# Natural hazards, public insurance, and private self-insurance: Total crowding effects and emergency drinking water

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**Abstract**

Recent history has highlighted the importance of disaster preparedness by both public and private decision-makers. One important question is whether additional preparedness efforts by public authorities crowd out private preparedness and if so, by how much. The present paper studies the existence and scale of such crowding out using data from a unique household survey on actual emergency drinking water (EDW) storage decisions of 19,000 households in the 2012 post-disaster environment of Japan. EDW is known to be critically important for post-disaster morbidity and mortality. In the EDW context, public and self-insurance are both essentially perfect substitutes and the only effective risk management options, opening an empirical window onto the total, rather than partial, crowding effect. Our evidence shows crowding out, but at an insubstantial level. Every additional liter per capita (*lpc*) of EDW stored by public authorities crowds out roughly 0.04*lpc* of private EDW preparedness, of which 0.01*lpc* are due to more households storing no EDW at all and 0.03*lpc* due to underprepared households storing less EDW. The results are robust to controlling for established determinants of disaster preparedness.

**Keywords**: Government relief, natural hazards, crowding-out effect

**JEL classification**: D78, D81, G22, Q54

**Acknowledgements**: We are grateful to Hiroki Onuma and Shinya Horie for research assistance. T. Goeschl's research has been supported by a travel grant from the HeKKSaGOn network. S. Managi' research has been supported by a Grant-in-Aid for Specially Promoted Research (26000001) by the Japan Society for the Promotion of Science, Japan.

## 1. Introduction

Recent history has highlighted that modern societies remain vulnerable to natural and man-made disasters such as earthquakes, hurricanes, and tsunamis. Even when the number of humans that are *immediately* injured or killed by such events is often small, their disruptive impact on transport and communication networks and destruction of vital infrastructure frequently leads to substantial secondary impacts. These impacts affect the lives of hundreds of thousands or sometimes millions of people, with often catastrophic consequences for the availability of essential supplies to the general population. In Japan, for example, the 2011 Tohoku Earthquake and the subsequent tsunami decreased the availability of commodityies by 17% of (Carvalho *et. al.* 2013). Earthquakes in urban centers such as Portland, Oregon will disrupt more than 50 percent of water supply (Chang et al. 2002). These observation underline that disasters, i.e. low-probability high impact events, are associated with substantial losses in human welfare.

Evidence shows that the magnitude of human welfare losses can be mitigated significantly by investments into emergency preparedness (Kahn 2005). In fact, even moderate levels of preparedness in the form of emergency supplies can have substantial impacts on morbidity and mortality when such events materialize (Conolly et al. 2004; Tanaka et al. 1999). As a result, many countries attempt to attain high levels of domestic preparedness by combining initiatives to encourage individual preparedness at the household level with a variety of governmental and non-governmental efforts to provide emergency relief in case of natural disaster.

The present paper contributes to a growing empirical literature that analyzes the relationship between such public and individual disaster preparedness, much of it motivated by the common observation that the average household is insufficiently prepared for catastrophic events (e.g. DIEM 2010). Understanding more about this relationship is important for both researchers and policy-makers: If publicly-provided emergency relief negatively affects households' choice of preparedness, this would provide additional empirical support for the 'crowding-out' effect of public interventions postulated in the seminal paper by Ehrlich and Becker (1972). If present, crowding-out can have significant impact on the effectiveness of public preparedness efforts since public investments have no or only fractional impact on the overall level of preparedness.

The presence and scale of a crowding out effect has been the subject of several empirical studies that draw on evidence from a variety of natural disasters such as floods, hurricanes, and earthquakes. Some of these studies find evidence in line with crowding-out (e.g. Kunreuther 2006, Botzen et al. 2009, Kousky 2013, Brunette et al. 2013) and highlight the possible causal channels through which crowding out can operate. One channel is the simple mechanism of risk compensation (Ehrlich and Becker 1972): Fully informed and perfectly rational households may want to avoid excessive preparedness in a setting where public measures reduce expected damages from a catastrophic event (Botzen et al. 2009). Such risk compensation can be, but need not be welfare-reducing. If preparedness can be generated more cheaply by a public provider, then private investments should be reduced in response to public investments under social efficiency considerations.

Less ambiguous in welfare terms is the channel of 'charity hazard' (Browne and Hoyt 2000): This concept is closely related to moral hazard and refers to the *strategic* reduction of damage-limiting prevention by households when governments already offer an efficient level of preparedness. Charity hazard captures the decision by private households to reduce preparedness below the efficient level because they know that government cannot credibly commit to *not* providing additional damage-relief in the event of a catastrophe. Such strategic behavior is welfare-distorting and means, as Buchanan (1975) pointed out, that governments face a 'Samaritan's dilemma' in emergency relief (Raschky and Schwindt 2013).

A third channel is perception bias: Private households may overestimate the effectiveness of public interventions in providing disaster relief and, as a consequence, lead households to underestimate the damages from potential disasters and to under-invest in market-based insurance and self-protection (Kunreuther, 1996). The three channels do not appear to be always operative at detectable magnitudes, however: Despite similar settings, other studies fail to identify crowding out in their data (Kousky et al. 2013, Koerth et al. 2013) or find that there is considerable heterogeneity across subjects (Osberghaus 2015). This points to important subtleties in the mechanisms and diagnostics of crowding out.

Empirical test of the crowding-out effect, such as the studies above, have to come to terms with a key challenge already discussed in Ehrlich and Becker's 1972 paper: In equilibrium, there should be no arbitrage left between publicly provided risk reduction on the one hand and across the three options of market insurance, self-insurance, and self-protection on the other. Ideally, therefore, the researcher would be able to observe choices across *all three* options in order to evaluate the efficiency and welfare effects of these choices before and after the exogenous change in publicly provided risk reduction. In practice, however, the researcher will typically observe only a subset of these choices, for example the change in households' demand for market insurance (e.g. Raschky et al. 2013, Kousky et al. 2013). While such data can inform statements on the *partial* impact of increased public intervention on market insurance, a *total* assessment of whether crowding out has occurred requires a comprehensive picture of the household's response to increased public intervention also across self-insurance and self-protection. The finding by Osberghaus (2015) that the overall vulnerability of households to flooding events is the result of a complex interplay between public flood protection, the private demand for flooding insurance, and private flood mitigation measures is a case in point.

