A framework to assess the economic vulnerability of farming systems: Application to mixed crop-livestock systems

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A framework to assess the economic vulnerability of farming systems: Application to mixed crop-livestock systems

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Highlights:

- Development of a framework to assess economic vulnerability of farming systems that considers the social dimension of vulnerability

- Diversification and interactions are key factors for low vulnerability of mixed crop-livestock systems
- The important role of initial conditions stresses the necessity to develop support public policies for farming system transition

Keywords: vulnerability, economic performance, sensitivity, exposure, adaptive capacity, mixed crop-livestock systems.

Introduction

Farming systems are facing increasing unpredictable perturbations that deteriorate their production quantitatively and qualitatively. For example, climate change leads to a global warming and the occurrence of extreme events as drought and flood (IPCC 2013). Those perturbations affect finally the economic result, which may be lower as expected, but also very different from one year to another. Moreover, an increasing price volatility is also expected due to the growing shortage of fossil resources and market liberalization (Hoekman et Martin 2012; Regnier 2007). Farmers also have to deal with sanitary risks linked to climate change but also to the increase pollutions (Jepson et al. 2014; Yang et al. 2014) or the recent technological revolution leading to the use of not well known materials (Takeuchi et al. 2014). In front of these hazards, the degree to which a farming system is susceptible to, or unable to cope with these adverse effects, i.e. its vulnerability, is different from farm to farm (IPCC 2001). The challenge is then to understand why and to propose solutions to mitigate this individual vulnerability when possible.

In all formulations, vulnerability is defined by three key parameters: the stress to which a system is exposed, its sensitivity and its adaptive capacity (Adger 2006). The level of **exposure** corresponds to the frequency, the intensity and duration of perturbations affecting the studied systems (Urruty et al. 2016). The level of **sensitivity** corresponds to the degree to which the studied system is affected by exposure to perturbations. The **adaptive capacity** corresponds to the ability of agricultural systems to transform their nature or structure to cope with an ever-changing environment (Milestad et al. 2012), i.e. to move toward a less vulnerable condition.

Assessments of farming system's vulnerability are primordial to be able to design policies that make it possible to anticipate sources of vulnerability, to reduce them and to preserve family size

farms in the long term. The conditions for low vulnerability are however not well known despite a whole range of literature on vulnerability assessment.

Many ways of studying and quantifying vulnerability of agricultural systems exist (Urruty et al. 2016).. Two approaches for ex-post vulnerability assessment, i.e. assessment from observed data, can be observed: the 'contextual approach' and the 'outcome approach'.

The 'contextual approach' refers to methods quantifying a composite index of vulnerability based on the evaluation and aggregation of various indicators defining the farming system management or livelihood and social factors (Williams et al. 2018; Aleksandrova et al. 2015; Nazari et al. 2015; Oliveira et al. 2015; Sharma et al. 2013). However, the applicability of those methods is limited as the determinants of vulnerability are supposed to be known as well as their relative impact on vulnerability (Wirhen et al.,2015).

In the 'outcome approach', vulnerability of farming systems is quantified by focusing first on the analysis of outputs and then by identifying explanatory variables. A commonly used method consists in analyzing a specific stressor and its corresponding impacts on one component of the farming system to assess vulnerability (Farhangfar et al. 2015; Dong et al. 2015; Mosnier et al. 2009, Reidsma et al. 2008, Luers et al. 2003). The main drawback of this approach is to limit the evaluation of vulnerability to a single driver of contextual changes, whereas farming systems have to deal with multiple hazards over time. Furthermore, this stream of research generally focuses on one specific outcome whereas considering interactions between farm components is primordial to understand farming system vulnerability (Adger 2006).

These drawbacks are overcome by another recent stream of literature of the 'outcome approach' that consider multiple contextual changes over time and a consideration of interactions between

farming system components (Bouttes et al. 2018; Martin et al. 2017). The vulnerability assessment is a year-to-year evaluation based on the quantification of farm productivity and economic efficiency of farming systems. Vulnerability patterns are then discussed according to the distribution of individual data points in a principal component analysis (PCA). In the same way, explanatory variables are used to explain component indicators of vulnerability. Even if this method permits considering multiple perturbations over time, it still fails considering the social dimension of vulnerability for two main reasons. First, the components of vulnerability are expressed by unit of production, preventing using this information as an indicator of the ability of a farmer to maintain a sufficient level of income per worker. Second, disruptive situations and recovery processes are not explicitly taken into account for the characterization of vulnerability patterns whereas these are key elements of the adaptive capacity component of vulnerability (Martin and Sauvant 2010). Another important drawback is that the analysis of vulnerability patterns doesn't end up on a definition of vulnerability levels - which prevents the characterization of vulnerability by explanatory variables (only components of vulnerability are explained through a year-to-year analysis). As consequence, farming system dynamics, i.e. tactical adjustments and trajectories, are not explicitly taken into account to explain vulnerability patterns.

