Modeling and Measuring Protective Action Decisions under Flood Hazards in Brazil*

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Abstract

This paper performs an econometric analysis based on selected dimensions of the Protective Action Decision Model (PADM) for Brazil. We empirically estimated the determinants of flood preparedness by using Seemingly Unrelated Regression models. PADM survey instrument validation was based on Cronbach alpha, inter-rater agreement index, factor analysis, and mean-comparison tests. The PADM was applied to a sample of 1,200 households in the municipality of Governador Valadares, State of Minas Gerais. The site was chosen because river floods are recurrent in the area, reaching thousands of households along the river. Building on a model of private insurance, we show that risk aversion determines the direction of influence of price and resource effectiveness on the probability of adopting protective action against flood hazard. We also prove that absolute and relative risk aversion determines how the effect of resource effectiveness dominates the effect of insurance price on the adoption intention. Our econometric model confirms the theoretical predictions for the analytical sample. These findings suggest that public action should promote educational campaigns aiming at the reduction of subjective uncertainty on resource effectiveness. *keywords* Risk aversion Private insurance River flooding Protective Action Decision Model Brazil

1 Introduction

Every year many lives are lost due to floods worldwide. According to the Centre for Research on the Epidemiology of Disasters in Brussels, in cooperation with the United States Office for Foreign Disaster Assistance (CRED/OFDA), about 100,000 lives were

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lost and over 1.4 billion persons were somehow affected by floods from 1990 to 2000. In addition to human impacts, the material impacts of floods create additional burden for the households, increasing their vulnerability to new environmental and social stress (Jonkman, 2005).

Floods are of special concern in areas where population vulnerability to flood hazard is high, such as in impoverished areas of developing countries. In these areas, unplanned urbanization, coupled with deforestation of riparian forests and sewage discharges into rivers, creates an ideal scenario for flooding. Jonkman (2005) estimates that the contribution of river floods to the total number of killed and affected persons is dominated by episodes in Asia, compared to floods in the Americas and Europe. According to The International Disaster Database, however, Brazil is ranked highest, along with the United States, in terms of flood disasters among American countries, justifying attention to the study of behavioral patterns related to flood preparedness in the country (EM-DAT/OFDA-CRED, 2014).

Although many studies on flood consequences focus on coastal areas, river floods can be as or even more impacting when they reach intensively urbanized areas. Risks of waterborne diseases are commonly reported after main river floods, especially in areas where untreated sewage is discharged along with unprocessed garbage directly into the river (Ohl and Tapsell, 2000; Prüss et al., 2002; Morua et al., 2011). Despite material and human impacts of floods, preparedness behavior to flood hazard is generally low (Terpstra, 2011). Evidence about adoption of flood preparations is mostly available for developed countries (Thieken et al., 2007; Miceli et al., 2008; Terpstra and Gutteling, 2008; Terpstra, 2010; Kreibich et al., 2011; Scolobig et al., 2012; Terpstra and Lindell, 2013), although many urban areas in the tropical zone are under flood risk. This study aims to model and measure preparedness behavioral intention to flood hazards.

We develop a theoretical framework based on a model of private insurance (Mas-Colell et al., 1995). As will be seen, our model establishes conditions on the magnitude of risk aversion that characterizes the influence of uncertainty parameters for price and resource effectiveness on insurance demand. Results are contingent on the level of risk aversion. For low levels of risk aversion, the demand for insurance declines with increased uncertainty on price and raises with higher expected insurance effectiveness. When risk aversion is high, an increase in insurance effectiveness leads to a decline in insurance demand, since the decision maker insures completely. The opposite holds for an increase in price uncertainty. Increased demand for insurance due to higher expected prices holds because of an increase in decision maker's relative deprivation. Finally, we establish conditions on the primitives of the model to prove that the growth rate of insurance demand in relation to the parameter of insurance effectiveness is larger than the growth rate for insurance effective price in absolute value. This result holds only for low levels of risk aversion relative to the nominal insurance payment.

We apply the Protective Action Decision Model (PADM) proposed by Lindell and Perry (2012) to a new probabilistic sample of 1,200 urban households in the municipality of Governador Valadares, Brazil. The site was chosen because river floods are recurrent in the region, reaching thousands of households along the river (IGAM, 2010). The urban environment of Governador Valadares has undergone dramatic change in the last decades, creating an ideal scenario for flooding: deforestation of the riparian forest, river silting, unplanned occupation of riverbanks, and garbage and sewage discharge into the river (Coelho, 2011). Our empirical data on PADM will provide the first population-based estimate of people's intention to prepare for floods in a Brazilian setting where risk is real and recurrent.

In the next section we review the literature on behavioral models applied to natural hazards. These models will provide the basis for situating our theoretical framework developed. We then advance by establishing the specification of our empirical model. This section is divided into Data, instrument validation, and econometric model specification. We end the section providing a method for transforming categorical ordinal variables into continuous variables by applying the Probability Integral Transform Theorem (Angus, 1994). Results are presented and discussed in the following section. We conclude the paper by situating our findings in the literature on risky behavior and environmental hazards, and their likely policy implications for flood risk management.

2 The Theoretical Model

We consider a model based on private insurance choices. For the sake of parsimony, we focus on two features of the PADM: the uncertainty in the effectiveness and the uncertainty in the opportunity cost of insurance acquisition. We show that the influence of uncertainty on the effectiveness of insurance acquisition dominates the effect of uncertainty in the opportunity cost for a generic agent. This result holds under certain conditions on the absolute and relative risk aversion. Our theoretical model allows us to make inference about the direction of changes in preventive measures choices as a function of the error in expectations about the cost and effectiveness. Moreover, these findings are key for the promotion of public policies aimed to foster preventive measures in settings under risk of natural hazards[1].

Assume a generic agent has a utility function $u : \mathbb{R}_+ \to \mathbb{R}_+$ representing the consumption benefit. Agents' endowment is denoted by w. We assume that u is twice differentiable with u' and u'' bounded. Moreover u' is bounded away from zero. A finite set S embodies all possible states of nature representing, in our case, flood intensity. We denote by $(\pi_s)_{s\in S}$ the objective probability distribution describing the probability law governing the states of nature. We assume that agents run a risk of a gross loss l_s in each state $s \in S$ and that an insurance is available for transferring wealth between states of nature. This insurance has a price $p \in \mathbb{R}_+$ representing the nominal costs. Agents are consider price takers, perceiving the opportunity costs as uncertain and, therefore, the effective price p. One unit of insurance offers a monetary amount t_s contingent on the realization of each state of nature s. We also assume that agents have uncertainty in effectiveness of the contingent transfers vector $(t_s)_{s\in S}$ made by the insurance.

Denote by $\epsilon := (\epsilon_p, \epsilon_t) \in E = [0, \epsilon_m] \times [0, \epsilon_m] \subset \mathbb{R}^2_+$ a realization of an underlying random variable describing agents' errors in insurance price and transfer respectively, with maximal value ϵ_m. We assume that this random variable is continuous with induced probability distribution represented by the parametrized family of probability densities $f : E \times B \to \mathbb{R}$ with $B \subset \mathbb{R}_+$ (Figure 1). The value $f(\epsilon, \beta)$ represents the probability density with variance $\sigma(\beta) = (\sigma_p(\beta), \sigma_t(\beta))$ evaluated on ϵ. In addition, we assume that $f = f_p f_t$ and $\epsilon_p \geq 1$ and $\epsilon_t \leq 1$, that is, ϵ_p and ϵ_t are independent. We also assume that $\lim_{\beta\to\infty} \sigma(\beta) = 0$. Intuitively, the assumption $\epsilon_p \geq 1$ means that agent's beliefs on the resource price can be higher than the nominal price announced due to his/her expectation

[1]The formalization of causality relations within an insurance model framework has the advantage of generating proofed theoretical predictions on core choice factors when individuals present some degree of uncertainty on insurance payment and costs, as implicitly suggested by PADM.

