A serious gaming approach to understanding household flood risk mitigation decisions

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Abstract
Voluntary household decisions about whether or not to structurally mitigate or insure can directly and indirectly influence the flood vulnerability of a community. We look to understand the factors that influence flood risk mitigation decisions using a serious game experiment. Serious games can augment existing data collection methods used to understand flood risk mitigation by tracking decisions over multiple turns within an experimental research framework. In this game, participants choose where to live and how to distribute income given information about flood risks. We analysed data using a generalised linear mixed model that accounted for repeated-measures effects. Experiencing an in-game flood had a strong positive association with mitigation decisions, compared to a much weaker effect of a participant having experienced a flood in real-life. We find that real-life low-income individuals were no less likely to implement in-game mitigation measures than their higher-income counterparts, suggesting that low income and/or cost is a practical barrier to risk mitigation. Our findings also suggest that incentivising flood risk mitigation should be done quickly following a flood.

KEYWORDS
decision-making, flood risk mitigation, insurance, serious games

1 | INTRODUCTION AND BACKGROUND

Flooding is costly, dangerous, and projected to increase in severity and frequency in many parts of the world. Private households are bearing an increasing responsibility for flood risk management (FRM) (Brody, Lee, & Highfield, 2017) by investing in private mitigation measures—such as buying flood insurance and investing in floodproofing—that supplements public FRM (Babcicky & Seebauer, 2017). However, the often voluntary nature of private household mitigation measures presents challenges to increasing overall FRM. In particular, it is well understood that humans do not always make decisions as economically rational actors, and instead use various heuristics to ease the cognitive load of decision-making, which can sometimes result in maladaptation in a disaster risk context (Kunreuther & Meyer, 2013).

Understanding the process that goes into household flood mitigation decision-making may help improve the implementation of private FRM measures in spite of behavioural biases. Specifically, Brody, Lee, and Highfield (2017) suggest that the implementation of
mitigation measures by communities could be improved if the factors that trigger the adoption of mitigation measures are known. Considerable research has explored individual and social factors that influence various flood risk management decisions, including demographics (Atreya, Ferreira, & Michel-Kerjan, 2015), income and mitigation price (Browne & Hoyt, 2000; Kousky, 2010; Zhai, Sato, Fukuzono, Ikeda, & Yoshida, 2006), objective flood risk (Atreya et al., 2015), perceptions of flood risk (Botzen & Van Den Bergh, 2012; Petrolia, Landry, & Coble, 2013), flood awareness campaigns (Owusu, Wright, & Arthur, 2015) and concerns about community disruption (Thunberg & Shabman, 1991). In this study, we attempt to advance the understanding of private flood mitigation decisions by using a serious game experiment that records decisions of study participants. As far as the authors are aware, private flood risk management decisions have never been explored using a decision game experiment approach. Given the novelty of game experiments in FRM research, we discuss it in more detail in the following section.

1.1 Serious games in research

Serious games can be broadly defined as games used for a purpose other than purely entertainment (Susli, Johannesson, & Backlund, 2007; Wilkinson, 2016). Serious games have been used in operations research and management science (Kimbrough, Wu, & Zhong, 2002; Villalobos, 2007), marketing (Vos, 2015), health care and medicine (Wang, DeMaria Jr, Goldberg, & Katz, 2016), public policy (Mayer, 2009), environmental sustainability (Katsaliaki & Mustafee, 2015; Rumore, Schenk, & Susskind, 2016), and most often for training and education (Loh, Sheng, & Ifenthaler, 2015). Serious games can include: interactive simulation games that give players the opportunity to explore environments and learn (Ruohomäki, 1994); role-playing games in which players take on unfamiliar identities to understand problems in new ways (Yee & Bailenson, 2007); and persuasive games that target changes in real-world behaviour (Bogost, 2007).