The aim of this study is to propose a framework for vulnerability assessment of farming systems that includes their social dimension. The focus on economic results instead of production or agricultural assets permits considering the overall system of agro-economic farming, i.e. integrated into a more global socio-economic system. This paper argues that analyzing the economic result per worker patterns on the long run permits (i) to conduct a systemic approach as it reflects the result of farming system component interactions to respond to multiple perturbations, (ii) to consider a hidden social dimension by focusing on the farmer's ability to maintain a sufficient

income per worker. Furthermore, the explicit translation of economic result per worker patterns into vulnerability levels and their characterization through the definition of farming systems production profiles – taking into account their dynamics – opens up the opportunity to discuss and understand key determinants of low vulnerability.

After describing the framework in details in a first part of the paper, a case study is presented on a constant sample of 208 farming systems during a period of 14 years to compare and understand vulnerability levels of mixed crop-livestock systems. The results obtained as well as the framework proposed are discussed in the last section of the paper.

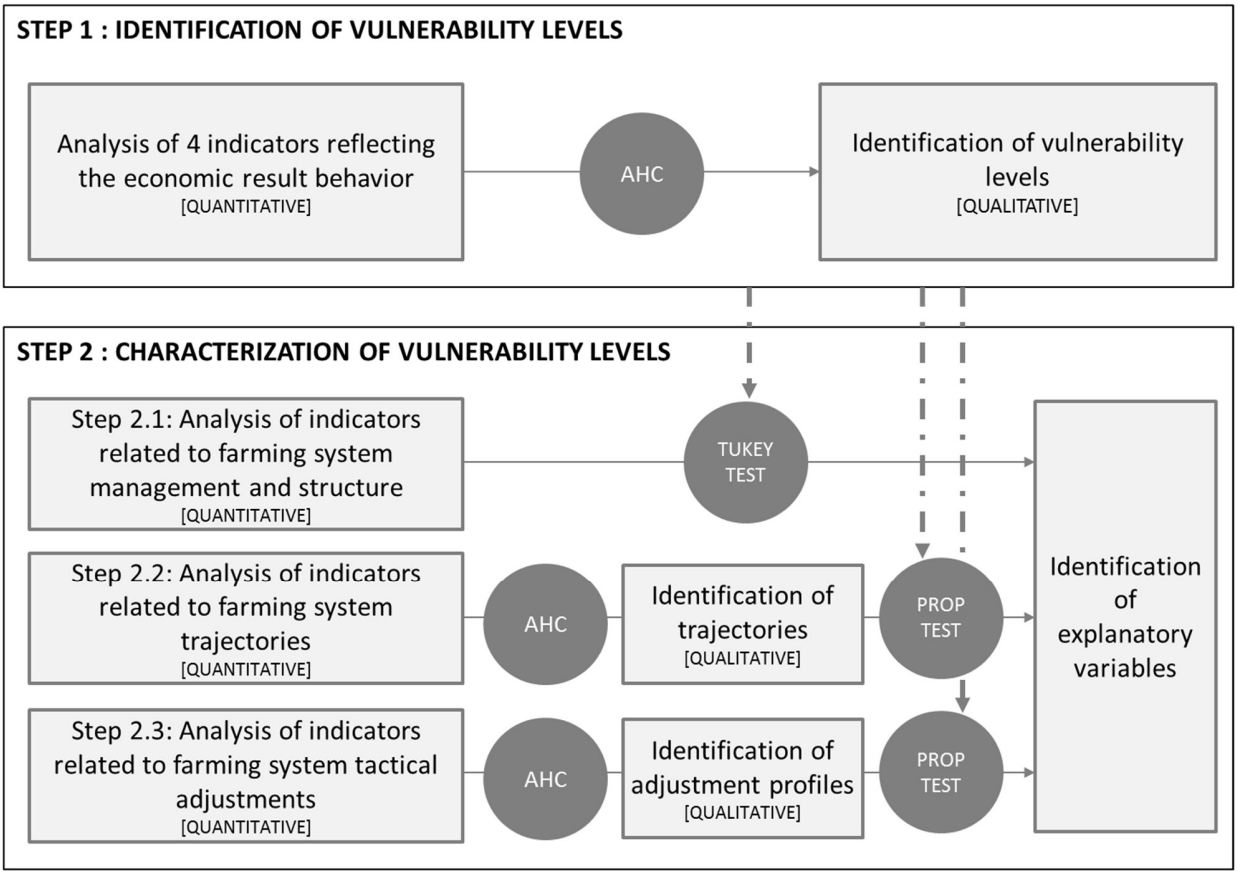
1 Description of the framework

Our framework is composed of tTwo main steps: the identification of different levels of vulnerability land then the description of each level (Figure 1).

The first step consists in analyzing four indicators reflecting the behavior of economic result per worker over the period of analysis. The rationale for the use of this set of indicators is explained in the next sub-section. Patterns of evolution for the four indicators are then identified through an ascending hierarchical classification (AHC), an algorithm based on the analysis of dissimilarities between indicators to cluster farming systems with similar patterns of evolution. Qualitative vulnerability levels are then defined through the statistical analysis of the identified patterns.

The second step consists in the in-depth analysis of farming system characteristics which are at a given level of vulnerability (step 1). Three components are studied: the farming system management and structure, the farming system trajectories and the farming systems tactical adjustments. Statistical analyses are then conducted to identify the correlation with the vulnerability levels. The rationale for the analysis of these explanatory components of farming systems and the methods used are explained in detail in the next subsections.