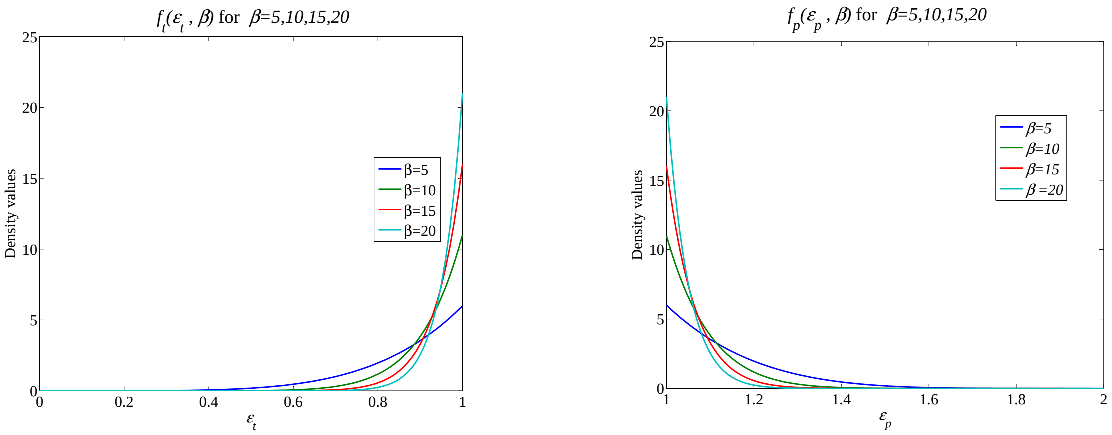

Figure 1: Parametrized Vector of ϵ for Price Error ϵ_p and Transfer Error ϵ_t

on how much time and effort, for instance, given in the model multiplicatively by $\epsilon_p p$, will take to manage the product to be bought. Assumption $\epsilon_t \leq 1$, by its turn, means that the generic agent is pessimistic on the protective resources, considering the advertised effectiveness of the resources equal or worse in practice, that is, $\epsilon_t t_s \leq t_s$ for all $s \in S$.

Each consumption choice is contingent upon the states of nature and the uncertainty profiles for price and transfer of the protective resource. We say a contingent consumption strategy $\{c_s\}_{s\in S}$ is feasible when there is a protective resource choice[2] $\theta(\epsilon) \in [0, 1]$ contingent upon price and transfer uncertainty $\epsilon = (\epsilon_p, \epsilon_t)$ satisfying

$$c_s(\epsilon) + p\epsilon_p\theta(\epsilon) \leq w - l_s + \theta(\epsilon)t_s\epsilon_t \text{ for all } \epsilon \in E \text{ and all } s \in S. \tag{1}$$

Agents' indirect utility function[3] is then given by

$$v(f) = \sup\left\{\sum_{s\in S}\pi_s \int_E u(c_s(\epsilon))f(\epsilon, \beta)d\epsilon\right\}$$

over all feasible $c_s : E \to \mathbb{R}_+$ and $\theta : E \to \mathbb{R}_+$.

Function $v(f)$ represents the optimal expected value for the benefit evaluated over all feasible consumption choices.

Remark 2.1. Observe that in states $s' \in S$ for which there is no loss, $l_{s'} = t_{s'} = 0$.

In the case of an interior solution, Equation (1) becomes

$$c_s(\epsilon) = (t_s\epsilon_t - p\epsilon_p)\theta(\epsilon) + w - l_s \text{ for all } (s, \epsilon) \in S \times E \tag{2}$$

therefore,

$$v(f) = \sup\left\{\sum_{s\in S}\pi_s \int_E u((t_s\epsilon_t - p\epsilon_p)\theta(\epsilon) + w - l_s)f(\epsilon, \beta)d\epsilon\right\} \tag{3}$$

over all measurable $\theta : E \to \mathbb{R}_+$ such that $(t_s\epsilon_t - p\epsilon_p)\theta(\epsilon) + w - l_s \geq 0$ for all $(s, \epsilon) \in S \times E$. The concavity of u and the interior solution assure that the F.O.C. is a sufficient condition for the optimality. Write

$$\hat{v}(\theta) = \sum_{s\in S}\pi_s \int_E u((t_s\epsilon_t - p\epsilon_p)\theta(\epsilon) + w - l_s)f(\epsilon, \beta)d\epsilon.$$

[2]We assume that θ is the fraction of total resources available for protection and the price p is given per unit of this fraction.

[3]That is, the utility evaluated at the optimal consumption level.

If $\tilde{\theta}(\,\cdot\,)$ is an interior solution of (3) then[4] $\lim_{\tau\to 0^+}(\hat{v}(\tilde{\theta}+\tau h)-\hat{v}(\tilde{\theta}))/\tau \le 0$ for each $h: E \to \mathbb{R}$. Define $g(\tau)=\hat{v}(\tilde{\theta}+\tau h)$. Then this is the same to state that $g'(0)\le 0$. Therefore the F.O.C. evaluated at the optimal insurance choice $\tilde{\theta}(\epsilon)$ satisfies

$$\int_E \left(\sum_{s\in S}\pi_s(t_s\epsilon_t - p\epsilon_p)u'((t_s\epsilon_t - p\epsilon_p)\tilde{\theta}(\epsilon)+w-l_s)\right)h(\epsilon)f(\epsilon,\beta)d\epsilon \le 0$$

and hence, choosing

$$h(\epsilon)=\sum_{s\in S}\pi_s(t_s\epsilon_t - p\epsilon_p)u'((t_s\epsilon_t - p\epsilon_p)\tilde{\theta}(\epsilon)+w-l_s) \text{ for all } \epsilon\in E$$

then we conclude that

$$\sum_{s\in S}\pi_s(t_s\epsilon_t - p\epsilon_p)u'((t_s\epsilon_t - p\epsilon_p)\tilde{\theta}(\epsilon)+w-l_s)=0 \text{ for all } \epsilon\in E. \tag{4}$$

Theorem 2.2. *Consider the Arrow-Pratt (Pratt, 1964) measure of absolute and relative risk-aversion given by* $\tilde{a}(c)=-u''(c)/u'(c)$ *and* $\tilde{a}_r(c)=-cu''(c)/u'(c)$ *respectively. Define* $||\tilde{a}||=\max\{\tilde{a}(c): c\in\mathbb{R}_{++}\}$ *and* $||l||=\max\{l_s: s\in S\}$*. Assuming that* $\tilde{\theta}$ *is interior and differentiable, then*

$$||\tilde{a}||\cdot||l||+||\tilde{a}_r||<1 \textit{ implies that } \partial_{\epsilon_p}\tilde{\theta}(\epsilon)<0 \textit{ and } \partial_{\epsilon_t}\tilde{\theta}(\epsilon)>0 \textit{ for all } \epsilon>0.$$

Proof: See appendix. □

Remark 2.3. Since $\tilde{\theta}$ is increasing in ϵ_t, and $f_t(\epsilon_t,\beta)$ yields higher probability mass close to 1 when β increases, then the expected value $\int_{\mathbb{R}_+}\tilde{\theta}(\epsilon_p,\epsilon_t)f_t(\epsilon_t,\beta)d\epsilon_t$ increases when β increases by Lemma 6.3 in the appendix. Furthermore, $\tilde{\theta}$ is decreasing in ϵ_p and $f_p(\epsilon_p,\beta)$ yields higher probability mass close to one when β increases implies that the expected value $\int_{\mathbb{R}_+}\tilde{\theta}(\epsilon_p,\epsilon_t)f_p(\epsilon_p,\beta)d\epsilon_p$ increases when β increases.