Serious games have been used in applications related to natural hazards, including flooding. Khoury et al. (2018) used a computer-based 3D simulation game to enhance awareness of flooding and flood mitigation options among a mixture of stakeholders, and found some evidence that a game could help spread information into the community. Mossoux et al. (2016) used a board game to increase awareness of geohazards among a breadth of participants, and found evidence that awareness of and attitudes towards hazards changed following gameplay. Games have been used to assist students in specific learning objectives; for example, Taillandier and Adam (2018) used a simulation game to educate engineering students about the concepts of coastal flood risk management. In a study of university students, Breuer, Sewilam, Nacken, and Pyka (2017) found that a computer-based flood management game could be used to increase flood risk awareness, particularly among non-experts. Other games have targeted expert users and decision-makers; for example, Becu et al. (2017) used a simulation game to enhance coordination awareness between decision-makers in a coastal flood management context. Games have also been used to explore water management issues beyond education and training. This includes games that explore competition over water access (Broadbent, Brookshire, Coursey, & Tidwell, 2014), the impact of market mechanisms on water resource management (Broadbent, Brookshire, Coursey, & Tidwell, 2017) and games that attempt to understand the dynamics of collaboration and cooperation on resource management decisions (Jean et al., 2018).

However, most flooding-related games are either educational or focus on strategic conflicts of water resource management; to date, few games have been used as experimental tools to understand individual flood risk management decision-making. Using games as an experimental tool has several advantages. Games can be used to simulate the experience of events that would otherwise be prohibitive to study in the real world due to time, cost, or safety concerns (van den Berg, Voordijk, Adriaanse, & Hartmann, 2017). The experience of floods within a gaming environment—with tangible consequences on player resources in the game—may be more meaningful than what can be achieved with a survey of stated preferences in response to purely hypothetical scenarios. Games can include the simulation of environments familiar to subjects, require little supervision, and have a low participant workload (Rosetti, Gomez-Tello, Victoria, & Apiquian, 2017). These benefits suggest that a game experience may offer useful new insights into the study of human decision-making, particularly related to rare events. Digital games in particular have the advantage of being able to track participant decisions made throughout the process (van den Berg et al., 2017), allowing for subsequent statistical investigation of those decisions.

The use of games as instruments for collecting data does suppose a level of player engagement that will result in realistic decision-making. If players do not take the game experience seriously, then the value of the data generated in the experiment is limited. However, this is true of most methods of collecting experimental or survey data from human subjects. Choice experiments are widely used in psychology and economics and have led to
breakthrough ideas, such as prospect theory (Kahneman & Tversky, 1979) and the endowment effect (Thaler, 1980). In typical choice experiments, subjects are told to express preferences across a mix of payoffs (hypothetical or real), often in a laboratory setting, and there remains considerable debate over whether these experimental conditions are sufficient to match real-world decision-making (Levitt & List, 2007). Similar questions should be asked in the experimental application of games; however, it is worth noting that games can be developed in a way that triggers sensory and cognitive engagement and intrinsic motivation that is not typical of laboratory experiments. While applications of enriched games as experimental instruments are relatively new, there is already evidence that engaging games can motivate a “Proteus effect,” where players immerse themselves into a game role (Yee & Bailenson, 2007) that could even have impacts on behaviour and decision-making outside a game (Yee, Bailenson, & Ducheneaut, 2009). There is also evidence that increased experimental realism corresponds to a greater agreement between experimental scenarios and the real world (de Kort, Ijsselsteijn, Kooijman, & Schuurmans, 2003; de Kort, Meijnders, Sponselee, & Ijsselsteijn, 2006).

In this study, we use a game experiment to understand key factors that influence decisions to invest in structural household-level flood risk mitigation or to purchase flood insurance. The subject matter in this study has been explored before; our primary contribution is to explore this question using a new methodology. In this game, players take on the role of homeowners and must decide on a mix of potential decision options, including flood risk management. This breadth of choice options is an important feature of the game since players are not primed with information about flood risk and are not self-selected into the study based on their interests in flood risk. For this reason, participant responses may be less affected by response and selection biases and the findings could usefully augment existing research on understanding flood risk management decisions.

2 | MATERIALS AND METHODS

2.1 | Recruitment

Participants in this study were recruited using online and in-person methods. In-person recruitment was performed at seven coffee shops and two community centres in Calgary, Alberta. The in-person response rate was not recorded but was estimated to be about one in ten agreeing to participate. Online participants were recruited using business cards, posters and social media (Facebook and Twitter). In addition, two environmental groups agreed to include a recruitment paragraph in their email newsletters. All participants visited a webpage that directed them to the pre-game survey. In total, 123 participants completed the game and accompanying survey on a computer or other Internet-enabled device.

