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Ex-Ante Assessment of Farm Resilience to Institutional Shocks: A Modeling Approach

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ABSTRACT

Using the agent-based model SWISSland, we simulate farm-level responses and interactions under two institutional shocks: tariff reductions and direct payment reductions. Using a framework we developed, we assess resilience capacities, resilience attributes, and the provision of private and public goods, following the shock. Results indicate that valley farms are vulnerable to tariff reductions and mountain farms to direct payment reductions. Payment cuts cause minor changes in private and public goods provision, while tariff reductions reduce provision levels. It shows that different shocks require different resilience attributes, underscoring the need for ex-ante resilience assessments to develop targeted measures strengthening farm resilience.

JEL Classification: Q10, Q12, Q18

1 | Introduction

A farming system is considered resilient if it can successfully cope with uncertainties and dynamic environments while ensuring the provision of private and public goods through robustness, adaptability and transformability (Meuwissen et al. 2019). While the Common Agricultural Policy of the European Union aims to strengthen the resilience and reduce the environmental and climate footprint of agriculture (EC 2020), its temporary reform processes with regularly changing support measures also pose institutional risks to farmers. However, the impacts of institutional risks on the resilience of the farming system are rarely analyzed (Komarek et al. 2020) despite their importance for farmers and policymakers. Furthermore, little is known about how institutional risks affect the provision of private and public goods. This is important; however, as farming systems can be resilient but not sustainable and vice versa (Meuwissen et al. 2021). Given that it is difficult to assess resilience before a shock occurs, as resilience becomes evident only in cases when farms need to respond to a shock (Bertolozzi-Caredio et al. 2022; Meuwissen et al. 2021), current studies rely on perception-based farmers' surveys or define indicators based on secondary data (Spiegel et al. 2020; Slijper et al. 2022). While informative, these methods cannot capture farms' heterogeneous responses to future policy changes, limiting their use for ex-ante policy assessment.

Against this background, using agent-based models is a promising approach as they have distinctive features that can be exploited for resilience assessments of farm systems. Such models are used to assess the impact of institutional changes ex-ante (El Benni et al. 2023; Möhring et al. 2016; Mack and Kohler 2019). They allow for the modeling of heterogeneous behaviour among farms and their interactions (i.e., agents), as well as spatially explicit differences (Kremmydas et al. 2018; Noland et al. 2009). This makes it possible to consider the diversity of farms and their various responses to institutional changes in an ex-ante resilience assessment. Although these models are not yet used to assess farm system resilience, meaning that both the concepts required for such assessments and the corresponding indicators are currently lacking, integrating resilience into ex-ante modeling would expand the policy evaluation toolbox and enable policymakers to design measures that support farmers in managing institutional risks while achieving agricultural policy goals.

The study has two main aims. Firstly, we will develop and apply a conceptual framework for assessing resilience against institutional shocks ex-ante using agent-based farm models. Assessing shocks before they occur helps develop targeted policy measures to strengthen farm system resilience. Using the agent-based model SWISSland, we ex-ante assess the impact of two institutional shocks on the resilience of 2383 individual farms, namely a tariff reduction and a direct payment reduction. Secondly, we use group comparisons and regression analyses to identify resilience attributes (i.e., farm and farmer characteristics) that are associated with farm resilience, and assess how the two institutional shocks affect the provision of private and public goods. The results are discussed in terms of their implications for research and policymaking.

Existing empirical literature shows that changes in agricultural policy represent an important institutional risk for farmers, significantly affecting their perceived resilience. For instance, Bertolozzi-Caredio et al. (2022) found that Spanish extensive sheep farmers identified reduced direct payments and changing input and output prices as the most threatening challenge, being strongly negatively correlated to the perceived resilience to all three resilience capacities. Direct payments have been shown to contribute to the robustness of various types of farms and in different countries by stabilizing the status quo, even for farms that would not be profitable without these payments (Léger 2018; Lievens and Mathijs 2018; Valchovska and Peneva 2018; Feindt et al. 2019; Daskiewicz and Balmann 2018; Ciechomska and Zawalińska 2018; Buitenhuis et al. 2020), even though exceptions exist showing no effect of agricultural policy on resilience capacities (Manevska-Taseuska et al. 2021). Furthermore, not all direct payments contribute to the resilience of farms. Based on FADN data (2004–2013) from eight European countries, Slijper et al. (2022) found that decoupled payments had insignificant or even negative effects on robustness, while rural development payments enhanced it. The strong reliance of European farms on direct payments implies high institutional risk if these payments change.

Farms can respond to shocks or stresses either robustly, adaptively or transformatively, depending on their structure, management and interactions with each other (Meuwissen et al. 2019). These three resilience capacities are central to resilience assessment: Robustness is the farms' capacity to withstand stresses and unanticipated shocks. Adaptability is the ability to adjust inputs, production, or risk management in response to shocks without changing the core structure of farming systems. Transformability is the capacity to significantly change the farms' structure in response to a shock or persistent stress and reflects a radical change in business focus (Meuwissen et al. 2019; Darnhofer 2014). Furthermore, specific farm and farmer characteristics that contribute to resilience are referred to as resilience attributes and have been widely analyzed in existing literature (Reidsma et al. 2020; Paas et al. 2021; Meuwissen et al. 2019; Slijper et al. 2022; Spiegel et al. 2020, 2021). Resilience attributes can either enhance or detract from a farm system's resilience (Kerner and Thomas 2014). These attributes include farm and farm characteristics supporting the generic principles of resilience such as diversity, openness, tightness of feedbacks, system reserves and modularity (Meuwissen et al. 2019).

In this study, we present a conceptual approach for identifying ex-ante the resilience capacities robustness and adaptability of a farm population based on three indicators, namely farm exits in response to a shock, the income decline caused by the shock and the income recovery after the shock. We focus on the resilience of Swiss farms against two institutional shocks, namely a reduction in import tariffs and a reduction of direct payments. Using the agent-based model SWISSland, we apply the approach to identify five resilience capacity clusters, reflecting different variants of the two resilience capacities robustness and adaptability. Transformative changes are not considered in this study since they cannot be modeled with our agent-based model SWISSland. Using data of the modeled farms, we calculate resilience attributes and use group comparisons and regression analysis to assess their association to the five resilience capacity clusters. Finally, we assess changes in the provision of private and public goods across all individual farms (i.e., within the farm population). The private goods considered are food production, on-farm employment and farm income. Biodiversity area and nutrient surpluses are considered public goods.

The remainder of this paper is structured as follows. In Section 2, we present our conceptual approach to ex-ante resilience assessment. Section 3 shows an application of this approach to two different shock scenarios using the agent-based model SWISSland. In Section 4, we present the results on resilience capacities, resilience attributes and the provision of private and public goods, followed by a discussion in Section 5. Section 6 concludes with recommendations for researchers and policymakers.

2 | Assessing Resilience in Ex-Ante Policy Analysis Using Agent-Based Farm Models

Agent-based simulation models are used to account for the heterogeneous decision-making processes of farmers and are increasingly being applied in the European context (Huber et al. 2018). Agent-based models provide three important features allowing to assess the resilience of farm systems before a policy change. At first, they depict the heterogeneity of farms allowing to assess different responses toward a shock dependent on farm and farmers characteristics. Second, farms (i.e., agents) interact with each other, allowing to assess how behavior of one farm affects the behavior of another farm. Third, agent-based model simulations can represent spatially differentiated responses. Furthermore, agent-based models are well suited to assessing farmers' responses to policy changes by simulating different policy scenarios, such as institutional shocks, and comparing them with a counterfactual reference scenario without policy changes. This comparison allows a clear distinction to be made between the effects of the specific shock and other underlying dynamics, such as generational change (Pitson et al. 2020), thus enabling a more accurate assessment of the impact of the policy. Figure 1 illustrates how agent-based models can be used to ex-ante assess the resilience of farming systems against institutional shocks in four steps.

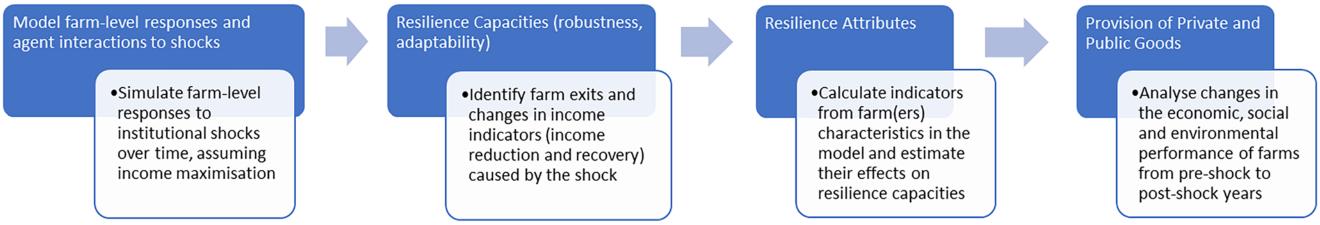

FIGURE 1 | How agent-based models can be used to ex-ante estimate resilience of farming systems.

In a first step, farmers' responses to the pre-defined institutional shocks are simulated. To model these responses, agent-based models often use farm optimisation models to predict production decisions of a heterogenous farm population, typically assuming that farmers act rationally and aim at maximising their farm income (Louhichi et al. 2015; Möhring et al. 2016). The simulation shows income development before and after the shock, as well as for the various scenarios over time. Furthermore, farms could exit the sector for economic reasons due to the shock.

In a second step, resilience capacities must be conceptualized. Depending on the model, it may not be possible to capture all three resilience capacities. This is the case for the agent-based model SWISSland that we apply in our study, as it is unable to model transformative change. We therefore focus on robustness and adaptability. We use three income related indicators to define a total of five resilience capacity clusters: (a) farms that exit the sector because their successors decide not to take it over; because the farm's income potential falls below a minimum threshold defined as the average income in the secondary and tertiary sectors, as reported by the Federal Statistical Office; or because the farm generates a negative cash flow for three consecutive years, (b) the shock-induced income decline, and (c) the subsequent income recovery up to the final year of the simulated period. Income decline is measured as a percentage change in income from the pre-shock year to the shock year. Income recovery is measured as the increase in income from the year of the shock to the final year of the simulation. The resulting resilience capacity clusters reflect different variants of the two resilience capacities robustness and adaptability. Transformative changes that lead to significant changes in the internal structure or business focus of the farm (Meuwissen et al. 2019), such as growing new crops or starting with direct sales or tourism activities cannot be modeled with our agent-based model SWISSland. We use farm income as a policy-relevant indicator of farm system resilience, as only economically viable farms can contribute to the resilience of farming systems (Finger and El Benni 2021). Economically viable farms are a prerequisite to provide a wide range of services expected from agriculture, including the provision of food and environmental goods and services, being key aspects of resilient farming systems (Swinton et al. 2007; Meuwissen et al. 2019).

As depicted in Figure 2, the resilience capacity clusters considered are: (1) Non-resilient farms that exit the sector because their income falls below a minimum level over several years or because potential successors are not willing to take over the farm due to low farm income, (2) Farms at risk that face severe income drops below a certain threshold and are not able to reach pre-shock income levels by the end of the simulated period, (3) Robust farms whose income remains within a certain range throughout the time period considered despite the shock, (4) Adaptive farms whose income recovers to pre-shock levels after a shock-induced income decline, and (5) Resilient farms whose income is robust to the shock and increases above pre-shock levels by the end of the simulated period.

In contrast to existing literature which defines robustness by an income decrease followed by an income recovery after a certain period of time (Grafton et al. 2019; Slijper et al. 2022), we define robustness as income developments within a certain range not falling below a certain threshold. This approach is considered more appropriate for ex-ante assessments of institutional shocks, as these are long-term stresses rather than short-term shocks (Meuwissen et al. 2019), and persist until the end of the simulated period. Therefore, farms can only be considered robust (or resistant) if the institutional change does not affect income, and if income recovery can only be achieved through adjustments at farm level. These adjustments reflect the farms' adaptability. To identify robustness and adaptability of farms, thresholds must be defined below which a farm is considered not to be robust. Also, for income recovery after the shock thresholds must be set above which a recovery of income is considered to contribute to resilience.