Observe that $|\partial_{\epsilon_t}\tilde{\theta}(\epsilon)|$ represents the magnitude of the rate of increase in the intention to take a protective action as a function of the error ϵ_p from the antecipation of the total cost, p. Furthermore, $|\partial_{\epsilon_t}\tilde{\theta}(\epsilon)|$ represents the magnitude of the rate of increase in the intention to take a protective action as a function of the error ϵ_t from the antecipation of the insurance transfer, t. The next result establishes a relation between $|\partial_{\epsilon_p}\tilde{\theta}(\epsilon)|$ and $|\partial_{\epsilon_t}\tilde{\theta}(\epsilon)|$.

Theorem 2.4. *Define* $\hat{\gamma}(c,s)=u'(c)\pi_s((w-l_s)\tilde{a}(c)-\tilde{a}_r(c)+1)$ *and* $\hat{\pi}(c,s)=\hat{\gamma}(c,s)/\sum_{s\in S}\hat{\gamma}(c,s)$ *for all* $s\in S$*. Assume that* $||\tilde{a}||\cdot||l||+||\tilde{a}_r||<1$*. Then*

$$p<\sum_{s\in S}\hat{\pi}(\tilde{c}_s(\epsilon),s)t_s \textit{ implies that } |\partial_{\epsilon_t}\tilde{\theta}(\epsilon)|>|\partial_{\epsilon_p}\tilde{\theta}(\epsilon)|.$$

where $\tilde{\theta}(\epsilon)$ *is the optimal insurance choice.*

Proof: See appendix. □

[4]This is the Gâteaux concept of derivative.

Corollary 2.5. *Assume that* $||\tilde{a}|| \cdot ||l|| + ||\tilde{a}_r|| < 1$. *Consider* $n_u = \inf\{u'(c) : c \in \mathbb{R}_{++}\}$, $n_a = \inf\{\tilde{a}(c) : c \in \mathbb{R}_{++}\}$, $N_a = \sup\{\tilde{a}(c) : c \in \mathbb{R}_{++}\}$ *and* $N_u = \sup\{u'(c) : c \in \mathbb{R}_{++}\}$. *Then*

$$p < \frac{n_u w n_a}{(N_a w + 1)N_u} \sum_{s \in S} \pi_s t_s \text{ implies that } |\partial_{\epsilon_t} \tilde{\theta}(\epsilon)| > |\partial_{\epsilon_p} \tilde{\theta}(\epsilon)|.$$

where $\tilde{\theta}(\epsilon)$ *is the optimal insurance choice.*

Proof: Under the assumption that $||\tilde{a}|| \cdot ||l|| + ||\tilde{a}_r|| < 1$ we can conclude that

$$\frac{n_u w n_a \pi_s}{(N_a w + 1)N_u} \leq \hat{\pi}(c, s)$$

for $\hat{\pi}(c, s) = \hat{\gamma}(c, s)/\sum_{s \in S} \hat{\gamma}(c, s)$ and $\hat{\gamma}(c, s) = u'(c)\pi_s((w - l_s)\tilde{a}(c) - \tilde{a}_r(c) + 1)$ for all $s \in S$. Indeed,

$$n_u w n_a \pi_s \leq \hat{\gamma}(c, s) \leq N_u \pi_s (N_a w + 1).$$

Thus $n_u w n_a \pi_s/(N_u(N_a w + 1)) \leq \hat{\gamma}(c, s)/\sum_{s \in S} \hat{\gamma}(c, s)$ and the conclusion comes directly from Theorem 2.4. □

3 Empirical model

Many psychological models of behavior have been established in the literature. Most of these models are general description of an individual decision-making, such as the Theory of Reasoned Action (TRA) (Fishbein and Ajzen, 2011), the Transtheoretical Model (TTM) (Prochaska, 2013), the Elaboration Likelihood Model (ELM) (Petty and Wegener, 1999), and the Precaution Adoption Process Model (PAPM) (Weinstein, 1988). The last two are typically applied to explain long-term health-related behavioral patterns. Two other behavioral models are more specific to preparedness behavior under risk exposure to natural hazards. These are the Protection Motivation Theory (PMT) (Rogers, 1975) and the Protective Action Decision Model (PADM) (Lindell and Perry, 2012). The PADM is the most appropriate framework to explain contingent actions related to threatening and imminent states of nature and to address agents' uncertainty on cost and effectiveness of protective resources.

The PADM "identifies a series of information-processing stages relevant to household adoption of protective actions and for each stage the typical activity performed, question asked, and outcome. The model is typically applied to situations in which emergency managers are transmitting information concurrently to large numbers of people who are responding to a single 'focusing event' rather than situations in which health professionals conduct personal interventions that are tailored to individuals in different stages of a behavioral change process." (Lindell and Perry, 2012: 624-625). The PADM has the advantage to model both short and long-term hazard adjustment. Because in this work we are modeling flood adjustment intentions in the long-run, PADM stands as an appropriate theoretical framework to select relevant variables for preparedness and establish main causality paths. As will be explained in the next subsections, we derived the variables used in our econometric model from the instrument shown in Terpstra and Lindell (2013) applied to a representative sample in Brazil.

3.1 Data

This study is based on novel survey data from a probabilistic sample of 1,200 households applied to urban residents of Governador Valadares, Brazil (see Figure 2). The survey is part of a FAPEMIG (Process # CSA - APQ-00244-12) and CNPq (Process # 483714/2012-7) funded research project entitled "Migração, Vulnerabilidade e Mudanças Ambientais no Vale do Rio Doce" (*Migration, Vulnerability, and Environmental Change in Vale do Rio Doce*). A minimum sample size was estimated based on known variances, proportions, and means for variables of interest from a survey previously conducted in another municipality of the Rio Doce macroregion (for details on the base survey, see Hora (2013)). This previous project has the same questionnaire as the one designed for the Governador Valadares survey, with the exception of the PADM and Flood Calendar modules. An error tolerance of 3%, a significance level of 5%, and correction for finite population were established (based on estimates for the total number of urban households and residents from IBGE projections). A minimum sample size of 1,069 was estimated. We decided to increase the minimum sample size to 1,200 to assure smaller variance for sample estimates.

Once sample size was estimated, we stratified the sample by age groups and sex to assure variance on the basic demographic characteristics affecting the main questions to be answered in the structured questionnaire (Groves et al., 2013). Age strata were defined as individuals from 18 to 39, 40 to 59, and 60 to 78 years old for each sex. We limited the lower age limit to 18 based on survey methodology studies that suggest 18 as a reasonably age for intensively cognitive and choice questions (Bradburn et al., 2004). Upper age limit was set to the estimated life expectancy at birth for women in Brazil. The upper limit is also justifiable since cognitively demanding questions applied to very old interviewees produce responses with more measurement errors (Schwarz and Oyserman, 2001). We allocated the estimated sample size to each city neighborhood proportional to size. Then, the estimated neighborhood sample was distributed according to the proportion to be assign to each age/sex stratum. The strata allocation per neighborhood produced some strata with very few cases; clusters of neighborhoods were then created to assure minimum number of interviews per stratum within the cluster. Decisions to cluster neighborhoods were based on spatial contiguity and socioeconomic classification of the neighborhood provided by the City Hall Office of Geo-technology. Within each cluster stratum, units were randomly assigned. The complex survey design produces unequal probability of selection for sampled units. Sampling weights were calculated to account for cluster and stratification design effects in final estimates and analysis.