The main contribution of the present paper is to provide evidence for the presence and scale of crowding-out of public preparedness efforts on private preparedness efforts in a setting in which the total effect can be estimated with considerable confidence. Specifically, we examine private and public investments in emergency drinking water (EDW) supply in Japan for the year 2012. The amount of EDW stored publicly and privately is a suitable measure for disaster preparedness since its availability has a dramatic impact on mortality and morbidity rates following a catastrophic event (Watson et al. 2007). For the researcher, EDW is an appealing object of inquiry because it is an investment in disaster preparedness with no close substitutes and because it can privately only be provided on a cost-effective basis through self-insurance[1] and not through market insurance or self-protection.[2] The response of private EDW storage to an increase in public EDW supply can therefore confidently be expected to provide a close approximation to the total impact. Also, since public and private EDWS provide a perfect substitute, namely drinking water, the setting allows

[1] Conceptually, self-insurance is the most appropriate definition for behavior in which households store EDW in their own home.

[2] Self-protection could – theoretically – take the shape of activities such as sinking private wells or purchasing water filtration equipment. Such measures are typically either not available (wells) or not cost-effective (water filtration).

crowding effects to be assessed on a liter-for-liter basis, making the effects stark.

To test for the existence and scale of crowding out of private emergency preparedness by public preparedness measures, we use unique household survey data from 19,000 households in Japan in 2012. The location, timing, and focus of the survey are significant: Japan is a country with areas that are exposed to a comparatively high risk of natural disasters and a recent history thereof. The population is therefore deeply aware of the presence of natural hazards and public measures intended to manage the resultant vulnerabilities. Japan is also a country in which the private cost of specific preparedness by ensuring adequate EDW storage is high. Internationally exceptional residential dwelling density (Keirstead and Shah 2012) and resultant housing costs (REFS) lead to a high opportunity cost of sacrificing residential space for emergency water storage, which amounts to around 24 liters for a typical family of four.

The timing of the survey is also significant: In 2012, the central coastal regions of Japan's main island constituted a typical post-disaster environment in the wake of the 2011 Tohoku Earthquake, the subsequent tsunami event, and the nuclear accident at Fukushima Daiichi. As a result, the topic of the survey had cognitive salience and the survey population was generally well informed about disaster relief, public preparedness etc. The most important source of variation in our dataset comes from the different levels of local public preparedness in the form of investments into public EDW storage. While there are national recommendations on how much EDW a community should store, communities vary considerably in their preparedness. Across the 47 districts from where we draw data, public EDW range from 01*l* per person to more than 65*l*.

A natural concern is the direction of causality that links public and private preparedness in EDW storage. *Prima facie*, variations in public preparedness could conceivably be driven by officials being informed about private preparedness and adjusting preparedness appropriately, rather than the other way around. While this possibility can no longer be excluded after 2014, when the first systematic assessment of private preparedness at the local level was conducted, at the time of our own survey such information is not considered to have been generally available. This makes reverse causality less likely for Japan in 2012.

Against this empirical background, we examine the presence of a negative statistical relationship between public and private EDW storage through multivariate regression analysis, using control variables to account for well-known determinants of self-insurance such as risk exposure, disaster experience, and other socio-demographic characteristics. The headline results confirm the presence of statistically significant, but unsubstantial crowding-out effects of governmental intervention on private households' disaster preparedness. At the extensive margin, every additional liter of EDW that government stores per head of population increases the propensity that the average household will decide not to store any EDW by approximately 0.1 percent. At the intensive margin, we find that among those households that store a positive amount of EDW, but less than the officially recommended amount, every additional liter per capita (*lpc*) of public EDW supply reduces private EDW storage by around 0.03*lpc*. Both effects are highly robust to the inclusion of controls and estimation method. Jointly, they imply a crowding-out of approximately 4 percent. An examination of the regression coefficients for the control variables shows that the extensive and intensive margin decisions broadly respond to the same factors. But there are also some important differences. For example, households' EDW provision is highly insensitive to the number of dependent members (children and elderlies in need of medical support). In other words, the private storage of EDW of households with and without dependent members is essentially the same. This points to the potential gains from EDW relief targeted at households with dependents.

In the following Section 2, we provide an overview of the existing literature. In Sections 3 and 4, we describe our data and estimation method. In Section 5, we present and interpret our estimation results, and in Section 6, we provide concluding remarks.

## 2. Related Literature

The theoretical study of a crowding out effect of public insurance on self-insurance goes back to at least the early seventies when Isaac Ehrlich and Gary Becker published their seminal study on the interaction between market insurance and self-insurance (Ehrlich and Becker 1972). Their insights were subsequently applied to the study of natural disaster preparedness (e.g. Lewis and Nickerson 1989, Quiggin 1992, Crocker and Shogren 1999, Zehaie 2005; Mahmud and Hassan 2014), lending theoretical support to the notion that there is an inverse relationship between public relief efforts and private preparedness for natural disaster risks.

