems' resilience (Paas et al., 2021a; Reidsma et al., 2020; Slijper et al., 2022b). Our study firstly reveals the importance of support by family and friends on farm activities for overcoming farm challenges (Caldwell and Boyd, 2009). Secondly, high honours legacy, which refers to feeling part of tradition, was also relevant for enhancing farm and farming systems' resilience, as also pointed out in previous studies (Reidsma et al., 2023; Bertolozzi-Caredio et al., 2021; Stotten, 2020). Finally, the importance of the infrastructure capital of the livelihood area for farm robustness also emerged in our study. The services and general infrastructure in areas where farmers and their families live are crucial for maintaining and attracting residents by improving living standards (Paas et al., 2021a; Pitson et al., 2020; Reidsma et al., 2020).

Unexpectedly, farm access to natural capital had a negative effect on adaptability. This means that farmers with more access to land considered their farms to be less adaptable. This result is counterintuitive, but might be related to the uncertainty associated with uncontrollable processes, such as climate or a heavier workload when managing natural resources. Farmers with more access to natural capital are involved in continuous fine-tuning dynamics that is not easy to manage (Darnhofer et al., 2016). As a result, some farmers tend to fail in the "command and control" strategy, i.e., unilateral focus on controlling the system to ensure efficiency (Holling and Meffe, 1996). From this perspective, the inability to control natural resources may lead farmers to perceive their farms as less adaptive despite having access to natural capital usually being considered positive for resilience (Perrin and Martin, 2021).

5.5. Modularity and openness

Both modularity and openess are not determinants of perceived resilience in our study. However for modularity, the connection with multiple buyers showed marked importance for transformability. This result may be related to the fact that opening new marketing channels helps to create new sources of income (Wästfelt and Zhang, 2016), and focusing on new markets or different consumer demands can also lead to transformations related to product and process quality (Knickel et al., 2018).

5.6. Considerations on the methodological approach

Our empirical research focuses on the study of individual farms' resilience. We argue that farm resilience is needed to secure farming systems' resilience. However, we recognise that this is not always the case. In some cases, closure of farms does not necessarily reduce the farming system's resilience as long as the remaining farms have sufficient access to capital and labour or technology to take over and manage the abandoned land or remaining livestock (Feindt et al., 2022). In other cases, individual farms' resilience might negatively impact that of the farming system. For example, the EU Common Agricultural Policy (CAP) may incentivise the continuation of uncompetitive farms by preventing necessary adaptations and/or postponing, or even provoking, the collapse of a farming system (Balmann et al., 2022). On the identified attributes and principles that enhance farm resilience, it can be argued that they likely improve over time at the farming systems level because the farms with low scores for these attributes and principles are more likely to stop farming. Considering that the same attributes are relevant for both farms and farming systems, this will also improve farming systems' resilience.

From a methodological perspective, we propose a theoretical framework in which we assume the conceptual independence of attributes. Our approach complements previous literature (Paas et al., 2021a) because it clearly delineates which attributes belong to each principle by avoiding conceptual overlaps. The framework allows to conceptually disentangle the farm and farmer attributes that can be used to define resilience principles. This helps to operationalise the association between farm(er) attributes and individually perceived resilience. However, this assumption may not always be the case in practice. Using PLS-SEM allowed us to simultaneously examine the influence of a wide range of attributes and principles on farmers' perceived resilience and their relative importance. Our approach helps to investigate which are the most relevant attributes and principles that drive perceived resilience in a large set, which is difficult when attributes' importance is based on stakeholder' opinions (Paas et al., 2021a) or when it is weighted by experts (Le Goff et al., 2022). However, extrapolating our results to other systems, or comparing them to other resilience assessments based on objective indicators, should be cautiously done. Farm resilience is a latent property that may be driven by different attributes depending on the considered challenge or the specific socio-economic and cultural context. Although the proposed framework covers the main farm resilience drivers according to the literature, we believe that it is a paramount challenge to capture all the specific characteristics that build farm resilience. We focused on farm attributes and principles, but farm management also depends on political decisions (Darnhofer, 2014). Policies supporting resilience strategies have also been identified as key attributes, but were not included in our study because it focused on the farm rather than on the farming system itself (Paas et al., 2021b).

It should be noted that our study focused on currently working farmers, which may cause a "survival bias" because those who lack resilience have already left the sector. This is a common weakness of resilience studies and a difficult one to address because it may be difficult to find former farmers or they may be reluctant to participate in research (Feindt et al., 2022). Including farmers who have stopped farming for various reasons could improve our understanding of how perceived resilience relates to farms' actual resilience. Similarly, longitudinal studies would help to confirm if the evaluation of resilience in the present can be demonstrated in the future.

One particularly noteworthy point is the respondents' perception of robustness and adaptability, which was higher than the perception of transformability (Appendix III), and suggests that farms can successfully face future challenges without implementing structural changes. However, it is reasonable to expect that structural changes in farming will be needed given the notable decline in the small ruminant sector in Spain in recent decades (MAPA, 2022; Paas et al., 2021c). The low perceived transformability score suggests that farmers are aware of future challenges that might force them to make structural changes. Such challenges include the non-existence of successors and the opportunity cost of labour, which may lead some farmers to stop farming or engage in part-time farming. We believe that these issues are central and need to be further explored to understand the resilience of both farms and farming systems, especially in transformability terms.

