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Taking into account recovery to assess vulnerability: application to farms exposed to flooding

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Abstract: In this paper, we discuss the necessity to take into account recovery processes in the field of vulnerability assessment, which is more and more widely used to help decision-making. Considering farm vulnerability to flooding, according to the literature, there is a need to better understand recovery after flooding to evaluate vulnerability. Nevertheless, quantitative methods, mainly developed to appraise damage completely neglect this. We present, in this paper, a modelling approach to assess vulnerability to flooding at farm level with quantitative indicators. The model takes into account processes which occur at farm scale until the farm recover to a state considered similar to its initial one. We first present the model and particularly focus on the difficulties related to modelling recovery processes. The description is illustrated by an application on a farm type in the Rhone River context. Then, we present damages born by several farmer profiles which illustrate the difference between taking or not into account recovery. These simulations show that, depending on the possibility to farmer to access external resources, damages endured can be much higher than direct damages usually evaluated when recovery is not taken into account. Finally, we discuss the interest and warnings to use this model and present remaining research challenges.

Keywords: Vulnerability assessment; Farm; Flood; Recovery process; Damage; Modelling

1 INTRODUCTION

Vulnerability is generally considered as hazard specific as defined by Wisner et al. [2004]. Knowing hazard spatial distribution helps decision makers to identify areas potentially exposed. But, to mitigate hazard effects, they also need information concerning asset vulnerability. Then, assessing vulnerability tends to be more and more commonly required in decision-making process for natural hazard management. Understanding and assessing vulnerability can be useful to evaluate potential damages on an exposed area, to identify measures to reduce asset vulnerability, to evaluate avoided damage due to the implementation of such projects. Particularly, this information is critical when decision makers have to prioritize between several options, specifically to compare measures to mitigate hazard with measures to mitigate vulnerability.

Globally, vulnerability assessments are carried out by two methods: multi criteria analysis (MCA) and modelling. Even if some conceptual frameworks have been proposed to homogenize indicators of multi criteria analysis and make vulnerability assessment more comparable, as for instance by Polsky et al. [2007], MCA often fails in explicating underlying processes to selected indicators as concluded by Scheuer et al. [2010]. Moreover, MCA does not aim at simulating vulnerability but more at explaining it. When considering modelling vulnerability to natural hazards, methods generally aims at evaluating damage but most of them fail in considering recovery processes and loss due to disruption of production as pointed out by Bubeck and Kreibich [2011].

According to Gallopin [2006], we consider that system vulnerability depends on sensitivity and ability to recover. Our research question is to determine whether particular attention should be paid on recovery process when one wants to assess vulnerability. Particularly, we are interested in farm vulnerability to flooding since the review of literature on vulnerability assessment revealed a paradox between qualitative studies and quantitative methods of vulnerability assessment. In the one hand, qualitative studies argue that recovery after flooding is particularly important to take into account; first, because, as Pivot and Martin [2002] pointed, it induces disturbance on work planning which depending on farm resource availability may lead to losses by delaying important tasks; second, because, as Posthumus et al. [2009] intuited, global economic losses may not reflect loss supported by farmer which determines risk of bankruptcy. On the other hand, the review of existing methods to evaluate damage due to flood reflecting farm vulnerability, carried out by Brémond and Grelot [2010], reveals that most of methods estimate agricultural vulnerability only by the loss of harvest. Not only do existing methods fail to consider the whole of impacts on farms components but also neglect impacts induced on economic activity during recovery and do not consider farm as economic systems.

The objective of this paper is to present a modelling approach to assess vulnerability to flooding at farm level with quantitative indicators. The originality of this approach is to take into account processes which occur at farm scale during recovery and determine whether they are significant when one wants to assess vulnerability. In section 2, we particularly highlight the difficulties related to modelling recovery processes and propose learning. In section 3, we present some results and analyze how taking into account disturbance until farm recovers a state similar to its initial state sheds light on vulnerability, specifically bankruptcy risk.