3.2 PADM - Construct validity

The PADM instrument applied in the questionnaire was based on the instrument proposed by Terpstra and Lindell (2013). The module corresponds to questions on hazard and resource related attributes, attribute importance, and adoption intentions in relation to six different flood hazard adjustments: (1) an emergency kit (food, water, battery power radio and light, etc.); (2) information about flood consequences; (3) a list defining a household emergency plan in case of need to evacuate the property; (4) agreements with close network members about mutual help in case of evacuation or during a flood episode; (5) assembling of sandbags or flood skirts; and (6) health and/or life insurance. There are also two questions related to perception of flood likelihood and flood consequences. As in Terpstra and Lindell (2013), all questions were performed on 5-point Likert-type scales,

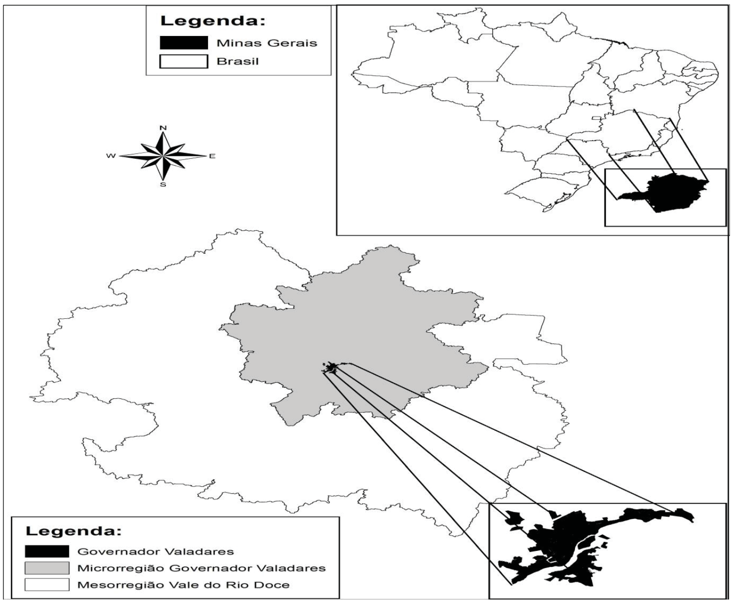

Figure 2: Study Area in Governador Valadares, Minas Gerais, Brazil

except for attribute importance. For the latter, respondents were asked to check as many as they considered to be the most important when deciding which protective actions to take.

To assess PADM's construct validity, we followed four methodological steps (Terpstra and Lindell, 2013):

1. Calculate the Cronbach alpha for the variables related to flood consequences in order to test internal scale consistency.

   The alpha value ($\alpha = 0.80$) suggests that correlation of flood consequences on different dimensions is high, yielding high internal consistency for the additive scale generated. After calculating alpha, a flood consequence weighted measure of risk perception was estimated by multiplying the mean of the four items on flood consequences by the perceived likelihood. The generated scale range from 1 (very low risk) to 25 (very high risk), with average of 7.97 and standard deviation of 6.69.

2. Test if distribution of scale ratings for each HRA is significantly different from a uniform distribution;

   This test determines if HRA responses were given in a non-randomly fashion. For this, we compute $\chi^2_{K-1} = (K-1)s^2_X/\sigma^2_{EU}$, where K is the number of raters, s^2_X is the observed variance in the responses on a specific rating dimension and σ^2_{EU} the variance of a uniform distribution[5]. Rejection of the null hypothesis supports non-random responses to attribute effectiveness. Except for information about flood consequences and agreements with close network members about mutual help, the null hypothesis was rejected at 5% for all HRA on the remaining four protective actions.

   Inter-rater agreement in the ratings of each hazard adjustment on each attribute can be measured by $r_{WG} = 1 - s^2X/\sigma^2_{EU}$. According to James et al. (1993),

[5] For any discrete uniform distribution $U[1, c]$, the variance $\sigma^2_{EU} = (c^2 - 1)/12$. In the case of a 5-point scale, $\sigma^2_{EU} = 2$.

$-1 \leq r_{WG} \leq +1$. When there is complete agreement (zero variance), $r_{WG} = 1$; when bipolar response is observed (complete disagreement), $r_{WG} = -1$. Inter-rater agreement varied between average values of 0.45 to 0.69, signalizing a pattern of response consistency, since there is considerable agreement among raters. The average values for inter-rater agreement were $r_{WG}^{HRA} = 0.64$, $r_{WG}^{RRA} = 0.57$ and $r_{WG}^{AI} = 0.45$ for hazard-related attributes, resource related attributes, and adoption intentions respectively.

3. Test if the mean ratings for each of the HRA is significantly different from the scale midpoint;

   Even with evidence of non-randomness in response to scales, response meaningfulness can be accessed by comparing mean differences between average scale ratings and the scale mid-point. Since each scale is formed by 5 points, with the central value representing somehow an indifferent position, a one-sample mean-comparison test for average scale rating, $H_0 : r_X = 3$, can provide statistical evidence on this direction. Among the 54 scales (9 for each of the six protective action), 46 were significantly different from the scale mid-point at 5% of significance. This is a strong evidence against the *central tendency error*, which reflects the tendency of respondents to rate more frequently the scale mid-point (indifferent category) when they feel they don't have sufficient information to position in favor or against a statement or object (Wayne and Aguinis, 2005).

4. Test if the three HRA scales load in a different dimension of the five RRA scales in a two-factor model.

   According to Lindell and Perry (2012), HRA and RRA should be two different dimensions of the psychological component related to decision-making. Our own theoretical framework also assumes uncertainty on attribute price (opportunity costs) and transfer (effectiveness), as we denote $\epsilon := (\epsilon_p, \epsilon_t) \in E \subset \mathbb{R}_+^2$. Thus, the three items representing hazard-related attributes (protection to property, protection to persons, utility for other purposes) should load on a different factor from resource-related attributes (costs, time, effort, knowledge and skill, cooperation). According to a 2-factor model with varimax rotation and Kaiser normalization (Kaiser rule: eigenvalue$\geq$ 1), the two factors explained 71.2 of items variance, with the three HRA loading on rotated factor 1 and the five RRA loading on rotated factor 2, as predicted by the theoretical models (see Figure 3).

Since all methodological conditions applied to test construct validity of the PADM instrument were successfully met, we believe PADM is a very solid instrument to be applied in different contexts and to different hazards. Previous studies successfully applied the measurement model to countries with high levels of development (Kreibich et al., 2011; Terpstra and Lindell, 2013) and different hazards such as ocean floods (Terpstra and Lindell, 2013) and earthquakes (Lindell et al., 2009).

3.3 Methods

3.3.1 Seemingly Unrelated Regressions

Since the PADM module has 6 different protective actions and 8 related attributes to each action, HRA and RRA effects on the probability of taking each protective action should

Dimension	Item	Factor 1	Factor 2	Uniqueness
Hazard-related attribute	Protect property	0.1066	**0.8385**	0.2856
	Protect persons	0.0666	**0.8677**	0.2427
	Other uses	0.1891	**0.7978**	0.3278
Resource-related attribute	Costs	**0.8149**	0.1221	0.321
	Time	**0.8549**	0.0407	0.2675
	Effort	**0.8869**	0.115	0.2002
	Knowledge and skill	**0.8821**	0.0928	0.2133
	Cooperation	**0.6924**	0.2748	0.4451
Explained variance [%]		43.6	27.6	

Factor extraction: Exploratory Factor Analysis
Factor rotation: Varimax with Kaiser Normalization.
Factor loadings over 0.4 highlighted in bold.