It has been noted that individuals' psychological resilience can influence the perceived resilience of their household (Jones and Tanner, 2017). Therefore, it is important to take this into account to acknowledge and correct for any potential biases. Accordingly, we considered personal resilience to include the farmer traits that may contribute to resilience, particularly optimism. However, we did not bear in mind certain psychological traits, such as risk aversion, self-efficacy, work satisfaction or the ability to deal with probabilities, which previous studies have shown may impact farm resilience perceptions (Béné et al., 2019; Perrin and Martin, 2021; Spiegel et al., 2021). This we did for practical reason, given the need to limit the number of statements included in the questionnaire and the statistical model, and also because we chose to conceptualise the personal resilience measurement using standard psychometric scales developed in the psychology field, which is a novelty compared to previous research. We selected a number of statements from four scales (see Section 3.1 "Questionnaire design") to ensure their interpretability by farmers. These statements covered various elements related to farmers' ability to cope with life challenges. So our results should be validated in future studies with regard the conceptualisation of personal resilience. In any case, our approach could be easily adapted to include other psychological traits of interest.

6. Conclusion

Broadening the framework of resilience principles by considering farmers' personal resilience, improves the assessment of farmers' perceived resilience. The approach followed in our study helps to identify the key attributes of farm(er) to explain farmers' resilience perceptions.

The consideration of robustness, adaptability and transformability capacities as combined components of resilience enabled us to explore the principles and attributes that contribute transversally to all three capacities. Considering the three capacities independently allowed us to explore the principles and attributes that contribute to each capacity specifically.

In small ruminant farming systems in Spain, personal resilience, diversity and tightness of feedbacks are the main principles to explain resilience as perceived by farmers. The more relevant attributes are optimism, response diversity and past exposure to disturbances.

This study stresses that farmers' perceptions are influenced not only by their assets, but also by their personal capacities and experiences as farm managers. Our study also highlights the importance of farm profitability, social support and access to infrastructure in the areas where farmers live.

Access to natural capital and product diversity have a negative effect on perceived adaptive capacity. This suggests that, in some situations, the complexity of farm management and product diversification could make farmers less adaptable to changing conditions.

CRediT authorship contribution statement

Alicia Prat-Benhamou: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alberto Bernués:** Writing – review & editing, Supervision, Investigation. **Paula Gaspar:** Writing – review & editing, Investigation, Conceptualization. **Joseba Lizarralde:** Writing – review & editing, Investigation, Conceptualization. **Juan Manuel Mancilla-Leytón:** Writing – review & editing, Investigation, Conceptualization. **Nerea Mandaluniz:** Writing – review & editing, Investigation, Conceptualization. **Yolanda Mena:** Writing – review &

editing, Investigation, Conceptualization. **Bárbara Soriano:** Writing – review & editing, Investigation, Conceptualization. **Daniel Ondé:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Daniel Martín-Collado:** Writing – review & editing, Writing – original draft, Funding acquisition, Supervision, Project administration, Methodology, Investigation, Data curation, Conceptualization.

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 original data base is available in an open repository at the following link: http://hdl.handle.net/10532/6915

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Appendix I. Principles, definition, implications for farm resilience included. Attributes linked with each principle and definition. Attributes used in the study as proxy indicators

Principles	Definition	Implications	Attributes linked	Definition	Attributes used as proxy indicators
System reserves (Resilience Alliance, 2010)	Natural, economic and social capital that the farm can access (Reidsma et al., 2020)	Farm reserves (i.e., natural, human, social, infrastructure, economic capital) allow losses due to disturbances to be buffered and compensated for, and to invest in the changes needed in systems to adapt or transform during and after disturbance	Reasonably profitable (Paas et al., 2021a)	Farmers are able to make a livelihood from farming	Reasonably profitable
			Natural capital (Paas et al., 2021a)	Having access to the natural resources found on farm agro-ecosystem's boundaries	Access to natural capital
			Infrastructure farm capital	Farm assets with a high degree of permanency, such as machinery and equipment, buildings and engineering construction	Infrastructure farm capital
			Infrastructure in the living area	Rural areas infrastructures and services that support farmers and their families to perform daily activities	Infrastructure capital: living area
			Human capital	The farm makes the most of, and builds from, knowledge and skills, which accumulate through forms of education attainment, training and experience	Human capital
			Socially self-organised and structured (Paas et al., 2021a)	Informal networks (e.g. relationship between farmers) in farming systems and social networks beyond farming to the wider livelihood of farmers and their families	Social capital: social support
			Honours legacy (Darnhofer, 2021)	Influence of past conditions and experiences on the configuration and future paths of farm	Social capital: honours legacy
			Satisfactory work and quality of life	Work characteristics and their contribution to farmers' satisfaction with their job	Social capital: quality of life
Diversity (Resilience Alliance, 2010)	The degree of a farm variation. This may include functional diversity, i.e., the degree of the variations of the components which maintain similar functions; or response diversity, i.e., the degree of the variations of components representing different responses to disturbances (Kharrazi et al., 2020)	Diverse farms are more flexible as can follow a wide range of pathways to face disturbances	Functional diversity (Paas et al., 2021a)	Functional diversity is the variety of components and services that farms rely on and provide. It specifically includes spatial and temporal variety of farm inputs and outputs	Inputs diversity Outputs diversity
			Response diversity (Paas et al., 2021a)	Response diversity is the range of farms' possible responses to disturbances. It relies on functional diversity, but similar farms/farming systems might	Response diversity

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(*continued*)