2 MODELLING FARM VULNERABILITY: LEARNING FROM A MODELLING PROCESS

2.1 General description of the model EVA

Purpose and links with other models The purpose of the model EVA is to evaluate flood consequences on farms with quantitative indicators in order to assess their vulnerability. In particular, EVA aims at evaluating impacts of a change in flood parameters and/or asset vulnerability. Concerning flood scenarios, EVA uses, as inputs, flood parameters such as duration, height, occurrence period and speed arising from hydrologic and hydraulic modelling. Concerning change in asset vulnerability, EVA uses, as inputs, modified farm's characteristics.

Spatial and temporal scales The system considered is a farm represented as a collection of physical components: on the one hand, buildings containing equipment and stocks of inputs; in the other hand, land plots containing crop production and orchard or vineyard. During and after the flood, these components are characterized by their usability which is a combination of their accessibility and state (normal, damaged, destroyed…). The usability defines if the component can be involved in the production process. As an example, as long as a piece of equipment is unusable, it cannot be used to achieve a production task which requires its use. EVA model crosses farm and flood temporalities. As explained in the next section, without flooding, farm task planning relies on the crop management sequence defined as a parameter of farm. When a flood is simulated, task planning is reorganized at the weekly time step until the end of the production cycle. Production tasks can be delayed or partially achieved and recovery tasks (cleaning) are added to the list of tasks to do. This point is specifically developed in subsections 2.3 and 2.4.

Outputs of EVA We aim at describing the flood effects on farm by several indicators. Three main indicators are produced by EVA:

1. the chronology of the usability of every farm physical component;
2. a quantification of changes induced in resources, mainly workforce and pieces of equipment, needed to carry on at the same time production and recovery tasks;
3. a quantification of damage induced, in monetary terms, by the achievement using external resources or the undoing of some production tasks depending on farmer's capacity to access to external resources.

2.2 What implies taking into account recovery in modelling vulnerability

Taking into account recovery in modelling vulnerability for its assessment, has implied mainly two kind of difficulties: modelling task planning and task achievement at farm level.

First, we needed to characterize task planning in terms of distribution in time and resources required to achieve them. To model task planning on farm, we mainly use conceptual framework of farm systemic modelling developed in France by INRA SAD in the 1980's. In particular, the concept of crop management sequence defined by Sebillote and Soler [1990] as the sequence of tasks that allows the farmer to control the environment and to obtain a production yield, has proved useful to model work organization and help farmer decision-making by Papy et al. [1988], Aubry et al. [1998] and Matthews et al. [2003]. In our modelling, two kinds of tasks need to be considered: production tasks and recovery tasks which are required to make every farm physical components that have been damaged by the flood returning to a normal state. According to Sebillote and Soler [1990], the task planning expected in the crop management sequence corresponds to the optimal decision process. Then, when a flood occurs, the farmer tries to come back as soon as possible to the crop management sequence.

Second, we needed to characterize required and available resources for task achievement. Multiple capital theory formalized by Ekins [1992] is a useful framework to categorize resources involved a production processes and to explicit assumptions on some capitals substitutability. The farm system has been divided into the following capital forms:

- The physical capital corresponds to the whole of physical goods (land plot, building and contents) which enables farmer to produce crop.
- The human capital corresponds to the workforce available on farm.
- The financial capital corresponds to financial resources (internal or external) available for the farm.
- The social capital corresponds to social resources (family, professional network. . .) that can be mobilized to help the farmer.

Interviews we did with farmers on Rhone River downstream (France) who has endured severe flooding in 2002 and 2003, revealed that recovery strategy is mainly determined by the possibility to access external resources after flooding. To analyze the consequences of the availability of external resources, we consider that some physical and human capitals can be substituted by financial or social capitals during the recovery. Then we defined three archetypical profiles of farmer which illustrate contrasting situations in terms of social and financial capital level: 'Internal' (no social and no financial capital), 'Solidarity' (high social capital), 'Services' (high financial capital). In the two following sections, we focus on the two main modelling difficulties and illustrate intermediary results by a case study on the Rhone River downstream. The simulations correspond to a farm type representative of the agricultural context on this area: a vineyard of 22 ha with two plots of 11 ha and a building. We assume that only one plot and the building are flooded. The flood scenario chosen refers to the last extreme flood that occurs on the case study are in December 2003 (occurrence on week 49). The height is set at 150 cm and duration at one week.