In a third step, resilience attributes are determined using the forecasting results. Resilience attributes are context-specific characteristics of a farming system, that is, farm and farmers characteristics, that enhance resilience by supporting generic principles of resilience, such as diversity or system reserves (Meuwissen et al. 2019). Farm characteristics that are associated with resilience include profitability, meaning that farmers can earn a liveable wage without depending heavily on subsidies (Reidsma et al. 2020; Paas et al. 2021); farm size by giving farmers more scope for internal flexiblity, such as reallocating land between enterprises (Reidsma et al. 2020; Slijper et al. 2022); labor input (Coomes et al. 2019; Renner et al. 2021); the degree of diversification, meaning a high variety of inputs, outputs, income sources or markets (Reidsma et al. 2020; Meuwissen et al. 2019; Slijper et al. 2022); and production intensity (Coomes et al. 2019; Renner et al. 2021). Farmer characteristics contributing to resilience include lower risk-aversion, a greater focus on providing public goods, a higher number of implemented risk management strategies such as financial savings or being a member of a producer organization, a greater involvement in networks and greater openness to innovation (Spiegel et al. 2020, 2021). Also age is related to resilience by increasing farmers' experiences with risk and uncertainties (Peerlings et al. 2014). Depending on

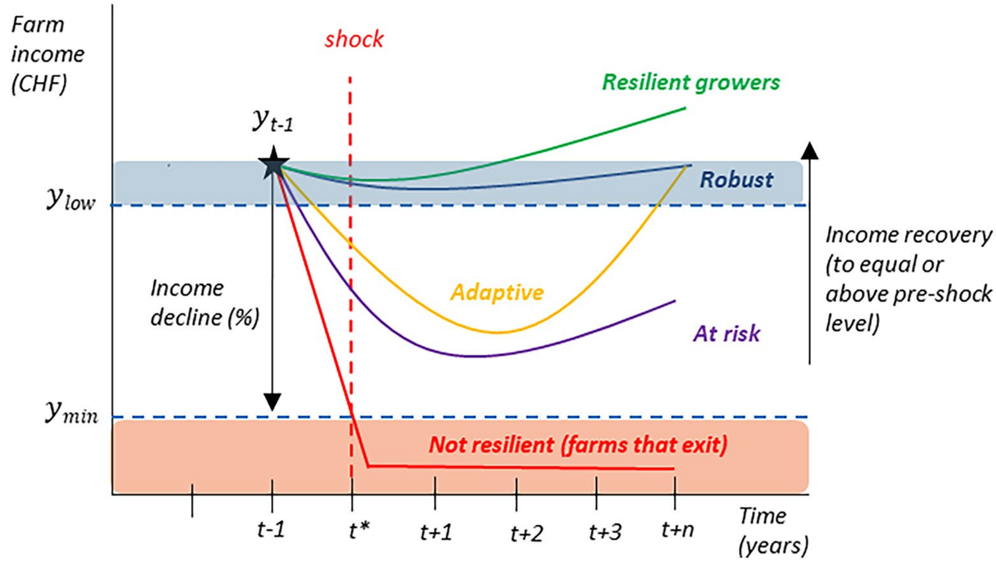

FIGURE 2 | Possible effects of a shock on farm exits, income decline and recovery to determine resilience capacities. y denotes the income level, $t-1$ denotes the pre-shock year, t^* denotes the year of the shock, $t+1$ to $t+3$ denotes the first to third post-shock years, and $t+n$ denotes the final year of simulation. y_{t-1} (star) denotes the pre-shock income level, y_{low} marks the lower bound of the pre-shock income level and y_{min} is the minimum-income exit threshold. Building on two indicators, income decline and income recovery, five resilience capacity clusters are distinguished: (a) **Exit**: farms exit the sector, and are classified as not resilient, if their income falls below y_{min} in the shock year or in any subsequent year, or if they generate a negative cash flow for three consecutive years, that is, $y_t < y_{\text{min}}$ for some $t \in \{t^*, \ldots, t+n\}$. y_{min} is not applied directly but farm exit is inferred from the simulation output, where an exiting farm is coded as missing (NA) income in the final simulation year. (b) **At risk**: Farms are at risk if their income falls below y_{low} at some point between the shock year and the year before the end of the simulation, and remains below the pre-shock level y_{t-1} at the end of the simulation, that is, $\min\{y_t: t=t^*, \ldots, t+n-1\} < y_{\text{low}}$ and $y_{t+n} < y_{t-1}$. (c) **Robust**: Farms are considered robust if their income remains above y_{low} in any year after the shock, and does not exceed the pre-shock level $y(t-1)$ by the end of the simulation, that is, $y(t) \geq y_{\text{low}}$ for all $t=t^*, \ldots, t+n-1$, and $y_{t+n} < y_{t-1}$. (d) **Adaptive**: Farms are considered adaptive if their income falls below y_{low} at some point between the shock year and the year before the end of the simulation, but recovers to at least the pre-shock level y_{t-1} by the end of the simulation, that is, $\min\{y(t): t=t^*, \ldots, t+n-1\} < y_{\text{low}}$ and $y_{t+n} \geq y_{t-1}$; (e) **Resilient growers**: Farms are considered resilient growers if their income never falls below y_{low} during the simulation period, and grows beyond the pre-shock level y_{t-1} by the end of the simulation, that is, $y_t \geq y_{\text{low}}$ for all $t=t^*, \ldots, t+n-1$, and $y_{t+n} \geq y_{t-1}$.

the data available in the model, various resilience attributes can be extracted and/or calculated and used to assess their correlation with farms resilience capacities.

In a fourth step, the provision of public and private goods is assessed. Due to its multifunctional role, agriculture provides various private and public goods. Private goods include farmers' income, farm labor provided, and food production. Public goods include the farm's contribution to agri-environmental programmes, such as providing biodiversity areas or reducing input surpluses from nutrient or pesticide use. The range of provided private and public goods considered in the resilience assessment also depends on the availability of data in the modeling approach.

3 | Ex-Ante Resilience Assessment Based on Data From the Agent-Based Model SWISSland

We here present an overview of the agent-based model SWISSland and introduce two institutional shock scenarios against which we evaluate the resilience of farms implemented in SWISSland. We also present the farm-level indicators used to assess the resilience capacities and resilience attributes. Finally, we outline the empirical methods applied to analyse farm-level responses to the two institutional shocks.

3.1 | The Agent-Based Model SWISSland

The agent-based model SWISSland is regularly used by Swiss agricultural policymakers to ex-ante evaluate the effects of policy changes on changes in land use, changes in the number and type of livestock, and exit from farming and land renting from neighboring farms (e.g., Bystricky et al. 2023; Mack and Kohler 2019; Mack et al. 2023; Schmidt et al. 2019). Thus, the effects of policy changes on farmers' incomes, agricultural structures, food production and selected environmental indicators can be simulated ex-ante.

SWISSland models heterogeneous farm responses to policy changes for a farm sample of 3063 FADN farms over a forecasting period of 10–15 years using bio-economic farm optimisation models (Möhring et al. 2016). Farm records from the FADN database (three-year averages of the years 2016–2019) are used to define the technical coefficients of the optimization models. In particular, data on the yields and production costs of agricultural activities, as well as product prices at farm gate were used to build the databases of the optimization models. In addition, the models include the current Swiss direct payment programs from the parliamentary initiative (Mack and Möhring 2021), including voluntary agri-environmental payments, whose adoption rates are taken into account in accordance with the information in the FADN data for the base year 2018 (Möhring et al. 2016).

For ex-ante simulations, price projections for inputs and outputs, as well as direct payment projections until 2030, defined by policymakers from the Federal Office for Agriculture, are implemented in the bio-economic farm optimization models. SWISSland uses positive mathematical programming to estimate land use and livestock decisions for each farm over a 10–15 year period (Mack et al. 2019). During the forecasting period, the adoption of various voluntary payment schemes by each farm agent is also modeled. These adoption decisions are forecasted under the assumption that farms will adopt voluntary direct payment schemes when their compliance costs are lower than the direct payments themselves (Mack and Huber 2017).

The agent-based sector model SWISSland takes into account interactions between agents in the land market (Möhring et al. 2016). It is assumed that farms exit the sector when a farmer reaches pension age and there is no successor to whom they can hand over the farm, or because the potential successor decides against taking it over because of low farm income. The average income in the secondary and tertiary sectors for the valley, hill and mountain regions, as reported by the Federal Statistical Office, defines the threshold at which farm incomes are considered to be too low to be taken over by successors. In addition, it is assumed that farms with a negative cash flow for three consecutive years will exit the sector before the farmer reaches retirement age.[1] All exiting farms rent their land plots to neighboring agents allowing continuing farms to increase their income by leasing additional land.[2]

Finally, SWISSland models farms representative of the valley, hill, and mountain regions, thus enabling spatially explicit analysis. The transfer of agricultural land from a farm that exit the sector to another is only possible within the neighborhood.

In summary, farms can adapt to a shock by increasing production in branches less affected by the shock and decreasing production in branches more severely impacted. For example, increasing the size of ecological compensation areas (i.e., increasing income from ecological direct payments) can effectively compensate income reductions resulting from the reductions of direct payments. Similarly, producers can switch to crops or livestock that are less susceptible to price reductions. However, the most important adaptation strategy is to increase the area by renting land from farms that are exiting the sector. Furthermore, a larger area enables farms to increase their number of livestock. Growth in both area and livestock numbers enables farms to offset losses from reductions in direct payments or prices due to the shock. Thus, growth in farm size allows farms to increase their market income and area-based direct payments, both of which contribute to farmers' incomes.

3.2 | Definition of Institutional Shock Scenarios

Swiss agricultural policy support to farmers largely influences the economic viability of farms. Policy changes can thus constitute an institutional shock for individual farms. Since economically viable farms are essential for providing the wide range of services, including food production and environmental goods and services, which are key aspects of resilient farming systems, farm incomes are not only a primary objective of agricultural policy, but also affect the resilience of farming systems. Swiss agricultural policy employs two primary instruments to support Swiss farmers (Huber et al. 2024): (1) direct payments and (2) tariffs. Direct payments are provided to farmers who fulfill minimum environmental requirements (known as proof of ecological compliance). The direct payment system in Switzerland adheres to the Tinbergen rule, which implies that each direct payment programme follows a specific agricultural policy goal (Mann and Lanz 2013). More specifically, direct payments for cultural landscapes aim to maintain open landscapes and compensate for the difficult production conditions in hilly and mountainous regions; food security payments aim to maintain production capacities; biodiversity payments aim to conserve and promote species and habitat diversity; landscape quality payments aim to promote the development of divers landscapes; and payments for specific production systems aim to promote environmentally and livestock-friendly production methods. Direct payments for cultural landscapes and food security account for two thirds of the 2.8 billion CHF direct payment budget, with 98% of Swiss farmers receiving this funding. Within this, food security payments account for the largest share of the direct payment budget, accounting for about 40% of all direct payments (Huber et al. 2024). The remaining third of the direct payment budget is provided to farmers who voluntarily subscribe to agri-environmental schemes, such as biodiversity payments (Huber et al. 2024). The import of most agricultural products into Switzerland is subject to tariffs.[3] Due to these tariffs, Swiss farmers receive prices that are about 45% higher than those on the international market (OECD 2023). As direct payments and import tariffs account for almost 50% of gross farm receipts in Switzerland (OECD 2023), removing them would be an institutional shock to farmers.

In order to analyze the resilience of Swiss farms to two institutional shocks, we defined one reference scenario and two shock scenarios (Table 1).[4] For the reference scenario, we assumed that the current direct payment system and import tariffs will not change until 2030. Therefore, product price projections in the reference scenario up to 2030 will not be affected by changes in tariffs. The reference scenario represents the projected development of farms under the current agricultural policy, which is assumed to remain unchanged throughout the modeling period (until 2030 in our case). It serves as a counterfactual scenario against which the outcomes of the shock scenarios are compared.

TABLE 1 | Overview of the policy scenarios.

Scenario	Description
Reference	No shock: Modeling the current agricultural policy up to 2030.
Direct payment reduction	Direct payment shock: 100% cut in food security payments from 2026 to 2030. No changes in import tariffs.
Tariff reduction	Import tariff shock: Complete removal of import tariffs from 2026 to 2030. No changes in direct payments.