The empirical literature on the topic has adopted a variety of research strategies in order to test for the presence, direction, and strength of crowding effects of government-provided disaster relief. A number of studies conduct surveys that elicit hypothetical willingness to pay for insurance against the backdrop of expectations about government assistance. Asseldonk et al. (2002) examine demand for crop insurance among Dutch farmers and find evidence for crowding out. So do Botzen et al. (2009) in a survey of Dutch homeowners that examines their willingness to provide self-protection through domestic mitigation measures. Botzen and van den Bergh (2012a,b) support this finding with similar results on flood insurance demand in a large sample of around 1000 Dutch homeowners. Raschky et al. (2013) survey around 500 households in Germany and Austria in a post-disaster period to elicit WTP for flood insurance and also find evidence for crowding out by governmental disaster relief, with additional nuances on account of differences in the certainty and volume of relief between the two countries. The consistent empirical evidence that hypothetical WTP for insurance negatively varies with expected government relief is also supported by related evidence derived under controlled conditions: Brunette et al. (2013) conduct a framed laboratory experiment with forest owners in which different treatments vary the nature and amount of "public support" in the case of an adverse forest event. They find that such relief reduces the demand for insurance, irrespective of whether the uncertainty is of a classic risk type or involves ambiguity. Turner et al. (2014) conduct experiments in post-disaster Pakistan with subjects affected and not affected by the flood event and find that having received government assistance for major disaster recovery reduces demand for insurance in the experiment.

Despite the clear evidence for crowding out from surveys that elicit hypothetical WTP and from a laboratory study, empirical studies that rely on actual insurance data do not always arrive at the same conclusion. Browne and Hoyt (2000) examine the frequency of flood-insured households in different US states and find evidence for crowding in of federal disaster assistance on private flood insurance at the state-level. Petrolia et al. (2013) confirm this finding based on individual-level survey data from the US Gulf

Coast and Florida's Atlantic Coast: The propensity of holding a flood policy increases with perceived eligibility for federal disaster assistance. Kousky et al. (2013) question the validity of these findings on the grounds of endogeneity problems. They propose an identification strategy based on that fact that federal disaster assistance has a politically discretionary component. Using political contestability ('swing state') as an instrument and individual flood contract data, Kousky et al. find a crowding out effect at the order to $6 for every $1 increase in federal aid grants, but no effect for government loans. Osberghaus (2015) examines German household survey data on individual flood event mitigation efforts in the wake of large-scale floods in 2013. This study does not find evidence for the hypothesis that expected relief payments by government crowd out private investments in preparedness.[3]

In light of the results in the literature, the empirical support of crowding out effect therefore is not clear-cut once we step beyond the domain of hypothetical WTP measures. The present study presents such a step: It adds to the current evidence base by bringing new insights from a large-scale survey about self-insurance to bear on the question of crowding. In this, the study relies on self-reported actual behavior rather than on hypothetical behavior and therefore adds evidence to the literature in that area where the presence of crowding out is most in question.

Without exception, investigations into the presence of a crowding out effect control for the presence of additional drivers of households' disaster preparedness for which the researcher needs to control. There is general agreement on risk exposure, disaster experience, risk management posture as well as socio-demographic characteristics as key variables of interest. These drivers have been identified and assessed both the papers interested in crowding effects (see above) as well as papers that choose not investigate this causal link (e.g. Donahue et al. 2013 or Koerth et al. 2013).

[3] Raschky *et al*. (2008) and Neumayer *et al*. (2013) show that crowding effects can also operate at the international level (see also Cohen and Werker, 2008).

**Table 1: Empirical findings on significance and direction of drivers of preparedness**

| Driver of preparedness | Estimated direction | Study |
|---|---|---|
| Public preparedness | Positive | Brown and Hoyte (2000); Petrolia et al. (2013). |
| | Insignificant | Osberghaus (2015). |
| | Negative | Asseldonk et al. (2002); Botzen et al (2009); Botzen and van den Bergh (2012a,b); Raschky et al. (2013); Kousky et. al (2013); Turner (2014) |
| Risk exposure | Positive | Donahue et al. (2013) ; Osberghaus (2015); Botzen et al (2009); Raschky et al. 2013; Asseldonk et al. (2002)[4] |
| | Insignificant | Asseldonk et al. (2002)[5] |
| | Negative | Koerth et al. (2013) |
| Disaster experience | Positive | Donahue et al. (2013) ; Koerth et al (2010) ; Brown and Hoyt (2000); Osberghaus (2015) ; Turner et al. (2014) ; Asseldonk et al. (2002)[6]; Raschky et al. (2013)[7] |
| | Insignificant | Botzen et al. (2009) ; Asseldonk et al. (2002)[8]; Raschky et al. (2013)[9] |
| Risk management posture (implicit risk premium) | Positive | Osberghaus (2015);Donahue et al. (2013); Petrolia et al. (2013) |
| | Insignificant | Raschky et al (2013) ; Asseldonk et al (2002) |
| Income | Positive | Osberghaus (2015); Raschky et al. (2013); Browne and Hoyt (2000) |
| | Insignificant | Botzen et al. (2009); Turner et al. (2014) |
| Education | Positive | Botzen et al. (2009); Donahue et al. (2013) |
| | Insignificant | Osberghaus (2015); Asseldonk et al. (2002) |
| Children present | Insignificant | Osberghaus (2015); Petrolia et al. (2013) |

As table 1 illustrates, there is considerable, but not universal agreement on the importance of these drivers and their direction of impact. The same drivers play a role despite inevitable differences in the empirical

[4] The positive result applies to the extensive margin estimation in a double-hurdle model.
[5] The insignificant finding applies to the intensive margin estimation in a double-hurdle model.
[6] Result for the extensive margin in a double-hurdle model.
[7] Result for the effect of damage size.
[8] Result for the intensive margin in a double-hurdle model.
[9] Result for the frequency of damage.

implementation of the underlying concepts given the available data for each empirical study and the different methodological strategies. Apart from public preparedness, for almost all of the identified drivers, there is consistent evidence of a nonnegative relationship between the level of the variable and the estimated direction of how it impacts on preparedness. This convergence in estimated effects provides a set of predictions on what patterns to expect in any new dataset, such as the one underlying the present paper.

