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Simulating the dynamics of individual adaptation to floods

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ABSTRACT

Individual adaptation measures are an important tool for households to reduce the negative consequences of floods. Although people's motivations to adopt such measures are widely studied in the literature, the diffusion of adaptations within a given population is less well described. In this paper, we build a dynamic agent based model which simulates the adoption of individual adaptation measures and enables evaluation of the efficiency of different communication policies. We run our model using an original dataset, based on a survey in France. We test the importance of different parameters of our model by implementing a global sensitivity analysis. We then compare the ranking and performance of different communication policies under different model settings. We show that in all settings, targeted policies that deal with both risk and coping possibilities, perform best in supporting individual adaptation. Moreover, we show that different dynamic parameters are of particular importance, namely the delay between the motivation to act and the implementation of the measure and the time during which households stick to a given adaptation measure.

1. Introduction

Floods cause major damage and disruptions worldwide. In Europe, between 1980 and 2011, floods affected more than 5.5 million people and resulted in more than 2500 fatalities and over 90 billion euros in economic losses (EEA, 2012). In France, one resident out of four and one job out of three are exposed to flood risk. Between 1988 and 2013, floods were responsible for around 30 billion euros of damage in France (MEDDE, 2012a,b).

Many different policies exist to address this risk: structural measures (dykes, dams) or non-structural measures (flood retention basins) may be established with the aim of reducing hazard. National compensation schemes and private insurance policies can be used to help people to recover after a crisis and hence increase resilience. Zoning policies may be designed with the aim of reducing vulnerability (Erdlenbruch et al., 2009), e.g. by enforcing building restrictions or the adaptation of buildings in risky areas. Among the vulnerability reducing actions, some reduce the negative consequences of floods at the individual level. Households can choose, e.g. to use water-resistant materials in their homes, or to store valuables upstairs. Following Blanco et al. (2017), we term such actions “individual adaptation measures” as opposed to collective mitigation measures, which reduce the probability of group loss.

Risks are reduced more effectively if adaptations at different scales are combined (Adger et al., 2005; Filatova, 2014). This may be the case when governments set up information policies or price signals for private stakeholders or when they support market based instruments (Filatova, 2014). In this paper, we focus on how individual adaptation measures can be promoted by public communication policies. To situate our approach with respect to the risk governance model (Aven and Renn, 2010; IRGC, 2005), we assume that risk appraisal and concern assessment as well as risk characterisation and tolerability assessment are carried out at the individual level. Different communication policies representing different regulatory styles are implemented by the risk management institutions, e.g. local water basin manager or the national ministry of the environment.

Some individual adaptation measures have been shown to be particularly cost efficient, reducing the ratio of total damage to total building values by nearly half (see Kreibich et al. (2005) for a study in Germany, Poussin et al. (2015) for a study in France, and Botzen et al. (2009) for a study in the Netherlands). Many other advantages of individual adaptation are discussed in the literature, among which the fact that they may help to maintain awareness about flood risk among people (Richert et al., 2017). Although the reasons to adopt individual adaptation measures are relatively well covered in the literature, little is known about the dynamic aspects of adaptation: how long do people stick to a chosen measure? Once people have the intention to adapt, how quickly do they implement the measure? At a more aggregated level: how rapidly do adaptation measures expand within a population? Our main research question in this paper is thus: how important are the dynamic aspects of the adoption of individual adaptation measures and how do they influence the predictions about the effectiveness of public

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policies supporting individual adaptation? To answer this question, we built an empirically based dynamic simulation model of the adoption of individual adaptation measures.

To study the driving forces of the adoption of individual adaptation measures, many studies have used the protection motivation theory (PMT) because it focuses on two complementary elements of risk perception, threat appraisal and coping appraisal. The theory was proposed by Rogers (1975) and originally applied in the health domain (see Milne et al. (2000) for a metanalysis). Following Grothmann and Reusswig (2006), the framework was extended to explain the adoption of individual adaptation measures against floods. Authors in various countries have used this approach, e.g. in Germany (Grothmann and Reusswig, 2006; Bubeck et al., 2013), Great Britan (Glenk and Fischer, 2010), Vietnam (Reynaud et al., 2013), and France (Poussin et al., 2014; Richert et al., 2017). Similarly, this approach has been used to explain the adoption of individual adaptation in the face of drought events (van Duinen et al., 2014, 2015). This is the framework we use in the following.

Several studies have drawn attention to the fact that risk perceptions and adaption behaviour should be modelled in a dynamic setting (Bubeck et al., 2012a,b). For example, risk perception satisfactorily explains the intention to adopt individual adaptation measures but not necessarily the presence of such measures, because there could be a feedback effect, which decreases risk perceptions once the measures are adopted (Bubeck et al., 2012a; Richert et al., 2017). On the other hand, households may decide to abandon measures if no flood occurs for a while, as the experience of flood events is an important element in explaining past implementation of individual adaptation measures (Osberghaus, 2017). Despite these results, longitudinal data on adaptation behaviour are scarce and time consuming to collect (Osberghaus, 2017). One way to investigate the dynamics of adaptation despite this missing data is to use simulation models, such as agent based models.