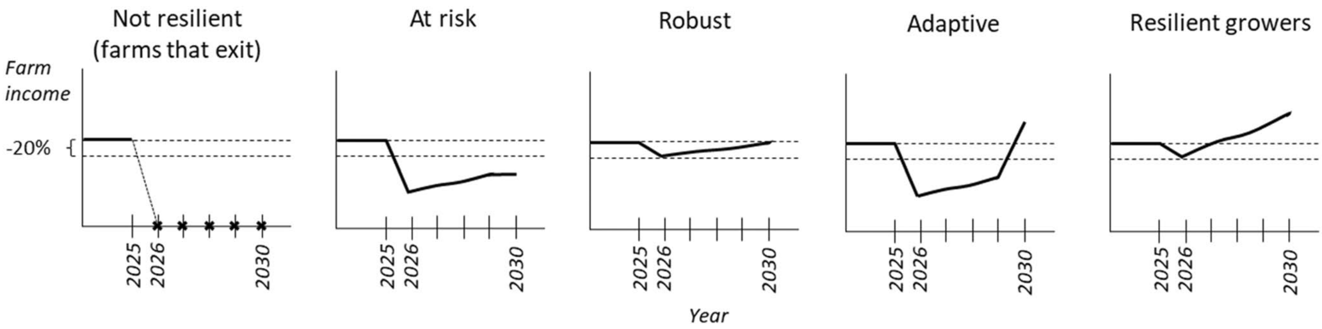

FIGURE 3 | The five resilience capacity clusters considered.

In the tariff reduction scenario, we assumed the complete removal of import tariffs on all agricultural products including arable crops for human consumption and animal feed, as well as fruits, meat, dairy products, and eggs. We calculated domestic product price reductions at the farm gate using the partial-equilibrium sector model CAPRI (Britz and Witzke 2008), and then implemented these price changes in the SWISSland model. Due to the reduction in import tariffs, the prices of pork meat (−59%), vegetables (−53%), and poultry meat and eggs (~40%) would drop sharply. Prices of arable crops and milk would drop by between 7% and 25% (see Table A1). The direct payment reduction scenario considers a complete removal of food security payments. In current Swiss agricultural policy, food security payments range from 600 CHF per ha (for grassland) to 1000 CHF per ha (for arable land). In the mountain region, supplementary payments are granted to compensate for the natural production difficulties (390–590 CHF per ha). We assume that these policy changes will come into effect in 2026 and remain in place until the end of the simulation period in 2030.

3.3 | Farm Indicators for Assessing the Resilience Capacities

We define resilience capacities based on three indicators: (1) whether or not a farm exits the sector due to the shock, (2) the change in income due to the shock, and (3) the recovery in income until the final year of the simulation. More precisely, we first distinguish between farms that exit the sector and those that remain in the sector despite the shock over the entire time period 2025–2030. In the agent-based model SWISSland, farms exit the sector when farmers without successor reach the retirement age (65) or if the successor is not willing to take over the farm due to low farm income[5] or when the farm have had negative cash flow for three consecutive years. In this case, the farmer exits the sector before the retirement age. It is therefore also possible that farms will exit the sector in the reference scenario, that is, the scenario without shock. As resilience becomes evident only when farms need to respond to a shock (Bertolozzi-Caredio et al. 2022; Meuwissen et al. 2021), we are only interested in farms that exit the sector as a result of the shock. We therefore only consider farms that remain in the sector in the reference scenario for the period 2025–2030. These farms form the sample for the scenario analysis. For these farms, we calculate the income change relative to 2025 (pre-shock year) for each year from 2026 to 2029 (shock and recovery period) and the income recovery rate between 2025 and 2030 (final simulation year). Following Article 39a of EU Regulation 2017/2393 and Severini et al. (2021), shock-induced income drops are categorized as either severe (more than 20%) or non-severe (less than 20%). Regarding income recovery, we distinguish between farms that remain below their pre-shock income level and those that exceed it.

We use these farm indicators to build five resilience capacity clusters (Figure 3): (1) Farms that exit the sector due to the shock are not resilient. However, they can enhance the resilience of neighboring farms by leasing their land to them, enabling these farms to become robust or adapt to shocks, for example by increasing their livestock numbers or having the flexibility to reallocate land to more profitable enterprises. (2) Farms at risk face severe income losses due to the shock and do not recover from this shock, that is, they do not reach pre-shock income levels by 2030. (3) Robust farms do not face severe income declines due to the shock, that is, income losses are 20% at most. (4) Adaptive farms face severe income losses due to the shock but are able to recover and reach at least 100% of their pre-shock income levels by 2030. (5) Resilient growers do not experience income declines of more than 20% relative to pre-shock levels at any point during the shock and recovery period and by the final simulation year their income has increased above pre-shock levels.

3.4 | Indicators for Assessing the Resilience Attributes and Private and Public Goods

Resilience attributes are context-specific characteristics of a farming system that either enhance or constrain one or more of its resilience capacities and include individual and collective competencies as well as the environment, which support the generic principles of resilience, such as diversity, openness, tightness of feedbacks, system reserves and modularity (Meuwissen et al. 2019). To select the resilience attributes, we drew on existing literature which has already identified farm system characteristics that enhance resilience. Given the system boundaries of our model SWISSland (e.g., only farms are represented but no upstream or downstream industry), our focus is on farm and farmer characteristics available in our model.

Table 2 shows the resilience attributes extracted from SWISSland for assessing their association with the resilience capacity clusters alongside related literature. In our analysis, we assess resilience attributes of the following generic principles of resilience: System reserves, assessed by the farms' profitability, farm size, labor use efficiency, farmers' age and direct payments. Diversity

TABLE 2 | Indicators to assess resilience principles and attributes from the agent-based model SWISSland.

Resilience principles	Resilience attributes	Indicators	References
System reserves	Profitability	Farm income is the difference between return and external costs (Hoop 2019) and measured by CHF/ha.	Reidsma et al. (2020) Paas et al. (2021)
		Farm revenues is the income from selling agricultural products and direct payments (Hoop 2019) and measured in CHF/ha.	
		Cash flow is the difference between receipts and payments of the farm (Jan and Weber 2019) and measured in CHF/ha.	
	Farm size	Hectare agricultural land	Reidsma et al. (2020) Slijper et al. (2022)
	Labor use efficiency	Working days of farm family members and hired labor measured in normalized working days (Bundesrat 2024) per ha.	Coomes et al. (2019) Renner et al. (2021)
	Age	Farmers' age in years (as the only farm characteristic available in SWISSland).	Peerlings et al. (2014)
	Dependence on direct payments	Share of direct payments on gross revenues in %.	Feindt et al. (2019) Bertolozzi-Caredio et al. (2022)
Diversity	Diversification	The Shannon Diversity Index considers the proportion of land covered by a crop and the number of different crops (Brady et al. 2009). A high value indicates high diversification, while a low value indicates high specialization.	Reidsma et al. (2020) Meuwissen et al. (2019) Slijper et al. (2022)
	Production intensity	Costs of mineral fertilizer and pesticides per ha are considered. Increasing values show increasing production intensity.	Coomes et al. (2019) Renner et al. (2021)
		Livestock units per ha are considered. Increasing values show increasing production intensity.	
Openness; Tightness of feedbacks	Regions	Farms are located in the valley, hill and mountain regions as defined in the Landwirtschaftliche Zonen-Verordnung (1998); SR 912.1. Land can be leased between neighbors within the regions.	Renner et al. (2021)

Note: The Shannon Index is calculated as follows (Brady et al. 2009): $\mathrm{SDI}_t = -\sum_{i=1}^{I} p_{i,t} \ln(p_{i,t})$, were SDI_t denotes the diversity at time t (year), and $p_{i,t}$ is the share of land covered by crop i at time t. We distinguish between six different crops, namely fodder crops (extensive grassland, less intensive grassland, intensive grass land, permanent meadows, permanent grassland, hedges, extensive meadows, summering grasslands), cereals (grains for human consumption, feed grain, silage maize, grain maize), legumes (soybeans, legumes), oilseeds (rapeseed, sunflowers), Fruits (perennial crops, other crops, berries, fruit, vines), and vegetables and root crops (sugar beet, fodder beet, vegetables, potatoes, peat moss, tobacco, fallow land).

is assessed by the degree of farm diversification measured by the Shannon index and production intensity. The two generic resilience principle, openness (i.e., the connectivity between systems; Carpenter et al. 2012) and tightness of feedbacks (i.e., the response of one part of the system to changes in other parts of the system; Walker and Salt 2006), are considered in our analysis through the ability of farm agents to lease land from neighbors within a region. Modularity (i.e., the internal division of the system in independent but connected modules (Carpenter et al. 2012) with potentially different functions (Meuwissen et al. 2019) cannot be assessed due to SWISSland's model boundaries).

Table 3 shows the indicators for assessing the provision of private and public goods by farms. These are provided by

TABLE 3 | Private and public goods from the agent-based model SWISSland.

	Variable	Description
Private goods	Farm income	Difference between return and external costs in CHF
	Family labor	Working days of family labor used for on-farm work
	External labor	Working days of hired labor used for on-farm work
	Plant products	Barley, grain maize, potatoes, pulses, rapeseed, sugarbeet, sunflower seeds, wheat in dt
	Animal products	Beef meat, pork meat, sheep and goat meat in kg & number of eggs
Public goods	Action-based biodiversity	Hectares in the action-based biodiversity payment scheme rewarding farmers for the provision of ecological focus areas (Mack et al. 2020; Wuepper and Huber 2022)
	Result-based biodiversity	Hectares in the result-based biodiversity payment scheme that reward farmers for the provision of a specific number of target species per square meter on ecological focus areas (Schaub et al. 2025; Wuepper and Huber 2022)
	Multi-actor-oriented biodiversity	Hectares enrolled in the multi-actor biodiversity payment scheme that rewards farmers for creating spatially connected ecological focus areas across neighboring farms (Huber et al. 2021).
	N surplus	Kg N surpluses based on farm gate N balances (Schmidt et al. 2021). N inputs considered are those from feeds and fertilizers bought, N fixation and atmospheric N deposition. N output is calculated based on plant and animals products produced. N inputs from farmyard manure and outputs of own consumed feed is not considered.

the SWISSland model at the farm-level and are aggregated across all farms to assess overall provision of private and pubilc goods.

3.5 | Group Comparisons and Regression Analysis

Model results of the SWISSland farm population are analyzed in three steps. At first, we analyze whether significant differences in the exit rates of farms, that is, survival curves, across the different scenarios exist using log-rank tests provided in the R package survival (Therneua 2024).

Second, we assess differences in the resilience attributes across the five different resilience capacity clusters. We used Levene's test to detect significant differences in resilience attribute variances and the Wilcoxon rank-sum test to test for significant differences in resilience attributes across resilience capacity clusters. Bonferroni correction is applied to both tests. Additionally, to assess the association between each resilience attribute and resilience capacity cluster membership while holding the other attributes constant, we use logit regression to predict the probability of belonging to resilience capacity Clusters 1–5:

$$\log it\left(P\left(y_i = 1 \middle| X_i\right)\right) = \ln\left(\frac{P\left(y_i = 1\right)}{1 - P\left(y_i = 1\right)}\right) = X_i'\beta$$

with $y_i \epsilon \{0, 1\}$ showing whether farm i is member of the respective resilience capacity cluster or not, X_i being the vector of resilience attributes and β being the vector of estimated coefficients. The coefficients depict the change in the log-odds of the outcome per unit increase in the predictor. A positive (negative) coefficient shows that the resilience attribute is positively (negatively) related to the log-odds, and thus the probability, of being member of the respective resilience capacity cluster. As robustness check, we also estimate multinomial logit models, with farms that exit being the baseline group.

Thirdly, we identify the effects of the two shock scenarios on private and public goods by comparing their provision in all three scenarios for the year 2030 descriptively.

4 | Results

We here present the effects of the shock scenarios on farm system resilience by first analyzing the occurrence of the five resilience capacity clusters. We then identify resilience attributes by analyzing which farm characteristics are related to resilience. Finally we show how the two shock scenarios affect the provision of private and public goods.

4.1 | The Resilience of Swiss Farms to Institutional Shocks

Figure 4 shows the exit rates of farms for the reference and the two shock scenarios over the time period 2018 to 2030. The shock takes place in 2026 and remains up to the final simulation year 2030. Descriptive statistics of the pre-shock year 2025 farm sample are shown in Table A2.