**3. Empirical strategy, data, and descriptive results**

The empirical strategy adopted in this paper focuses on EDW for three reasons: First, immediate access to EDW is essential in a post-disaster environment. Second, EDW is a generic good, with government relief a very close to a perfect substitute for private provision. Third, private EWD provision is costly. Exploiting this particular setting, we assess the impact of local governments' preparedness with respect to EDWS on household-level preparedness. The particular setting also contains important corroborating institutional details that allows us to argue that the direction of causality is not in question. Local governments in Japan, like governments elsewhere, are subject to long planning horizons and a high degree of institutional and procedural inertia. This limits the responsiveness of local government to intertemporal variations in disaster preparedness by private households. The most important piece of evidence is, however, the fact that the first study to inform local governments about citizen preparedness following the 2011 Tohoku disaster was only conducted in 2014 (Nakayachi et.al 2015). Even before that, local governments' supply side orientation in disaster relief has meant that households' risk perception or patterns of preparedness were rarely investigated in Japan. This is, in fact, not unusual: Also in countries such as the US, officials are typically vaguely aware of the true level of disaster preparedness in the population, and regional or local variations within these levels (Donahue 2011).[10] Japanese households, on the other hand, have traditionally received information about how their local governments reinforce disaster preparedness, a trend that has increased through the use of social media in recent

[10] Donahue et al (2013) also find that there are fundamental differences between officials' perceptions of citizens' preparedness and citizens' perception of own preparedness.

years (GoJ 2012). This leads to a situation in which households are much better able to condition their individual levels of preparedness on what they know about the government's efforts rather than the other way around.

Household data on disaster preparedness comes from a large-scale survey, the 2012 Survey of Individual-Level Preparedness for Natural Disaster. The purpose of the survey was to generate a comprehensive picture of disaster preparedness among Japanese households. For the purposes of this study, disaster preparedness of each household is measured by reference to the amount of EDW that the household should – given its size - store according to official guidelines and the amount of EDW that the household actually stores. Households are expected to store independently enough water in order to survive the first 72 hours after a disaster. The officially recommended EDW amount is 6 liters of water per household member, with appropriate reductions for younger HH members.[11] This allows a first rough categorization of households according to preparedness status. We will refer to a household as *unprepared* if the amount of EDW it stores is zero. A household will be categorized as *underprepared* if there is a positive amount of EDW stored, but the amount falls short of official guidelines. Finally, *prepared* households store an amount of EDW that fulfils or exceeds official guidelines and therefore have no shortfall.

In addition to information on preparedness, the survey also collected data that relate to those determinants of disaster preparedness that the literature has established as important drivers (see section 2). These are variables that measure risk experience and risk attitudes, in addition to a number of socioeconomic variables. On risk experience, households are asked on a yes/no basis whether they have personally been affected by a disaster in the past (*EX-disaster*), whether they have personal experience of seeking refuge in an emergency shelter (*EX-shelter*), whether they were personally affected by the 1995 Kobe earthquake (*EX-Kobe*). For experience of the 2011 Tohoku earthquake (*EX-Tohoku*), we compare the residence location of a household at the time of the earthquake with its impact zone and code for experience if the residence was located there. On risk attitude, the survey collected yes/no responses on whether the

[11] For a HH member of 13 years of age or older, the amount is 6 liters. For the age group between 8 and 12 years, the supply is set at 4.5 liters and at 3 liters for ages below 8 years. Given the age composition of a HH, there is a specific recommended level of EDWS (in liters) composed of the sum of individual EDW needs. So a family with two adults, child aged 10 and another aged 6 would have to maintain a total supply of 19.5*l* EDW in storage continuously in order to comply with the recommendations.

household head had participated in a disaster drill in the last five years (*training*) or considered himself generally compliant with official guidelines and health recommendations (*compliance*). Socio-demographic variables covered household income (*income*), household size, years of secondary education (*education*), number of children under 5 years of age (*children*), and the number of elderlies above 64 years of age that require medical care (*elderlies*).

Data on public preparedness and on households' risk exposure comes from local governments' natural disaster aid data available from the Fire and Disaster Management Agency (FDMA), which is a part of the Japan Ministry of Internal Affairs and Communication (MIC). FDMA provides disaggregated annual data on the provision of drinking water and other emergence commodities. With the survey conducted in 2012, we use data from 2011 on the basis that citizens' decision making is based on the information about the previous year. FDMA also provides data on the number of FDMA officers allocated by the national government to each community and on the city-level budget expenditures for the mitigation and recovery from disaster. We choose to proxy *risk exposure* of a household through two variables: One variable captures past exposure through the cumulative expenditures on disaster recovery per square kilometer by the relevant district since YEAR (*expenditure*). The other variable measures officially expected future exposure measured through the number of professional emergency workers per one thousand inhabitants allocated by the national government to the community in which the household is located (*professionals*).

The survey sample consisted of 19,214 households from across Japan. The sampling frame was designed to randomly select respondents while preserving the population composition of Japan's population between the ages 20 to 69 in key socio-demographic dimensions. We designed and outsourced the survey to a marketing company (Nikkei Research). The survey was web-based and administered nationwide.

Table 2 shows the structure of respondents and a number of key descriptive results. A number of features stand out. For example, the average household have a shortfall of about 9 liters below the official EDW storage guidelines. This is in line with previous international findings that most households are insufficiently prepared (compare also DIEM 2010). Categorizing households by preparedness status, we find that 8503 out of 19000 households that answered the question stated that they do not store any EDW.