Principles	Definition	Implications	Attributes linked	Definition	Attributes used as proxy indicators
				respond differently to the same disturbances	
Modularity (Resilience Alliance, 2010)	Property of a system whose components can be separated or integrated without changing their properties or into those of the rest of the system (Kharrazi et al., 2020)	Farms with high modularity can isolate a module and limit shocks from spreading across other system components. So they limit the potential of cascading damage	Spatio-temporal heterogeneity (Paas et al., 2021a)	Patchiness on the farm and across the landscape and time, a mosaic pattern of managed and unmanaged land, diverse cultivation practices, crop rotations and pasture lands	Geographical distribution of resources Temporal distribution of resources
			Optimally redundant (Paas et al., 2021a)	Critical components of farms or farming systems are duplicated	Multiple suppliers Multiple buyers
			Globally autonomous	The farming system is relatively independent of exogenous (global) control and influences	Globally autonomous
			Sanitary isolation	Availability to isolate farms from one another and from external vectors (i.e. wildlife species) to avoid the spread of pathogen agents that can affect livestock or wildlife	Sanitary isolation
Openness (Resilience Alliance, 2010)	Connectivity within the farm and with other systems beyond it (Reidsma et al., 2020)	Connection with stakeholders outside the farm inside or outside the agricultural sector helps to create the enabling environment for innovations to maintain or improve farms' functioning and to timely introduce changes	Socially self-organised and structured (Darnhofer, 2021)	The stakeholders of the farming system are able to create formal organisation structures based on their needs and desires	Belonging to sector organisations
			Knowledge and innovation networks (Darnhofer, 2021; Paas et al., 2021a)	Networks that connect the stakeholders inside the farming system and outside it to create and facilitate the diffusion and uptake of knowledge and innovations	Learning through sector organisations
Tightness of feedbacks (Resilience Alliance, 2010)	The degree to which the farm and its (natural and social) sub-components and processes can create signals and interact in reaction to internal and external signals from other overarching systems; including signals from slow variables and feedback (Reidsma et al., 2020)	Feedback within and between natural and social farm components allow them to respond quickly to disturbances by enabling farmers to avoid dangerous thresholds	Exposed to disturbances	The farm is exposed to discrete, low-level events that cause disruptions without pushing the system beyond a critical threshold	Exposed to disturbance
			Socially self-organised and structured (Paas et al., 2021a)	The stakeholders of the farming system are able to form informal organisations and structures based on their needs and desires	Learning through informal networks
			Locally interdependent (Darnhofer, 2021)	The system exhibits a high level of cooperation between stakeholders more locally	Cooperation with local farmers Cooperation with other local economic sectors
			Ecologically self-regulated (Darnhofer, 2021)	Ecological farm agro-ecosystem components are well-conserved, functional and able to self-regulate by stabilising feedback mechanisms without external inputs and/or management	Environment conservation state No negative impact on the environment
			Coupled with natural capital	The farm functions as much as possible within the means of the available bioregional natural resource base and ecosystem services	Coupled with natural resources
Personal resilience	Farmer's ability to adapt successfully to adversity, stressful life events, significant threats or trauma (Feder et al., 2019)	Farmers' are at the forefront of farm management and their psychosocial factors influence responses to challenges (Béné et al., 2019; Darnhofer, 2014)	Fast mental recovery after trouble (Smith et al., 2008)	Farmers' ability to bounce back quickly after hard times	Fast mental recovery trouble
			Past success confidence (Connor and Davidson, 2003)	Farmers believe that past success provides them with confidence for new challenges	Past success confidence
			Self-goals achievement (Connor and Davidson, 2003)	Farmers feel they can achieve their goals	Self-goals achievement
			People support (Connor and Davidson, 2003)	Farmers are socially supported so they know who to ask for help	People support
			Pride of own achievements (Connor and Davidson, 2003)	Farmers are proud of their own achievements	Pride of own achievements
			Optimism (Scheier and Carver, 1985)	Farmers are optimistic about the future	Optimism
			Confidence about doing better things (Cann et al., 2010)	Farmers believe they are able to do better things with their lives	Confidence about doing better things

Appendix II. The statements used to assess farm attributes

Attributes were adapted from those proposed by Cabel and Oelofse (2012) and statements were designed according to literature recommendations (Jones and Tanner, 2017). The column "Variable name" corresponds to the code used in the data analysis for each attribute.

Farm resilience attribute	Statement	Variable name	Mean	SD[1]
Reasonably profitable	My farm is profitable enough to earn a living	SR1	4.34	1.68
Access to natural capital	My farm has access to the natural resources it needs to guarantee its viability	SR2	4.62	1.69
Infrastructure farm capital	My farm has the necessary infrastructure and equipment to properly function	SR3	5.53	1.34
Human capital	I have enough knowledge to manage my farm	SR4	5.84	1.09
Social capital: social support	I have my family and friends' support to help me on the farm when I need it	SR5	5.27	1.63
Social capital: honours legacy	I feel part of my region's livestock tradition	SR6	5.96	1.25
Infrastructure capital: living area	My family and I have access to the services we need in our daily lives in areas close to our home	SR7	5.48	1.52
Social capital: quality of life	My work as a farmer allows me good quality of life	SR8	4.17	1.81
Inputs diversity	My farm uses a variety of resources	D1	5.63	1.22
Outputs diversity	My farm generates different types of products	D2	5.15	1.59
Response diversity	If my farm faces a difficult time, I have different alternatives to manage it	D3	4.21	1.57
Geographical distribution of resources	The resources that I use on my farm come from various geographical areas	M1	4.77	1.70
Temporal distribution of resources	The feed resources that I use on my farm are produced during different seasons of the year	M2	5.51	1.37
Multiple suppliers	My farm has multiple resource suppliers	M3	4.72	1.77
Multiple buyers	My farm has multiple buyers and/or product distribution channels	M4	3.75	2.14
Globally autonomous	My farm is independent of external influences, so it would not be badly affected by events that occur beyond my area or region	M5	2.10	1.78
Sanitary isolation	My farm is prepared to prevent infectious diseases that affect the herd from entering or exiting	M6	3.74	1.89
Belonging to sector organisations	I am part of various livestock and agricultural organisations and/or cooperatives with which I share objectives and interests	O1	5.67	1.41
Learning through sector organisations	The associations, organisations and/or cooperatives to which I belong allow me to be informed of innovations, technology and advances in the sector	O2	5.64	1.31
Learning through informal networks	I have access to people, networks and institutions that allow me to be informed of innovations, technology and advances	TF1	5.67	1.37
Exposed to disturbances	Over time, my farm has successfully overcome many difficulties	TF2	5.80	1.08
Cooperation with local farmers	Locally, farmers cooperate with one another, so we support one another	TF3	3.77	1.87
Cooperation with other local economic sectors	Locally, farmers cooperate with other sectors, so we can support one another	TF4	3.87	1.78
Environment state of conservation	The natural environment in which my farm is located is well-preserved	TF5	4.76	1.65
Negative impact on the environment	My farming has no negative impact on the natural environment in which it is located	TF6	5.80	1.21
Coupled with natural resources	My farm uses natural resources from the area to a large extent	TF7	5.33	1.59