2.2 | The decision game

To address the research question, we developed a web-based game experiment (referred to as the “Decision Game”) in 2017 to gather data about flood risk mitigation decisions with the ultimate goal of understanding the decisions to purchase flood insurance or structural mitigation measures. The game was an Internet browser-based scenario that put participants in the role of a homeowner tasked with deciding where to live and how to spend income. As a decision-based game, the primary player activity involves making decisions in response to information presented. These decisions were made by clicking options presented on the screen. An overview of the game’s operation can be seen in Figure 1, which shows the flow of player decision-making from left to right. For each game turn, participants make decisions in two stages. In Stage 1, participants are presented with an interactive map that can be used to gather information about the city, including information about crime levels, walkability, property costs, school accessibility and flood risk. Once they make a decision about place of residence, they progress to Stage 2, where they make decisions about levels of household spending. Decisions are made by moving slide bars to the left or right, which indicate the amount of income spent on that particular good or service. Players receive qualitative feedback (in the form of emojis) on their spending levels are very low for key household items (such as food). When participants complete a turn, they progress to Stage 3, where they see the results of decisions, as well as game events. The game events are the experimental treatments and include a drop in income, an increase in income, and a flood event.

At the outset of the game, all participants were told they would be participating in a household decision-making game in which they would have to make decisions about where to live and how to spend income. No specific reference was made to flooding or other environmental hazards at any point prior to the game. In-game costs were indexed to prices in Calgary. Most spending decisions did not affect the game in future turns; however, employing physical flood mitigation measures lowered the cost of flood insurance, and certain upfront purchases like solar panels could slightly raise future...
income through lower utility costs. Plausible insurance premiums were based on online insurance quotes.

Each participant that completed the game played 10 game turns. This turn limit was chosen after testing the experiment in order to limit gameplay to roughly 20 min. In addition to the game, pre and post-game surveys gathered information on real-life situational factors, attitudes, and demographic attributes relevant to decisions about flood risk (Supplementary file 1). The post-game survey used questions similar to those used by Sobiech (2013) to identify how people rank on various factors identified in the literature as having an impact on mitigation decisions.

2.3 Data

We use “in-game” data generated from within the game (IG) and “in real life” data generated from surveys (IRL) to understand flood mitigation decisions. Not all the survey response variables were included in the final model due to a high degree of correlation between many of these variables. We used the chi-square tests of independence to identify highly correlated survey variables and included independent variables in the final model based on a judgement of their importance based on the literature. Our description here focuses on variables used in our final models to predict flood mitigation. IG factors include flood risk and experimental effects (change in income and flood event). IRL factors include income, flood risk perception, coping appraisal, flood experience, and previous flood mitigation, each of which has been used in previous research. Income is typically found to have a positive association with mitigation decisions (Botzen, Aerts, & van den Bergh, 2009b; Botzen & Van Den Bergh, 2012; Bubeck, Botzen, & Aerts, 2012; Grothmann & Reusswig, 2006; Osberghaus, 2014). IRL measures of risk perception and coping appraisal are included in our analysis, both of which are informed by protection motivation theory (Rogers, 1975). IRL flood experience was used in our analysis, and has been found to have a positive relationship with mitigation decisions Brody, Highfield, Wilson, Lindell, & Blessing, 2017; Osberghaus, 2014), but that the effect fades over time (Atreya, Ferreira, & Kriesel, 2013; Brody, Highfield, et al., 2017; Tobin & Montz, 1994). We used IRL information about history of flood mitigation in FIGURE 1 Detailed serious game experimental procedure of a turn
our analysis. Previous implementation of mitigation measures is positively associated with future flood mitigation; for example, flood insurance policyholders are more likely to implement mitigation measures, contrary to what one might expect due to moral hazard (Hudson, Botzen, Czajkowski, & Kreibich, 2017; Osberghaus, 2014). Having mitigation measures in place has been found to reduce risk perception and decrease the likelihood of implementing further measures (Poussin, Botzen, & Aerts, 2013; Richter, Erdlenbruch, & Figuieres, 2017). Objective flood risk, or living in a high-risk IG neighbourhood, is included as a fixed effect in our analysis, and has been found to be positively related with risk perceptions (Botzen et al., 2009b; Botzen, Kunreuther, & Michel-Kerjan, 2015; Siegrist & Gutscher, 2006), though the relationship with mitigation decisions has been found to be weak (Poussin, Botzen, & Aerts, 2014; Siegrist & Gutscher, 2006).