**Table 2. Descriptive Statistics for All Samples**

| Variable | Definition | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|---|
| *Shortfall* | Gap between HH EDW and official guideline (*in liters*) | 19000 | 14.12 | 14.15 | -25.5 | 49.5 |
| *Public EDW* | Public EDW per person in district (*in liter*) | 19000 | 0.817 | 5.882 | 0.011 | 65.45 |
| *Expenditure* | Past district government expenditure on disaster recovery (*in k¥/capita*) | 19000 | 0.000 | 0.002 | 0 | 0.130 |
| *Professionals* | Number of professionals in community-based fire department service | 19000 | 0.312 | 0.705 | 0 | 14.02 |
| *EX-Disaster* | Any other personal experience of disaster, except the 2011 Tohoku and 1995 Kobe incidents (*dummy)* | 19000 | 0.167 | 0.373 | 0 | 1 |
| *EX-shelter* | *Personal experience of emergency shelter* (*dummy*) | 19000 | 0.102 | 0.303 | 0 | 1 |
| *EX-Tohoku* | 2011 Residence located in 2011 Tohoku earthquake impact zone (*dummy*) | 19000 | 0.025 | 0.156 | 0 | 1 |
| *EX-Kobe* | Personal experience of 1995 Kobe earthquake (dummy) | 19000 | 0.052 | 0.223 | 0 | 1 |
| *Training* | Participation in disaster drill in last five years (*dummy*) | 19000 | 0.167 | 0.373 | 0 | 1 |
| *Compliance* | Subjective perception of rule compliance | 19000 | 0.328 | 0.470 | 0 | 1 |
| *Education* | Years of secondary education | 19000 | 5.142 | 2.659 | 0 | 10 |
| *Income* | Monthly HH Income (*in k¥*) | 18929 | 640.81 | 378.39 | 200 | 2000 |
| *Children* | Number of small children (< 5a) | 19000 | 0.147 | 0.438 | 0 | 4 |
| *Elderlies* | Number of elderlies (> 64a) requiring care | 19000 | 0.061 | 0.239 | 0 | 1 |

The share of unprepared households is therefore 45 percent. The share of underprepared household, i.e. those that store some EDW, but have a shortfall relative to the official guidelines, lies at 40 percent (7662 out of19000). Only 15 percent of households (2835 out of 19000) have no shortfall and can therefore properly be described as "prepared".

Public supply of EDW per head in Japan in 2012 was around one liter (0.*72l)* on average, but with considerable variation. Some households are located in districts in which there is essentially no public EDW stored (0.01*l*) while other household can count on access to more than 65 liters of EDW per head. We exploit this variation in the next section to understand how private household respond to this variation in public EDW storage.

## 3. Hypotheses and Estimation Method

Theory and previous empirical evidence allow both for the possibility that private households' EDW storage decision is unaffected by public EDW storage levels and for the possibility that it responds negatively to higher levels of public EDW storage. In the latter case, the crowding-out effect can operate at two different margins of the households' decision making process. An extensive margin effect would positively affect a household's choice to be *unprepared.* An intensive margin effect would affect those households that are prepared or underprepared and induce a reduction in their level of EDW storage. The presence and scale of these margins is of obvious interest to policy-makers, particularly in the case of EDWS. Households crowded out at the extensive margin are particularly vulnerable in the case of a disaster, leading to a disproportionate mortality impact. The intensive margin mostly affects the time pressure under which government needs to bring disaster relief to the affected population. The empirical validity of these hypotheses is therefore of considerable significance.

In light of these considerations, we test two hypotheses. The first hypothesis considers the extensive margin.

**Hypothesis 1 (Extensive crowding out):** *Everything else equal, a household's decision whether to store a positive amount of EDW is unaffected by variations in the locally available public EDW supply.*

The second hypothesis examines the extent to which the level of EDW storage decisions varies with the level of public EDW supplies.

**Hypothesis 2 (Intensive crowding out):** *Everything else equal, a household's shortfall in EDW storage is unaffected by variations in the locally available public EDW supply.*

We first test hypothesis 1 by conducting a probit estimation of preparedness for the entire survey population, with public EDW supply as the main explanatory variable. The dependent variable for the probit is the household's preparedness status, which is set to 1 for prepared and underprepared households and to zero for unprepared households. The sign and significance of the coefficient estimate for public EDW storage then forms the basis for a basic rejection test on hypothesis 1 and for statements on the strength of the extensive margin effect.

In a second step, we examine hypothesis 2 by testing how variations in public EDW supply affect the level of preparedness among underprepared and prepared households. The natural object of interest here are underprepared households: Unlike prepared households, underprepared households subject to crowding out have immediate implications for expected mortality and morbidity of catastrophic events. A first test of hypothesis 2 consists of an OLS regression with the level of shortfall in EDW preparedness as the dependent variable and, again, public supply of EDW per head of population as the main explanatory variable.

As controls, we include in the tests for both hypotheses variables that capture, individually and jointly, a household's risk exposure, disaster experience, risk management attitude, and socioeconomic characteristics. For the variables that proxy for risk exposure, disaster experience, and risk management attitude, economic intuition and previous empirical evidence lead to the general prediction that they correlate positively with the propensity to prepare and negatively with the degree of shortfall in preparedness. We also include controls for income, education, and the number of dependent children and elderly people in the household.

## 5. Estimation Results

### *5.1. Core results*

Table 3 and 4 report the regression results for the extensive margin (table 3) and intensive margin (table

4) for a number of different specifications. Table 3 shows six columns providing marginal effects at the sample mean based on a probit model, with standard errors clustered at the district level. Column (1) reports the results for a univariate model of crowding without additional controls. Columns (2) through (5) report on specifications that regress preparedness status on measures of risk exposure (2), risk experience (3), risk management attitudes (4), and sociodemographic characteristics of the household (5). The last column (6) estimates all effects jointly.

The first observation about the table entries concerns the high degree of robustness of the coefficient estimates and significance levels: Across model specifications, the sign and value of the sample mean effects remain close, except for the coefficient on post-disaster expenditure. The second observation concerns the coefficient associated with the main explanatory variable, namely the amount of public EDW per head of population. This coefficient is the subject of result 1.

**Result 1**: *We find clear and statistically significant evidence of crowding out of public EDW supply on a household's propensity to store a positive amount of EDW. The size of the effect is negligible, however: At the sample mean, one additional liter per capita of public EDW supply increases the likelihood that a household will be unprepared by roughly 0.1 percent.*

Result 1 highlights the existence of a statistically significant, but quantitatively small trade-off for the public disaster preparedness: Higher public investments in preparedness increase the likelihood that households do not store any amount of EDW at a rate of 0.1 percent per liter per head at the sample mean. To put this finding in perspective, by storing one additional liter per head, the community induces slightly more than 0.1 percent of households to incur an EDW shortfall of 6*lpc* (the recommended amount), implying an additional burden of only 0.006 *lpc* on public supply.

