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The effect of risk communication on consumers' risk perception, risk tolerance and utility of smart and non-smart home appliances

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A B S T R A C T

This paper advances our understanding of consumers' risk perception, risk tolerance and utility of novel technologies (e.g., smart functionality) in home appliances and the extent to which consumers' risk perception changes given risk communication about products from different actors in the network (e.g., government, manufacturer and media). Two experiments with a 2×2×2 design were conducted, each with a different product (microwave and vacuum cleaner) and sample of 400 British consumers. The following three factors were manipulated (between-subjects): product type (smart vs non-smart), risk communication scenario (government vs manufacturer) and media coverage scenario (small vs large). The results of the experiments indicate that consumers perceive the smart versions of home appliances as riskier, are less tolerant of the risks and find them less useful than the non-smart versions. Also, risk communication from the government, manufacturer and media increases perceived risk, decreases perceived utility and decreases risk tolerance of smart and non-smart home appliances. Also, men and women judge risk the same, and there is an inverse relationship between education and perceived risk. Overall, our results highlight that consumers' risk perception, utility and risk tolerance of home appliances are impacted by the product, product type (smart and non-smart), the risk communication source (government, manufacturer and the media) and demographics (gender and education).

1. Introduction

Home appliances can present serious risks such as fire and electric shock (European Commission, 2021; Which.co.uk, 2019). Moreover, risk perception, risk tolerance and utility of home appliances may differ due to demographic variables such as gender and education (DeJoy, 1992; Flynn et al., 1994; Gutteling and Wiegman, 1993; Slovic, 1999; Fischer, 2017). Despite the differences in the perceived risk of home appliances, it is essential that consumers are informed about the risks associated with these devices to protect them from potential injury or damage to their environment (Kim, 2017). Consumers are informed about product risks by manufacturers, safety regulators (both government and independent bodies) and consumers via several media vehicles such as traditional media (e.g., television), social media platforms (e.g., Twitter), events (e.g., community meetings) and product-related material (e.g. product labels) (Kim, 2017; Prior, Partridge, & Plant, 2014). The method used for risk communication by different actors in the network (i.e., manufacturers, government and media) depends on the target audience and the purpose and objectives of the risk communication (Kim, 2017). Since risk communication sources can influence consumer risk perception, risk tolerance and utility of products, including home appliances (Frewer, 2004; Frewer, Scholderer, & Bredahl, 2003), it is essential to understand their impact for better risk communication management and to protect consumers from potential harm associated with products' risks. However, there is little or no previous research on the impact of risk communication sources, e.g., manufacturer, on consumer risk perception, risk tolerance and utility of home appliances. In fact, risk tolerance is rarely studied in this domain.

Furthermore, advances in information technology, such as the internet of things (IoT) and artificial intelligence, have transformed traditional home appliances into "smart" devices. These smart home appliances can collect, process and store information and interact with their operating environment (Rijsdijk & Hultink, 2009). Since smart home appliances may pose novel and unknown risks to consumers, it is essential to understand how consumers perceive these devices' risks and whether there are unique differences (or not) when compared to non-smart versions before and after risk communication.

In the present study, we provide insights on consumers' perception of

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home appliances, specifically the differences in risk perception between smart and non-smart versions of such appliances. We evaluate how communication from various sources, e.g., manufacturers, about risks and hazards associated with home appliances influence consumers' perceived risk, utility and risk tolerance of these devices. The present study is the first of its kind to have directly contrasted smart with non-smart equivalent products to examine the relative impact of smartness on judged risk, utility and risk tolerance.

This study also complements previous work on using causal Bayesian networks (BNs) for product risk assessment (Hunte, Neil, & Fenton, 2022). Hunte, Neil and Fenton (2022) proposed a causal BN for product risk assessment that estimates the risk of consumer products by considering factors such as device use, manufacturer process information and product instances. The BN model resolves the limitations with traditional risk assessment methods such as the Rapid Exchange of Information System (RAPEX) Risk Assessment Guidelines (i.e., the primary method or guideline used to assess the risk of consumer products in the European Union) and provides reasonable risk estimates with little or no relevant historical product data. A key feature of the BN model is modelling consumer risk perception and risk tolerability. The BN fragment (i.e., a component of the BN model) shown in Fig. 1 models the impact of risk communication from the media, manufacturer and government about potential risks associated with products on consumers' risk perception, utility and risk tolerability. The risk communication sources included in the BN model (i.e., media coverage, manufacturer and government) were selected since they are the most common and familiar sources of risk communication about products' risks for the general public (Prior et al., 2014). However, due to the lack of research on the impact of different sources of risk communication on consumers' risk perception, utility and risk tolerance of products, the model structure, variables and results require validation. Hence, the results of this study can inform and validate the consumer risk perception and risk tolerability component of the BN model, allowing it to accurately predict the change in consumer risk perception, utility and risk tolerability given risk communication about products' risks from different sources.

The rest of the paper is organised as follows: Section 2 provides a review of the literature, including types of home appliances, perception of product risks, and risk communication. Section 3 describes the study; it includes our method for evaluating consumers' risk perception of home appliances and the effect of different sources of risk communication on perceived risk, utility and risk tolerance. Section 4 presents the results of our study. The results, limitations and recommendations for further research are discussed in Section 5. Finally, the conclusion is presented in Section 6.

2. Background

2.1. Home appliances: Smart and non-smart

Modern home appliances can now operate autonomously, interact with their environment and communicate with other devices (Rijsdijk & Hultink, 2009). These "smart" products use artificial intelligence (AI), IoT technology (e.g., Wi-Fi), and embedded technology (e.g., sensors) to collect, process and store information and to communicate and interact with their operating environment, users, and other products. Examples of such smart products are robot vacuum cleaners, smart microwaves, smart refrigerators and smart TVs (Abramovici, Göbel, & Savarino, 2016; Pardo, Ivens, & Pagani, 2020; Püschel et al., 2016; Rijsdijk & Hultink, 2009). Products that are not dependent on information technology are described as "non-smart". However, to a limited extent, non-smart products may possess some of the characteristics of smart products (Rijsdijk & Hultink, 2009). For instance, modern washing machines have some level of autonomy.

2.2. Consumers' perception of product risks, utility and risk tolerance

Perceived risk is consumers' subjective judgement of risk when purchasing or using a product or service (Cox & Rich, 1964; Gidron, 2013). The risk associated with products, including home appliances, consists of two components: the probability of harm and the severity of that harm (European Commission, 2015; ISO/IEC, 2014). Previous research shows that both components can influence the risk perception of products (Slovic, Fischhoff, & Lichtenstein, 1981; Vaubel & Young, 1992). For instance, Vaubel et al. (1992) show that risk perception is multidimensional and is influenced by both risk components and product familiarity.