Figure 3: Factor analysis for Hazard and Resource Related Attributes Dimensionality

be modeled within a system of equations econometric framework. In this paper, each person, of n, answer a set of g dependent variables and k_i regressors. As it can be seen in the theoretical approach, personal risk aversion is correlated with the probability of acquiring prevention resources. It was not possible to obtain a variable representing risk aversion and no proxy/instrument was used representing this variable. Furthermore, other psychological characteristics that affect decisions on risk (eg, experiences with past events) are not directly controlled in the model. Therefore, it is natural to assume a correlation structure between the set of dependent variables, since the questions are answered by the same person in the household. This correlation structure will be addressed through the use of a Seemingly Unrelated Regression model (see Zellner (1962)), SUR system for short.

Let y_i denote de n-vector of observations on the i^{th} dependent variable, X_i denote the $n \times k_i$ matrix of regressors for the ith equation, β_i denote the $k_i - vector$ of parameters, and u_i denote the n-vector of error terms. The ith SUR model with g dependent variables, can be written as:

$$\begin{aligned} y_i &= X_i \beta_i + u_i, \; E\left(u_i u_i^\top\right) = \sigma_{ii} I_n, \\ E\left(u_{ti} u_{tj}\right) &= \sigma_{ij} \text{ for all } t \text{ and } E\left(u_{ti} u_{sj}\right) = 0 \text{ for all } t \neq s \end{aligned}$$

where I_n is the $n \times n$ identity matrix, σ_{ij} is the ij^{th} element of the $g \times g$ positive definite matrix Σ. With the conditions above, the SUR system allows u_{ti}, the error term for observation t of equation i, should be correlated with u_{tj}, the error term for observation t of equation j.

The estimation of β_i by ols yields consistent, but inefficient results, along with g vectors of least-squares residuals $\hat{u}_i$. The natural estimator of Σ is given by:

$$\hat{\Sigma} \equiv \frac{1}{n} \hat{U}^\top \hat{U}$$

where $\hat{U}$ is an $n \times g$ matrix with i^{th} column $\hat{u}_i$. The feasible GLS estimator is given by: $\hat{\beta} = (X^\top (\hat{\Sigma}^{-1} \otimes I_n) X)^{-1} X^\top (\hat{\Sigma}^{-1} \otimes I_n) y$ and $\widehat{var}(\hat{\beta}) = (X^\top (\hat{\Sigma}^{-1} \otimes I_n) X)^{-1}$ where the symbol $\otimes$ indicates the Kronecker product (for more details, see Davidson and MacKinnon (2004)).

3.3.2 Transforming Ordinal into Continuous Variables

As discussed in the PADM validity section, most of the variables were performed on Likert-type scales, yielding categorical ordinal variables. Because we are using an econometric model based on a system of linear equations, ordinal variables would be a poor approximation for linear regression assumptions that depend on continuous distributions. To transform these ordinal into continuous variables, preserving the same cumulative probability distribution, we use the Probability Integral Transform Theorem (Angus, 1994).

Given a latent continuous random variable X with its cumulative strictly increasing distribution function F_X, the Probability Integral Transform Theorem states that the variable $Y = F_X(X)$ follows a $U[0,1]$ distribution. The observable variable $\widetilde{X}$ is discrete and we aim to simulate a sample of X using an observable sample of $\widetilde{X}$. Therefore, generating an i.i.d. sample $\{y_n\}_{n \leq N}$ of Y and calculating $x_n = F_X^{-1}(y_n)$, we obtain a sample $\{x_n\}_{n \leq N}$ of a random variable with the same distribution of X.

The variables related to the Protective Action Decision Model instrument as well as informants' income were continuously approximated by means of a common simulated uniform distribution. Intuitively, we are assuring that observed variables that are highly correlated retain the same degree of correlation in their simulated form. The new continuous variables were applied to a Seemingly Unrelated Regression model, and then compared to Generalized Ordinal Regression model using the observed ordinal variables. Figure 4 shows the very close fit of simulated and original cumulative distributions for selected variables used in our regression analysis.

4 Results

4.1 Exploratory Analysis

As discussed by Lindell et al. (2009) and Terpstra and Lindell (2013), questions on adoption intention to flood hazard adjustments can yield poor information, leading to inferential bias in the translation of respondents' answers to respondents' characteristics (Groves et al., 2013). Thus, construct validity is a necessary condition to evaluate quality of response patterns obtained from any complex, non-intuitive, or not usual construct. According to the four criteria presented in the PADM Construct Validation section, response patterns and interpretations were consistently given by respondents (raters), validating the use of the PADM instrument in our context. We saw that (1) an scale generated by means of the four questions on perceived consequences of floods has high internal consistency ($\alpha = 0.80$). (2) Ratings to each of the hazard and resource related attributes were given in a non-random fashion, with relative high levels of inter-rater agreement; the same holds for preparedness intentions. (3) Respondents also seem to use perceived values and previous information to position in regards to each of the attributes, since for 85% of scale items average rates differ statistically from the scale mid-point. (4) Finally, as expected by the PADM and our own theoretical model, HRA should load in a different factor from RRA, representing two different and independent dimensions. This is a very important aspect of the attribute vector, since we assume $f = f_p f_t$, that is, ϵ_p and ϵ_t are independent. The independence of ϵ_p and ϵ_t is also important for regression purposes, since it reduces the likelihood of multicollinearity[6].

[6] We also estimated the correlation matrix for the continuously simulated HRA and RRA, as well as the variance inflation factor after regressions. No formal evidence of high collinearity was found.