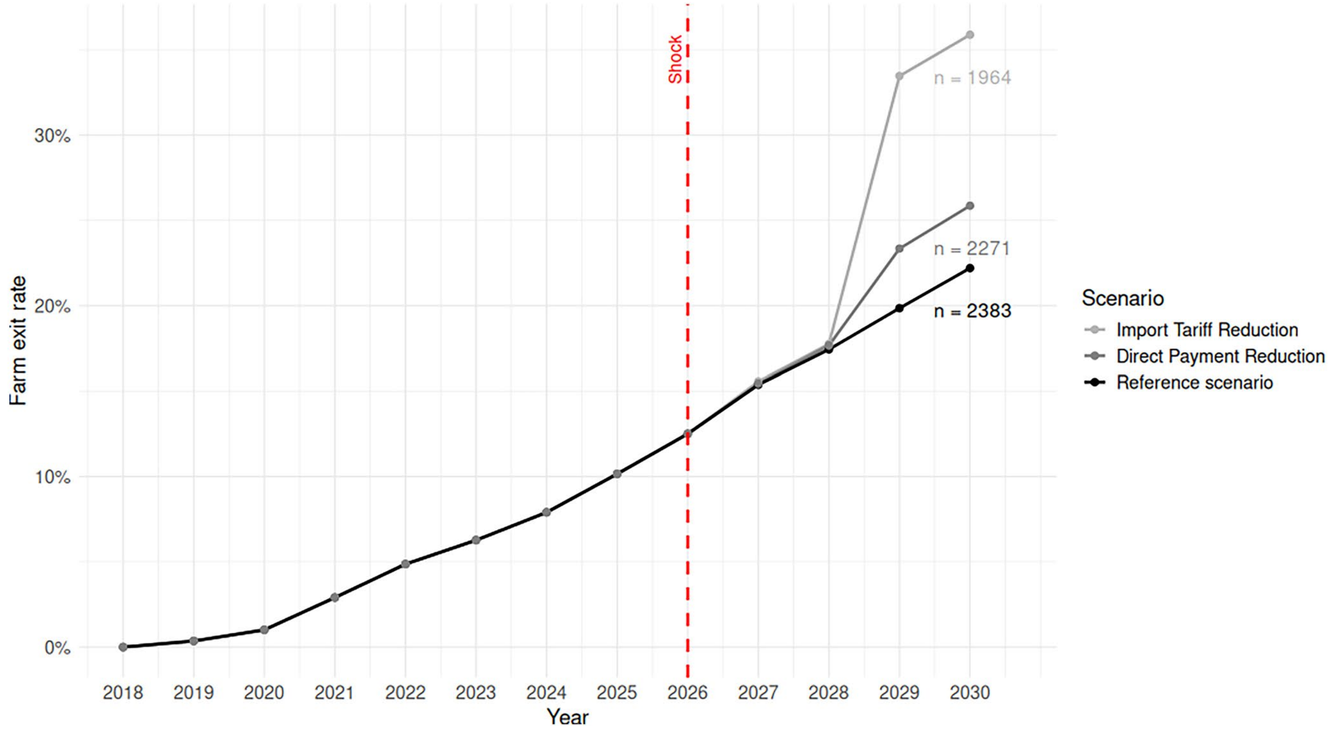

FIGURE 4 | Farm exits in the reference and the two shock scenarios 2018–2030. The number of farms that stay in the sector until 2030 is depicted (e.g., 2383 farms stay in the sector in 2030 in the reference scenario).

In the reference scenario without shock, the number of farms decreases by 22.2% from 3063 in 2018 to 2383 farms in 2030. As the reference scenario assumes that agricultural policy would not change during the simulation period up to 2030, these exits can be attributed to either farms reaching retirement age without a successor who is willing to take over the farm due to low farm income or to farms experiencing negative cash flows for three consecutive years. In the tariff reduction scenario, the exit rate is 17.6% higher than in the reference scenario, corresponding to an additional decline of 419 farms (to 1964 farms by 2030). In the direct payment reduction scenario, the exit rate is 4.7% higher, corresponding to an additional decline of 112 farms (to 2271 farms by 2030). The higher exit rates in the shock scenarios show the substantial impact of the shocks on the resilience of Swiss farms. Farms that exit the sector as a result of the shocks are not resilient to them. Log rank tests reveal significant differences in farm survival across all scenarios, indicating that farms are not resilient to either shock scenario, especially the reduction in import tariffs.

An analysis of farms remaining in the sector despite the shock (see Figure A1) shows that farms at risk make up 75.8% of all farms when tariffs are reduced and 68.1% when direct payments are reduced. Furthermore, farms are less robust against tariff reductions (11.7%), compared to direct payment reductions (18.4%). The share of resilient growers is low in both scenarios (4.2% when tariffs are reduced and 8.8% if direct payments are reduced). Adaptive farms are slightly more likely in the tariff reduction scenario (8.4%) compared to direct payment reductions (4.8%), which can be explained by the higher exit rates allowing remaining farms to lease more land and increase incomes.

Figure 5 shows the number and share of farms in valley, hill and mountain regions across the five resilience capacity clusters for the Tariff Reduction scenario (Panel A) and the Direct Payment Reduction scenario (Panel B). The high number of farms at risk in all regions highlights the vulnerability of Swiss farms to both types of shock. However, regions are affected differently depending on the type of shock. In the tariff reduction scenario, 24.3% of valley farms exit the sector, compared to 5.0% of the mountain farms. The share of farms at risk is about 62% to 64% similar across regions. Considerably more mountain farms (18.4%) are robust against tariff reductions compared to valley farms (4.3%). When direct payments are reduced, a substantially higher share of mountain farms is at risk (80.4%) compared to valley farms (51.0%) and also a slightly higher share of farms in mountain regions exit the sector (6.8%) than in valley regions (3%). Furthermore, farms in valley regions are more robust to direct payment reductions (27.0%) than farms in mountain regions (6.5%) and also the share of resilient growers is much higher in the valley regions (13.8%) compared to the mountain region (2.1%). Adaptive farms are present across all regions and can adjust to both types of shocks, but they represent a relatively small share of all farms.

4.2 | Resilience Attributes Across Resilience Capacity Clusters

At first the results for the Tariff Border Reduction scenario are presented. Figure 6 shows the median and interquartile range of farm and farmers characteristics, that is, the resilience attributes, for the five resilience capacity clusters before the shock

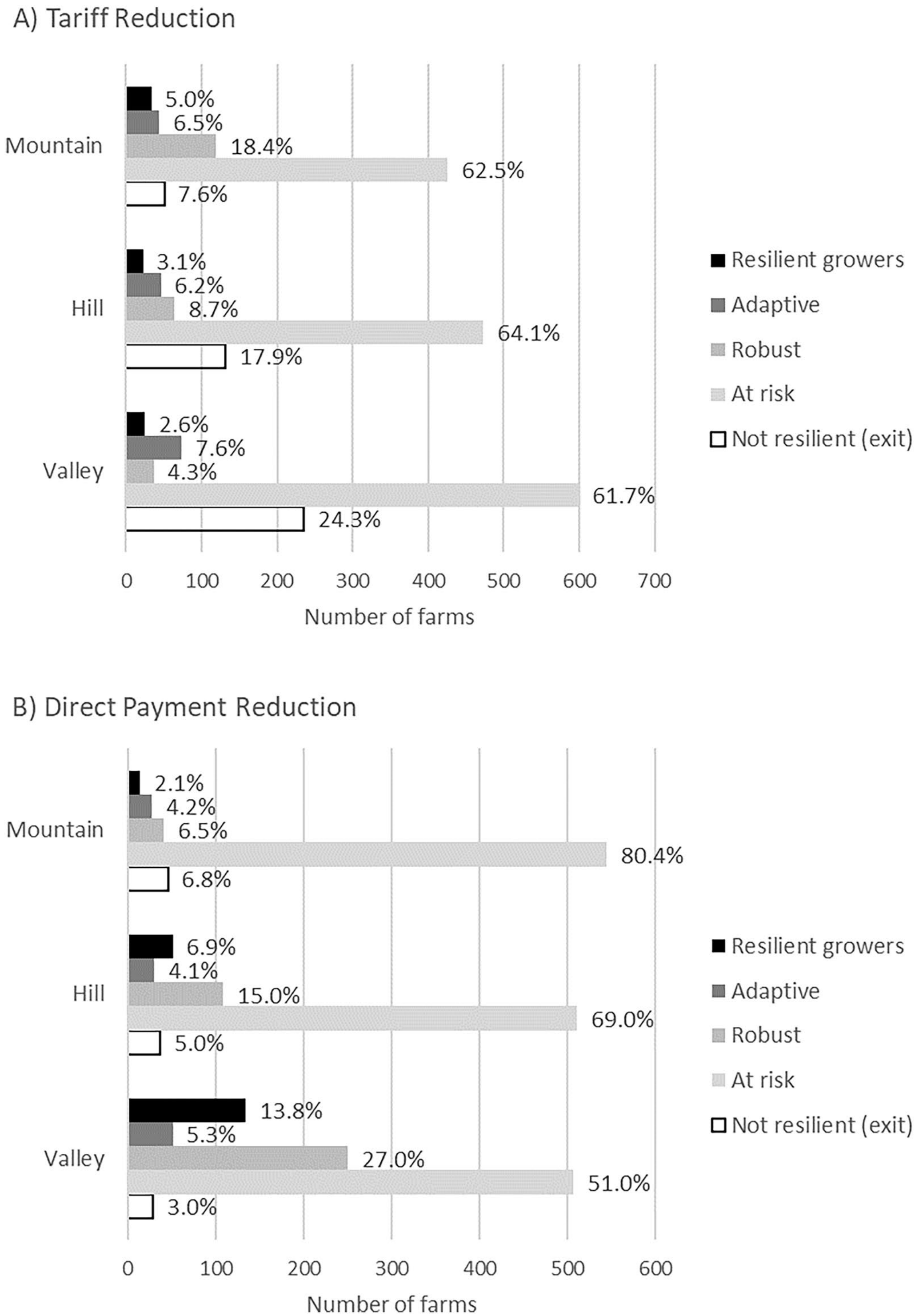

FIGURE 5 | Distribution of farms across the five resilience capacity clusters across regions.

(i.e., year 2025). Groups are compared using Wilcoxon rank-sum tests and Levene's tests, both correcting for multiple comparison using the Bonferroni correction. Test results are shown in Tables A3 and A4.

Table 4 shows the results of the logit-regressions used to identify which resilience attributes predict the log-odds (and thus the probability) of belonging to one of the resilience capacity clusters if all other attributes are held constant. To avoid multicollinearity issues (see correlation matrix in Figure A2), we select farm income per hectare agricultural land as a productivity indicator and do not consider cash flow and market revenues in the regressions. The results of the multinomial logit model are presented in Table A5.

For the tariff reduction scenario, our results show significant differences between the farms that exit the sector compared to all other resilience capacity clusters. The descriptive results (Figure 6) are reflected in the multinomial models (Table A5). Farms that exit the sector have significantly lower profitability

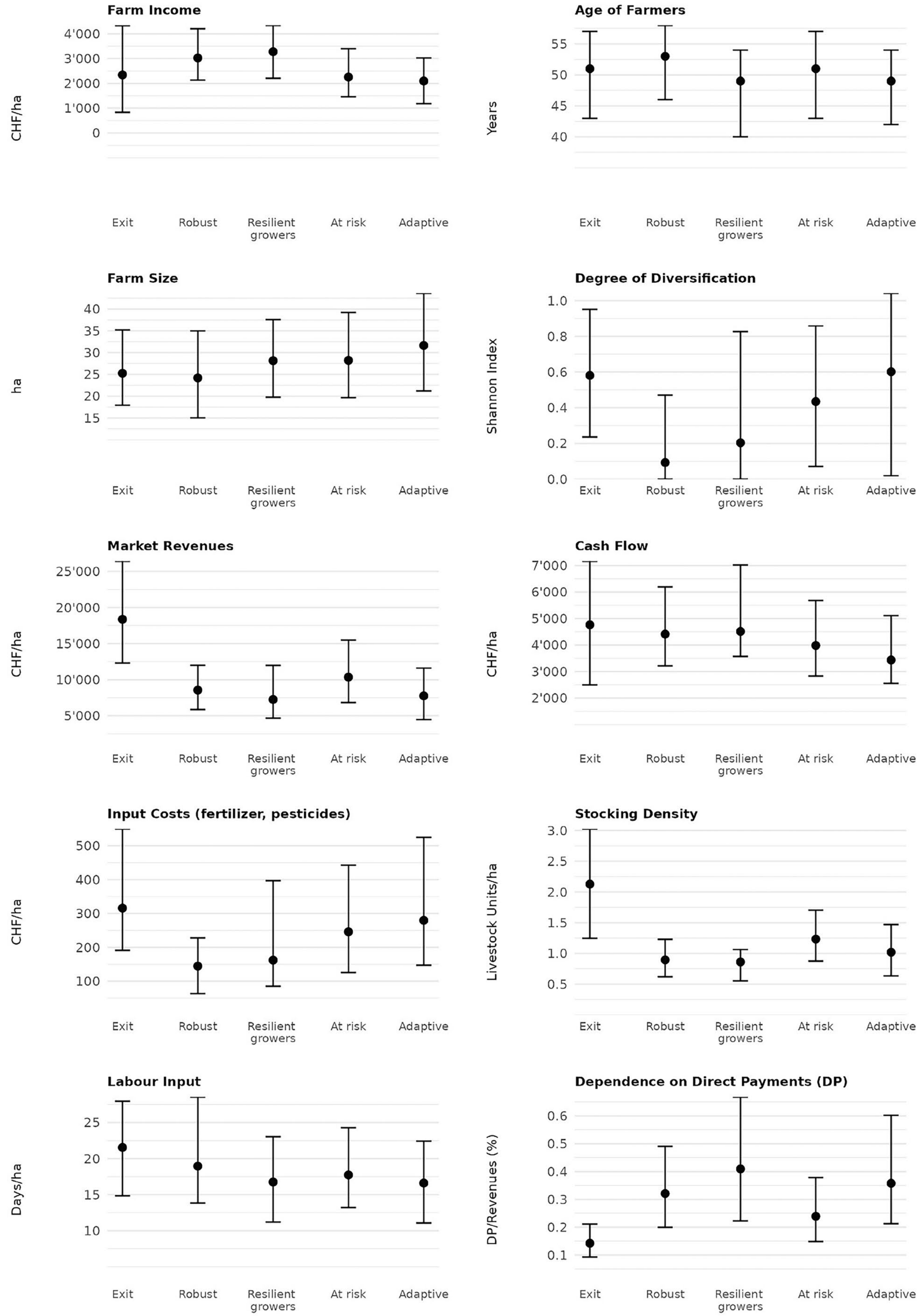

FIGURE 6 | Legend on next page.