The perceived risk of a product may depend on a single attribute (feature) of the product or the product as a whole (Fischer, 2017). In situations where the perceived risk is dependent on a single attribute of the product, if that particular attribute is perceived as risky, then the whole product is perceived as risky. This is usually the case with novel technology such as autonomous products, which are generally considered high risk and more complex compared to other products (Fischer, 2017; Fischer, Trijp, Hofenk, Ronteltap, & Tudoran, 2012; Rijsdijk & Hultink, 2003; Siegrist, Stampfli, Kastenholz, & Keller, 2008). In situations where the perceived risk of the product is based on the product as a

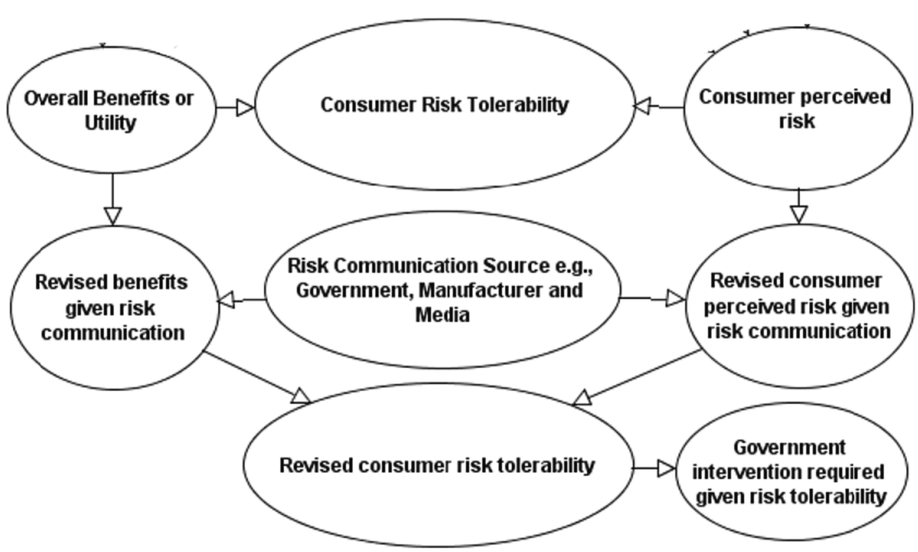

Fig. 1. Consumer risk perception and risk tolerability BN fragment.

whole, the perceived risk may depend on the trade-off between risk and utility (Fischer, 2017; Grunert, 2002). For example, the risk of using a mobile phone, such as electromagnetic radiation, is perceived as low due to the benefits, such as instant communication with family and friends (Fischer, 2017; Van Kleef, Fischer, Khan, & Frewer, 2010).

The effect of consumer characteristics on risk perception is usually investigated using the psychometric risk perception model (Fischer, 2017). This risk perception model assumes that risk is subjective and is influenced by socio-demographic factors such as gender. It measures risk perception of different hazards by asking questions directly about them and using psychometric scaling methods such as numerical rating scales to capture responses (Slovic, 1987, 1990). When applied to products, consumers perceive risks as high if they lead to serious harm or damages, e.g., death or if they are unknown and novel (Fischer, 2017; Slovic, 1987, 1990). Additionally, men perceived risks are lower than women, and higher education is associated with lower perceived risk (DeJoy, 1992; Flynn et al., 1994; Gutteling and Wiegman, 1993; Slovic, 1999).

Utility (value or benefit) is the (perceived) benefits consumers receive from using a product. Since each consumer is unique, utility is personal and situational. For example, a consumer will assign utility or value to a product based on their personality, situation and experience (Balasubramanian, Raghunathan, & Mahajan, 2005; Horn, 2017; Leroi-Werelds, Streukens, Brady, & Swinnen, 2014). In general, perceived utility has an inverse relationship with perceived risk (Alhakami and Slovic, 1994; Fischhoff et al., 1978). For instance, Alhakami and Slovic (1994) found that when persons perceive an item as having high utility, they perceive it as low risk (and vice-versa).

Risk tolerance (tolerability) is the amount of (perceived) risk consumers are willing to accept or tolerate to obtain the benefits (value or utility) of a product (Roszkowski, 2010). It is influenced by individual characteristics, knowledge (or experience) of the product, product's risks, risk controls and benefits. For instance, some research suggests that risk tolerance is a personality trait (Barsky, Juster, Kimball, & Shapiro, 1997; Eysenck & Eysenck, 1978; Wong & Carducci, 1991). For example, consumers with a high propensity to take risks are more tolerant of risks. On the other hand, other research suggests that risk tolerance is based on experience and knowledge (Corter & Chen, 2006; Kemp, 1991; Slovic, 1964). For example, consumers that are more familiar with a particular product via experience or knowledge will be more tolerant of its risks.

Given the increased availability and use of smart home appliances, there is a need to examine how consumers perceive their risks, utility and risk tolerance and whether or not they are perceived the same as non-smart versions. Previous research indicates that consumers perceive smart products or products with complex and novel technology as posing more risk (Fischer, 2017; Fischer et al., 2012; Rijsdijk & Hultink, 2003, 2009; Siegrist et al., 2008). However, previous research has not examined whether consumers exhibit the same level of risk tolerance for smart and non-smart products.

2.3. Risk communication and risk perception

Risk communication is the exchange of information between different stakeholders (such as consumers and the government) about the risks associated with products (Kim, 2017). The most common and familiar sources of risk communication about risks associated with products are the government, manufacturers and the media (Prior et al., 2014). Overall, the success of risk communication depends on the risk information (message) and the media vehicle. For instance, the risk message should be accurate and understandable, and the chosen media vehicle should be suitable for the risk message (Kim, 2017).

Additionally, the source of the risk communication can influence risk perception (Frewer, 2004; Frewer et al., 2003). For instance, media coverage and its availability (i.e. the amount of coverage) can influence risk perception since consumers become more concerned about potential risks when exposed to several news and reports about the risk (Keown, 1989; Koné & Mullet, 1994; Mazur & Lee, 1993; Morgan et al., 1985; Wåhlberg & Sjöberg, 2000). However, the effect of media coverage on risk perception is not permanent and usually fades when the media coverage fades (Wåhlberg & Sjöberg, 2000). Likewise, trust in the risk communication source can affect risk perception. For example, if consumers perceive the risk communication source as reliable and trustworthy, e.g., the government, they will most likely adhere to the risk message. However, they may ignore or reject the risk message if they perceive the risk communication source as unreliable and untrustworthy, e.g., non-experts. Hence, a lack of trust in the risk communication source will limit the effect of the risk communication (Fessenden-Raden, Fitchen, & Heath, 1987; Slovic, 1999).

Since consumers are usually informed about potential risks associated with home appliances by safety regulators, manufacturers, and media coverage, it is essential to understand the impact of the safety information from these sources on consumers' risk perception, utility and risk tolerance of home appliances (smart and non-smart). However, there is little or no previous research in this domain.