[1] SD = Standard deviation.

Appendix III. The statements used to assess resilience capacities

Statements were designed according to literature recommendations (Jones and Tanner, 2017). The column "Variable name" corresponds to the code used in the data analysis for each attribute.

Resilience capacity	Statement	Variable name	Mean	SD[1]
Robustness	In the event of unexpected difficulties, my farm would be able to withstand them and continue to function	Robustness	5.01	1.26
Adaptability	In the event of difficulties, my farm would be able to adapt to the new situation and make the necessary changes to continue operating	Adaptability	5.11	1.22
Transformability	In the event of difficulties, my farm would be able to make the necessary transformations to continue operating, even if it had to change its structure and internal functioning	Transformability	3.71	1.69

[1] SD = Standard deviation.

Appendix IV. The descriptions and statements used to assess robustness, adaptability and transformability

Those organising surveys read the introduction and the given descriptions of robustness, adaptability and transformability to farmers before asking them to rate the statements used as proxy indicators of resilience capacities.

1. Introduction

"Farms' ability to face difficulties depends on three complementary aspects: their ROBUSTNESS, ADAPTATION CAPACITY and TRANSFORMATION CAPACITY. With the following three questions, we would like to know your opinion of your farm in relation to these three aspects".

2. Robustness description

"The first aspect is ROBUSTNESS. Robustness is a farm's ability to absorb unexpected difficulty, so that it can maintain the same functioning and is able to quickly return to the previous situation.

That is to say, when a difficulty arises resistance requires your farm continuing to function in the same way until the bad situation ends. This may require minor adjustments, but without changing the farm's structure and operation.

In other words, the ability to resist means that when faced with difficulties of any kind (economic, social, environmental or political), you can continue working in the same way."

"On a scale from 'I strongly agree'(number 7) to 'I strongly disagree'(number 1), can you tell me to what extent do you agree or disagree with the following statement?"

"In the event of unexpected difficulties, my farm would be able to withstand them and continue functioning".

3. *Adaptability description*

"The second aspect is ADAPTATION CAPACITY, which shows your farm's ability to readjust or change when faced with difficulties.

Adaptation means that when difficulty arises, you change or adjust some things on your farm. It can imply changes at any level: animal management, changes in food, in the organisation of work and labour, in the final product, in infrastructures… Or anything else you can think of.

In other words, adaptation consists of making the necessary changes or adjustments so that your farm can continue functioning."

Using the same scale as in the previous question, to what extent do you agree or disagree with the following statement?

"In the event of difficulties, my farm would be able to adapt to the new situation and make the necessary changes to continue operating".

4. *Transformability description*

"*The last aspect is TRANSFORMATION CAPACITY, which is the ability to completely reorganise farming.*

Transformation means you change your business to face difficulty. This implies that you can start another economic activity from your livestock or you completely change the activity you have been doing."

To what extent do you agree or disagree with the following statement?

"In the event of difficulties, my farm would be able to make the necessary transformations to continue operating, even if its structure and its internal functioning had to change".

Appendix V. The statements used to assess personal attributes

Statements were selected from the psychometric scales in brackets. The column "Variable name" corresponds to the code used in the data analysis for each attribute.

Personal resilience attribute	Statement	Variable name	Mean	SD[1]
Fast mental recovery after trouble	I tend to bounce back quickly after hard times (BRS; Smith et al., 2008)	PR1	5.31	1.36
Past success confidence	Past success gives confidence about a new challenge (CD-RISC; Connor and Davidson, 2003)	PR2	5.41	1.28
Self-goals achievement	You can achieve your goals (CD-RISC; Connor and Davidson, 2003)	PR3	5.76	1.01
People support	Know where to turn for help (CD-RISC; Connor and Davidson, 2003)	PR4	5.70	1.06
Pride of own achievements	Pride in your achievements (CD-RISC; Connor and Davidson, 2003)	PR5	5.89	1.06
Optimism	I'm always optimistic about my future (LOT-R; Scheier et al., 1994; Scheier and Carver, 1985)	PR6	4.59	1.59
Confidence about doing better things	I'm able to do better things with my life (PTGI-SF; Cann et al., 2010)	PR7	5.57	1.15

[1] SD = Standard deviation.