### 2.4 Data analysis

Analysis involves the estimation of two statistical models; one predicts the likelihood of structurally mitigating against floods, and the other predicts the likelihood of purchasing flood insurance. We use a generalised linear mixed model (GLMM) to analyse the data, choosing a binomial distribution with a logit link function. GLMMs combine two often-used statistical frameworks: generalised linear models and linear mixed models (Bolker et al., 2009). GLMMs are used in situations in which there are random effects and a non-normally distributed dependent variable (Bolker et al., 2009). Random effects are useful when observations are correlated due to multiple measurements from the same source. In our model, we assume fixed effects for psychological and situational factors (e.g., risk perception, IRL flood experience), and design effects for IG events. We also include a participant-level random effect which accounts for within-participant effects not accounted for by fixed effects. The model we use is specified in Equation (1). The fixed effects and design effects are all treated in the same way when estimating the model; however, we draw a distinction since the design effects are not independent variables, as they occur at the same time and in the same way for all participants. We use the following model,

\[
y_k = h\left(\sum_{i=1}^{n} (x_i\beta_i) + \sum_{j=1}^{m} (z_j\gamma_j) + \beta_0 + u_k + \epsilon\right),
\]

where \(y_k\) represents the probability of insuring or mitigating for a given respondent \(k\); \(h(\cdot)\) represents the inverse of the logit link function; \(n\) represents the number of fixed effects; \(x_i\) represents the fixed effects; \(\beta_i\) represents the regression coefficient of the fixed effects; \(m\) represents the number of design effects; \(z_j\) represents the design effects; \(\gamma_j\) represents the regression coefficient of the design effects; \(\beta_0\) represents the fixed intercept; \(u_k\) represents the random intercept for a given participant \(k\), which can be thought of as the error between participants—note that we assume that \(u_k \sim N(0, \sigma_u^2)\); and \(\epsilon\) represents the residual error within participants. We assume an unstructured variance–covariance matrix for within-participant residuals.

### 2.5 Software used

The Decision Game is a browser-based application optimised for Google Chrome and Mozilla Firefox. Front-end coding was in Javascript, HTML and CSS, and server-side coding was in PHP. All code for the Decision Game is available from the authors on request. We use the lme4 package (Bates, Mächler, Bolker, & Walker, 2015) in R (R Core Team, 2017), choosing the glmer function to execute the statistical analysis. We use the BOBYQA optimizer (Powell, 2009) with starting values for coefficient estimates obtained from bivariate versions of the model using one independent variable at a time as the predictor. We investigate the sensitivity of the model to both optimizer choice and starting values.

### 3 RESULTS

#### 3.1 Independent and dependent variables and sample demographics

The frequencies of responses for the independent variables are presented in Table 1. The last variable in the table, IG flood risk, describes the number of turns players spent in neighbourhoods with low to medium or high objective flood risk. The numbers are large because they are recorded for each player in each turn (totaling 123 players times 10 turns). We compare the distribution of the demographics of the participants and the 2016 Canadian census (Government of Canada, 2017a; Government of Canada, 2017b; Government of Canada, 2017c) in Figure 2. Study participants were younger, wealthier, and more educated than the average Canadian. Approximately 6 out of every 10 participants performed the experiment online. All participants completed the 10 turns of the game, during which they had flood insurance for an average of 4.77 turns and had a floodproofed home for 3.85 turns.
### 3.2 General model results

Table 2 contains the key results of the model. The participant-level random effect term and corresponding standard errors are 64.82 (8.05) for predicting mitigation with insurance, and 28.55 (5.34) for predicting floodproofing. The largest fixed effect size is associated with having previously implemented mitigation measures IRL, which has a greater positive association with mitigation decisions than having experienced a flood IRL for both insurance and floodproofing. We observe that all fixed and design effects have the same direction across both models, except for IRL flood experience. Having IRL income of $50,000 or above has a negative association with both mitigation decisions; in contrast, an increase of IG income has a positive association with mitigation. Real-life flood experience has a negative association with insurance and a relatively small positive association for floodproofing, while the IG flood event design effect has the largest effect size estimated in the model aside from the random effects.