3. The study

3.1. Conceptual framework and hypotheses

This study investigates how different sources of risk communication affect consumers' risk perception, utility and risk tolerance of smart and non-smart home appliances to explore whether changes in risk perception, utility and risk tolerance conform to the BN model predictions. This study also investigates the difference in risk perception, utility and risk tolerance of smart and non-smart home appliances and whether it varies by gender and education. In this study, we used the following hypotheses to investigate these questions:

- *H1: The perceived risk is greater for smart home appliances when compared to non-smart home appliances.*
- *H2: The perceived utility is greater for smart home appliances when compared to non-smart home appliances.*
- *H3: The perceived risk tolerance is less for smart home appliances when compared to non-smart home appliances.*
- *H4: Risk communication from government, manufacturer and media will increase perceived risk, decrease utility and decrease risk tolerance of smart and non-smart products.*
- *H5: The perceived risk of smart and non-smart home appliances is less for men when compared to women.*
- *H6: The perceived risk of smart and non-smart home appliances is less for consumers with higher education.*

The conceptual framework that guided this study is shown in Fig. 2.

3.2. Study design and material

We conducted two experiments to test the study hypotheses. In each experiment, consumers were given information about a home appliance (i.e., its type and features) and a risk communication scenario and were asked questions on risk perception, utility and risk tolerance. In Experiment 1, the Microwave oven was investigated, and in Experiment 2, the Vacuum cleaner was investigated. These home appliances were chosen because they are familiar products and are available on the market as smart and non-smart (traditional) versions (see Fig. 3). The following between-subject independent variables were manipulated in each experiment:

- *Product type*: (1) Smart (2) Non-smart.

Risk communication scenarios:

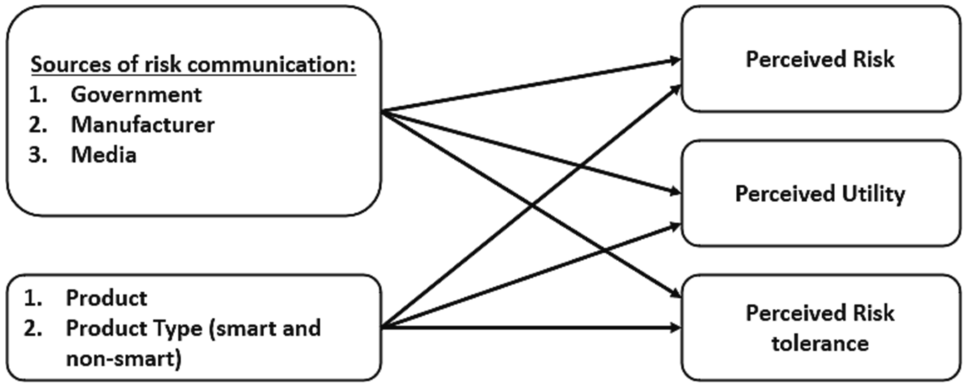

Fig. 2. Conceptual framework.

Fig. 3. Types of home appliances used in Experiments.

Table 1
Description of risk communication scenarios used in Experiments.

Scenario Name	Scenario Description
Government recall	Imagine you have bought the [product name] and the government announces a product recall due to a fire risk as follows: "The manufacturer has identified the [product name] to be recalled or replaced due to a potential risk of fire. If you have this [product type], please immediately stop using it and contact the manufacturer's hotline for a full refund or replacement".
Manufacturer recall/ warning	Imagine you have bought the [product name] and the manufacturer issues the following warning about a fire risk: "The [product name] has a potential risk of fire during use. If you have this [product name], please immediately stop using it and contact our hotline for a full refund or replacement."
Large media coverage/ story	Imagine you have bought the [product name] and there are media stories on several news outlets for many months about a fire risk including the following headline. "My [product name] catches on fire: Consumers fear for their safety as there are multiple reports of the [product name] catching fire".
Small media coverage/ story	Imagine you have bought the [product name] and there is one media story that appeared online about a fire risk with the following headline. "My [product name] catches on fire: Consumer warns of fire risk while using [product name]".

- *Risk information*: (1) Government recall (2) Manufacturer recall. (See Table 1).
- *Media coverage*: (1) Large media coverage/story (2) Small media coverage/story (see Table 1).

These independent variables were chosen based on the study's aims and hypotheses.

In Fig. 3, please note that TENCIX is a hypothetical brand created for this study. Also, the images used to represent the products (adapted from pixabay.com and pexels.com) are for illustrative purposes only.

Each experiment had a 2×2×2 design, and the dependent variables, i.e., risk, utility and risk tolerance, were assessed using the following questions:

1. *Risk:* To what extent do you consider the [product name] as posing a risk?

   Scale 1 to 100 (low risk to high risk).

2. *Utility:* How useful do you think the [product name] is?

   Scale 1 to 100 (not useful to very useful).

3. *Risk tolerance:* Please rate your ability to tolerate the risk associated with the [product name]

   Scale 1 to 100 (low tolerance to high tolerance).

3.3. Sample description

British consumers were recruited for each experiment using Prolific (https://www.prolific.co). The inclusion criteria were that they were UK residents, born in the UK, their first language is English and a pre-specified age range of 18 to 65.

For Experiment 1 (Microwave oven), $N = 400$ with women ($n = 263$, 65.8 %), men ($n = 131$, 32.8 %), non-binary ($n = 3$, 0.8 %) and prefer not to say ($n = 3$, 0.8 %). The largest age group in the sample was 25–34 ($n = 110$, 27.5 %) followed by 18–24 ($n = 103$, 25.8 %), 35–44 ($n = 103$, 25.8 %), 45–54 ($n = 47$, 11.8 %) and 55+ ($n = 37$, 9.3 %). The participants were randomly assigned to one of the eight experimental groups (2 product types × 2 risk information scenarios × 2 media coverage scenarios); group sizes varied between n = 49 and n = 51.

For Experiment 2 (Vacuum cleaner), N = 400 with women (n = 254, 63.5 %), men (n = 142, 35.5 %), non-binary (n = 3, 0.8 %) and prefer not to say (n = 1, 0.3 %). The largest age group in the sample was 25–34 (n = 130, 32.5 %) followed by 35–44 (n = 106, 26.5 %), 18–24 (n = 71, 17.8 %), 45–54 (n = 49, 12.3 %), 55+ (n = 43, 10.8 %) and prefer not to say (n = 1, 0.3 %). The participants were randomly assigned to one of the eight experimental groups (2 product types × 2 risk information scenarios × 2 media coverage scenarios); group sizes varied between n = 49 and n = 51.