Figure 1: Description of the framework to assess vulnerability of farming systems



(AHC: Ascending Hierarchical Classification, Tukey Test: Statistical test of multiple mean comparison, Prop Test: Statistical test of proportion comparison)

1.1 Clustering farming systems according to their vulnerability

Four indicators are proposed to describe the economic result behavior of farming systems throughout time: the relative standard deviation over time (RSD), the relative mean distance to a minimum wage (RD), the number of economic disruptions (nED) and the economic recovery time (RESIL). Their specificities and links with the three components of vulnerability are described here below. The idea is that it is possible to identify consistent combinations if those four indicators which represent different level of vulnerability for the corresponding farming systems.

The Relative standard deviation (RSD) of the annual consolidated current result before tax per worker (CR.LU) for a period of time corresponds to the absolute value of the standard deviation divided by the mean (Eq.1).

$$RSD^{CR.LU}\ (\%) = \left| \frac{SD^{CR.LU}}{\mu^{CR.LU}} \right| * 100 \qquad \text{(Eq.1)}$$

This indicator gives some insights about the sensitivity and exposure of each farming system to hazards. A high value means a high sensitivity and/or exposure to hazards, and thus a high vulnerability (Figure 2). A lower sensitivity and/or exposure to hazards is translated by a lower RSD (Figure 2).

The mean relative distance (RD) of the annual consolidated current result before tax per worker (CR.LU) to the minimum wage (MIN) (Eq.2).

$$RD^{CR.LU}\ (\%) = \text{mean}\ (\frac{CR.LU - MIN}{MIN}) * 100 \qquad (2)$$

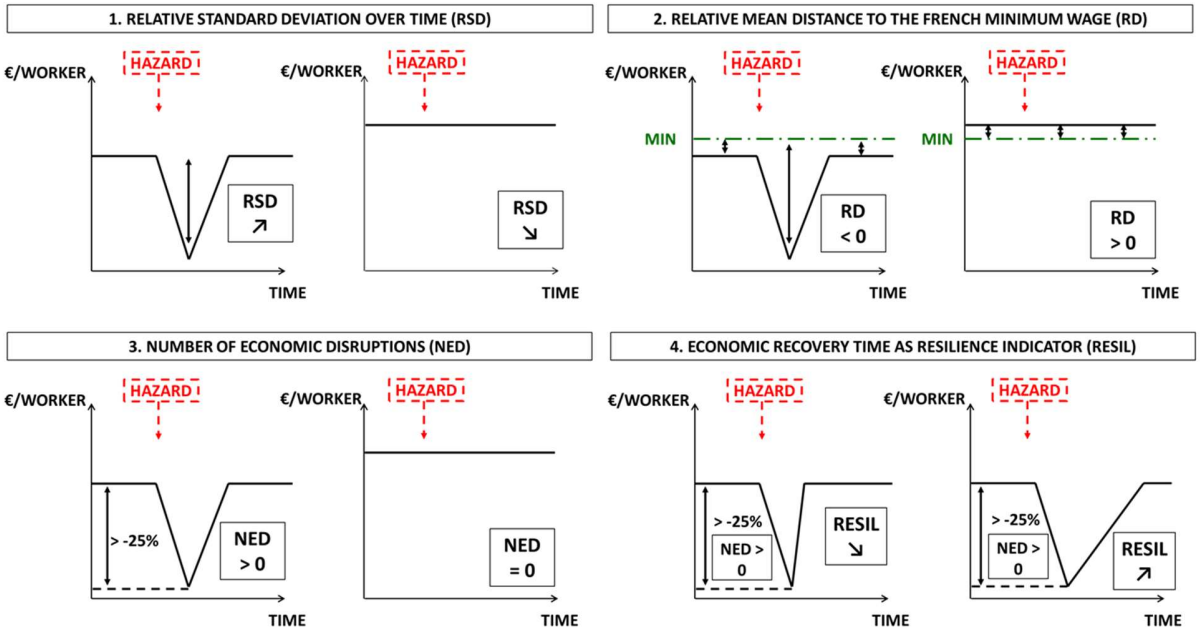
This indicator is complementary to the RSD indicator and permits integrating a social dimension in the evaluation of vulnerability. Indeed, a low variability of ErLu is a necessary but not sufficient

condition to have a low vulnerability: a good economic performance is primordial to be able to cope with risks. The national minimum wage is considered as threshold for defining the ability of a farmer to maintain a sufficient income per worker. Consequently, a RD below zero indicates a high vulnerability as it translates a high sensitivity, a high exposure and/or an unability to cope with adverse effects (Figure 2). Conversely, a positive value of RD means that the farmer is able to maintain a sufficient income per worker.

The number of economic disruptions (ED) is defined as the number of times the annual consolidated current result before tax per worker (CR.LU) diminished more than 25% from one year to another. A high number of ED indicates a high sensitivity and/or exposure to hazards (Figure 2). The identification of disruptive situations permits pointing out the beginning of recovering and/or reorganizational processes, and thus shedding light on the adaptive capacity of farming systems (UMI Resiliences, Dubois and Ouattara 2014).