2.3 Focus on modelling task planning at farm level

A task is defined by the six following attributes:

- a place where the task is done (localizator);
- a date of beginning (t_b);
- a date of end (t_e);
- the time needed to achieve the task (d_T);
- the list of the pieces of equipment required to achieve the task (M_T);
- the list of inputs required (I_T).

To model task planning and flood consequences on it, we go through three steps. First, a standard situation is defined with production tasks only. The time needed to achieve the task (d_T) is homogeneously distributed between t_b and t_e. Second, when a flood occurs, we consider that recovery tasks are generated. The flood implies that the localizator may not be accessible before the date l_e. The time needed to achieve these tasks depend on the intensity of the flood scenario and is also homogeneously distributed between $t_b = l_e$ (accessibility of the localizator) and $t_e = l_e + d_T$. We assume recovery tasks are achieved in a certain amount of time (4 weeks for building and 8 weeks for plots). Third, if the flood occurs during a production task is planned, this task may be stopped if $t_e < l_e$ or delayed ($t_e \geq l_e$). In the last case, the remaining work is distributed between l_e and t_e.

2.4 Focus on modelling task achievement at farm level

Once workforce and tool required to achieve the task have been modelled, it is necessary to determine whether the task can be done, under which conditions and what are the consequences. A task can be achieved only if, the farmer has access to resources necessary to do it. This condition is related to what we call farmer's profile and represents the ability for the farmer to access external resources during recovery. We assume that farmers with Internal profile only can use internal resources when Solidarity and Service profiles can benefit from external resources to achieve the tasks.

Constraint due to equipment usability If the farm building is flooded, the equipment contained in it remains unusable during the flood because of inaccessibility. After flooding, depending on the flood height and the sensibility of each piece of equipment, some can have been damaged or destroyed. As a consequence, they remain unusable to achieve task if they are required until the tool is repaired (3 weeks) or re bought (8 weeks). The table 1 shows the consequences of the flood scenario chosen on farm equipment. The theoretical unavailability corresponds for each tool to the total duration of unusability (inaccessibility and reparation or re buying) and is independent from the period of occurrence. The real unavailability corresponds to the duration for which the tool is required to achieve a task but unusable. This duration depends on production task planning. As an example, even if the pesticide sprayer remains unusable during four weeks this has no consequences on task achievement. Contrarily, the two tractors are required to achieve tasks during 8 and 9 weeks but remain unusable during 9 weeks. That implies that solidarity and financial profiles use external equipment (respectively from solidarity and service provider) and the internal profile does not achieve production tasks if tools required are unusable.

Tool	Theoretical unusability	Real unusability
chopper	4	4
cleaner	9	8
cultivator	4	3
cultivator intervine	1	0
grape conveyor	4	0
pesticide sprayer	4	0
pre pruner	4	4
secator	9	9
topper	4	0
tractor 2m	9	9
tractor 4m	9	8
turner	4	4
weeding tank	4	0

Table 1: Unusability of tools (Vineyard, week 49)

Constraint due to workforce The flood induces a new planning of tasks. As shown in table 2, after flooding the need of total workforce globally increases (40 %) mainly due to additional cleanning tasks. In the table 2, the workforce distribution corresponds to the profiles solidarity and financial which can access additional external workforce. The needs in external workforce are trebled. This implies that the internal profile can not achieve some production tasks.

	Internal workforce	External workforce
Production task	2 375	23
Plot cleaning	824	12
Building cleaning	110	2
Total workforce	3 309	37
Standard workforce	2 386	12

Table 2: Workforce (h) for the December flood compared to standard workforce

Consequences of task unachievement Each production task has two additional attributes:

- δ_T, a coefficient which represents the loss of yield induced by unachievement;
- θ_T, a coefficient which represents the achievement ratio.

For every task that can not be completely achieved due to constraints, θ_T is calculated. The total loss of harvest is then calculated as follow : $\Delta = 1 - \prod(1 - \delta_T \times \theta_T)$. For each task unachieved, production costs are also calculated and subtracted to the damage endured.