**Table 3: Marginal effects after probit**

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Public EDW | -0.00163*** | | | | | -0.00109** |
| | (0.000585) | | | | | (0.000507) |

| | | | | | | |
|---|---|---|---|---|---|---|
| Expenditure | | 0.776 | | | | -5.124* |
| | | (5.567) | | | | (5.319) |
| Professionals | | -0.0548*** | | | | -0.0466*** |
| | | (0.0121) | | | | (0.0109) |
| EX-Disaster | | | 0.0614*** | | | 0.0580*** |
| | | | (0.0128) | | | (0.0129) |
| EX-Shelter | | | 0.0433*** | | | 0.0275** |
| | | | (0.0123) | | | (0.0116) |
| EX-KobeEQ | | | -0.0199 | | | -0.0297 |
| | | | (0.0286) | | | (0.0261) |
| EX-Tohoku EQ | | | 0.0558 | | | 0.0888** |
| | | | (0.0454) | | | (0.0376) |
| Training | | | | 0.146*** | | 0.137*** |
| | | | | (0.0145) | | (0.0136) |
| Compliance | | | | 0.108*** | | 0.0976*** |
| | | | | (0.00741) | | (0.00777) |
| Education | | | | | 0.00846*** | 0.00800*** |
| | | | | | (0.00177) | (0.00170) |
| Income | | | | | 0.000190*** | 0.000170*** |
| | | | | | (1.38e-05) | (1.35e-05) |
| Children | | | | | 0.00372 | 0.0176** |
| | | | | | (0.00779) | (.00793) |
| Elderlies | | | | | 0.0405** | 0.0333* |
| | | | | | (0.0184) | (.0185) |
| Observations | 19,000 | 19,000 | 19,000 | 19,000 | 18,929 | 18,929 |
| Log Likelihood | -12305 | -12245 | -12256 | -12045 | -12022 | -11695 |
| Pseudo R2 | 0.000324 | 0.00522 | 0.00429 | 0.0214 | 0.0199 | 0.0466 |

**Note**: Dependent variable is the decision to store some positive amount of EDW (dummy = 1). Coefficients are marginal effects at sample mean. Standard errors clustered at district level. Significance levels are * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The estimated effects for the alternative explanatory variables are add evidence to the previous research on drivers: The variables capturing risk exposure are insignificant (for expenditure) or negatively related (emergency staff) to preparedness, thus supporting findings by Koerth et al. (2013) and Asseldonk et al. (2002), respectively. Risk experience is positively related to the decision to prepare, with the exception of experience of the 1995 Kobe disaster, an event more than 20 years in the past.[12] A greater affinity to risk management, expressed through active participation in drills and a general compliance with rules and recommendations, increases the likelihood of EDW storage, as do income, education, and the number of dependent individuals (children and elderlies requiring care) in the home.

Table 4 shows seven columns providing OLS estimates for the crowing effect at the intensive margin, with columns (1) through (6) using the private EDW storage of underprepared households as the dependent variable. Standard errors are again clustered at the district level. As above for the extensive margin, column 1 reports the results for a univariate model and columns (2) through (5) report on specifications with alternative explanatory variables. The last column (6) estimates all effects jointly. Column (7) differs from the other specifications: Here we report on the results of the multivariate model on the subsample of *prepared* households, i.e. those storing at least the recommend amount of EDW. This allows us to examine crowding effects in this particular subgroup and compare it to underprepared households.

As in table 3, we find robust coefficient estimates and significance levels across model specifications (1) through (6). It is also immediately apparent from column (7) that the subsample of prepared households responds in a fundamentally different way to variations in public EDW. We summarize as follows.

**Result 2***: We find clear and statistically significant evidence of crowding out of public EDW supply on the level of EDW that underprepared households store. On average, one additional liter per capita of public EDW supply decreases the amount an underprepared household stores by roughly .03 liter per capita. Prepared households' EDW supply is not subject to crowding.*

Result 2 provides evidence that the crowing effect established at the extensive margin also affects household behavior at intensive margin. Depending on the specification, the effect is somewhere between 0.023*lpc* and 0.032*lpc*: Public EDW crowds out around 3 percent of EDW supply among underprepared households. Put differently, at least 96 percent of public investment in EDW add to the preparedness of

[12] This is in line with previous papers that have noted the relatively rapid decline in the impact of disaster experience on preparedness (Botzen et al. 2009; Kunreuther et al. 1985). Note that we do not control for the age of the head of the household, which could be expected to mitigate the decline in preparedness (Osberghaus 2015).

underprepared households in net terms. Column (7) also makes clear that prepared households' EDW storage does not vary with public EDW supply. These households are not operating at a margin.

The estimated effects for the additional explanatory variables show both similarities and differences between extensive and intensive margin responses. While risk exposure fully and risk experience mostly play the same role at both margins, experience of the 1995 Kobe disaster has a mixed effect. Likewise, the risk management variable of participating in training increases the *likelihood* of being prepared, but leads to a lower *level* of preparedness, as does income. The most consequential dimension is the presence of dependent household members. While their presence positively affected the propensity to prepare, every child under five in a household reduces EDW storage by approximately 1.75*lpc* and every elderly person with care needs by around 5.4*lpc*. The shortfalls for these groups are more than half of their requirements of 3*lpc* and 6*lpc*, respectively. This means that the private EDW preparedness fails to reflect most of the EDW requirements of these two groups. One explanation for this finding is that such households face higher opportunity costs of EDW preparedness than the average due to less disposable income and less space.

Combining the extensive and the intensive margin effect, we find that increasing public EDW supply by 1*lpc* has two effects: It raises the burden on public EDW supply by 0.006*lpc* on account of raising the share of unprepared households in the population (which require 6*lpc*) by roughly 0.1 percent. It also raises the burden on public EDW supply by 0.03*lpc* on account of underprepared households reducing their level of EDW storage. In sum, an increase in public EDW supply therefore crowds out approximately 0.04*lpc*. In other words, while present, the crowding out effect is negligible in quantitative terms.