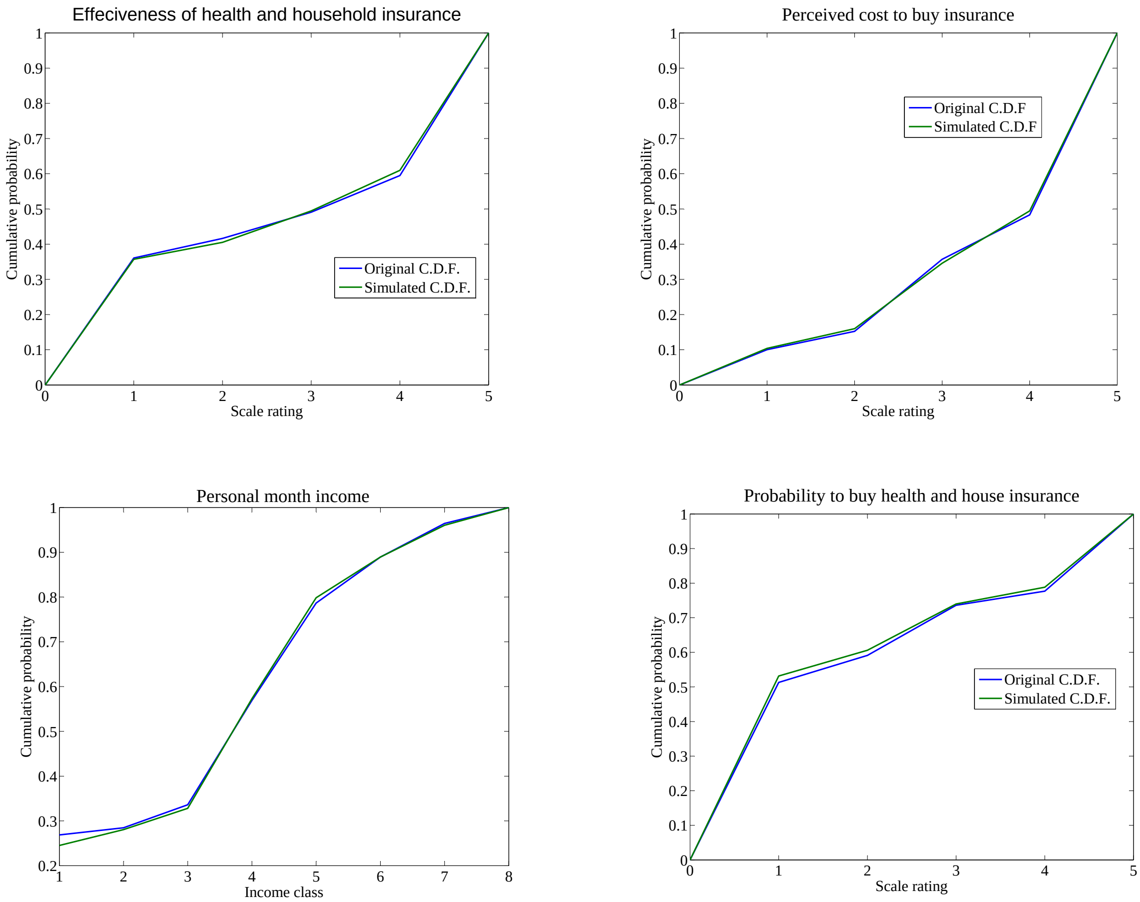

Figure 4: Cumulative Probability Distribution for Original and Simulated Selected Variables

	Emergency kit		Emergency information		Household plan		Family agreements		Sandbags and flood skirts		Insurance		Attribute Importance[b]	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Core PADM variables														
Adoption intention	2.78	1.71	3.94	1.44	2.88	1.68	3.78	1.54	2.04	1.47	2.37	1.63	-	-
Protect persons	3.15	1.72	4.35	1.19	3.47	1.67	4.35	1.19	2.20	1.51	3.14	1.79	0.90	0.30
Protect property	2.45	1.59	4.17	1.28	3.28	1.64	4.07	1.34	2.10	1.43	3.54	1.66	0.85	0.35
Other uses	3.12	1.54	3.80	1.46	3.28	1.61	3.89	1.42	1.88	1.39	3.40	1.64	0.71	0.45
Cost	3.00	1.39	1.78	1.19	1.97	1.32	1.89	1.30	2.91	1.52	3.90	1.35	0.22	0.41
Time	2.49	1.41	2.20	1.36	2.62	1.43	2.38	1.46	3.55	1.58	2.68	1.47	0.22[a]	0.41
Effort	2.58	1.53	2.27	1.43	2.64	1.55	2.32	1.49	3.68	1.57	2.93	1.57	-	-
Knowledge and skill	2.66	1.49	2.16	1.39	2.37	1.41	2.21	1.44	3.33	1.63	2.93	1.61	0.24	0.43
Cooperation	2.78	1.64	3.11	1.68	2.81	1.64	3.73	1.58	3.64	1.60	2.62	1.60	0.23	0.42
Control Variables														
Male	0.39	0.49												
Age	43.13	17.05												
Income	3.99	2.16												
Risk perception	8.02	6.70												
Near distance to river	2004.18	1002.22												

Observations: 300 (sample) - 37,335 (population)
Note a: Question was asked for time and effort as a single question.
Note b: Proportion of respondents who selected attributes as "most important" when preparing for floods.
Source: GV Survey Data, 2014

Figure 5: Descriptive statistics on core PADM variables and control variables - Governador Valadares, Brazil - 2014

Figure 5 shows means and standard deviations for core PADM variables and other control variables. Sampled population is 39% male, with mean age of 43.13 years. Average household income is 2-3 Brazilian minimum salaries (around US$600.00-900.00). On a scale from 1 to 25, average risk perception is considerably low (8.02). Households are located approximately 2km far from the river, on average. Compared to the descriptive findings reported in Terpstra and Lindell (2013), our statistics have very similar patterns, with small differences in mean level for core variables. On average, adoption intention is rated as below the scale midpoint, except for emergency information and family agreements. These two protective actions reflect the importance of family and social networks in the process of protective behavior under flood hazards among Governador Valadares citizens. All actions were considered effective to protect persons and properties, except for sandbags and flood skirts. They are also considered useful for other purposes beyond flood protection, except for insurance. Thus, in general all hazard related attributes are considered highly effective in protecting individuals from flood hazards in the city. Attribute importance for hazard-related attribute is also very high; between 0.71 and 0.90 of individuals consider HRA as a very important protective action from floods. Also as predicted by our theoretical model, resource related attributes are ranked below the scale midpoint, except for sandbags and flood risks.

The theoretical PADM (Lindell and Perry, 2012) suggests that the effect of HRA and RRA on adoption intention is contingent upon attribute importance. Put it simply, an increase in resource effectiveness would increase the probability of adoption intention only among those considering that resource as important. Following Terpstra and Lindell (2013), we estimated the average scale rating for each of the seven attributes (three HRA and four RRA), as well as adoption intention for all six protactive actions. These averages where centered to 0 and scaled to 1 standard deviation. We then performed a weighted least square (WLS) regression of these 7 mean attribute standardized ratings and dummy variables for importance of each of the 7 attributes on non-standardized mean adoption intention rating. Since attribute importance is a Bernoulli variable, the interaction term would capture conditional effect of attribute importance. According to Figure 6, we found no evidence of conditional dependence, since all interaction terms between attribute and importance have $p \geq 0.05$. These results suggest attribute importance can be omitted from final econometric specification of our PADM regression models. Furthermore, the

Variable	Coefficient	p-value
Hazard-ralated attributes		
Protection to property	-0.032	[0.111]
Importance of protection to property	0.275	[0.207]
Interaction	0.308*	[0.126]
Protection to persons	0.084	[0.109]
Importance of protection to persons	0.135	[0.132]
Interaction	0.144	[0.123]
Utility for other purposes	0.274**	[0.085]
Importance of utility for other purposes	-0.084	[0.112]
Interaction	-0.051	[0.097]
Resource-ralated attributes		
Costs	0.019	[0.088]
Importance of costs	-0.120	[0.133]
Interaction	-0.177	[0.136]
Time and effort	0.077	[0.088]
Importance of time and effort	0.050	[0.168]
Interaction	-0.044	[0.180]
Knowledge and skill	0.046	[0.080]
Importance of knowledge and skill	0.132	[0.145]
Interaction	0.133	[0.164]
Cooperation	0.156*	[0.078]
Importance of cooperation	0.189	[0.145]
Interaction	-0.062	[0.137]
Constant	2.084**	[0.204]
Observations	268	
R-squared	0.4680	

Robust standard errors in brackets
** p<0.01, * p<0.05, + p<0.1
Source: GV Survey Data, 2014

Figure 6: Testing Conditional Effect of Hazard and Resource Related Attributes on Adoption Intentions by Attribute Importance

test of interaction performed is useful to justify the use of insurance models with rational agents, since an optimal null choice would not be rational if an insurance payment is positive.

4.2 Regression Analysis

We now turn to our regression results. Models here were estimated on a sub-sample corresponding to 25% of the 1,200 sampled households. Because we are interested in flood preparedness, we selected the sampled areas with real risks of floods, according to the Municipal Civil Defense inventory on city floods. We first provide inefficient estimates given by Ordinary Least Squares. As explained in the methodological section, OLS variance-covariance array for all 6 independent equations were used to estimate a weighting matrix in the Feasible Generalized Least Square estimates. These are more efficient parameter estimates than OLS. Test of independent equations was significant at 1% for all equations tested against the remaining others. Linear restriction tests for coefficients were based on unilateral hypothesis testing, since all predictions are established in our theoretical model.