3 RESULTS

3.1 Financial damage supported by farmer for the first scenario (December flooding)

The model presented enables us to calculate the total flood damage at farm level including direct costs and induced costs on activity due to recovery. We present here the costs born by farmer depending on their profile. The main following assumptions concerning resource costs are made for calculations (table 3). The difference between Solidarity and Service profiles is the cost of the resources for the farmer. Solidarity profile benefits from free cost resources when Service profile can use them at market costs.

Damage	Solidarity	Service	Internal
Internal workforce	0	0	0
External workforce	0	cost of employment	-
Internal equipment	cost of use	cost of use	cost of use
External equipment	cost of use	cost of rent	-

Table 3: Cost of use for workforce and equipment (figures are expressed in €/h)

The total damage is then calculated for each farmer's profile for the flood scenario in December (week 49, duration 1 week, 150 cm on one of the two plots and on the building). Solidarity profile bears the lower damage. It corresponds to the damage without considering recovery effects. Service profile bears damage with additional costs of resources which come from services and Internal profile bears damage due to task unachievement. The gross damage corresponds to the damage born by farmer without insurance. The net damage considers insurance indemnities for damage on equipment, building, soil plot and direct loss of harvest[1]. Table 4 shows the gross damage for internal profile is more than 20 % higher than gross damage for Solidarity and Service profiles. When considering net damage, this difference is even more critical. The net damage is more than 70 % higher for the Internal profile.

The distribution of gross and net damage for each profile is shown on figure 1. Concerning gross damages, damages to equipment and soil represent a large share of the total damage. When considering net damage, most of the damages to equipment is compensated by insurance and not really born by the farmer. The damage due to task

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[1] We used the so-called ”Calamités Agricoles” system.

Damage	Solidarity	Service	Internal
gross	60 744	64 499	82 991
net	8 445	11 485	30 693

Table 4: Damage endured depending on profile and insurance for a flood in week 49 (€)

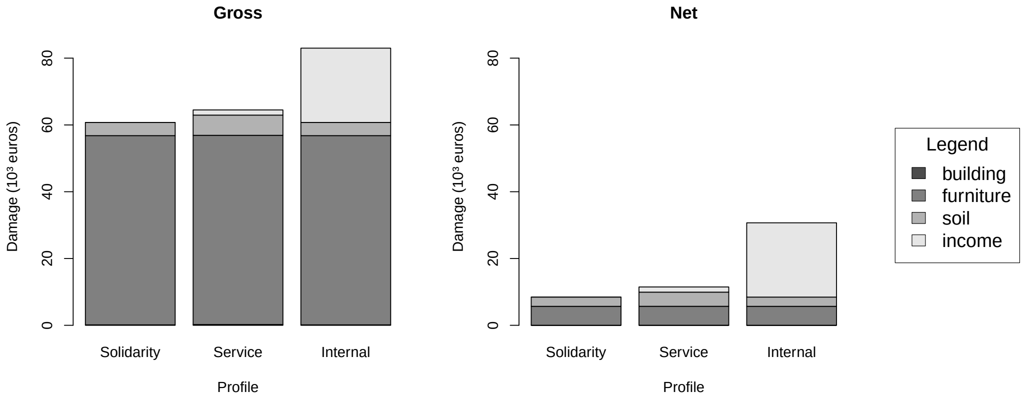

Figure 1: Distribution of damage depending on profile and insurance for a flood in week 49

unachievement for the Internal profile represents 70 % of the total net damage. This result shows that, in some cases, the way the farmer can access external resources highly influences the amount of damage he has to born and then his vulnerability to the event. By comparing gross and net damage for each farmer profile, we point that classical insurrances also do not cover the damage induced during the recovery period which makes Internal profile even more vulnerable. Although these results reflect the case of a specific farm type (vineyard) exposed to a specific flood scenario, they highlight the need to consider the recovery process to evaluate vulnerability.

3.2 Exploration of farm vulnerability in function of flood parameters

As agriculture is a highly seasonal activity, we propose to analyze the influence of the flood period of occurrence on the net damages (figure 2). For this, we have made the period of occurrence varying on all the weeks of a year (1 to 52). The other parameters have remained set (height 150 cm on one of the two plot and building, duration one week). Depending on when the flood occurs, the difference between damage endured by Solidarity, Service and Internal profiles varies. The difference is the highest during vegetative period. In fact, the amount of direct damages, specifically on crop, is relatively low and a large share of the damage comes, for Internal profile, from the constraints on task achievement during recovery. Without considering recovery process illustrated on figure 2 by the damage endured by Solidarity profile, an important share of damage can be missed depending on the probabilities associated to the flood period of occurrence. On the Rhone River downstream where this case study has been carried out, winter floods are the most frequent which confirms the need to take into account recovery when assessing farm vulnerability.