**Table 4: OLS estimates for private EDW shortfall**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | Shortfall | Shortfall | Shortfall | Shortfall | Shortfall | Shortfall | Shortfall |
| Public EDW | 0.0226*** | | | | | 0.0318*** | -0.00267 |
| | (0.00564) | | | | | (0.00606) | (0.00340) |
| Expenditure | | -12.82*** | | | | 80.53 | 3.263 |
| | | (57.71) | | | | (53.92) | (106.2) |
| Professionals | | 0.509*** | | | | 0.481** | -0.0127 |
| | | (0.166) | | | | (0.180) | (0.217) |
| EX-Disaster | | | -0.759* | | | -0.575 | -0.429 |
| | | | (0.392) | | | (0.423) | (0.529) |
| EX-Shelter | | | -0.608*** | | | -0.712* | 0.411 |
| | | | (0.360) | | | (0.379) | (0.440) |
| EX-Tohoku | | | 1.159*** | | | 1.241*** | 0.535* |
| | | | (0.374) | | | (0.399) | (0.310) |
| EX-Kobe | | | 0.0530 | . | | -0.242 | -0.291 |
| | | | (0.462) | | | (0.446) | (0.518) |
| Training | | | | 1.215*** | | 0.946*** | -0.0713 |
| | | | | (0.287) | | (0.263) | (0.1713) |
| Compliance | | | | -0.668*** | | -0.800*** | -0.557** |
| | | | | (0.173) | | (0.171) | (0.215) |
| Education | | | | | -0.197*** | -0.191*** | 0.0275 |
| | | | | | (0.0386) | (0.0373) | (0.0461) |
| Income | | | | | 0.00437*** | 0.00444*** | 0.0011*** |
| | | | | | (0.000278) | (0.000283) | (0.00031) |
| Children | | | | | 1.765*** | 1.716*** | 1.095*** |
| | | | | | (0.252) | (0.253) | (0.306) |
| Elderlies | | | | | 5.476*** | 5.393*** | 1.345** |
| | | | | | (0.406) | (0.398) | (0.551) |
| Constant | 15.47*** | 15.35*** | 15.66*** | 15.49*** | 12.79*** | 12.80*** | -8.429*** |
| | (0.280) | (0.287) | (0.304) | (0.267) | (0.306) | (0.370) | (0.403) |
| Observations | 9,202 | 9,202 | 9,202 | 9,202 | 9,171 | 9,171 | 3,116 |
| R-squared | 0.000 | 0.001 | 0.002 | 0.003 | 0.054 | 0.060 | 0.013 |
| F | 16.13 | 4.741 | . | 17.01 | 108.5 | . | . |
| Adjusted R2 | 0.00005 | 0.000869 | 0.00120 | 0.00282 | 0.0539 | 0.0586 | 0.00893 |

**Note**: Dependent variable is the amount of shortfall of a household with positive EDW storage below the recommended amount in liters. Standard errors clustered at district level. Significance levels are * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The crowding out effect estimated above takes on additional significant in light of our earlier discussion on the benefits of EDW for measuring total, rather than partial, crowding effects. Public insurance through public EDW supply and self-insurance through EDW storage by households themselves effectively exhaust a household's options for managing EDW risks in the event of a catastrophe.[13] The estimated joint crowding effects of -0.04*lpc* of private EDW storage per 1*lpc* of public EDW supply therefore provide an unusually close approximation of the total crowding effect of public intervention.

### *5.2. Robustness checks*

The estimation results reported in Tables 3 and 4 provide headline results, but are potentially contaminated by systematic factors that make certain households sort into being unprepared, underprepared, or fully prepared. Also, the OLS estimates on underprepared households in Table 4 possibly suffer from bias on account of being truncated above (towards unprepared) and below (towards prepared households) by construction. To check whether our core estimates are robust to the existence of such biases, we run an additional Heckman selection model that allows the decision to store any EDW to be determined by the data and estimate both extensive and intensive margins simultaneously. We report the results in Table 5. As even a cursory inspection shows, that the results are very close to those reported in Tables 3 and 4. The intensive margin effect increases from 0.0318 to 0.0328 and the extensive margin effect increases from -0.00109 to -0.00145. Overall, this implies no changes to the headline results.

## 6. Conclusion

In light of the recent evidence on how important disaster preparedness is for limiting morbidity and mortality impacts of catastrophes, the relationship between public disaster preparedness and private preparedness intervention has attracted renewed attention. Over the last few years, this has led to a literature that has unearthed important evidence for the presence of a crowding out effect, but also pointed to

[13] There may be a small role for insurance through neighbors and other social networks. However, disaster entail highly correlated risk events that render risk sharing ineffective.

important subtleties in the presence and scale of the effect. These subtleties in part reflect empirical challenges identified already at the inception of the crowing literature.

**Table 5**: Estimation Results of Heckman Selection Model

| VARIABLES | (1)<br>Shortfall | (2)<br>Shortfall | (3)<br>Shortfall | (4)<br>Shortfall | (5)<br>Shortfall | (6)<br>Shortfall |
|---|---|---|---|---|---|---|
| Public EDW | 0.0317*** | | | | | 0.0328*** |
| | (0.00684) | | | | | (0.00622) |
| Expenditure | | -14.01 | | | | 84.95 |
| | | (77.47) | | | | (56.94) |
| Professional | | 0.811*** | | | | 0.530*** |
| | | (0.219) | | | | (0.189) |
| EX-Disaster | | | -0.994** | | | -0.627 |
| | | | (0.393) | | | (0.415) |
| EX-Shelter | | | -0.776** | | | -0.731* |
| | | | (0.363) | | | (0.376) |
| EX-Tohoku | | | 1.215*** | | | 1.254*** |
| | | | (0.427) | | | (0.402) |
| EX-Kobe | | | -0.117 | | | -0.310 |
| | | | (0.522) | | | (0.447) |
| Training | | | | 0.490* | | 0.818*** |
| | | | | (0.284) | | (0.253) |
| Compliance | | | | -1.091*** | | -0.871*** |
| | | | | (0.161) | | (0.164) |
| Education | | | | | 0.106* | -0.202*** |
| | | | | | (0.0548) | (0.0372) |
| Income | | | | | 0.00835*** | 0.00416*** |
| | | | | | (0.000382) | (0.000280) |
| Children | | | | | 2.601*** | 1.616*** |
| | | | | | (0.333) | (0.251) |
| Elderlies | | | | | 6.931*** | 5.235*** |
| | | | | | (0.558) | (0.395) |
| Constant | 19.51*** | 19.42*** | 19.82*** | 19.87*** | -4.997*** | 13.96*** |
| | (0.504) | (0.490) | (0.572) | (0.508) | (0.690) | (0.389) |