The number of years for economic recuperation after disruption corresponds to the number of years necessary to recover the annual consolidated current result before tax per worker (CR.LU) that was observed before the disruption. Based on the definition proposed by Sauvant and Martin (2010), this indicator is called “resilience” (RESIL) as it permits quantifying a rate of return to the situation before the perturbation, determining the capacity of recuperation or regeneration of the system. A low number of years indicates an important adaptive capacity whereas a higher number of years translates an unability to adapt and cope with hazards (Figure 2).

Figure 2: Description of the four variables used to characterize the economic behaviour of farming systems (result per worker)



These four indicators are then analyzed through an Ascending Hierarchical Classification (AHC) in order to identify clusters of farming systems with similar vulnerability patterns.

1.2 Description of the different vulnerability levels

Three aspects of farming systems are taken into account to characterize to understand the level of vulnerability for a given farming system: (i) the management and structure, (ii) the trajectory of evolution and (iii) the tactical adjustments made by farmers (Figure 1).

Farming system management and structure refer to the production types, the structural and the organizational factors that may affect economic vulnerability of farming systems. Once the key quantitative management and structural indicators are identified, some statistical analyses (multiple mean comparison, Tukey Test) allow to identify if initial configurations may have an impact on vulnerability levels, i.e. on their sensitivity, exposure and capacity to cope an adapt to hazards.

The analysis of farming system trajectories aims at identifying if organizational and structural changes occurring under the period of evaluation may have an impact on vulnerability levels, i.e. may correspond to adaptation strategies or recovery processes to better cope with adverse effects. Organizational and structural components refer to production decisions that are made between annual production planning, eg decisions on increasing the agricultural area or producing both crop and livestock. So, the first step is to identify evolution patterns through an ascending hierarchical classification based on indicators reflecting the percentage of deviation of key parameters between the beginning and the end of the period of analysis. The second step consists in statistical analyses to identify significant correlation with vulnerability levels (comparison of proportion).

Tactical adjustments refer to production decisions that are made considering the intra- or inter-annual evolution of decisional factors, such as prices and climatic conditions. For instance, the amount of feed concentrates distributed per animal reflects a tactical decision in front of the variation of feed prices and of the expected crop yields.

2 Application

In this section, the framework is used to better understand why mixed crop-livestock systems may be less vulnerable than specialized systems. Concretely, the following research questions are addressed: are mixed crop-livestock systems less vulnerable than non mixed crop-livestock systems? Are there disparities among mixed crop-livestock systems regarding their vulnerability levels? If yes, what are the determinants of low vulnerability?

2.1 Data

The evaluation framework is applied on a constant sample of farming systems from three regions of France (Picardie, Auvergne, Poitou-Charentes), containing structural, economic and organizational data for 208 farms during a period of 14 years (2001-2014) (Agreste). These data come from the Farm Accountancy Data Network (FADN), a European instrument designed to evaluate agricultural holdings' income and the impacts of the Common Agricultural Policy.

Data were available over a 14 year-period, which allowed to consider farming system dynamics and to discuss their correlation with their economic vulnerability level. Furthermore, different climatic and economic hazards occurred over the period of analysis. The Picardy region is a plainland that is mainly characterized by cropping systems. The Auvergne region is a central mountainous region of France characterized by smaller and more diversified farming systems. The Poitou-Charentes is plainland area, a historic region of mixed crop-livestock systems in France. Furthermore, climatic variabilities and hazards are specific to each region and, as a consequence, farmers may have developed different strategies to minimize the vulnerability of their system.

One half of the sample (104 farms out of 208) is composed of mixed crop-livestock systems, equally distributed between the three regions (Table 1). The other half is composed of farming

systems producing only crops (67%), only livestock (6%), only fruits and legumes (2%) or changing technical orientation during the period of analysis (25%).

Table 2: Data description

Farming system categories	Auvergne (n=55)	Picardie (n=96)	Poitou-Charentes (n=57)	Total (n=208)
Mixed crop-livestock systems	38	36	30	104
Other farming systems	17	60	27	104

Data source: FADN data, Agreste.

2.2 Three levels of vulnerability for mixed crop-livestock systems

Combining the the four vulnerability indicators presented previously, enabled identifying three clusters of farming systems with a similar evolution of current economic result per worker (Table 2). The first cluster concerns 37.5% of the sample (78 farms). These farming systems are characterized by a very low variability of their current result per worker and a significantly higher performance than the minimum wage considered in this study, the French minimum salary (SMIC). These farms have also faced significantly less disruptive situations than those of the two other identified clusters, with an average of three breaks.This first cluster concerns farms that appeared to be the less vulnerable to hazards along the period of analysis: this is the “Low vulnerability” cluster.

More than half of the farms analyzed (57.7%, n=120) compose the second cluster. The corresonding farming systems are characterized by an intermediate current result variability per worker (89% on average), and by a current result per worker value moderately higher than the

minimum wage (+64% on average). The average number of disruptive situations is twice higher than in the previous cluster, reaching an average of five disruptions along the period of analysis. This cluster thus groups farming systems that have shown a "Moderate vulnerability" along the period of analysis.