3.4. Data analysis

This study used the Bayesian approach to hypothesis testing (Fenton & Neil, 2018) to investigate the hypotheses discussed in Section 3.1 (see Appendix A for BN model). The main differences between the Bayesian approach and the classical statistical hypothesis testing are:

1. In classical statistics, the data is random, and the parameters are fixed, whereas in the Bayesian approach, the parameters are unknown (random), and the data is known (fixed).
2. Classical statistics focus on obtaining sufficient evidence to justify rejecting the null hypothesis with a probability less than 1 % or 5 %. In contrast, the Bayesian approach focuses on determining the probabilities of truth of the hypotheses without any arbitrary cut-off between truth or falsehood at a specified number.

We also investigated possible interactions between product, product type, gender and risk communication using a BN model with parameters learnt from data (see Appendix A for BN model). All data analysis was done using AgenaRisk and SPSS 27 (Agena Ltd., 2022; IBM Corp, 2020).

4. Results

4.1. Risk perception, utility and risk tolerance for smart and non-smart home appliances

A summary of the mean perceived risk, mean utility and mean risk tolerance for smart and non-smart microwave ovens and vacuum cleaners is shown in Fig. 4, and the patterns indicated here were statistically examined to assess support for our hypotheses.

4.1.1. Experiment 1 results

For the microwave oven, Fig. 4 and the results of the Bayesian analysis revealed that, in support for Hypothesis 1, consumers judged the smart microwave oven as riskier (M = 33.86, 95 % CI [30.28, 37.48]) compared to the non-smart version (M = 24.75, 95 % CI [21.71, 27.73]). The mean difference was 9.13, 95 % CI [4.42, 13.92]. However, contrary to Hypothesis 2, consumers judged the smart microwave oven as having less utility (M = 60.10, 95 % CI [56.12, 64.09]) compared to the non-smart version (M = 76.99, 95 % CI [74.36, 79.60]). The mean difference was −16.88, 95 % CI [-21.68, −12.07]. In support of Hypothesis 3 consumers were less tolerant of the risks associated with the smart microwave oven (M = 63.66, 95 % CI [59.51, 67.82]) compared to the non-smart version (M = 75.99, 95 % CI [72.55, 79.47]). The mean difference was −12.34, 95 % CI [-17.80, −6.63]. Finally, a correlation analysis revealed (see Fig. 5) a negative correlation between risk and utility ratings (r = -0.25, p = 6.9e-7) and risk and risk tolerance ratings (r = -0.51, p = 4.9e-28). However, there was a positive correlation between utility and risk tolerance ratings (r = 0.31, p = 2.5e-10).

4.1.2. Experiment 2 results

For the vacuum cleaner, contrary to Hypothesis 1, the results revealed that there was little or no difference in the way consumers judged the risk of the smart vacuum cleaner (M = 24.12, 95 % CI [21.05, 27.16]) and the non-smart version (M = 21.09, 95 % CI [18.28, 23.87]). The mean difference was 3.03, 95 % CI [-1.1, 7.18]. Like the smart

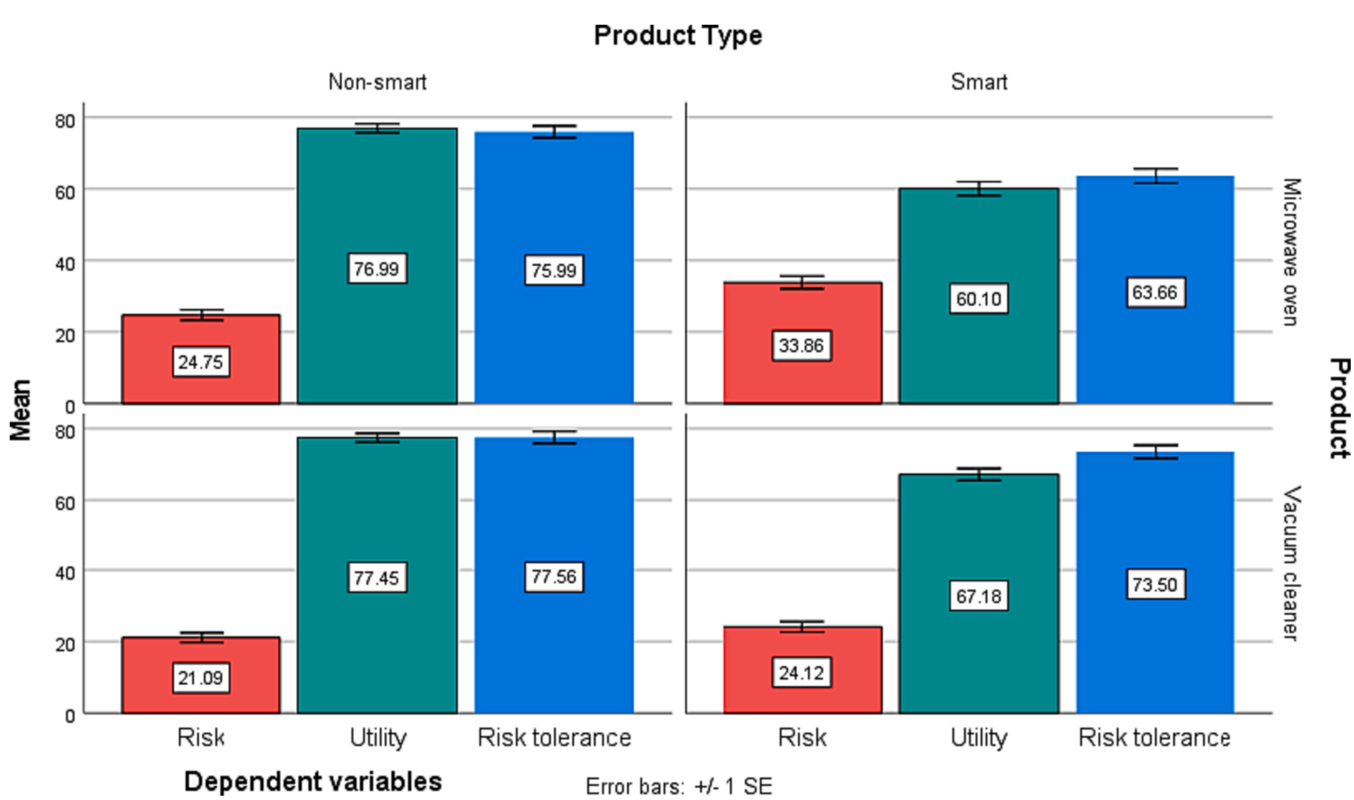

Fig. 4. Mean perceived risk, utility and risk tolerance for non-smart and smart microwave ovens and vacuum cleaners.