FIGURE 6 | Resilience attributes by resilience capacity clusters—Tariff reduction scenario. Data are from the year 2025. Median values are indicated by dots. Bars show the interquartile range, that is, the 25th and 75th quartiles.

TABLE 4 | Results of the logit regressions predicting membership of resilience capacity clusters—Import tariff reduction.

	Exit	At risk	Robust	Adaptive	Resilient growers
Intercept	−4.635***	1.243***	−1.247**	−0.687	−0.335
	(0.625)	(0.329)	(0.591)	(0.664)	(0.874)
Farm income	−0.000***	−0.000	0.000**	0.000	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Age	0.016**	−0.001	0.028***	−0.026***	−0.022*
	(0.007)	(0.005)	(0.009)	(0.009)	(0.013)
Farm size	0.007*	0.007**	−0.019***	−0.005	−0.007
	(0.004)	(0.003)	(0.006)	(0.005)	(0.007)
Degree of diversification	0.473**	−0.145	−0.510**	0.197	−0.200
	(0.212)	(0.142)	(0.255)	(0.279)	(0.424)
Input costs	0.001***	0.000***	−0.002***	0.000	−0.001*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Stocking density	1.227***	−0.352***	−1.602***	−0.340***	−1.098***
	(0.126)	(0.052)	(0.164)	(0.129)	(0.232)
Labor input	0.008	0.000	0.004	−0.009	−0.001
	(0.005)	(0.002)	(0.003)	(0.008)	(0.010)
Dependence on direct payments	−0.964	−0.622***	−1.119***	1.240***	0.571**
	(0.754)	(0.156)	(0.323)	(0.237)	(0.219)
Hill	−0.024	0.0643	0.868***	−0.247	0.198
	(0.162)	(0.117)	(0.261)	(0.231)	(0.352)
Mountain	−0.057	−0.145	1.106***	−0.787**	−0.110
	(0.265)	(0.153)	(0.285)	(0.320)	(0.393)
AIC	1709.8	3087.5	1250.0	1128.0	655.4
McFadden R^2	0.237	0.027	0.188	0.074	0.104

Note: Coefficients depict the change in the log-odds of the outcome per unit increase in the predictor. *, **, *** denote significance at the 10%, 5%, and 1% level respectively. The standard errors are heteroskedasticity-robust Huber-White sandwich estimators, shown in parentheses. The respective resilience capacity cluster is compared to a baseline including farms from all other clusters, including those that exit the sector.

than farms staying in the sector; they are more diversified, have higher input costs and use more labor, have higher stocking densities and are significantly less dependent on direct payments. In addition, the regression results show that farms that exit the sector tend to be older and slightly larger. The age effect can be explained by the link between farm succession and farm income. Since farm succession only occurs for farms that generate sufficient income, those with lower income are less likely to find a successor and exit the sector. Taking other factors into account, the results show that farms in all regions are affected to roughly the same extent, with no regional differences in farm exits. Furthermore, the Levene's tests show the farms that exit the sector are highly heterogeneous with regard to stocking density but similar with regard to their low dependence on direct payments. Farms at risk are similar to farms that exit the sector due to the tariff reduction shock. They are significantly bigger, have high input costs, and are significantly less dependent on direct payments. However, compared to farms that exit the sector, farms at risk have a significantly lower stocking density. Robust farms and resilient growers show similar importance of resilience attributes. They are more profitable compared to all other farms, have lower input costs and lower stocking densities but are also less diversified (especially the robust farms share a low degree of diversification as shown by the Levene's tests). However, both resilience capacity clusters differ with respect to age, with robust farms being significantly older and resilient growers being significantly younger. Furthermore, robust farms are significantly less dependent on direct payments whereas resilient growers are significantly more dependent on direct payments. Robust farms are more likely located in the hill and mountain regions whereas location does not predict the probability of being a resilient grower. Adaptive farms are significantly younger, have low stocking densities, are highly dependent on direct payments and are less likely located in the mountain regions.

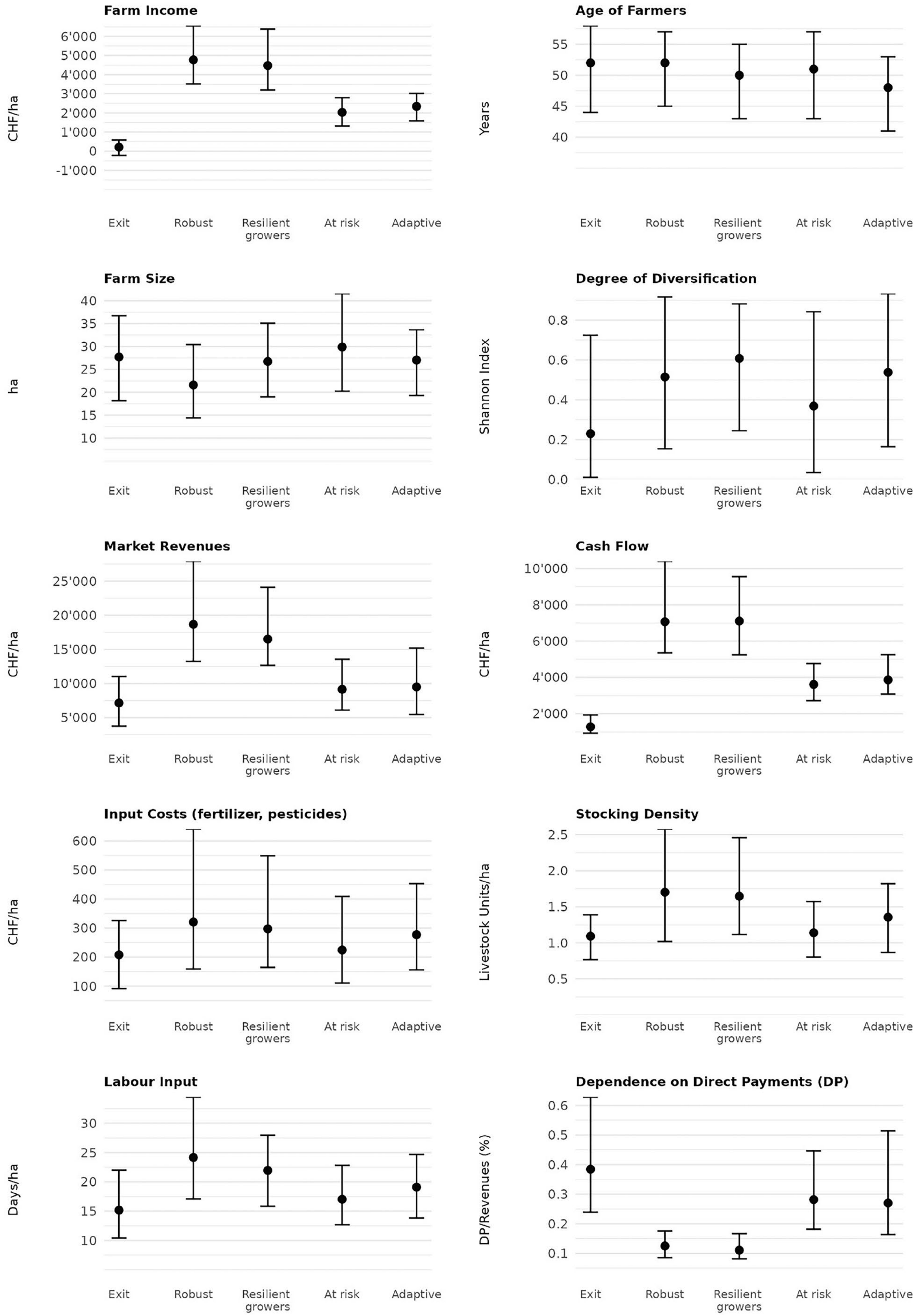

FIGURE 7 | Legend on next page.

FIGURE 7 | Resilience attributes by resilience capacity clusters—Direct Payment Reduction scenario. Data are from the year 2025. Median values are indicated by dots. Bars show the interquartile range, that is, the 25th and 75th quartiles.

TABLE 5 | Results of the logit regressions for predicting membership of resilience capacity clusters—Direct Payment Reduction.

	Exit	At risk	Robust	Adaptive	Resilient growers
Intercept	−2.310** (0.920)	0.615 (0.408)	−1.024* (0.568)	−0.082 (0.708)	1.066* (0.566)
Farm income	−0.002*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)	0.000*** (0.000)
Age	0.026** (0.012)	0.013** (0.005)	0.017 (0.008)	−0.036*** (0.010)	−0.018** (0.009)
Farm size	−0.009 (0.008)	0.016*** (0.005)	−0.019*** (0.006)	−0.031*** (0.008)	−0.002 (0.006)
Degree of diversification	0.113 (0.401)	0.490*** (0.158)	−0.219 (0.195)	0.306 (0.302)	−0.228 (0.239)
Input costs	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Stocking density	0.026 (0.186)	−0.326*** (0.059)	0.161*** (0.059)	0.042 (0.101)	−0.014 (0.064)
Labor input	−0.014 (0.014)	0.016*** (0.004)	−0.012 (0.004)	−0.016* (0.010)	−0.026*** (0.006)
Dependence on direct payments	0.811*** (0.214)	−0.193 (0.249)	−4.465*** (0.896)	0.547*** (0.202)	−9.903*** (1.213)
Hill	0.416 (0.315)	0.979*** (0.134)	−0.536*** (0.161)	−0.373 (0.268)	−0.323 (0.204)
Mountain	0.484 (0.395)	1.365*** (0.175)	−0.802*** (0.244)	−0.432 (0.343)	−0.733** (0.340)
AIC	639.07	2486.6	1655.8	866.13	1127.2
McFadden R^2	0.317	0.202	0.261	0.046	0.193

Note: Coefficients depict the change in the log-odds of the outcome per unit increase in the predictor. *, **, *** denote significance at the 10%, 5%, and 1% level respectively. The standard errors are heteroskedasticity-robust Huber-White sandwich estimators, shown in parentheses. The respective resilience capacity cluster is compared to a baseline including farms from all other clusters including those that exit the sector.

For the Direct Payment Reduction scenario, Figure 7 shows the median and interquartile range of the resilience attributes using Wilcoxon rank-sum and Levene's test corrected for multiple comparison using the Bonferroni correction (test results are shown in Tables A6 and A7). Table 5 shows the logit-regression results identifying attributes predicting resilience capacities. We considered farm income per hectare agricultural land to depict productivity. The results of the multinomial logit models with farms that exit being the baseline group are presented in Table A8.

The results show significant differences between the farms that exit the sector compared to all other resilience capacity clusters. Both Wilcoxon rank-sum tests and regression results show that farms that exit the sector are significantly less productive and more dependent on direct payments, even though Levene's tests show a high heterogeneity in the dependence on direct payments within this cluster. In tendency, older farms are more likely to exit the sector (according to regression results) and are more specialized (according to Wilcoxon rank-sum tests). The descriptive results (Figure 7) are also reflected in the multinomial models (Table A8).