The third cluster identified concerns "High vulnerability" farming systems. It gathers ten farming systems that have shown a very high variability of the current result per worker along the period of analysis (684% on average) and with a much lower performance than the minimum wage on average (-87%). The number of disruptive situations is identical to the one observed for farms with moderate vulnerability.

Table 3: Description of three vulnerability profiles (208 farms)

	Low vulnerability (n=78)	Moderate vulnerability (n=120)	High vulnerability (n=10)
$RSD^{CR.LU}$ (%)	53%[a]	89%[b]	684%[c]
$RD^{CR.LU}$ (%)	259%[a]	64%[b]	-87%[c]
EC (n years)	2.8[a]	5.0[b]	5.5[b]
RESIL (n years)	1.7	2.1	2.0

a,b,c,d : values having a different letter as exponent on a given row have a significantly different average (p-value <0.05, Tukey Test, n=208).

The farms' breakdown in the different vulnerability profiles is not influenced by their geographical location (Table 3, p-value > 0.05). In Picardie, 39.6% of farms have a low vulnerability and 56.3% are moderately vulnerable. In Auvergne and Poitou-Charentes, the "Low vulnerability" cluster

concerns 30.1% and 40.6% of the farms respectively. The same observation is made for mixed crop-livestock systems.

Table 4: Distribution of farming systems (n=208), among vulnerability profiles and geographical localizations

	Low vulnerability (n=78)	Moderate vulnerability (n=120)	High vulnerability (n=10)
Picardie	38	54	4
Auvergne	17	35	3
Poitou-Charentes	23	31	3

Fisher Exact Test (p-value > 0.05)

Mixed crop-livestock systems are significantly less classified as “Low vulnerable” than the other categories of farming systems (Table 5, Test 1), as 29% of of mixed crop-livestock systems have a low vulnerability whereas 46% of non-mixed crop-livestock systems have a low vulnerability. The proportion of mixed crop-livestock systems that is classified “Moderate vulnerability” is significantly higher (65%) than those classified in the “Low vulnerability” class (Table 4, Test 2).

Table 5: Distribution of farming systems (n=208), among vulnerability profiles and production strategies

Farming system categories	Low vulnerability (n=78)	Moderate vulnerability (n=120)	High vulnerability (n=10)

Mixed crop-livestock systems	30	68	6
Others	48	52	4

Test of proportion 1 ("Low vulnerability" versus "Moderate and High vulnerability", p-value < 0.05), Test of proportion 2 ("1. Low vulnerability" versus "2. Moderate vulnerability" versus "3. High vulnerability", p-value "1-2" < 0.1 & p-value "1-3 & 2-3" > 0.1)

2.3 Why mixed crop-livestock systems are less vulnerable

2.3.1 Farming system management and structure

Twenty-one indicators are used to describe the management and structure of mixed crop-livestock farming systems:

- Four of them describe the general characteristics of the farming system: the agricultural area (ha), the number of labour units (n), the number of production units (n), energy consumption by hectare (€/ha).
- Four are chosen to describe the livestock production management: the number of livestock units (LU), the stocking rate (LU/ha), the amount of concentrates distributed per animal (€/LU), the number of livestock production units, corresponding to the number of FADN animal categories that are produced (n).
- Six other indicators are used to illustrate the crop production management: the percentage of crop (%), the wheat yield (quintals/ha), the percentage of transformed vegetal products sold (%), the number of crop production units – corresponding to the number of FADN crop categories that are produced, the amount of seeds per hectare (€/ha), the amount of irrigation water per hectare (€/ha).
- Two indicators reflect the crop-livestock interactions, the percentage of self-consumption (%) and the amount of fertilizers per hectare (€/ha).

- Finally, five indicators give information on the financial situation of farming systems: the working capital requirements (€), the cash surplus (€/ha), the debt ratio (%), the net cash (€) and public subsidies (€).

Statistical analyses permit identifying significant mean differences between the three vulnerability clusters identified previously. Mixed crop-livestock systems with low vulnerability are characterized by (i) a higher agricultural area (168.8 ha on average); (ii) a higher number of labor units (2.4 on average) and (iii) a higher diversification level (7.6 production units on average) compared to the two other profiles (Table 6). The energy consumption per hectare is significantly lower than that of the moderately vulnerable farming systems.

Regarding livestock production, less vulnerable farms differ from moderately vulnerable ones by their larger flock size together with a lower stocking rate (respectively 2.4 versus 5.2 livestock unit/ha on average). This lower stocking rate leads to a lower dependency on feed concentrate purchases. It should also be noted that animal diversification is higher in the less vulnerable systems than in other ones.