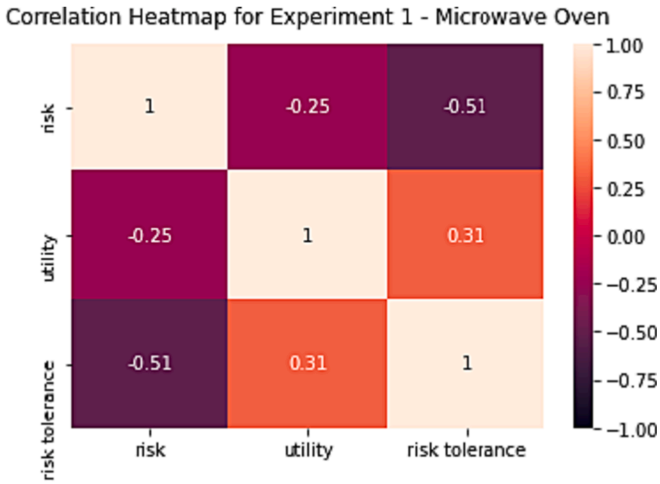

Fig. 5. Dependent variables Correlation Heatmap for Experiment 1.

microwave oven, and contrary to Hypothesis 2, consumers judged the smart vacuum cleaner as having less utility (M = 67.18, 95 % CI [63.73, 70.64]) compared to the non-smart version (*M* = 77.45, 95 % CI [74.83, 80.09]). The mean difference was −10.27, 95 % CI [-14.68, −5.89]. Similar to the perceived risk, and contrary to Hypothesis 3, there was little or no difference in the way consumers judged the risk tolerance of the smart vacuum cleaner (*M* = 73.50, 95 % CI [69.69, 77.32]) and the non-smart version (*M* = 77.56, 95 % CI [74.02, 81.09]). The mean difference was −4.05, 95 % CI [-9.29, 1.27]. Similar to Experiment 1, a correlation analysis revealed (see Fig. 6) a negative correlation between risk and utility ratings (r = -0.25, p = 4.2e-7) and risk and risk tolerance ratings (r = -0.47, p = 5.6e-23). However, there was a positive correlation between utility and risk tolerance ratings (r = 0.35, p = 2.7e-13).

4.2. *The effect of different sources of risk communication on consumers' risk perception, utility and risk tolerance of smart and non-smart home appliances*

4.2.1. *Experiment 1 results*

To investigate support for Hypothesis 4, we used Bayesian analysis to examine the effect of different sources of risk communication on risk perception, utility and risk tolerance of non-smart and smart microwave ovens. We computed the mean difference for the perceived risk, utility and risk tolerance for non-smart and smart microwave ovens before and after each risk communication scenario. The mean difference was computed as $y - x$, where x is the mean value of the perceived risk, utility and risk tolerance for a particular product before the risk communication scenario and y is the mean value of perceived risk, utility and risk tolerance for a particular product after the risk communication scenario. For instance, as shown in Fig. 7, given a government recall, the mean increase in the perceived risk is 58.10, the mean decrease in perceived utility is 33.58, and the mean decrease in perceived risk tolerance is 51.98.

According to the mean difference plot shown in Fig. 7 and the results of the Bayesian analysis shown in Table 2 and Table 3 for non-smart and smart microwave ovens, respectively, risk communication from the government, manufacturer and media stories increased perceived risk, decreased perceived utility and decreased perceived risk tolerance. Thus, we find support for Hypothesis 4.

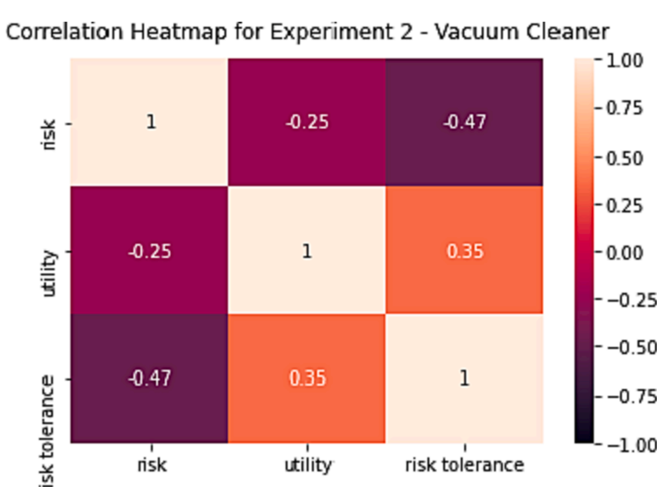

Fig. 6. Dependent variables Correlation Heatmap for Experiment 2.

4.2.2. *Experiment 2 results*

Similar to the results obtained in Experiment 1, Experiment 2 also supports Hypothesis 4. Risk communication from the government, manufacturer and media stories increased perceived risk, decreased perceived utility and decreased perceived risk tolerance for non-smart and smart vacuum cleaners (see Fig. 8 and Tables 4 and 5).

4.3. *The effect of demographics on consumers' risk perception of smart and non-smart home appliances*

4.3.1. *Gender*

According to the combined results shown in Fig. 9 and Table 6, we did not find support for Hypothesis 5. There was little difference in the perceived risk for smart and non-smart microwave ovens and vacuum cleaners between men and women.

4.3.2. *Education*

In general, for the smart and non-smart microwave ovens, the perceived risk decreases as the level of education increases (see Fig. 10), lending support for Hypothesis 6. This pattern was the same for the smart vacuum cleaner; however, for the non-smart vacuum cleaner, there was little difference between the perceived risk for lower and higher education levels. Further analysis revealed (see Fig. 11) that the pattern of ratings of risk for the microwave oven was the same for each education level, i.e., the smart version was judged riskier than the non-smart version. This pattern was the same for the vacuum cleaner only at lower education levels (i.e., Secondary and Higher education); at higher education levels, there was little difference in the perceived risk for the smart and non-smart versions.

4.4. *Investigating interaction effects between product type, gender and risk communication on perceived risk, utility and risk tolerance*

4.4.1. *Experiment 1*

For the smart microwave oven, before a large media story, the perceived risk for women (*Median* = 34, IQR [17, 50]) was similar to men (*Median* = 31, IQR [14, 48]) and the perceived utility for women (*Median* = 62, IQR [43, 81]) was greater compared to men (*Median* = 54, IQR [36, 72]). After the large media story, the perceived risk for women was greater (*Median* = 83, IQR [68, 97]) compared to men (*Median* = 72, IQR [58, 87]). The difference in perceived risk between men and women after the large media story though the evidence was not strong, can be explained by the inverse relationship between risk and utility since the perceived utility for women (*Median* = 28, IQR [8, 47]) was lesser compared to men (*Median* = 34, IQR [15,52]) after the large media story.