Figure 7 confirms our model predictions. For most protective actions, hazard-related attributes are positive and statistically significant. Thus, an increase in perceived resource effectiveness increase the probability to take the protective action for all six resources. Significance holds for both, OLS and Feasible GLS estimates. Resource-related attributes were found not significant for most actions. Although expected effect is negative, under certain conditions on risk aversion the sign and significance can change. Since we did not control for risk aversion because there is no good proxy in the questionnaire, coefficient sign and significance for RRA yields inconclusive evidence. Risk perception, on the other hand, positively affects adoption intention as expected, except for insurance. Personal income is also positively associated with adoption intention for emergency kit, information seeking, and insurance (OLS estimates only).

In all, perceived risk of flooding, efficacy of hazard adjustments to protect people and

Variables	Emergency kit		Information seeking		Escape plan		Network agreements		Sandbags and flood skirts		Insurance	
	OLS	SUR	OLS	SUR	OLS	SUR	OLS	SUR	OLS	SUR	OLS	SUR
					Hazard-related attributes							
Protection to property	**0.233****	**0.218****	**0.235****	**0.200****	**0.256****	**0.190****	**0.329****	**0.245****	0.106	**0.160***	**0.215****	**0.189****
	[0.000]	[0.000]	[0.003]	[0.003]	[0.000]	[0.005]	[0.000]	[0.004]	[0.134]	[0.014]	[0.001]	[0.002]
Protection to persons	**0.093+**	0.071	**0.218****	**0.183****	0.031	0.056	-0.025	-0.019	0.128	0.071	**0.124+**	**0.096+**
	[0.094]	[0.136]	[0.005]	[0.005]	[0.340]	[0.220]	[0.369]	[0.407]	[0.109]	[0.174]	[0.067]	[0.100]
Utility for other purposes	**0.117+**	0.088	**0.138***	**0.113***	**0.288****	**0.213****	**0.217****	**0.205****	**0.351****	**0.279****	0.035	0.041
	[0.075]	[0.104]	[0.014]	[0.020]	[0.000]	[0.000]	[0.002]	[0.001]	[0.000]	[0.000]	[0.333]	[0.285]
					Resource-related attributes							
Costs	0.069	0.046	-0.026	-0.035	0.079	0.032	-0.055	0.003	-0.041	-0.067	0.049	0.039
	[0.214]	[0.284]	[0.385]	[0.326]	[0.160]	[0.316]	[0.268]	[0.484]	[0.279]	[0.128]	[0.283]	[0.314]
Time	0.050	0.067	0.007	-0.044	**-0.124+**	**-0.143***	0.034	-0.011	-0.046	-0.073	-0.082	**-0.105+**
	[0.284]	[0.192]	[0.469]	[0.293]	[0.077]	[0.020]	[0.349]	[0.441]	[0.291]	[0.138]	[0.188]	[0.090]
Effort	0.015	-0.042	**-0.132+**	-0.081	0.003	0.072	0.032	0.028	0.064	0.075	0.034	0.017
	[0.427]	[0.298]	[0.070]	[0.152]	[0.487]	[0.157]	[0.337]	[0.360]	[0.248]	[0.165]	[0.359]	[0.417]
Knowledge and skill	0.066	0.095	**0.138***	**0.113+**	0.052	0.037	-0.011	-0.069	0.006	-0.009	0.039	0.028
	[0.205]	[0.123]	[0.030]	[0.066]	[0.296]	[0.307]	[0.448]	[0.180]	[0.460]	[0.443]	[0.334]	[0.361]
Cooperation	**0.149***	**0.127***	0.030	0.033	**0.243****	**0.217****	0.046	0.025	**0.130***	0.084	0.061	0.059
	[0.027]	[0.028]	[0.293]	[0.255]	[0.000]	[0.000]	[0.233]	[0.330]	[0.022]	[0.102]	[0.210]	[0.188]
					Control variables							
Risk perception	**0.034***	**0.037****	**0.034***	**0.035****	0.011	0.013	0.012	0.014	0.001	0.003	**-0.030***	**-0.028***
	[0.014]	[0.007]	[0.011]	[0.004]	[0.206]	[0.161]	[0.190]	[0.159]	[0.481]	[0.413]	[0.032]	[0.039]
Personal monthly income	**0.128***	**0.110+**	**0.077+**	**0.080+**	0.029	0.022	0.031	0.027	0.024	0.019	**0.084+**	0.080
	[0.026]	[0.054]	[0.082]	[0.080]	[0.300]	[0.353]	[0.320]	[0.334]	[0.325]	[0.371]	[0.095]	[0.120]
Constant	-0.570	-0.203	0.562	0.935*	0.009	0.418	0.970*	1.500**	0.146	0.564+	0.298	0.601
	[0.121]	[0.344]	[0.148]	[0.023]	[0.490]	[0.148]	[0.037]	[0.002]	[0.346]	[0.084]	[0.256]	[0.117]
Observations	300	300	300	300	300	300	300	300	300	300	300	300
R-squared	0.2336	0.2273	0.1957	0.1903	0.3951	0.3796	0.1635	0.1522	0.2617	0.2472	0.1429	0.1387

Robust standard errors in brackets
** p<0.01, * p<0.05, + p<0.1
Source: GV Survey Data, 2014

Figure 7: Regression Results for the Protective Action Decision Model: OLS and Feasible GLS Estimates

the property, as well as usefulness of adjustments to other purposes increase the likelihood of preparedness intention. These hazard-related attributes were more important to explain intentions than resource-related attributes. Exploratory results on flood event calendar suggest that impacts on the daily lives of GV citizens are not very strong due to adaptation to floods and the effective role played by the Civil Defense police. These adaptations are predominantly related to temporary lodging by relatives and friends, as well as by second-floor construction. Construction costs are reduced by use of first-floor as small business during the dry season, justyfing the above-average ratings for the use of actions for other purposes.

5 Concluding Remarks

This paper performed an econometric analysis based on the Protective Action Decision Model (PADM) for Brazil. We empirically estimated preparedness determinants by using Seemingly Unrelated Regression models. PADM survey instrument validation was based on Cronbach alpha, factor analysis, and mean-comparison tests, rendering promising results in terms of construct validity.

The PADM was applied to a representative sample of 1,200 households in the municipality of Governador Valadares, State of Minas Gerais. The site was chosen because river floods are recurrent in the area, reaching thousands of households along the river. Its urban environment has undergone dramatic change in the last decades, creating an ideal scenario for flooding: riparian deforestation, river silting, unplanned occupation of riverbanks, and garbage and sewage discharge into the river. In addition to the econometric analysis, event calendar of major floods in the area, also collected in the survey, allows for comparison between intended and actual preparedness behavior.

Building on models of private insurance, we provide a theoretical framework stating that risk aversion is a key factor affecting the directions of influence given by the price and resource effectiveness on the probability of adopting preventive behavior. Thus, for a given nominal budget constraint an increase in insurance price could change one's risk aversion, leading to a higher propensity to buy insurance. We found that, under certain conditions on risk aversion, hazard-related attributes (HRA) positively affect propensity to take protective actions. This was confirmed by our regression results. In contrast, resource-related attributes (RRA) positively or do not affect propensity to adopt protective actions. This non-intuitive finding can be justified by our theoretical framework.

Finally, the impact of HRA was empirically higher than RRA on preventive behavior since the effective cost of preventive actions is low relative to a person's budget constraint. These findings suggest that public action should promote educational campaigns aiming the reduction of subjective uncertainty on resource effectiveness.