Agent based models (ABM) make it possible to test hypotheses concerning the relationship between individual behaviours and macroscopic regularities (Epstein and Axtell, 1996), for instance the rate of adaptation in a population as the outcome of many individual adaptation decisions. ABMs can also be used to explore non equilibrium dynamics (Epstein and Axtell, 1996) and to test the importance of sets of parameters for which empirical data are missing. It is thus an interesting tool to test changes in rates of adaptation in the population as a function of different dynamic parameters of individual adaptation. Finally, ABMs can be easily combined with spatial models and can consequently represent the networks and interactions among individuals which are crucial in social systems. In this paper, we consider a typical social network, exhibiting the small-world characteristics, which have been shown to exist in many social interactions (Watts and Strogatz, 1998).

Agent based models have already been applied to flood risk management. Dawson et al. (2011) for example built a flood-incidence model which mimics the short-term reaction of individuals during a flood, applied to the coastal town of Towyn, UK. Filatova et al. (2011), Filatova (2015) and Dubbelboer et al. (2017) modelled the long-term effect of flood risk on the housing market. Other studies showed the influence of different behavioural assumptions on changes in land-use or in investment decisions: for example, Filatova et al. (2011) show how a skewed risk perception distribution leads to more high valued development in risky coastal zones. Haer et al. (2016a) investigated three economic decision models for investments in loss-reducing measures in the context of river flooding. Finally, Haer et al. (2016) and van Duinen et al. (2016) combined protection motivation theory and agent based models of adaptation diffusion, applied to drought risks in van Duinen et al. (2016) and flood risk in Haer et al. (2016).

The model built by Haer et al. (2016) is closest to ours. They tested the effectiveness of four different flood-communication policies in promoting individual adaptation measures in the Dutch Rotterdam-Rijnmond area. Risk communication can be top down or people centered, i.e. tailored to the specific needs of an individual. One example of top down policies is when governments communicate about risk zoning. One example of people centered policies is when experts advise homeowners how to make their home flood-proof. The information provided in these communication campaigns can deal with the occurrence and consequences of flood risk or it can describe actions and measures that people can use to cope with the risk. One could for example imagine a photo exhibition showing past events to describe the risk and advise on how to behave in the case of a crisis to describe how to cope with different types of risk. Haer et al. (2016) show that polices perform best if the information is people centered and if it deals with both the risk and coping with risk.

Our model differs from their model in three main ways: first, whereas Haer et al. (2016) construct an artificial society based on data found in Bubeck et al. (2013), we use our own dataset and only model households on which we have detailed information. Second, Haer et al. (2016) construct a social network based on the characteristics of networks in the Netherlands, we construct a spatially explicit small-world network on the basis of our data. Third, and most importantly, we adapt our model to be able to represent two important dynamic features: the average delay of implementation of the measure and the average adaptation duration. We analyse the importance of the different parameters of our model by comparing it to a similar aggregate model and by performing a global sensitivity analysis. We then investigate the impacts of the four communication policies in this model, considering different dynamic adaptation configurations. In particular, we show that the delay of implementation is the most influential parameter, next to the duration of individual adaptation measures.

The paper is organized as follows: In Section 2, we describe the survey and the empirical data we use. In Section 3, we present our empirical decision model: we first describe how protection motivation can be represented as the probability to adopt adaptation measures and we then present the results of estimating this probability from the underlying dataset. In Section 4, we describe the model of adaptation diffusion, with a special emphasis on the construction of the social network and the dynamic parameters. We also compare the individual based model to an aggregate model to gain some additional insights into the dynamics modelled and to demonstrate the interest of individual-based modelling in this specific case. In Section 5, we present the experimental plan of our simulations. In Section 6, we present the results: first we assess the importance of different parameters of our model, by comparing it to the aggregate model and by implementing a sensitivity analysis. We then observe how different model configurations affect the ranking and efficiency of the four communication policies. This allows us to represent the diffusion of individual adaptation measures under different dynamic settings. Finally, in Section 7 we present our conclusions. Fig. 1 summarizes the main steps of our work.

2. Material

2.1. Survey and geographical sampling

Our data is based on a survey of 331 households in the Aude and the Var departments in the South of France, conducted in summer 2015. The distribution of the surveyed households and their location in the floodplains are shown in the maps in Fig. 2. All the sampled municipalities were hit by important floods in the years preceding the survey: in the Var department in 2010, 2011, 2013 and 2014, and in the Aude department in 1999 and 2014. Some municipalities are flooded regularly while others were hit only by major floods, namely in the Aude departement in 1999 and in the Var department in 2010. The majority of the respondents live in flood-prone areas: 80% of the respondents had already experienced a flood, as defined in the survey by “the flood reached your street”. About half of the respondents live in big municipalities, the other half in rural municipalities. In the survey, we also collected information on location of the households in the flood prone