Table 6: Characteristics of mixed crop-livestock systems according to their level of vulnerability, using a farm.year metric (104 farms during 14 years = 1456 observations)

	Low vulnerability (n= 420)	Moderate vulnerability (n= 952)	High vulnerability (n= 84)
General characteristics			
Agricultural area (ha)	168.8 [a]	148.6 [b]	125.5 [c]

Labour unit	2.4 [a]	2.2 [b]	1.9 [c]
Production units	7.6 [a]	7.3 [b]	6.4 [c]
€ energy/ha	63.2 [a]	71.8 [b]	69.8
Livestock production			
Livestock units (LU)	142.2 [a]	129.1 [b]	129.2
Stocking rate (LU/ha)	2.4 [a]	5.2 [b]	3.0
Feed concentrates/Livestock unit (€/LU)	198.7 [a]	243.8 [b]	245.1
Livestock production units	1.4 [a]	1.2 [b]	1.3
Crop production			
Crop percentage (%)	52.2 [a]	56.9 [b]	46.2 [a]
Wheat yield (quintal/ha)	57.4 [a]	55.6 [a]	41.7 [b]
Percentage of transformed vegetal products sold (%)	2.5 % [a]	1.0% [b]	0.1% [b]
Crop production units	4.1 [a]	4.1 [a]	3.2 [b]
Seeds/ha (€/ha)	52.6	53.7	55.1
Irrigation water/ha (€/ha)	0.4 [a]	1.3 [b]	0.0
Crop-Livestock interactions			
Selfconsumption (%)	1.6% [a]	2.4% [b]	2.0%
Fertilizers/ha (€/ha)	111.0	118.3	120.7
Financial situation			
Working capital requirements (€)	6 700	3 400	-200
Cash surplus (€/ha)	457 [a]	390 [b]	303 [c]
Debt ratio (%)	36.0 [a]	46.9 [b]	51.6 [b]

Net cash (€)	1 020	-70	-600
Public subsidies (€)	387	396	369

a,b,c,d : values having a different letter as exponent on a given row have a significantly different average (p-value <0.05, Tukey Test, n=1456).

Regarding crop production, the least vulnerable farming systems differ from moderately vulnerable ones by (i) a lower proportion of crop in the total agricultural area, (ii) a lower dependence on irrigation and (iii) a higher sales level of transformed vegetable products. Compared to "highly vulnerable systems", wheat yields and the number of crops within rotations are also significantly higher.

Finally, farming systems characterized by a low vulnerability have a lower percentage of self-consumption compared to moderately vulnerable ones. They also have a significantly higher cash surplus, much more public subsidies and a lower debt ratio compared to the two other types of vulnerability profiles (Table 6).

2.3.2 Evolution of organizational and structural components of farming systems

Four indicators are considered in this study: the total agricultural area, the number of labor units, the percentage of crops in terms of agricultural area and the number of production units on the farm.

Three clusters are identified through the analysis and comparison of organizational and structural evolutions of mixed crop-livestock systems. The statistical analysis of these clusters permits characterizing their profile of evolution (Table 6):

- Type 1 - “Low evolution”: This first type is characterized by a low evolution of both agricultural area and number of labor units, and a rather stable crop percentage. The number of production units tends to fall.
- Type 2 - “Moderate evolution”: This type of evolution is characterized by a moderate growth of agricultural area and a stable evolution of labor units. The percentage of crop in agricultural area and the number of production units tend to increase (through the introduction of a new crop in rotations).
- Type 3 - “High evolution”: This third and last type is characterized by a very high increase of agricultural area accompanied by an increase in labor units and in the crop percentage in the total agricultural area. The number of production units remains stable.

Table 7: Characterization of three profiles of evolution of mixed crop-livestock systems (104 farms)

	No evolution (n=52)	« Moderate » evolution (n=27)	« High » evolution (n=25)
Agricultural area (ha)	5.2 [a]	14.6 [a]	77.2 [b]
Labour units	-0.3 [a]	-0.2 [a]	1.0 [b]
Crop percentage (%)	-1.7% [a]	4.3% [b]	7.8% [b]
Nb of production units	-0.9 [a]	1.6 [b]	0.6 [c]

a,b,c,d: values having a different letter as exponent on a given row have a significantly different average (p-value <0.05, Tukey Test, n=104)

The comparison of these evolution profiles with the vulnerability levels of mixed-crop livestock systems shows that no link exists between the evolution strategies identified in Table 6 and the

vulnerability levels (Table 7, p-value > 0.05). Indeed, 33% of farming systems with a low evolution of its organizational and structural components are low vulnerable, 22% when the evolution is moderate and 28% when the evolution is more important.

Table 8: Links between adaptive strategies and level of vulnerability in 104 mixed crop-livestock farms

Evolution profiles of organizational and structural components	Low vulnerability	Other levels of vulnerability
Low evolution	17	35
Moderate evolution	6	21
High evolution	7	18

Test of proportion (p-value > 0.05)

2.3.3 Tactical adjustments: a distinction between « rigid » and « flexible » farming systems

As FADN data are monitored on an annual basis, this study investigates inter-annual fluctuations without considering the detailed intra-annual fluctuations. Eight indicators were chosen to reflect the tactical adjustments of farmers. First, the amount of fertilizers and seeds purchased by hectare are interesting factors to reflect potential needs to relaunch a campaign of production after a climatic hazard. Furthermore, both indicators, together with the quantity of energy consumed by hectare and the percentage of transformed products sold, may also reflect an effort to cope with market price volatility. In the same way, the feeding strategy may be adjusted to climatic and economic hazards by varying the percentage of self-consumption, the stocking rate (by selling or buying animals) and the quantity of feed concentrates purchased. Finally, irrigation may also be an important adjustment lever to cope with drought periods.