Robust farms are characterized by a high profitability, smaller farm sizes and higher stocking densities as shown by both group comparisons and regression results. Furthermore, they are significantly less dependent on direct payments and are more likely located in the valley regions. While group comparisons suggest that robust farms use more labor, regression results suggest that farmers in this capacity cluster are older. Resilient growers are significantly more profitable, younger, have low labor input, are significantly less dependent on direct payments and more likely located in the valley regions. Although they have comparable stocking densities to robust farms, the regression analysis shows that membership of this cluster is not determined by production intensity. As shown by the Levene's tests, farm profitability and stocking density are highly heterogeneous within the robust and resilient grower cluster but rather homogeneous with respect to their low dependence on direct payments. Adaptive farms are significantly more profitable and younger, but are also significantly smaller and more dependent on direct payments which distinguish them from robust farms and resilient growers. The farms' location does not influence the probability of being in the adaptive farm cluster. Farms at risk are significantly more profitable, have bigger farms, a significantly higher degree of diversification and lower stocking densities. They also need slightly more labor. Farms at risk are more likely located in the hill and mountain regions.

4.3 | The Provision of Private and Public Goods

In order to assess the extent to which the two institutional shocks would have an impact on the provision of private and public goods, we compare model results from the agent-based model SWISSland across the reference and the two shock scenarios. As private goods we consider farm income, family and non-family labor resources, and production volumes of plant and animal products. As public goods, we consider the area under three different biodiversity payment schemes and N-surplus. Furthermore, we assess overall changes in agricultural structures, considering changes in land use, livestock units, and number of farms per region.

For the tariff reduction scenario, the results show a dramatic decline in the provision of private goods by halving farm incomes and reducing the amount of labor resources in agriculture by one fifth (Table 6). Furthermore, food production would decrease substantially, of between 67% (pork) and 8% (raw milk). Only for sugar beet a slight increase in production can be expected because sugar beet prices are not affected by a tariff reduction. With regard to environmental outcomes, a reduction in the area under biodiversity payment schemes of about 8% can be expected. However, N-surplus would reduce substantially by about 26%, which can be explained by the strong decline in livestock units by 20%. Especially in the valley and hill regions, the number of farms would decline drastically if tariffs on agricultural products were reduced.

For the Direct Payment Reduction scenario, the provision of private goods is reduced, especially when it comes to farm income (−27% as compared to the reference scenario). However, only for barley, pulses, and sunflower seeds a strong decline in production can be observed; the production of all other food products hardly change. With regard to environmental outcomes, slightly less biodiversity area is made available and N-surpluses will decrease by 3.5% compared to the reference scenario. Agricultural structures are changing only slightly, and the decline in mountain farms is higher than the decline in valley farms.

5 | Discussion

Our ex-ante resilience assessment, which uses simulation results of the agent-based model SWISSland, shows that institutional risks are highly relevant for the resilience of the Swiss farm system. Whilst this effect is certainly particularly pronounced in Switzerland due to the high level of support to farmers, this is consistent with the findings of surveys of farmers across Europe (Feindt et al. 2019). The modeling results showed that farm exit rates are much higher in case of tariff reductions compared to direct payment reductions. Furthermore, the majority of Swiss farms would experience a severe decline in income of more than 20% immediately following the shock, and would be unable to return to pre-shock income levels after 5 years, regardless of whether import tariffs or direct payments were reduced. In addition, our results show spatially different responses with valley farms being more resilient to direct payment reductions while farms in mountain regions are more resilient to tariff reductions. This can be explained by the lower production potential in marginal areas such as the mountain region and the Swiss direct payments scheme that compensates farmers by higher food security payments for steep slopes and unfavorable production conditions in hilly and mountainous regions (Huber et al. 2024), making these farms more dependent on direct payments. The spatially different responses of farms to the shock are also reflected in the provision of private and public goods. Regarding private goods provision, tariff reductions would significantly decrease farm income (−50%), on-farm work (−20%) and food production, particularly for pork (−67%) and eggs (−64%) due to the higher exit rates of intensively producing valley farms. In contrast, when direct payments are reduced, the decline in farm income is lower (−27%), and on-farm work and food production remain relatively stable. This is because less intensively producing mountain farms are particularly affected by this shock. Regarding public goods provision, tariff reductions would result in a sharp decrease in nitrogen surpluses (−26%), mainly due to a decline in livestock numbers. However, due to the abandonment of farmland, biodiversity areas would also be reduced by up to −9%. In case of direct payment reductions, nitrogen surpluses would decrease by only −3.5%, and biodiversity areas by up to 3%. These findings can inform the development of support measures tailored to individual farms, farm types or regions. For instance, farms in the valley region could be supported to transition to sustainable intensification by providing them with farm-specific advisory programs or financial resources to invest in environmentally friendly technologies. This would enable them to continue providing food even if import tariffs were reduced. For farms in mountainous regions, reallocating direct payments from food security to agri-environmental payments with clear environmental goals could be a measure to secure income while improving the provision of public goods. To ensure that the measures developed to strengthen resilience are both effective and efficient, it would be important to model less extreme scenarios as well. This would help to identify farms that would not be resilient in the face of even minor policy changes, thereby providing a clearer indication of the scope and focus of the support measures required.

Farm attributes associated with resilience differ between institutional shocks. When tariffs are reduced, a high dependence on direct payments is associated with greater farm resilience. In contrast, a high dependence on these payments is associated with lower resilience in the direct payment reduction scenario. Therefore, policymakers should link tariff reductions to increases in direct payments, and consider expanding the range

TABLE 6 | The provision of private and public goods across the different scenarios 2030.

	Sum over all farms			%-change compared to the reference scenario	
	Reference	**Tariff reduction**	**Direct payment reduction**	**Tariff reduction**	**Direct payment reduction**
Farm income in CHF	213′455′754	98′719′699	156′478′401	−53.8	−26.7
Family labor in days	927′655	775′835	892′249	−16.4	−3.8
External labor in days	420′292	332′386	419′336	−20.9	−0.2
Plant products in dt					
Barley	137′314	114′992	119′584	−16.3	−12.9
Grain Maize	50′368	34′633	48′057	−31.2	−4.6
Potatoes	499′570	421′932	500′447	−15.5	0.2
Pulses	7′012	5′546	5′683	−20.9	−19.0
Rapeseed	46′075	33′517	43′870	−27.3	−4.8
Sugarbeet	913′444	948′378	925′965	3.3	1.4
Sunflower seeds	4′379	3′969	3′812	−9.6	−13.0
Wheat	271′549	243′604	257′837	−10.3	−5.1
Animal products in kg					
Beef meat	12′308′545	10′551′463	12′464′422	−14.3	1.3
Eggs	79′038′945	28′677′268	76′019′557	−63.7	−3.8
Pork meat	5′937′652	1′956′445	5′929′860	−67.0	−0.1
Raw milk	380′807′083	351′133′784	376′799′134	−7.8	−1.1
Sheep and goat meat	79′186	71′702	76′084	−9.5	−3.9
Environmental outcomes					
Action-based biodiversity area in ha	24′022	22′008	23′446	−8.4	−2.7
Result-based biodiversity area in ha	10′832	9′863	10′538	−8.9	−2.7
Multi-actor-oriented biodiversity area in ha	16′951	15′663	16′661	−7.6	−1.7
N surplus in kg	4′372′234	3′243′919	4′221′163	−25.8	−3.5
Agricultural area in ha	78′972	73′735	77′632	−6.6	−1.7
Livestock units	103′844	82′762	102′762	−20.3	−1.0
Farms per region					
Valley	971 (40.8%)	735 (37.4%)	942 (41.5%)	−24.3	−3.0
Hill	738 (31.0%)	606 (30.9%)	701 (30.9%)	−17.9	−5.0
Mountain	674 (28.3%)	623 (31.7%)	628 (27.7%)	−7.6	−6.8
Total number of farms	2383	1964	2271	−17.6	−4.7

of direct payments available to farmers. This would allow for diversification in the use of direct payment programs and reduce dependence on any one program. Direct payment specific effects on resilience, as shown by Slijper et al. (2022), should be analysed in detail before any direct payment changes are implemented.

In line with existing literature (Reidsma et al. 2020; Cabell and Oelofse 2012; Paas et al. 2021), our results show that profitability is positively related to farm resilience. Particularly when direct payments are reduced, farms that exit the sector show significantly lower productivity levels than farms staying in the sector. Also in the tariff reduction scenario, robust farms and resilient growers are characterized by higher productivity.

In contrast to existing literature that found a positive correlation between farm size and farm resilience (Slijper et al. 2022), our results show mixed effects. When tariffs are reduced, especially large farms exit the sector while robust farms are significantly smaller compared to all other farms. This is because larger farms depend more on market income than on direct payments, and are therefore more affected by tariff reductions and subsequent price declines when border protection measures are reduced. If direct payments are reduced, farms at risk are significantly bigger whereas robust and adaptive farms are significantly smaller. This is because direct payments are paid per hectare, so larger farms receive a greater absolute amount and are therefore more adversely affected when these payments are cut. Farm size is therefore not a consistent predictor of resilience to institutional shocks. Whether larger or smaller farms are more resilient depends on the nature of the shock being analyzed.

Changes in production intensity can be used by farmers to adapt to new circumstances induced by a shock or stress, such as climate change (Howden et al. 2007) or price changes (Schaub and El Benni 2024). Our results show that production intensity is indeed related to the resilience of farms. When tariffs are reduced, more intensively producing farms are more likely to exit the sector, whereas farms robust against this shock produce more extensively. In contrast, if direct payments are reduced, less intensively producing farms are at risk and more intensively producing farms are robust. Thus, whether an intensification or extensification strategy enhances resilience depends on the shock.

Adjusting labor is an adaptation strategy in response to changes in framework conditions (Meuwissen et al. 2019; El Benni and Schmid 2022). Our results show that farms with a low labor productivity exit the sector when tariffs are reduced. Farms that are at risk when direct payments are reduced are also characterized by low labor productivity, while resilient growers have higher labor productivity. Thus, labor productivity appears to be positively associated with the resilience of farms.

Independent of the shock, our results show that younger farmers are more likely to be adaptive or resilient growers, while older farmers are more likely to exit the sector or are robust. This result reflects farms' adaptation to the Swiss direct payment conditions, as farmers in Switzerland are no longer entitled to direct payments after reaching the age of 65 (Zorn 2025).

Interestingly, farm diversification seems not to be a determinant for more resilient farms but rather do more diversified farms exit the sector or diversification reduces robustness (tariff reduction shock scenario) or farms are at risk (direct payment reduction shock scenario). This is in contrast to existing literature showing that diversification reduces risk and increases resilience from farm to regional scale (El Benni et al. 2012; Reidsma et al. 2020; Meuwissen et al. 2019; Fabri et al. 2024) and might be explained by the limitation of SWISSland to model diversification decisions.

The agent-based model SWISSland is a structural supply model that has some limitations in terms of modeling the responses of farms to institutional shocks. The model limitations also affect the assessment of resilience in our analysis. Firstly, SWISSland underestimates the diversification potential of farms. On-farm diversification through changes in the production portfolio for crops and livestock is only possible for the crops and animal categories that the farm had in its portfolio in the model's calibration year (2016–2018). Off-farm risk management, such as off-farm income or direct marketing, cannot be modeled with SWISSland. Therefore, transformation cannot be modeled as one of the resilience capacities with SWISSland. This limitation could also explain the rather limited effect of diversification as a resilience attribute. Secondly, in reality, there are various reasons why farmers leave the sector and/or transfer their land to neighboring farms. In SWISSland, farms exit the sector at the retirement age of 65, when the farms' cash flow is negative for three consecutive years and (in the case of shocks) when farm incomes fall to levels too low to be taken over by successors. While the first rule reflects the fact that almost no farms in Switzerland leave the sector before reaching retirement age, the second rule is based on expert estimates and the third rule is assumed due to the lack of empirical evidence on farm exits caused by shock-induced financial constraints, as Swiss farms have not experienced a comparable shock in recent decades. This could lead to exit rates that tend to be higher than can be expected in reality.

Furthermore, many agent-based agricultural models assume that farms maximize their income, with only a few considering a limited number of additional potential behaviors (Huber et al. 2018). This depends on the system boundaries of the respective model and affects how resilience can be assessed using these models. In SWISSland, for example, farmers only interact with one another via the land market, ignoring other market actors. Thus, SWISSland farms can primarily rely on system reserves rather than modularity to adapt to a shock. Moreover, most of the resilience attributes expressed in farmers' characteristics are unavailable in SWISSland, thereby limiting the modeling exercise to the available resilience attributes. For instance, factors such as learning, innovation, social capital, organization and governance are not modeled in SWISSland, resulting in an underestimation of farm resilience to the two shocks. For this reason, a mixed-methods approach should always be adopted in order to comprehensively assess the resilience of farming systems. The results of ex-ante modeling can, for example, be used in follow-up qualitative studies involving policy-makers to develop measures aimed at improving the resilience of farms.