| VARIABLES | (1)<br>EDW>0 | (2)<br>EDW>0 | (3)<br>EDW>0 | (4)<br>EDW>0 | (5)<br>EDW>0 | (6)<br>EDW>0 |
|---|---|---|---|---|---|---|
| Public EDW | -0.00125 | -0.000520 | -0.000492 | -0.000548 | -0.00028*** | -0.00145* |
| | (0.000787) | (0.000703) | (0.000711) | (0.000705) | (8.87e-05) | (0.000794) |
| Expenditure | -3.662 | -3.362 | -3.600 | -3.564 | -2.527** | -5.820 |
| | (7.009) | (7.902) | (6.949) | (6.958) | (1.043) | (8.782) |
| Professional | -0.0511*** | -0.0700*** | -0.0507*** | -0.0511*** | -0.00664*** | -0.0691*** |
| | (0.0176) | (0.0205) | (0.0176) | (0.0176) | (0.00205) | (0.0207) |
| EX-Disaster | 0.0585 | 0.0583 | 0.0823** | 0.0584 | 0.00206 | 0.0806** |
| | (0.0375) | (0.0376) | (0.0365) | (0.0375) | (0.00470) | (0.0358) |
| EX-Shelter | 0.0108 | 0.00976 | 0.0298 | 0.0107 | 0.0157*** | 0.0302 |
| | (0.0304) | (0.0304) | (0.0300) | (0.0304) | (0.00433) | (0.0300) |
| EX-Tohoku | 0.0118 | 0.0121 | -0.0164 | 0.0121 | 0.00678* | -0.0206 |
| | (0.0291) | (0.0290) | (0.0309) | (0.0291) | (0.00401) | (0.0308) |
| EX-Kobe | 0.0913* | 0.0903* | 0.0954* | 0.0903* | 0.0323*** | 0.103** |
| | (0.0497) | (0.0495) | (0.0506) | (0.0498) | (0.00614) | (0.0520) |
| Training | 0.212*** | 0.212*** | 0.212*** | 0.199*** | 0.0209*** | 0.203*** |
| | (0.0342) | (0.0341) | (0.0341) | (0.0355) | (0.00676) | (0.0350) |
| Compliance | 0.0786*** | 0.0779*** | 0.0779*** | 0.105*** | 0.00758 | 0.109*** |
| | (0.0183) | (0.0181) | (0.0182) | (0.0171) | (0.00504) | (0.0172) |
| Education | 0.0110*** | 0.0108*** | 0.0109*** | 0.0109*** | 0.00788** | 0.0169*** |
| | (0.00351) | (0.00348) | (0.00352) | (0.00353) | (0.00317) | (0.00379) |
| Income | 0.000521*** | 0.000523*** | 0.000521*** | 0.000522*** | 0.000532*** | 0.000439*** |
| | (2.49e-05) | (2.49e-05) | (2.47e-05) | (2.47e-05) | (2.42e-05) | (2.41e-05) |
| Children | 0.184*** | 0.184*** | 0.184*** | 0.184*** | 0.196*** | 0.156*** |
| | (0.0231) | (0.0230) | (0.0231) | (0.0230) | (0.0210) | (0.0236) |
| Elderlies | 0.375*** | 0.378*** | 0.377*** | 0.376*** | 0.402*** | 0.251*** |
| | (0.0391) | (0.0387) | (0.0390) | (0.0387) | (0.0340) | (0.0381) |
| Constant | -0.541*** | -0.536*** | -0.547*** | -0.549*** | -0.473*** | -0.511*** |
| | (0.0419) | (0.0417) | (0.0426) | (0.0421) | (0.0357) | (0.0425) |
| | | | | | | |
| Observations | 18,929 | 18,929 | 18,929 | 18,929 | 18,929 | 18,929 |
| Censored Observations | 9758 | 9758 | 9758 | 9758 | 9758 | 9758 |
| Log Pseudo Likelihood | -46801 | -46791 | -46791 | -46791 | -45298 | -46595 |
| Chi square | 420.2 | 488.4 | 393.6 | 551.9 | 6834 | 43.58 |

**Notes**: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The present paper exploited an empirical opportunity created by a unique dataset from a large disaster preparedness survey conducted in Japan in 2012 to address some of these challenges. By focusing on the survey's evidence on emergency drinking water, the paper studies a form of disaster preparedness in which public and self-insurance are essentially perfect substitutes and the only effective risk management options. Such a setting provides the most conducive environment in which to observe and measure the total impact of a crowding mechanism, if present, in a direct fashion.

Our statistically robust finding that public EDW supply crowds out private EDW storage at a rate of 0.04 to 1 provides clear support for the hypothesis that crowding effects are present, but small. The institutional conditions around EDW provision in Japan suggest therefore a quantitatively small amount of risk compensation. The results also highlight the particular importance of dependent household member in determining shortfall in preparedness: While households with dependents are marginally more likely to take some preparation, these preparations fall short of the requirements by at least half. This suggests that targeted supply of public EDW to these households is likely to have disproportionate impact.

In sum, the present paper adds evidence on non-hypothetical self-insurance behavior by households. This evidence weighs heavily in the direction that crowding out effects are present, but insubstantial.

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