The ascending hierarchical classification on the adjustment components of agricultural systems results in the identification of five adjustment profiles (Table 8). Four of these profiles are characterized as "flexible" systems given their ability to adjust at least one component of their production system in order to cope with an ever-changing context. Identified "Flexible" systems adjusted either on their percentage of self-consumption, their stocking rate, their water consumption for irrigation, their fertilizer and seed consumptions, and their feed concentrates consumption per livestock unit. The latter profile is composed of "rigid" farms because they never adjust (or the annual sum of their intra-annual adjustments is constant), whatever the context.

Table 9: Identification and characterization of tactical adjustment profiles in 104 mixed crop-livestock farms

	With adjustments – Flexible farming systems				No adjustments – rigid farming systems
	Self consumption	Stocking rate & Irrigation	Fertilizers & Seeds consumption	Feed concentrates consumption	
Nb farms	15	12	12	8	57
Self-consumption	281% [a]	31% [b]	88% [b]	72% [b]	47% [b]
Stocking rate	17% [a]	49% [b]	16% [a]	26% [a]	16% [a]
Quantity of transformed vegetal products sold	206%	183%	97%	142%	122%

Energy consumption/ha	55%	54%	49%	53%	54%
Fertilizers consumption /ha	51% [a]	53% [a]	64% [c]	49% [a,b]	43% [b]
Seeds consumption /ha	20% [a]	25% [a,b]	53% [d]	36% [c]	28% [b,c]
Irrigation water consumption /ha	0% [a]	143% [b]	32% [a]	28% [a]	3% [a]
Feed concentrates consumption /UGB	55% [a]	50% [a]	58% [a]	306% [b]	49% [a]

a,b,c,d : values having a different letter as exponent on a given row have a significantly different average (p-value <0.05, Tukey Test, n=104)

The comparison of the tactical adjustments profiles with the vulnerability levels of mixed crop-livestock systems permits identifying that “flexible” farming systems are significantly more classified in the category “Low vulnerability” than the “rigid” farming systems (Table 9, p-value < 0.1). Indeed, in 21% of cases « rigid » farming systems have a low vulnerability level whereas this proportion rises up to 38% for the “flexible” farming systems (Table 9).

Table 10: Links between strategical adjustment, tactical adjustment and vulnerability profiles in 104 mixed crop-livestock farms

Tactical adjustments profiles	Low vulnerability	Other levels of vulnerability
Rigid	12	45

Flexible	18	29

Test of proportion ("% Low vulnerability – Rigid" versus "% Low vulnerability – Flexible", p-value < 0.1)

3 Discussion

4.2. The level of vulnerability of mixed crop-livestock systems

Non-mixed crop-livestock systems are more likely to be low vulnerable in comparison with mixed crop-livestock systems and that their localization has no impact on their vulnerability level. Our framework allows to show that diversification practices alone do not provide solutions to reduce farm vulnerability (Bouttes et al., 2018). Indeed, if crop and livestock productions are no integrated, i.e. no interaction between both components, the farming systems isn't benefiting from synergies between crop and livestock production (Sneessens et al., 2016). For instance, internal nutrient recycling is a key issue to decrease vulnerability as it allows achieving productivity and technical and economic efficiency (Bonaudo et al., 2013). The absence of impact of the geographical localization may be seen as a proof that farming systems adapt their way of producing in function of the environmental specificities (climate, soil, etc.) they are facing, leading to an equal distribution of vulnerability levels among farms.

The second part of the analysis permits identifying the key drivers of low vulnerability for mixed crop-livestock systems. Low vulnerable farming systems are characterized by a higher diversification and crop-livestock interactions that permits decreasing dependence on markets. Indeed, low vulnerable systems have lower expenses regarding energy per hectare, water per hectare and feed concentrates consumption per animal. These results are in line with the whole body of literature on mixed crop-livestock systems that discuss production diversification (Bonaudo et al. 2014; Lemaire et al. 2014) and the reduction of market dependency through self-

sufficiency and efficiency improvement (Bernués et al. 2011; Thomas 2008) as main strategies for risks dispersion. Furthermore, the low vulnerable farming systems identified show higher financial performances (higher cash surplus and lower debt ratio). Indeed, a better management of financial factors permits generating sufficient profit to enable savings, the repayment of loans and/or the relaunching of production activity in case of hazards (Simelton et al. 2009; Ullah et al., 2015).

The analysis of farming systems trajectories and dynamics led to two findings. First, there is no link between the evolution of organizational and structural components and the level of vulnerability of mixed crop-livestock systems. Martin et al. (2017) and Marshall et al. (2014) also found that farm initial configurations mainly determine the vulnerability of farming systems. Farmers have to face various constraints which limit adaptive capacity at farm level (Abid et al., 2018). However, mixed crop-livestock systems that have shown interannual tactical adjustments are more likely to be less vulnerable than other farming systems. Other authors also have highlighted and discussed the benefits of various adjustment factors such as the modification of the percentage of crops self-consumed on the farm, the quantity of feed concentrates purchased per livestock unit, the quantity of water used for irrigation, etc. (Jones et al., 2006; Mosnier et al. 2009).