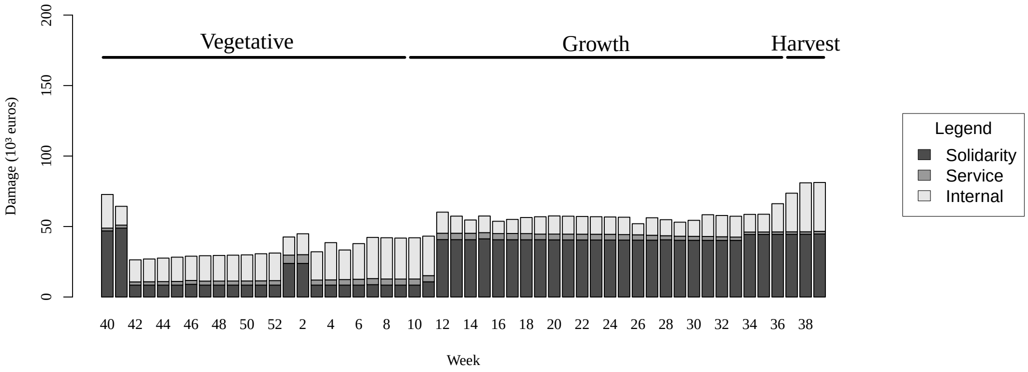

Figure 2: Variation of damage depending of the period of occurrence of the flood

4 CONCLUSIONS AND DISCUSSIONS

Modelling vulnerability taking into account farm recovery has implied to finely model on the one hand, task planning and the effects on flood on it and in the other hand, the way farmers can deal with internal resources (workforce and equipment) constraints and the consequences when they can not access external resources. Our research question was to determine whether the recovery process influences farm vulnerability to flooding and analyze this point with quantitative results. We showed that depending on the possibility to farmer to access external resources, the damage endured can be much higher than direct damage usually evaluated when recovery is not taken into account. The amount of damages born by a farm which meets constraint to recover (Internal) are much higher than those born by the profile which benefits from free cost resources (Solidarity). The amount of damage born by the Internal profile is even higher than the damage born by a farmer who pays at cost market the resources lacking to keep on achieving production tasks. Depending on the occurrence period, the difference in these amount of damage can be more or less significant. However, it seems to be critical to consider consider recover when floods have a high probability of occurrence during the vegetative period of the crop considered. Those results confirm that when a vulnerability assessment has to be carried on a zone containing agricultural assets, recovery should be taken into account. Those findings have also important practical consequences both for damage assessment and design of policies such as vulnerability mitigation. Specifically, for vulnerability mitigation measures which aims at enhancing recovery, EVA model will be useful to evaluate avoided damage .

The development of this model was highly time demanding although a lot of previous work has already been carried out by numerous research teams on modelling farmer practices. This should be considered when one wants to develop similar model on other activities. It would be time demanding to collect information on task planning whereas in agriculture, the crop management sequences have been very helpful for our modelling. The model also requires a lot of data, mainly at a micro scale. This implies that these data should be collected by interviews or survey and must rely on a detailed data base model.

Some challenges still remains in the modelling approach. One of these is related to task unachievement. The damage is appraised for Internal profile by an indicator of yield loss when production tasks are partly or totally unachieved. This damage is obviously highly dependent on the evaluation of the loss of yield. However, for some tasks, it was really difficult for experts interviewed to associate a loss of yield to some production tasks either because the task achievement impact is highly uncertain or because the task achievement is not totally linked to an impact on yield. Further researches are needed: on the one hand, more empirical data should be collected to determine whether other indicators than loss yield should be included in the model (increase in work time, loss of quality…); on the other hand, by carrying on a sensitivity analysis of the model, the influence of this variable could be precisely determined.

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