6 | Conclusions

Agent-based models are useful tools for ex-ante policy evaluation. They can simulate the heterogeneous responses of farms to changes in agricultural policy, allow farms to interact with each other, and can also explicitly model spatial heterogeneity. In this study, we develop a conceptual approach showing that these functions are also well suited to ex-ante assess the resilience of farms against institutional shocks. Using the agent-based model SWISSland, we assess resilience capacity clusters, resilience attributes, and the provision of private and public goods against two shock scenarios, namely import tariff reductions and direct payment reductions. The approach we have developed can be applied to various agent-based models and adapted to meet the specific requirements of policymakers and researchers. For instance, the thresholds of income indicators used to define resilience capacities of farms can be adjusted together with policymakers, or other resilience attributes can be defined.

Our results show the low resilience of Swiss farms to both shocks but also spatial differences. Valley farms are highly vulnerable to tariff reductions, while mountain farms are highly vulnerable to direct payment reductions. Tariff reductions would have severe consequences on farmers' incomes, employment in agriculture and food production, and would also lead to the abandonment of agricultural land with negative effects on the provision of biodiversity area. At the same time, the decreasing number of livestock would lead to a substantial decrease in nitrogen surpluses. In contrast, a direct payment reduction results in moderate income losses and largely stable employment and food production and only slight decreases in nitrogen surpluses and biodiversity area.

A high profitability and high labor productivity are consistently associated with farm system resilience. Also, younger farmers are more adaptive to the considered shocks. Farm size shows mixed effects, with large farms exiting the sector more likely in the case of tariff reductions, but if farms stay in the sector despite the shock, they are more robust compared to small farms. Production intensity is associated with farm resilience differently depending on the shock. More intensive farms exit the sector in case of tariff reductions but are robust when direct payments are reduced. In contrast to existing literature, we do not find any positive associations between farm diversification and resilience, which may reflect limitations in how diversification is modeled in SWISSland.

Before implementing changes in agricultural policy, policymakers should be aware of the farm and regional specific impact these changes will have on farm system resilience. Tariff or direct payment reductions must be accompanied by targeted and tailored policy support measures, such as the redistribution of financial resources toward agri-environmental programs for mountain farms (if food security payments are reduced) or advisory services for valley farms, to support farmers in defining a farm-specific strategy to deal with tariff reductions.

Research should increasingly provide policymakers with the tools and analyses needed to assess the impact of policy changes on farm system resilience.

Author Contributions

Nadja El Benni: conceptualization, formal analysis, methodology, visualization, writing – original draft, writing – review and editing. **Gabriele Mack:** conceptualization, methodology, writing – review and editing.

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The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Endnotes

[1] There is a lack of empirical evidence regarding the timing of farm exits due to financial constraints. This is especially true for shock scenarios, as Swiss farms have not experienced a shock in recent decades. Therefore, the three-year period was aligned with the five-year modeling horizon (2026–2030), implying farm exits within approximately two-thirds of the shock period.

[2] Land reallocation is implemented via a plot-level bidding mechanism in which nearby farms compete for available plots, with each plot assigned to the farm achieving the highest expected income gain. If no lease occurs at the initial rental price, the pool of potential renters is gradually expanded and the rent is reduced stepwise by 20% until the plot is leased (Mack et al. 2013; Zimmermann et al. 2015). Land prices are assumed to be exogenous and are represented by average prices for arable land and permanent grassland.

[3] Except for cheese, for which a bilateral free trade agreement exists with the European Union (Hillen and con Cramon-Taubadel 2019).

[4] The two scenarios were defined by an advisory group for a policy evaluation, which consisted of representatives from various Federal Offices and the Farmers' Association (Bystricky et al. 2024).

[5] The successor will not take over the farm, if the farms' income is lower than the average income of the valley, hill and mountain region respectively, as published by the Federal Statistical Office.

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Appendix A

TABLE A1 | Changes in output prices compared to the reference scenario due to the tariff reductions based on CAPRI-simulations.

Products	**Output price changes in %**
Plant products for human consumption	
Potatoes	−7
Wine	−14
Cereals for human consumption	−19
Sunflowers	−19
Fruits	−20
Rapeseed	−25
Vegetables	−53
Plant products for animal feed	
Pulses	−3
Mixed fodder	−12
Maize	−17
Fodder cereals	−15
Soja	−9
Animal products: Meat	
Sheep and goat	−24
Beef	−32
Poultry	−42
Pork	−59
Animal products: Other	
Milk	−7
Eggs	−40

Source: Prices for the SWISSland model based on the CAPRI model simulations carried out by the Swiss Federal Office for Agriculture for the evaluation of Bystricky et al. (2024, 88).

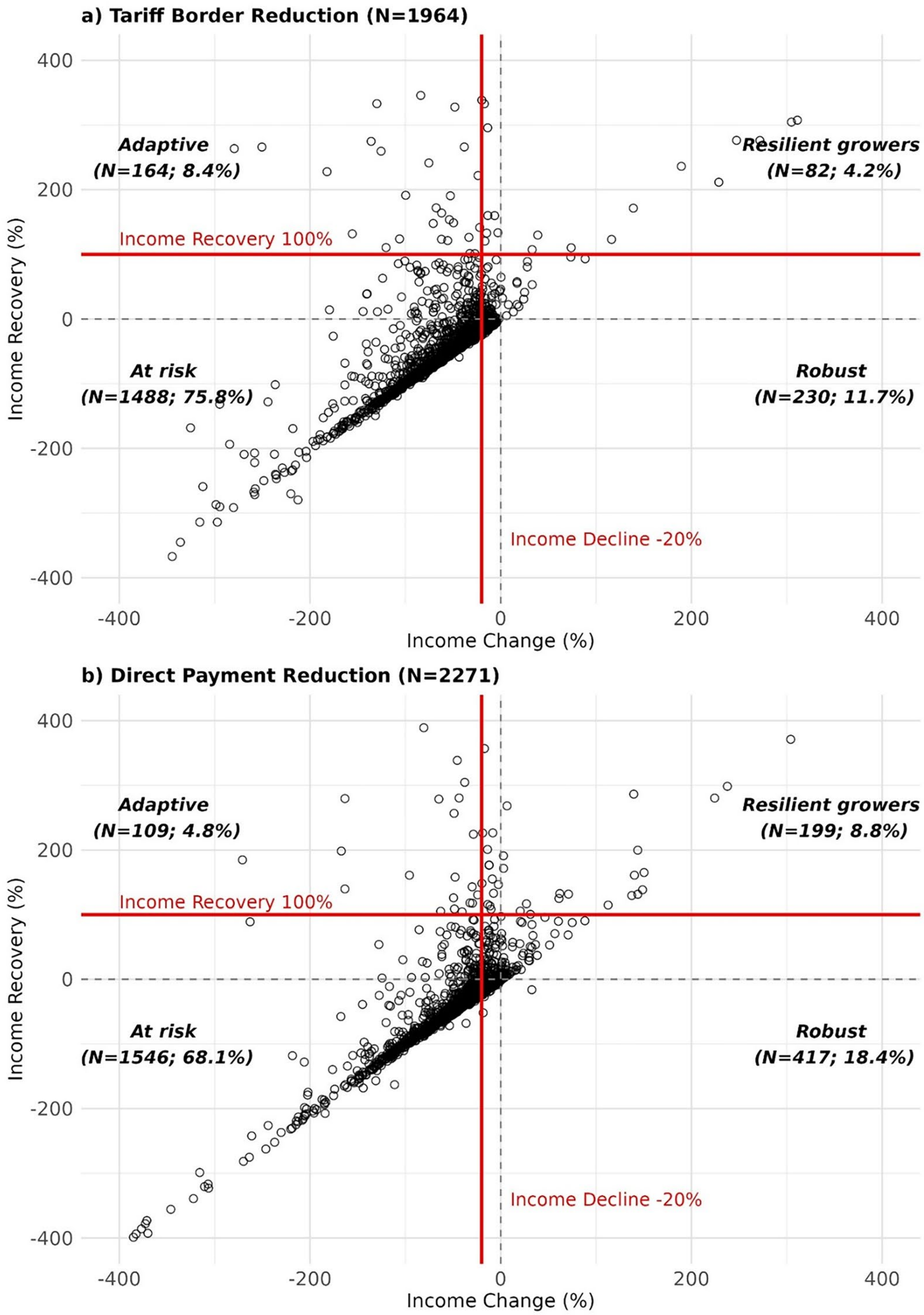

FIGURE A1 | Distribution of farms that stay in the sector after the shock across resilience capacity clusters. Adaptive: Recovery after shock-induced income decline, Resilient: Income growth despite shock, Not resilient: Persistent income decline following the shock, Robust: Stable income despite shock. The solid red line depicts the thresholds used to identify resilience group membership.

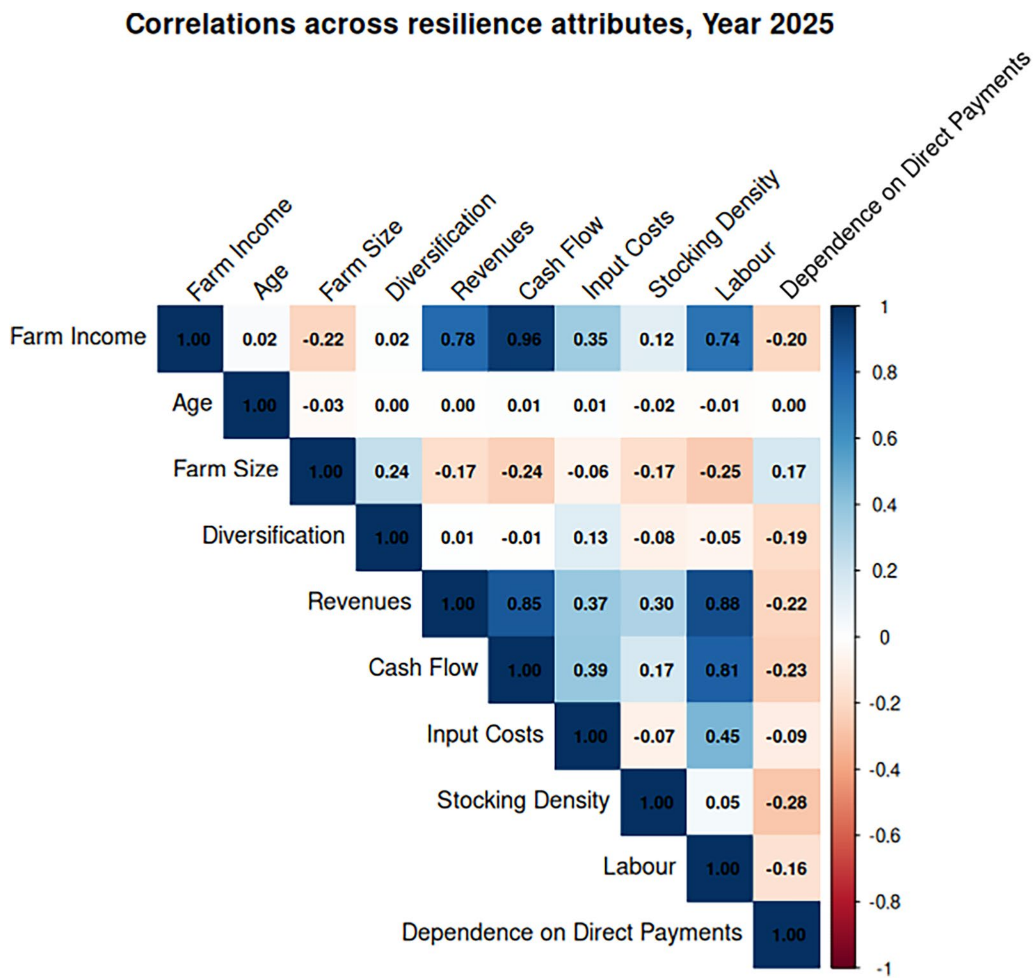

FIGURE A2 | Correlations across resilience attributes and incomes, Year 2025.

TABLE A2 | Descriptive statistics of the pre-shock year 2025 farm sample: Farm-level means and quartiles (Q1–Q3).