4.4.2. *Experiment 2*

For the smart vacuum cleaner, before the government recall, the perceived risk for women (*Median* = 26, IQR [12, 40]) was similar to men (*Median* = 20, IQR [6, 34]) and the perceived utility for women

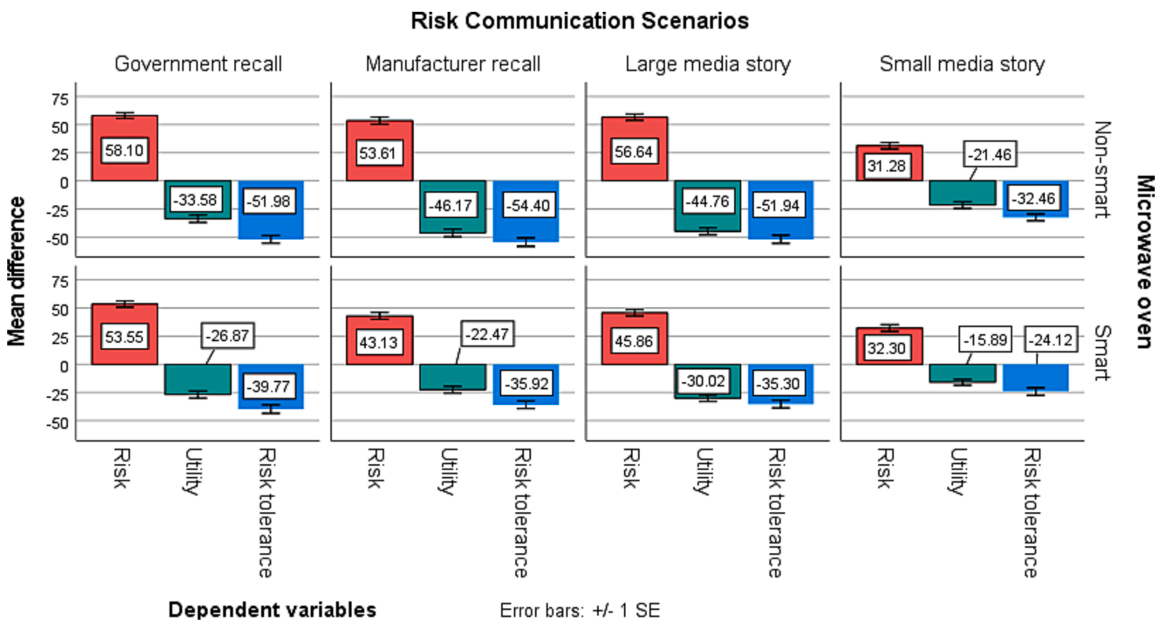

Fig. 7. The mean difference in the perceived risk, utility and risk tolerance for non-smart and smart microwave ovens for each risk communication scenario.

Table 2
Results of Bayesian two means hypothesis test for non-smart microwave oven.

Product	Risk communication	Dependent variables	*n*	Before risk communication: *x*			After risk communication: *y*			Mean difference: *y* – *x*	L-95 % CI	U-95 % CI
				Mean	L-95 % CI	U-95 % CI	Mean	L-95 % CI	U-95 % CI			
Non-smart microwave oven	Government recall	Risk	100	23.78	19.46	28.02	81.88	78.19	85.6	58.1	52.39	63.82
		Utility	100	78	74.22	81.79	44.42	37.85	50.90	−33.58	−41.19	−26.02
		Risk tolerance	100	75.06	69.95	80.15	23.08	18.15	27.96	−51.98	−59.16	−44.87
	Manufacturer recall	Risk	100	25.72	21.39	30.09	79.33	73.75	84.87	53.61	46.42	60.65
		Utility	100	75.97	72.33	79.6	29.8	23.15	36.46	−46.17	−53.80	−38.53
		Risk tolerance	100	76.92	72.22	81.66	22.52	16.42	28.49	−54.4	−62.26	−46.76
	Large media story	Risk	100	22.99	18.70	27.25	79.63	75.22	84.07	56.64	50.46	62.83
		Utility	100	78.68	75.42	81.92	33.92	27.60	40.21	−44.76	−51.92	−37.59
		Risk tolerance	100	76.82	71.94	81.76	24.88	19.46	30.25	−51.94	−59.37	−44.61
	Small media story	Risk	100	26.51	22.11	30.95	57.79	52.23	63.35	31.28	24.09	38.44
		Utility	100	75.29	71.18	79.42	53.83	47.52	60.07	−21.46	−29.02	−13.92
		Risk tolerance	100	75.16	70.19	80.17	42.7	36.85	48.61	−32.46	−40.19	−24.66

Table 3
Results of Bayesian two means hypothesis test for smart microwave oven.

Product	Risk communication	Dependent variables	*n*	Before risk communication: *x*			After risk communication: *y*			Mean difference: *y* – *x*	L-95 % CI	U-95 % CI
				Mean	L-95 % CI	U-95 % CI	Mean	L-95 % CI	U-95 % CI			
Smart microwave oven	Government recall	Risk	100	31.15	26.16	36.17	84.7	80.82	88.60	53.55	47.15	59.94
		Utility	100	60.75	55.07	66.44	33.88	27.69	40.08	−26.87	−35.28	−18.37
		Risk tolerance	100	65.78	59.72	71.79	26.01	20.38	31.71	−39.77	−48.08	−31.34
	Manufacturer recall	Risk	100	36.57	31.24	41.83	79.7	74.39	84.98	43.13	35.57	50.68
		Utility	100	59.45	53.72	65.32	36.98	31.06	43.05	−22.47	−30.92	−14.02
		Risk tolerance	100	61.54	55.60	67.42	25.62	19.95	31.43	−35.92	−44.18	−27.50
	Large media story	Risk	100	34.18	28.80	39.47	80.04	75.49	84.52	45.86	38.82	52.94
		Utility	100	61.26	55.29	67.17	31.24	25.18	37.40	−30.02	−38.55	−21.35
		Risk tolerance	100	60.48	54.36	66.59	25.18	19.83	30.49	−35.3	−43.54	−27.08
	Small media story	Risk	100	33.54	28.43	38.63	65.84	60.47	71.18	32.3	24.84	39.79
		Utility	100	58.94	53.57	64.36	43.05	37.46	48.60	−15.89	−23.78	−8.11
		Risk tolerance	100	66.84	61.20	72.48	42.72	36.92	48.42	−24.12	−32.32	−16.04

(*Median* = 67, IQR [50, 84]) was the same as men (*Median* = 67, IQR [54, 79]). After the government recall, the perceived risk for women was greater (*Median* = 82 [72, 92]) compared to men (*Median* = 74, IQR [61, 88]). The difference in perceived risk between men and women after the government recall though the evidence was not strong, may be due to the inverse relationship between risk and utility since the perceived utility after the government recall was slightly less for women (*Median* = 42, IQR [24, 63]) compared to men (*Median* = 44, IQR [24, 65]).