### 3.3 Model fixed effects

Using the estimated models, we generate predictions of the probability of purchasing flood insurance and floodproofing using our sample data as inputs. In Figures 3 and 4, each plot portrays the difference in predictions when separating the data by each fixed effect while holding other effects constant. Boxplots show the difference in predictions at both levels of each fixed effect. Horizontal black lines represent the median prediction, boxes contain the middle 50% of predictions, whiskers represent the outside 50% of predictions, and the black dots represent outlier predictions. Comparing across pairs of boxplots demonstrates how the predictions change as participants experience the design events sequentially in the game.

Overall, it appears that the greater the difference in the median predictions within a pair of boxplots, the greater the effect size of the fixed effect. We observe a particularly large fixed effect for personal measures when predicting insurance purchase, and a small fixed effect for IRL flood experience when predicting the likelihood of floodproofing. In addition, as we observe pairs of
To illustrate the magnitude of the effect of the flood event, consider that all the median predictions of insurance likelihoods in the post-flood category are over 0.75.

### TABLE 2  GLMM results—fixed and design effect estimates

| Fixed/design effect                        | Estimate | SE   | p-value | Estimate | SE   | p-value |
|--------------------------------------------|----------|------|---------|----------|------|---------|
| Insurance                                 | −4.1698  | 1.7752 | .0188   | −5.4371  | 1.2859 | <.0001  |
| Turn 3–5 (income lower)                    | 1.1695   | 0.4863 | .0162   | 0.7493   | 0.3529 | .0337   |
| Turn 6–7 (income higher)                   | 2.8059   | 0.5546 | <.001   | 2.4267   | 0.4014 | <.001   |
| Turn 8–10 (post flood)                     | 6.4629   | 0.6928 | <.001   | 3.5316   | 0.4109 | <.001   |
| Has experienced a flood (IRL)              | −2.1455  | 1.9915 | .2813   | 1.8719   | .3244 | <.001   |
| Has implemented Mitigative measures against flooding (IRL) | 5.6766 | 2.6914 | .0349 | 3.4505 | 1.4575 | .0179 |
| Risk evaluation of community is “medium” or above (IRL) | 1.5446 | 2.1652 | .4756 | 1.2910 | 1.4642 | .3779 |
| Income greater than $50,000 (IRL)         | −1.8447  | 1.8719 | .3244   | −1.7832  | 1.2395 | .1503   |
| Has implemented Mitigative measures against flooding (IRL) | 5.6766 | 2.6914 | .0349 | 3.4505 | 1.4575 | .0179 |
| Positive coping appraisal (IRL)            | 2.4329   | 1.9404 | .2099   | 1.3342   | 1.2194 | .2739   |
| High flood risk neighbourhood (in game)    | 0.6533   | 0.5645 | .2471   | 0.7616   | 0.4505 | .0909   |

### FIGURE 3  Predictions of in-game likelihood of purchasing flood insurance. A—initial conditions, B—income drop, C—income raise, D—flood event

boxplots further to the right, we see increases in predicted probability, reflecting the magnitudes of the design effect sizes.
4 | DISCUSSION

4.1 | Model fitness

Absolute goodness-of-fit tests like R squared are problematic for GLMMs, for reasons including that residual variance is not easily defined for these models (Nakagawa, Schielzeth, & O'Hara, 2013). The random effects are larger in magnitude than the fixed effects, suggesting that key features of participant choices to mitigate are not explained by the models estimated here. This also implies that Figures 3 and 4 very likely underestimate the variability of predicted probabilities and that these predictions are more useful for visualising the general impacts of model coefficients, and should not be used to make specific forecasts of mitigation uptake. For this reason, the interpretation of these figures should be focussed on the comparisons across IG events for the different fixed effects.