Appendix VI. Model results extracted from the SmartPLS software

The figures below depict the structural model diagram with the proxy indicators that measure attributes and capacities in square boxes and the latent constructs in circles. Arrows represent the links between indicators and latent constructs. Inserted in each arrow is the weight or loading coefficient, and the *p*-value is in brackets, obtained for each indicator through a bootstrapping procedure by setting 10,000 repetitions. The proportion of variance explained (R^2) by the constructs *Resilience*, *Robustness*, *Adaptability* and *Transformability* is included in the corresponding circle.

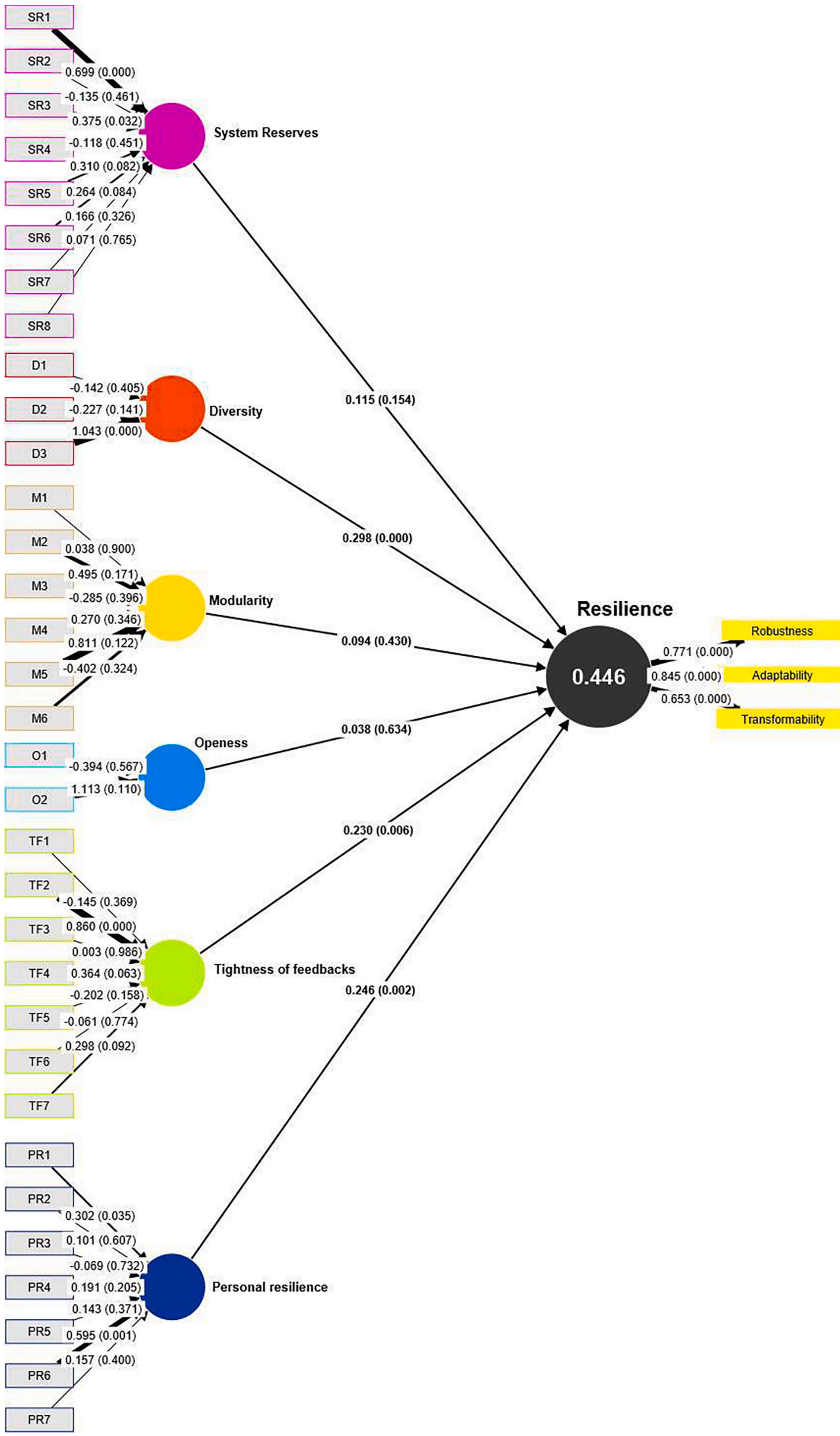
SR1
SR2
SR3
SR4
SR5
SR6
SR7
SR8
0.699 (0.000)
-0.135 (0.461)
0.375 (0.032)
-0.118 (0.451)
0.310 (0.082)
0.264 (0.084)
0.166 (0.326)
0.071 (0.765)
System Reserves
D1
D2
D3
-0.142 (0.405)
-0.227 (0.141)
1.043 (0.000)
Diversity
M1
M2
M3
M4
M5
M6
0.038 (0.900)
0.495 (0.171)
-0.285 (0.396)
0.270 (0.346)
0.811 (0.122)
-0.402 (0.324)
Modularity
O1
O2
-0.394 (0.567)
1.113 (0.110)
Openess
TF1
TF2
TF3
TF4
TF5
TF6
TF7
-0.145 (0.369)
0.860 (0.000)
0.003 (0.986)
0.364 (0.063)
-0.202 (0.158)
-0.061 (0.774)
0.298 (0.092)
Tightness of feedbacks
PR1
PR2
PR3
PR4
PR5
PR6
PR7
0.302 (0.035)
0.101 (0.607)
-0.069 (0.732)
0.191 (0.205)
0.143 (0.371)
0.595 (0.001)
0.157 (0.400)
Personal resilience
0.115 (0.154)
0.298 (0.000)
0.094 (0.430)
0.038 (0.634)
0.230 (0.006)
0.246 (0.002)
Resilience
0.446
0.771 (0.000)
0.845 (0.000)
0.653 (0.000)
Robustness
Adaptability
Transformability

Fig. 1. Resilience model, also referred to as Model 1.