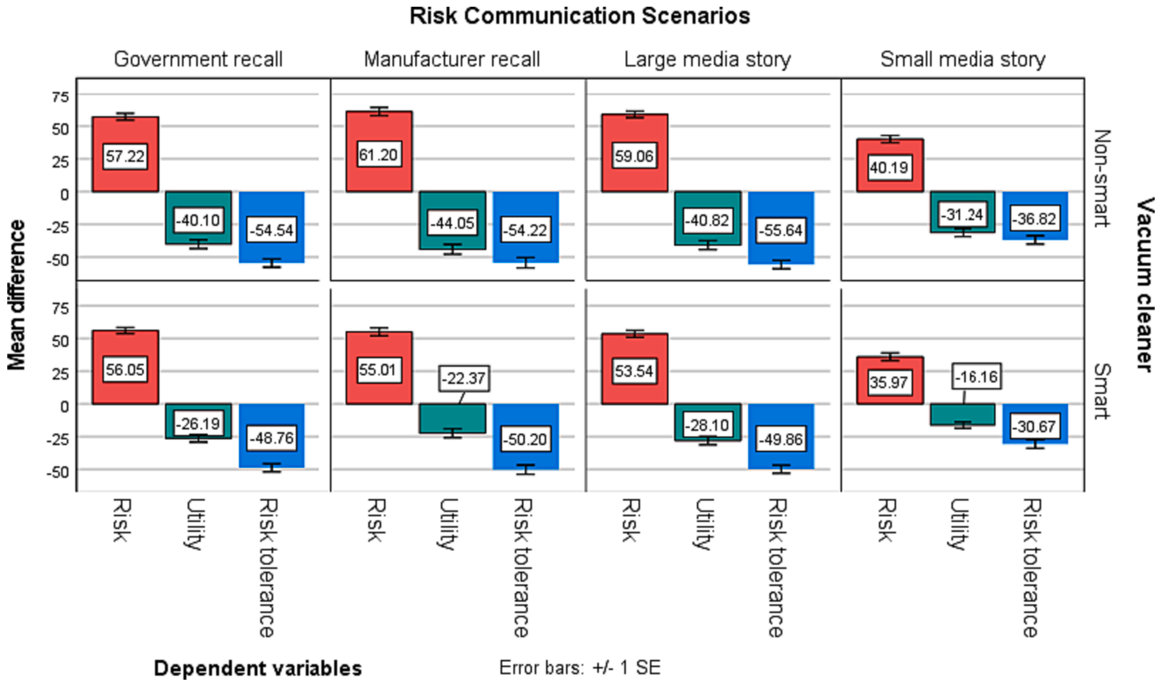

Fig. 8. The mean difference in the perceived risk, utility and risk tolerance for non-smart and smart vacuum cleaners for each risk communication scenario.

Table 4
Results of Bayesian two means hypothesis test for non-smart vacuum cleaner.

Product	Risk communication	Dependent variables	*n*	Before risk communication: *x*			After risk communication: *y*			Mean difference: *y* – *x*	L-95 % CI	U-95 % CI
				Mean	L-95 % CI	U-95 % CI	Mean	L-95 % CI	U-95 % CI			
Non-Smart Vacuum cleaner	Government recall	Risk	*101*	*23.85*	*19.66*	*28.09*	*81.07*	*76.69*	*85.48*	*57.22*	*51.01*	*63.32*
		Utility	*101*	*75.69*	*72.22*	*79.15*	*35.59*	*29.54*	*41.63*	*−40.1*	*−47.12*	*–33.05*
		Risk tolerance	*101*	*77.06*	*72.25*	*81.91*	*22.51*	*17.86*	*27.14*	*−54.55*	*−61.33*	*−47.85*
	Manufacturer recall	Risk	*100*	*18.31*	*14.68*	*21.91*	*79.51*	*73.93*	*85.07*	*61.2*	*54.48*	*67.86*
		Utility	*100*	*79.23*	*75.48*	*82.95*	*35.18*	*28.23*	*42.12*	*−44.05*	*−52.01*	*−36.10*
		Risk tolerance	*100*	*78.06*	*72.76*	*83.38*	*23.84*	*17.97*	*29.67*	*−54.22*	*−62.20*	*−46.28*
	Large media story	Risk	*101*	*21.7*	*17.48*	*25.89*	*80.76*	*76.4*	*85.13*	*59.06*	*52.98*	*65.20*
		Utility	*101*	*74.31*	*70.33*	*78.30*	*33.49*	*27.11*	*39.72*	*−40.82*	*−48.46*	*–33.35*
		Risk tolerance	*101*	*75.96*	*71.07*	*80.89*	*20.32*	*15.94*	*24.73*	*−55.64*	*−62.32*	*−48.96*
	Small media story	Risk	*100*	*20.48*	*16.76*	*24.25*	*60.67*	*55.31*	*66.03*	*40.19*	*33.57*	*46.75*
		Utility	*100*	*80.63*	*77.51*	*83.75*	*49.39*	*43.31*	*55.46*	*−31.24*	*−38.10*	*−24.35*
		Risk tolerance	*100*	*79.17*	*74.07*	*84.20*	*42.35*	*36.68*	*48.02*	*−36.82*	*−44.44*	*−29.12*

Table 5
Results of Bayesian two means hypothesis test for smart vacuum cleaner.

Product	Risk communication	Dependent variables	*n*	Before risk communication: *x*			After risk communication: *y*			Mean difference: *y* – *x*	L-95 % CI	U-95 % CI
				Mean	L-95 % CI	U-95 % CI	Mean	L-95 % CI	U-95 % CI			
Smart Vacuum cleaner	Government recall	Risk	*100*	*24.2*	*19.79*	*28.66*	*80.25*	*76.58*	*83.86*	*56.05*	*50.25*	*61.83*
		Utility	*100*	*68.5*	*64.02*	*72.91*	*42.31*	*36.00*	*48.63*	*−26.19*	*–33.94*	*−18.36*
		Risk tolerance	*100*	*73.74*	*68.51*	*78.93*	*24.98*	*19.89*	*30.09*	*−48.76*	*–56.11*	*−41.4*
	Manufacturer recall	Risk	*99*	*24.03*	*19.74*	*28.30*	*79.04*	*73.72*	*84.30*	*55.01*	*48.12*	*61.83*
		Utility	*99*	*65.85*	*60.62*	*71.10*	*43.47*	*36.86*	*50.06*	*–22.38*	*−30.85*	*−13.86*
		Risk tolerance	*99*	*73.26*	*67.56*	*78.85*	*23.06*	*17.98*	*28.07*	*−50.2*	*−57.79*	*−42.53*
	Large media story	Risk	*100*	*24.69*	*20.26*	*29.13*	*78.23*	*73.09*	*83.25*	*53.54*	*46.66*	*60.30*
		Utility	*100*	*64.61*	*59.26*	*70.15*	*36.51*	*30.20*	*42.94*	*−28.1*	*−36.66*	*−19.60*
		Risk tolerance	*100*	*72.98*	*67.64*	*78.32*	*23.12*	*18.49*	*27.71*	*−49.86*	*−57.00*	*−42.68*
	Small media story	Risk	*99*	*23.54*	*19.23*	*27.71*	*59.51*	*53.76*	*65.41*	*35.97*	*28.78*	*43.37*
		Utility	*99*	*69.78*	*65.30*	*74.30*	*53.62*	*48.21*	*59.09*	*−16.16*	*–23.24*	*−9.03*
		Risk tolerance	*99*	*74.03*	*68.55*	*79.49*	*43.36*	*37.17*	*49.61*	*−30.67*	*−38.96*	*–22.29*