4.2 | Model results: Income

In the literature, the relationship between income and flood mitigation behaviour is typically positive (Botzen et al., 2009b; Botzen & Van Den Bergh, 2012; Bubeck, Botzen, Kreibich, & Aerts, 2012; Grothmann & Reusswig, 2006; Osberghaus, 2014). In our results, IRL income was found to have a modest, negative association with both IG mitigation decisions. All else constant, IRL low-income participants were choosing to mitigate more than those with higher IRL income. When participants were given a higher IG income, the likelihood of purchasing flood insurance or floodproofing increased. The contrast between the IG and IRL income effects provides evidence that monetary barriers to mitigation may be more important than any behavioural differences due to being in a lower income group. This result suggests that having less income is a practical barrier to flood mitigation, rather than an indirect indicator of risk management behaviour. While this finding may support some policy options (such as price subsidies), our results are not compelling enough to recommend any specific policy without further work.

4.3 | Model results: Objective flood risk

Living in an IG high flood risk area had a small, positive association with the decision to insure or floodproof. As
noted above, participants were not primed to be concerned about flooding at the outset of the game. In choosing where to live (Stage 1 of the game turn), participants could consider several factors to inform their choice of residence, including flood hazard. However, some participants may not have noticed or concerned themselves with this information in their decisions. For this reason, the impact of information about flood hazard on risk mitigation choices may underestimate the effect that would be observed in the real world, where awareness of flood hazard would very likely be stronger, and in turn, could have a greater influence on risk mitigation decisions. In a survey of flood-prone regions in France (Poussin et al., 2014) and Switzerland (Siegrist & Gutscher, 2006), researchers found that objective risk levels did not have a significant impact on flood mitigation behaviour. However, other research has found that people living in flood-prone areas do have heightened risk perception of flooding (Botzen, Aerts, & van den Bergh, 2009a; Botzen et al., 2015; Poussin et al., 2014; Siegrist & Gutscher, 2006). Several reasons could explain maladaptive responses including avoidance, wishful thinking, and postponement (Bubeck, Botzen, Kreibich, & Aerts, 2013). It seems plausible that our observations provide a lower-bound estimate on the impact of objective flood risk, and that more priming of participants could have increased the impact of objective flood risk on mitigation choices.

4.4 | Model results: Real-life flood experience

Having experienced a flood IRL was negatively associated with the insurance decision and had a positive but relatively small association with the floodproofing decision. This finding is somewhat contrary to several studies which note the positive impact of flood experience on flood preparedness (Bradford et al., 2012; Bubeck et al., 2013; Kreibich & Thieken, 2008; Poussin et al., 2014; Siegrist & Gutscher, 2006). Evidence from the literature also suggests that over time, the positive effect of a flood on public interest and individual motivation for action wanes (Atreya et al., 2013; Brody, Highfield, et al., 2017; Tobin & Montz, 1994). Since many participants were located in Calgary, where the last major flood occurred in 2013, it is possible that our sample contains many people with flood experience but reduced flood memory or less social memory of flooding in the city as a whole. It is also important to note that the participants were younger than average and may not have had direct experience in making decisions in response to the 2013 flood or other major flood events in Canada. The lack of representativeness may help explain some of the inconsistencies with other research.

4.5 | Model results: In-game flood experience

The results indicate that the experience of the IG flood had a great influence on a participant’s likelihood of purchasing flood insurance or floodproofing. The effect size was several orders of magnitude larger than living in a high IG flood risk area. This suggests that the experience of being flooded is more important than objective flood risk information with respect to mitigation. As above, this finding is consistent with the concept of a recency bias for the effect of flood experience observed in other research (Burn, 1999). From a policy perspective, these findings are consistent with the idea that it may be important to highlight and market mitigation options in the time immediately after a flood.

4.6 | Model results: Personal measures

The personal measures variable refers to whether the participant has previously taken preventative measures (such as moving wiring to the ceiling, using water-resistant materials, relocating furniture and electronic devices) against flooding IRL. One of the commonly cited feedback effects of having insurance is moral hazard. There is evidence that people who have previously purchased flood insurance are no less likely to implement and are in some cases more likely to implement physical mitigation measures (Hudson et al., 2017; Osberghaus, 2014). This is evidence for advantageous selection, where insurance policyholders are more risk-averse, and therefore more likely to seek to reduce risk, particularly when incentives are present to lower premiums to people who structurally mitigate. We find evidence that all other factors equal, participants who had previously implemented measures were more likely to have employed mitigation measures in the game. This effect size was relatively large and positive for both dependent variables. This finding adds credibility to the idea that, ignoring feedback effects, those who have previously insured or mitigated are more likely to seek to reduce future flood risk.