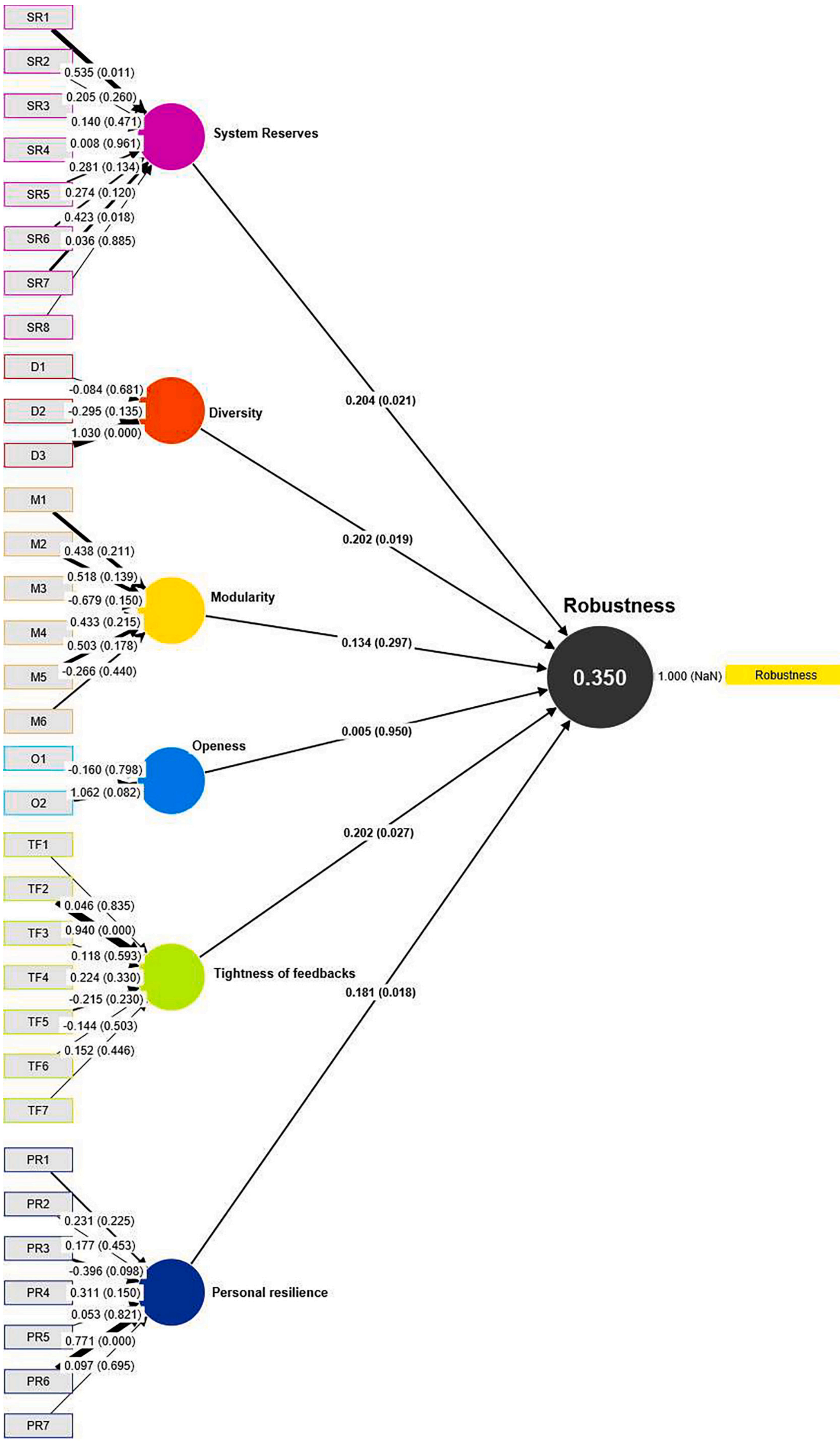
SR1
SR2
SR3
SR4
SR5
SR6
SR7
SR8
0.535 (0.011)
0.205 (0.260)
0.140 (0.471)
0.008 (0.961)
0.281 (0.134)
0.274 (0.120)
0.423 (0.018)
0.036 (0.885)
System Reserves
D1
D2
D3
-0.084 (0.681)
-0.295 (0.135)
1.030 (0.000)
Diversity
M1
M2
M3
M4
M5
M6
0.438 (0.211)
0.518 (0.139)
-0.679 (0.150)
0.433 (0.215)
0.503 (0.178)
-0.266 (0.440)
Modularity
O1
O2
-0.160 (0.798)
1.062 (0.082)
Openess
TF1
TF2
TF3
TF4
TF5
TF6
TF7
0.046 (0.835)
0.940 (0.000)
0.118 (0.593)
0.224 (0.330)
-0.215 (0.230)
-0.144 (0.503)
0.152 (0.446)
Tightness of feedbacks
PR1
PR2
PR3
PR4
PR5
PR6
PR7
0.231 (0.225)
0.177 (0.453)
-0.396 (0.098)
0.311 (0.150)
0.053 (0.821)
0.771 (0.000)
0.097 (0.695)
Personal resilience
0.204 (0.021)
0.202 (0.019)
0.134 (0.297)
0.005 (0.950)
0.202 (0.027)
0.181 (0.018)
Robustness
0.350
1.000 (NaN)
Robustness

Fig. 2. Robustness model, also referred to as Model 2.