	All regions	Valley	Hill	Mountain
No of farms	3063	1231	975	857
Farm income (CHF)	75′693 (34′620–98′564)	95′590 (44′886–123′643)	67′890 (32′846–87′292)	56′111 (27′840–73′437)
Market revenues (CHF)	316′415 (134′251–415′786)	426′152 (201′774–565′302)	285′201 (139′789–374′030)	194′300 (93′575–255′537)
Cash flow (CHF)	128′838 (70′660–160′534)	156′717 (86′584–200′803)	118′095 (67′104–147′134)	101′190 (59′917–128′205)
Age (years)	51 (44–59)	51.55 (45–59)	51.75 (45–59)	51.27 (44–59)
Farm size (ha)	28.89 (17.78–35.91)	30.75 (19.68–38.30)	26.88 (16.10–23.90)	28.49 (17.12–36.73)
Degree of diversification (Shannon Index)	0.49 (0.06–0.83)	0.78 (0.51–1.08)	0.41 (0.08–0.66)	0.17 (0.00–0.25)
Input costs (CHF/ha)	454.04 (124.06–462.96)	756.31 (283.20–727.64)	289.07 (129.52–335.52)	207.74 (43.82–178.09)
Stocking density (Livestock Units/ha)	1.45 (1.24–1.79)	1.49 (0.71–1.97)	1.68 (1.10–2.04)	1.14 (0.76–1.31)
Livestock units	38.6 (19.7–49.3)	42.4 (18.7–60.0)	41.7 (23.4–49.5)	29.8 (17.7–37.6)
Labor input (days/ha)	25.4 (13.8–26.6)	28.4 (13.5–26.4)	23.4 (14.8–27.3)	23.3 (13.0–24.9)
Family labor input (days)	387.8 (296.2–464.6)	387.6 (296.7–468.3)	380.8 (295.1–454.7)	395.8 (297.8–1156.7)
External labor input (days)	167.8 (0.7–229.5)	250.2 (29.3–293.6)	124.7 (0.0–203.7)	98.9 (0.0–153.0)
Dependence on direct payments (share of direct payments in revenues, %)	31.35 (13.93–38.46)	20.29 (10.39–23.91)	26.80 (16.10–33.90)	52.10 (27.30–63.70)
Total direct payments (CHF)	73′363 (43′642–92′419)	68′944 (41′962–86′293)	70′942 (41′629–86′901)	82′341 (47′754–110′085)
Action-based Biodiversity area in ha	9.3 (4.1–11.5)	9.7 (4.1–11.4)	9.6 (4.6–11.8)	8.3 (3.6–11.2)
Result-based biodiversity area in ha	4.1 (0.3–5.3)	4.1 (0.05–4.9)	4.2 (0.3–5.5)	4.0 (0.8–5.5)
Multi-actor- oriented biodiversity area in ha	6.5 (1.7–8.4)	6.7 (1.4–8.1)	6.4 (2.1–8.7)	6.2 (2.0–8.3)
N surplus in kg	1670.0 (737.3–2204.5)	1755.5 (602.4–2430.7)	1663.8 (773.6–2095.4)	1555.3 (842.6–1977.4)

TABLE A3 | p-values for group comparisons between resilience capacity clusters using Bonferroni-corrected Wilxocon rank-sum tests—Tariff Reduction shock scenario (2025).

Group comparisons		Farm income	Age	Farm size	Diversification	Revenues	Cashflow	Input costs	Stocking density	Labor	Direct payments
Exit	Robust	< 0.01	ns	ns	< 0.01	< 0.01	ns	< 0.01	< 0.01	ns	< 0.01
	Resilient	< 0.01	ns	ns	< 0.01	< 0.01	ns	< 0.01	< 0.01	0.011	< 0.01
	Not resilient	ns	ns	< 0.01	< 0.01	< 0.01	0.048	< 0.01	< 0.01	< 0.01	< 0.01
	Adaptive	ns	0.012	0.01	ns	< 0.01	< 0.01	ns	< 0.01	< 0.01	< 0.01
Robust	Resilient	ns	0.006	ns	ns	ns	ns	ns	ns	ns	ns
	Not-resilient	< 0.01	ns	< 0.01	< 0.01	< 0.01	0.013	< 0.01	< 0.01	ns	< 0.01
	Adaptive	< 0.01	< 0.01	< 0.01	< 0.01	ns	< 0.01	< 0.01	ns	0.007	ns
Resilient	Not-resilient	< 0.01	ns	ns	ns	< 0.01	0.026	ns	< 0.01	ns	< 0.01
	Adaptive	< 0.01	ns	ns	ns	ns	< 0.01	ns	ns	ns	ns
Not-resilient	Adaptive	ns	< 0.01	ns	ns	< 0.01	0.047	ns	< 0.01	ns	< 0.01

Note: Bonferroni-corrected p-values below 0.05 are considered statistically significant and shown in this table.

TABLE A4 | p-values for group comparisons between resilience capacity clusters using Bonferroni-corrected Levene's tests—Tariff Reduction shock scenario (2025).

Group comparisons		Farm income	Age	Farm size	Diversification	Revenues	Cashflow	Input costs	Stocking density	Labor	Direct payments
Exit	Robust	ns	ns	ns	< 0.01	ns	ns	ns	< 0.01	ns	< 0.01
	Resilient	ns	ns	ns	ns	ns	ns	ns	< 0.01	ns	< 0.01
	Not resilient	< 0.01	ns	ns	ns	< 0.01	< 0.01	< 0.01	< 0.01	0.017	< 0.01
	Adaptive	0.021	ns	ns	< 0.01	0.046	0.021	ns	< 0.01	ns	< 0.01
Robust	Resilient	ns	ns	ns	0.032	ns	ns	ns	ns	ns	< 0.01
	Not-resilient	ns	ns	ns	< 0.01	ns	ns	ns	< 0.01	ns	ns
	Adaptive	ns	ns	ns	< 0.01	ns	ns	ns	ns	ns	0.030
Resilient	Not-resilient	ns	ns	ns	ns	ns	ns	ns	ns	ns	< 0.01
	Adaptive	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Not-resilient	Adaptive	ns	ns	ns	< 0.01	ns	ns	ns	ns	ns	< 0.01

Note: Bonferroni-corrected p-values below 0.05 are considered statistically significant and shown in the table.

TABLE A5 | Results of the multinomial regressions predicting membership of resilience capacity clusters—Tariff Reduction shock scenario (Baseline: Farms that exit the sector due to the shock).

	At risk	Robust	Adaptive	Resilient growers
Intercept	3.816***	2.7624**	3.121***	2.915**
	(0.582)	(1.115)	(0.909)	(1.348)
Farm income	0.000***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Age	−0.017**	0.009	−0.047***	−0.049***
	(0.007)	(0.011)	(0.012)	(0.011)
Farm size	−0.011***	−0.036***	−0.013	−0.023***
	(0.005)	(0.010)	(0.008)	(0.008)
Degree of diversification	−0.599***	−1.380***	−0.237	−0.721*
	(0.207)	(0.370)	(0.311)	(0.401)
Input costs	−0.001	−0.001	−0.000**	−0.001
	(0.000)	(0.001)	(0.000)	(0.001)
Stocking density	−0.938***	−2.094***	−1.133***	−1.379**
	(0.143)	(0.496)	(0.205)	(0.565)
Labor input	−0.012**	−0.016	−0.014*	−0.021*
	(0.005)	(0.011)	(0.008)	(0.011)
Dependence on direct payments	1.292*	0.463	2.760***	2.540***
	(0.746)	(0.747)	(0.806)	(0.843)
Hill	−0.074	0.774**	−0.302	−0.049
	(0.164)	(0.335)	(0.274)	(0.334)
Mountain	0.146	1.441***	−0.611	0.080
	(0.268)	(0.434)	(0.414)	(0.443)
Log-likelihood		−2283.652		
Adjusted McFadden R^2		0.132		

Note: Coefficients depict the change in the log-odds of the outcome per unit increase in the predictor. *, **, *** denote significance at the 10%, 5%, and 1% level, respectively. The reported standard errors (in parentheses) are robust bootstrap standard errors obtained from 500 non-parametric bootstrap replications. The respective resilience capacity cluster is compared to a baseline including farms that exit the sector.

TABLE A6 | p-values for group comparisons between resilience capacity clusters using Bonferroni-corrected Wilxocon rank-sum tests—Direct payment reduction shock scenario (2025).

Group comparisons		Farm income	Age	Farm size	Diversification	Revenues	Cashflow	Input costs	Stocking density	Labor	Direct payments
Exit	Robust	< 0.01	ns	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Resilient	< 0.01	ns	ns	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Not resilient	< 0.01	ns	ns	ns	< 0.01	< 0.01	ns	ns	ns	< 0.01
	Adaptive	< 0.01	0.021	ns	ns	0.011	< 0.01	ns	ns	0.022	0.031
Robust	Resilient	ns	0.036	< 0.01	ns	ns	ns	ns	ns	ns	ns
	Not-resilient	< 0.01	ns	< 0.01	0.012	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Adaptive	< 0.01	< 0.01	< 0.01	ns	< 0.01	< 0.01	ns	0.003	< 0.01	< 0.01
Resilient	Not-resilient	< 0.01	ns	0.022	< 0.01	< 0.01	< 0.01	< 0.01	ns	< 0.01	< 0.01
	Adaptive	< 0.01	ns	ns	ns	< 0.01	< 0.01	ns	0.005	ns	< 0.01
Not-resilient	Adaptive	ns	< 0.01	ns	ns	ns	ns	ns	ns	Ns	ns

Note: Bonferroni-corrected p-values below 0.05 are considered statistically significant and shown in the table.

TABLE A7 | p-values for group comparisons between resilience capacity clusters using Bonferroni-corrected Levene's tests—Direct payment reduction shock scenario (2025).

Group comparisons		Farm income	Age	Farm size	Diversification	Revenues	Cashflow	Input costs	Stocking density	Labor	Direct payments
Exit	Robust	< 0.01	ns	ns	ns	ns	0.011	ns	< 0.01	ns	< 0.01
	Resilient	< 0.01	ns	ns	ns	0.027	< 0.01	ns	0.01	ns	< 0.01
	Not resilient	ns	ns	ns	ns	ns	ns	ns	ns	ns	< 0.01
	Adaptive	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Robust	Resilient	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
	Not-resilient	< 0.01	ns	< 0.01	ns	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	Adaptive	0.008	ns	ns	ns	ns	0.029	ns	ns	ns	< 0.01
Resilient	Not-resilient	< 0.01	ns	ns	ns	< 0.01	< 0.01	< 0.01	< 0.01	ns	< 0.01
	Adaptive	< 0.01	ns	ns	ns	ns	< 0.01	ns	ns	ns	< 0.01
Not-resilient	Adaptive	ns	ns	0.016	ns	ns	ns	ns	0.024	ns	ns

Note: Bonferroni-corrected p-values below 0.05 are considered statistically significant and shown in the table.

TABLE A8 | Results of the multinomial regressions predicting membership of resilience capacity clusters—Direct payment reduction shock scenario (Baseline: Farms that exit the sector due to the shock).

	At risk	Robust	Adaptive	Resilient growers
Intercept	1.940**	1.535	2.364**	2.745**
	(0.950)	(1.219)	(1.118)	(1.250)
Farm income	0.001***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)
Age	−0.022	−0.026	−0.061***	−0.050***
	(0.013)	(0.015)	(0.016)	(0.016)
Farm size	0.011	−0.009	−0.024*	0.007
	(0.009)	(0.012)	(0.012)	(0.011)
Degree of diversification	−0.065	−0.731	−0.005	−0.845
	(0.427)	(0.488)	(0.530)	(0.503)
Input costs	0.000	0.000	0.000	0.000
	(0.000)	(0.001)	(0.001)	(0.001)
Stocking density	−0.087	0.126	0.109	0.036
	(0.204)	(0.224)	(0.236)	(0.228)
Labor input	0.015	0.016	−0.007	−0.028
	(0.015)	(0.018)	(0.017)	(0.019)
Dependence on direct payments	−0.878***	−6.310***	−0.195	−0.107***
	(0.270)	(1.173)	(0.304)	(1.892)
Hill	−0.273	−1.282***	−1.041**	−1.190***
	(0.340)	(0.408)	(0.449)	(0.420)
Mountain	−0.299	−1.587***	−1.204**	−1.654***
	(0.424)	(0.534)	(0.547)	(0.575)
Log-likelihood		−1808.879		
Adjusted McFadden R^2		0.132		

Note: Coefficients depict the change in the log-odds of the outcome per unit increase in the predictor. *, **, *** denote significance at the 10%, 5%, and 1% level, respectively. The reported standard errors (in parentheses) are robust bootstrap standard errors obtained from 500 non-parametric bootstrap replications. The respective Resilience Capacity Cluster is compared to a baseline including farms that exit the sector.