4.7 | Model results: Risk perception and coping appraisal

Risk perception has been found to have a positive relationship with flood preparedness (Fuchs et al., 2017; Grothmann & Reusswig, 2006; Miceli, Sotgiu, & Settanni, 2008). Contradictorily, studies that find no relationship between risk perception and flood preparedness exist (Bradford et al., 2012; Bubeck et al., 2013; Siegrist &
Serious game experiments are a combination of stated and revealed preference methods, and could usefully augment existing research (Arnal et al., 2016). Like stated preference surveys and most choice experiments, this game experiment was played in a hypothetical context in which participants were presented information and had to make decisions within a scenario that was not real. However, features of the game may have helped to make it more enriching for player engagement than a survey or laboratory-based choice experiment, including multiple turns, graphical elements, and feedback about decisions. More generally, serious games may create some feelings of realism, allowing players to reflect on scenarios within an assumed role that they may never have actually experienced. While serious game experiments are played in a hypothetical context similar to stated preference surveys, since the context is often richer than what a survey would typically afford, they can be used like revealed preference data collection tools—in which the game is a platform for revealing choices. Future game experiments can be used to explore flood policy interventions—such as insurance or floodproofing subsidies, mandatory insurance programs or risk communication strategies—that could be safely explored within a game without real-world unintended consequences.

There is evidence that hypothetical bias can be reduced through providing options to participants, such as those used in discrete choice experiments (Murphy, Allen, Stevens, & Weatherhead, 2005). This is more pronounced if participants can make a non-choice to avoid forced decisions, since non-decisions are reflective of real market behaviour, especially when participants may be unfamiliar with the choice categories (Adamowicz, Louviere, & Swait, 1998; Hensher, 2010). Additionally, Hensher (2010) highlights the value of reference alternatives or choice contexts in reducing hypothetical biases, such as using a trip to Paris to ground valuations of other goods. One advantage of serious games is that these choice contexts and reference alternatives can be presented intuitively within the game (Rosetti et al., 2017). In the Decision Game, players were presented with a list of purchase options and responsibilities so that the costs of the target good (flood insurance and floodproofing) were presented in a meaningful context. Moreover, the ability to receive feedback on decisions, learn, and adapt throughout the experiment could further immerse the participant in the context of the experiment, helping to reduce hypothetical bias and improve the quality of data.
Ultimately, more research is needed to validate experimental games as useful tools in research on human decision-making, but our results suggest that this is worth pursuing in future work.

Finally, there are a number of features in this study that limit its generalizability, making it possible that future studies may not replicate our results, and furthermore that even if the results were externally valid, they may not be usefully applied to most populations. The demographics of the sample differ from the Canadian average; participants were younger, wealthier, and more educated. The high incomes in particular may have had an effect on the perception of household value, tolerance for risk, and inclination to buy insurance. In-person recruitment was mostly done in Calgarian urban coffee shops for convenience sampling, mainly due to the availability of reliable Internet access, high volume of patrons, and a relatively high likelihood of finding participants with disposable time. Our sample included few residents from rural areas and did not cover the breadth of regions across Canada. The lack of generalizability could have reduced variability in some measures—specifically income and age—meaning that our results may underestimate both income and age effects in the population.

5 | CONCLUSIONS

Our key observations are firstly that incentivising flood risk mitigation should be done quickly following a flood event given that the effect of flood experience may decay over time. Moreover, we found that IRL low-income individuals were no less likely to implement mitigation measures than IRL higher-income counterparts, suggesting that lack of income and mitigation costs are important determinants of risk mitigation. Finally, our results suggest that communicating objective risk information may not be enough to encourage mitigation uptake.

Our results are from a relatively small sample of participants and may be most useful for comparison to other research on the same topic using other methods. Some of our results are consistent with existing literature, but others are not. The chief contribution of this research is in the illustration of how serious game experiments in research on natural hazards generally, and flooding in particular, may offer insights that augment extant research using alternative methods. Experimental games combine features of both stated and revealed preference methods; games are experimentally controlled and offer the flexibility of stated preference methods, while at the same time, capture decision information that reveal preferences within the game scenarios. Future experimental game research that increases levels of realism and user engagement may provide opportunities for novel research on flood-related decision-making and natural hazards more generally.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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