4.1 Four main originalities of the framework

Indicators characterizing vulnerability of farming systems are describing the behavior of the economic performance of farming systems, taking into account a social dimension. Indeed, our framework proposes using a minimum threshold of economic result per worker to identify the ability of a farmer to maintain a sufficient income. The consideration of disruptive situations and the ability to recover from these disruptive situations are also key variable to better understand the susceptibility of farming system to be harmed and their subsequent adaptive capacity. The social dimension of vulnerability is generally omitted in

vulnerability assessments. It's generally considered in studies using composite indicators to assess vulnerability from farming systems characteristics making the hypothesis that the link between vulnerability and management characteristics is known (Nazari et al. 2015; Oliveira et al. 2015). Conversely, this study proposes a vulnerability assessment framework that permits identifying vulnerable management practices. Another stream of literature analyzing the social dimension of vulnerability focus on farmers perceptions of risk and the identification of adaptation options without proposing a quantified figure of vulnerability (Abid et al. 2019, Marschall et. 2014, Nicholas et Durham 2012)

Vulnerability assessments are often reduced to one variable and missed considering the complexity of the vulnerability concept (Dong et al. 2015, Reidsma et al., 2010). Some authors use composite indicators to assess farming systems vulnerability but they either focus on farming management characteristics assuming a known correlation with vulnerability (Nazari et al. 2015; Oliveira et al. 2015), either on technical aspects of the farming systems without proposing an aggregated assessment of vulnerability preventing the consideration of social aspects and the clear identification of factors explaining vulnerability levels (Bouttes et al. 2018, Martin et al. 2017).

The framework proposes a whole farm approach that consider all hazards occurring during a long period of time whereas vulnerability analyses are often restricted to the analysis of the impact of one specific hazard (Dong et al., 2015, Farhangfar et al. 2015; Mosnier et al. 2009). Whereas these analyses have their importance to better understand specific processes, they fail considering real farm exposure to risk and thus identifying determinants of low vulnerability in front of various hazards.

The framework permits identifying the farm management practices that explain economic vulnerability considering farming systems dynamics through the definition of evolution and

tactical adjustments profiles. Bouttes et al. (2018) and Martin et al. (2017) propose the same kind of approach but without defining patterns of evolution, only yearly evaluations are compared. Conversely, our method identifies evolution profiles and their link with vulnerability levels enabling better understanding how to reduce vulnerability and how to make it possible to preserve family size farms in the long term.

However, our study did not consider farms that disappeared between 2001 and 2014 as this information is not available in FADN data. It would have been interesting to identify and characterize those highly vulnerable systems. Furthermore, our study focused on agricultural activities. Other economic activities also play an important role in farming systems vulnerability as it can partially or totally compensate weaknesses of farming systems (Ingrand et al. 2007).

4 Conclusion

This article proposes a framework to assess vulnerability of farming systems from an economic point of view. It consists in analyzing the past economic results and to characterize the vulnerability through indicators reflecting farming systems management and structure as well as their dynamics along the period of analysis.

In comparison with other researches (Bouttes et al., 2018 ; Martin et al., 2017), our methodology puts forward the idea of combining new categories of farming systems. Thanks to this approach, it is possible, in combining quantitative et qualitative data in a processual manner, allows identifying discrete levels of vulnerability.

The application of this framework on a group of 208 mixed crop-livestock farming systems from three regions of France (Picardy, Auvergne, Poitou-Charentes) along a period of 14 years allowed to cluster them according to three levels of vulnerability. “Low vulnerable” systems are

characterized by a low variation of economic result per labour unit (53% on average), a mean performance on average 259% higher than the minimum salary level in France (SMIC) and a low number of economic disruption along the period in comparison with other farming systems (3 on average). “Moderate vulnerable” systems have a mean performance that is much closer to the minimum salary and show a higher economic sensitivity along the period with a relative standard deviation (RSD) of 89% on average. Finally, “high vulnerable” systems are characterized by a much lower performance than the minimum salary (-87% on average) and a very high variation of their economic results per labour unit (average RSD of 684%).

The key determinants of low vulnerability were highlighted in the in-depth analysis of mixed crop-livestock systems characteristics. In that respect, public policies should promote the diversification of farming systems: low vulnerability is reached with a higher number of production units and a higher percentage of economic product coming from the sales of transformed vegetal products. Interactions between production units also have to be promoted in order to benefit from scope economies and flexibility. A good management of interactions between production units permits benefiting from a higher energy consumption efficiency. Farmers who adjust their consumptions in front of intra-annual fluctuations of the context are more likely to decrease the vulnerability of thei system. Livestock production should be managed taking into account of diversification constraints (labour units) and interactions opportunities.

Further research is needed to investigate the role of the initial conditions on the system vulnerability throughout time. This would contribute to an enhanced academic understanding of farming systems vulnerability, to better advice farmers in operational projects and to question the role and responsibility of policymakers, particularly regarding support policies for farming system transition (as well as transmission and acquisition policies).

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