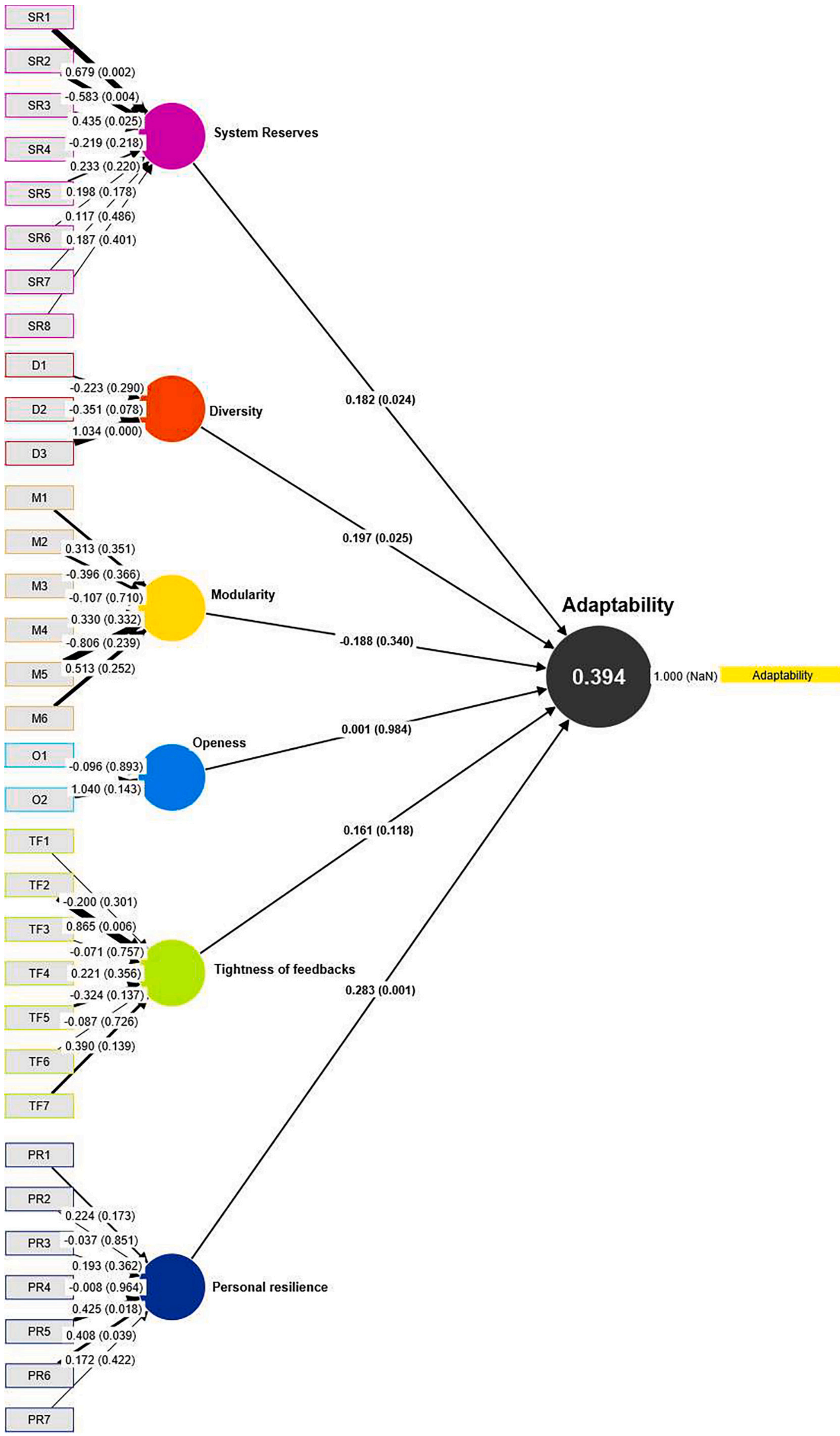
SR1
SR2
SR3
SR4
SR5
SR6
SR7
SR8
0.679 (0.002)
-0.583 (0.004)
0.435 (0.025)
-0.219 (0.218)
0.233 (0.220)
0.198 (0.178)
0.117 (0.486)
0.187 (0.401)
System Reserves
D1
D2
D3
-0.223 (0.290)
-0.351 (0.078)
1.034 (0.000)
Diversity
M1
M2
M3
M4
M5
M6
0.313 (0.351)
-0.396 (0.366)
-0.107 (0.710)
0.330 (0.332)
-0.806 (0.239)
0.513 (0.252)
Modularity
O1
O2
-0.096 (0.893)
1.040 (0.143)
Openess
TF1
TF2
TF3
TF4
TF5
TF6
TF7
-0.200 (0.301)
0.865 (0.006)
-0.071 (0.757)
0.221 (0.356)
-0.324 (0.137)
-0.087 (0.726)
0.390 (0.139)
Tightness of feedbacks
PR1
PR2
PR3
PR4
PR5
PR6
PR7
0.224 (0.173)
-0.037 (0.851)
0.193 (0.362)
-0.008 (0.964)
0.425 (0.018)
0.408 (0.039)
0.172 (0.422)
Personal resilience
0.182 (0.024)
0.197 (0.025)
-0.188 (0.340)
0.001 (0.984)
0.161 (0.118)
0.283 (0.001)
Adaptability
0.394
1.000 (NaN)
Adaptability

Fig. 3. Adaptability model, also referred to as Model 3.