6 Appendix

Theorem 6.1. *Consider the Arrow-Pratt measure of absolute and relative risk-aversion given by* $\tilde{a}(c) = -u''(c)/u'(c)$ *and* $\tilde{a}_r(c) = -cu''(c)/u'(c)$ *respectively. Define* $||\tilde{a}|| = \max\{\tilde{a}(c) : c \in \mathbb{R}_{++}\}$ *and* $||l|| = \max\{l_s : s \in S\}$*. Assuming that* $\tilde{\theta}$ *is interior and differentiable, then*

$$||\tilde{a}|| \cdot ||l|| + ||\tilde{a}_r|| < 1 \text{ implies that } \partial_{\epsilon_p}\tilde{\theta}(\epsilon) < 0 \text{ and } \partial_{\epsilon_t}\tilde{\theta}(\epsilon) > 0 \text{ for all } \epsilon > 0.$$

Proof: Write $\nu_s = p\epsilon_p - t_s\epsilon_t$. Recall by (2) that $\tilde{c}_s(\epsilon) = -\nu_s\tilde{\theta}(\epsilon) + w - l_s$ for all $s \in S$. Therefore $\nu_s\tilde{\theta}(\epsilon) = w - l_s - \tilde{c}_s(\epsilon)$ and differentiating (4) with respect to ϵ_p then

$$\partial_{\epsilon_p}\tilde{\theta}(\epsilon)\sum_{s\in S}\pi_s\nu_s^2 u''(\tilde{c}_s(\epsilon)) = \sum_{s\in S}\Big(-\pi_s p\nu_s\tilde{\theta}(\epsilon)u''(\tilde{c}_s(\epsilon)) + \pi_s p u'(\tilde{c}_s(\epsilon))\Big) \tag{5}$$

$$= \sum_{s\in S}u'(\tilde{c}_s(\epsilon))\pi_s p\Big(\tilde{\theta}(\epsilon)\nu_s\tilde{a}(\tilde{c}_s(\epsilon)) + 1\Big) \tag{6}$$

$$= \sum_{s\in S}u'(\tilde{c}_s(\epsilon))\pi_s p\Big((w - l_s - \tilde{c}_s(\epsilon))\tilde{a}(\tilde{c}_s(\epsilon)) + 1\Big)$$

$$= \sum_{s\in S}u'(\tilde{c}_s(\epsilon))\pi_s p\Big((w - l_s)\tilde{a}(\tilde{c}_s(\epsilon)) - \tilde{a}_r(\tilde{c}_s(\epsilon)) + 1\Big)$$

This implies that $\partial_{\epsilon_p}\tilde{\theta}(\epsilon) < 0$. Indeed, by hypothesis $||\tilde{a}|| \cdot ||l|| + ||\tilde{a}_r|| < 1$.

Moreover, differentiating the integrand of (4) with respect to ϵ_t then

$$\partial_{\epsilon_t}\tilde{\theta}(\epsilon)\sum_{s\in S}\pi_s\nu_s^2 u''(\tilde{c}_s(\epsilon)) = \sum_{s\in S}\Big(\pi_s t_s\nu_s\tilde{\theta}(\epsilon)u''(\tilde{c}_s(\epsilon)) - \pi_s t_s u'(\tilde{c}_s(\epsilon))\Big) \tag{7}$$

$$= -\sum_{s\in S}u'(\tilde{c}_s(\epsilon))\pi_s t_s\Big(\tilde{\theta}(\epsilon)\nu_s\tilde{a}(\tilde{c}_s(\epsilon)) + 1\Big) \tag{8}$$

$$= \sum_{s\in S}u'(\tilde{c}_s(\epsilon))\pi_s t_s\Big((w - l_s - \tilde{c}_s(\epsilon))\tilde{a}(\tilde{c}_s(\epsilon)) + 1\Big)$$

$$= \sum_{s\in S}u'(\tilde{c}_s(\epsilon))\pi_s t_s\Big((w - l_s)\tilde{a}(\tilde{c}_s(\epsilon)) - \tilde{a}_r(\tilde{c}_s(\epsilon)) + 1\Big)$$

This implies that $\partial_{\epsilon_t}\tilde{\theta}(\epsilon) > 0$. □

Theorem 6.2. *Define* $\hat{\gamma}(c,s) = u'(c)\pi_s((w-l_s)\tilde{a}(c)-\tilde{a}_r(c)+1)$ *and* $\hat{\pi}(c,s) = \hat{\gamma}(c,s)/\sum_{s\in S}\hat{\gamma}(c,s)$ *for all* $s \in S$. *Assume that* $||\tilde{a}|| \cdot ||l|| + ||\tilde{a}_r|| < 1$. *Then*

$$p < \sum_{s\in S} \hat{\pi}(\tilde{c}_s(\epsilon), s) t_s \text{ implies that } |\partial_{\epsilon_t}\tilde{\theta}(\epsilon)| > |\partial_{\epsilon_p}\tilde{\theta}(\epsilon)|.$$

where $\tilde{\theta}(\epsilon)$ *is the optimal insurance choice.*

Proof: By equations (5) and (6) we conclude that

$$\partial_{\epsilon_p}\tilde{\theta}(\epsilon) \sum_{s\in S} \pi_s(t_s\epsilon_t - p\epsilon_p)^2 u''(\tilde{c}_s(\epsilon)) = p \sum_{s\in S} \hat{\gamma}(\tilde{c}_s(\epsilon), s)$$

and by equations (7) and (8) we conclude that

$$\partial_{\epsilon_t}\tilde{\theta}(\epsilon) \sum_{s\in S} \pi_s(t_s\epsilon_t - p\epsilon_p)^2 u''(\tilde{c}_s(\epsilon)) = \sum_{s\in S} \hat{\gamma}(\tilde{c}_s(\epsilon), s) t_s.$$

Therefore, $|\partial_{\epsilon_t}\tilde{\theta}(\epsilon)| > |\partial_{\epsilon_p}\tilde{\theta}(\epsilon)|$. □

Lemma 6.3. *Suppose that* $f, g : \mathbb{R} \to \mathbb{R}_+$ *are two probability density functions such that there exists* $\bar{x}$ *which* $f(x) \le g(x)$ *for* $x \le \bar{x}$ *and* $f(x) > g(x)$ *for* $x > \bar{x}$. *Then*

$$\int_{\mathbb{R}} h(x)f(x)dx \ge \int_{\mathbb{R}} g(x)f(x)dx \text{ for all non decreasing } h : \mathbb{R} \to \mathbb{R}_+.$$

Proof: Observe that $h(x) \ge h(\bar{x})$ for $x \ge \bar{x}$ and $h(x) \le h(\bar{x})$ for $x \le \bar{x}$. Therefore

$$\begin{aligned}
\int_{\mathbb{R}} h(x)(f(x)-g(x))dx &= \int_{-\infty}^{\bar{x}} h(x)(f(x)-g(x))dx + \int_{\bar{x}}^{\infty} h(x)(f(x)-g(x))dx \\
&= \int_{-\infty}^{\bar{x}} -h(x)(g(x)-f(x))dx + \int_{\bar{x}}^{\infty} h(x)(f(x)-g(x))dx \\
&\ge -h(\bar{x}) \int_{-\infty}^{\bar{x}} (g(x)-f(x))dx + h(\bar{x}) \int_{\bar{x}}^{\infty} (f(x)-g(x))dx \\
&= h(\bar{x}) \left(\int_{-\infty}^{\bar{x}} (f(x)-g(x))dx + \int_{\bar{x}}^{\infty} (f(x)-g(x))dx \right) \\
&= h(\bar{x}) \int_{\mathbb{R}} h(x)(f(x)-g(x))dx = 0
\end{aligned}$$

□

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