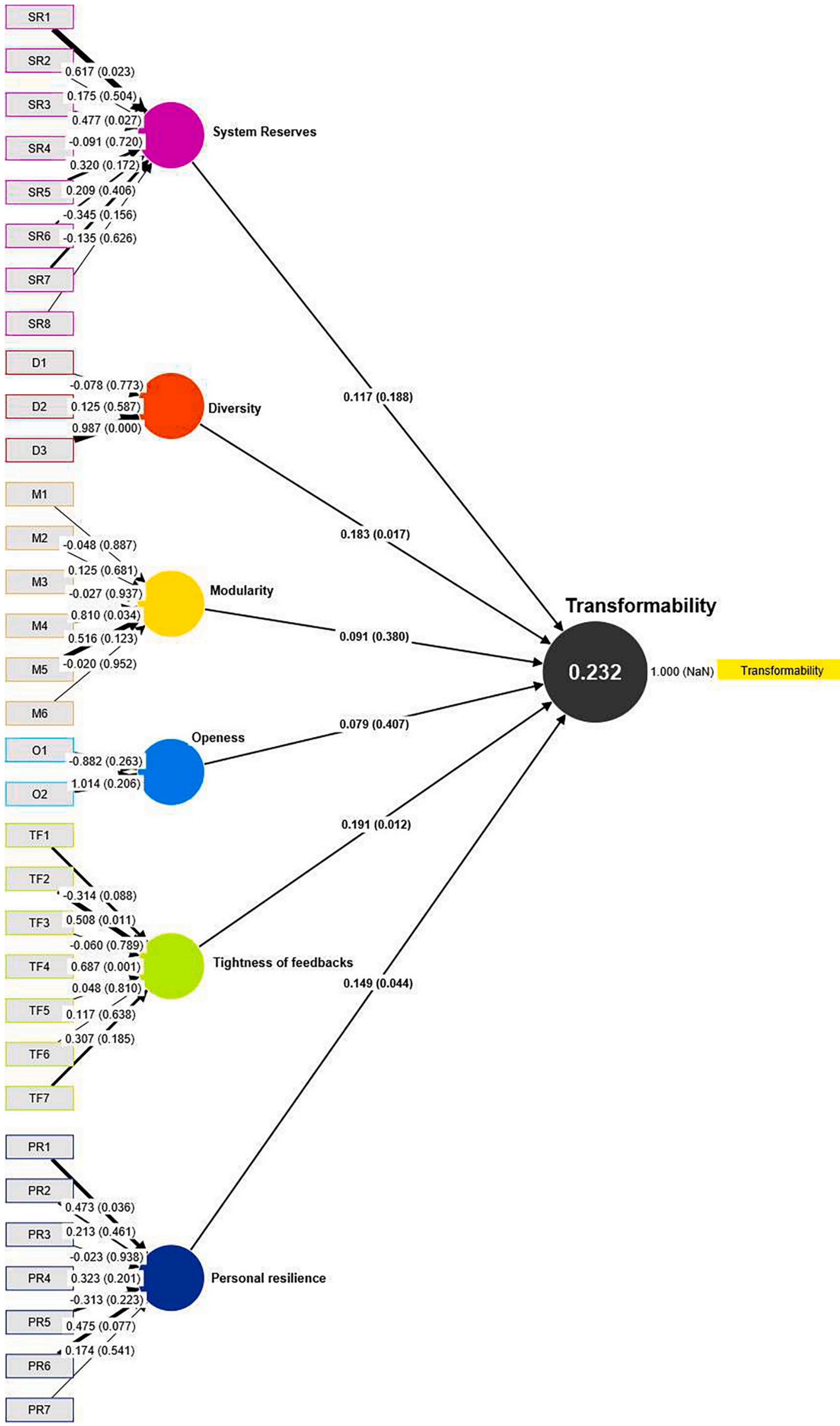
SR1
SR2
SR3
SR4
SR5
SR6
SR7
SR8
0.617 (0.023)
0.175 (0.504)
0.477 (0.027)
-0.091 (0.720)
0.320 (0.172)
0.209 (0.406)
-0.345 (0.156)
-0.135 (0.626)
System Reserves
D1
D2
D3
-0.078 (0.773)
0.125 (0.587)
0.987 (0.000)
Diversity
M1
M2
M3
M4
M5
M6
-0.048 (0.887)
0.125 (0.681)
-0.027 (0.937)
0.810 (0.034)
0.516 (0.123)
-0.020 (0.952)
Modularity
O1
O2
-0.882 (0.263)
1.014 (0.206)
Openess
TF1
TF2
TF3
TF4
TF5
TF6
TF7
-0.314 (0.088)
0.508 (0.011)
-0.060 (0.789)
0.687 (0.001)
0.048 (0.810)
0.117 (0.638)
0.307 (0.185)
Tightness of feedbacks
PR1
PR2
PR3
PR4
PR5
PR6
PR7
0.473 (0.036)
0.213 (0.461)
-0.023 (0.938)
0.323 (0.201)
-0.313 (0.223)
0.475 (0.077)
0.174 (0.541)
Personal resilience
0.117 (0.188)
0.183 (0.017)
0.091 (0.380)
0.079 (0.407)
0.191 (0.012)
0.149 (0.044)
Transformability
0.232
1.000 (NaN)
Transformability

Fig. 4. Transformability model, also referred to as Model 4.

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