5. Discussion

The present study advances our understanding of consumers' risk perception, risk tolerance and utility of smart and non-smart home appliances and the extent to which consumers' risk perception changes given risk communication from different actors in the network (e.g.,

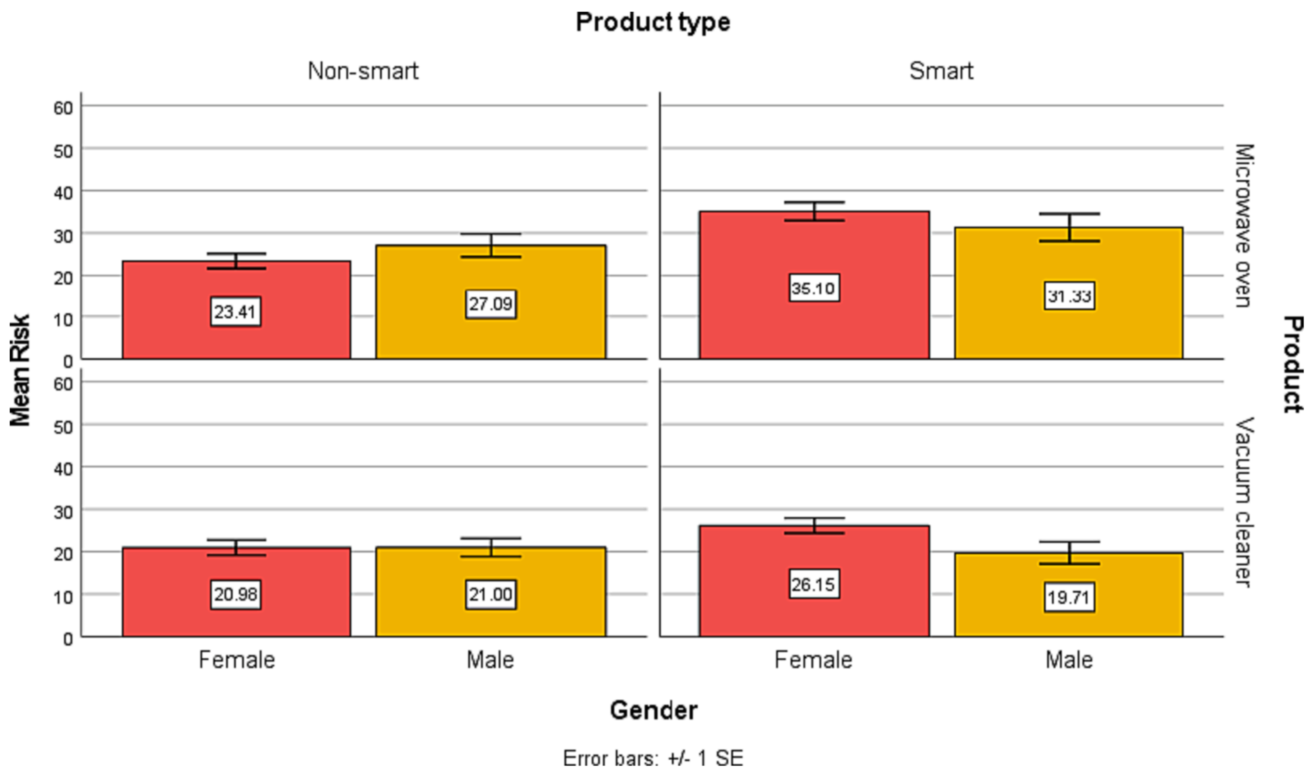

Fig. 9. Mean perceived risk for microwave oven and vacuum cleaner by gender.

Table 6
Results of Bayesian two means hypothesis test for gender.

Product	Dependent variables	Women: *x*				Men: *y*				Mean difference: *y* – *x*	L-95 % CI	U-95 % CI
		n	Mean	L-95 % CI	U-95 % CI	*n*	Mean	L-95 % CI	U-95 % CI			
Non-smart microwave oven	Risk	*127*	*23.41*	*19.84*	*27.23*	*70*	*27.09*	*21.42*	*32.82*	*3.68*	*−3.12*	*10.52*
Smart microwave oven	Risk	*136*	*35.1*	*30.64*	*39.49*	*61*	*31.33*	*24.5*	*38.02*	*−3.77*	*−12.01*	*4.33*
Non-smart vacuum cleaner	Risk	*118*	*20.98*	*17.32*	*24.68*	*80*	*21*	*16.49*	*25.56*	*0.02*	*−5.91*	*5.96*
Smart vacuum cleaner	Risk	*136*	*26.15*	*22.43*	*29.87*	*62*	*19.71*	*14.26*	*25.26*	*−6.44*	*−13.1*	*0.31*

government, manufacturer and media). Overall, the results show that risk perception of home appliances is influenced by product type (smart and non-smart), risk communication and demographics. In the following subsections, we will discuss the results and their implications, the strengths and limitations of the study and recommendations for further research.

5.1. Risk perception

As expected, we found that consumers generally judge smart home appliances as riskier and were less tolerant of their risks when compared to non-smart home appliances. Our results corroborate previous research, suggesting that smart products or products with novel technology are perceived as riskier when compared to other products (Fischer, 2017; Fischer et al., 2012; Rijsdijk & Hultink, 2002, 2003, 2009; Siegrist et al., 2008; Slovic, 1987). For instance, Slovic (1987) demonstrated this through the unknown risk dimension of the psychometric approach. This finding suggests that product manufacturers should aim to reduce the perceived risk associated with smart products. Product manufacturers could do this by informing consumers about product functionality and safety controls, while retail stores could do it through product trials and demonstrations which will allow consumers to evaluate the product functionality and safety controls before purchase (Rijsdijk & Hultink, 2009).

Contrary to our expectations, we found that consumers perceived smart home appliances as having less utility than non-smart home appliances. Our results contradict previous research suggesting that smart products generally offer better utility than non-smart products (Rijsdijk & Hultink, 2009). However, our results are consistent with previous research highlighting the inverse relationship between perceived risk and utility, i.e., higher risks are associated with less utility or benefits (Alhakami and Slovic, 1994; Fischhoff et al., 1978). Since the inverse relationship between risk and utility explains our results, product manufacturers should aim to reduce the perceived risk associated with smart products since it also impacts the perceived utility. Our finding also suggests that product demonstrations and trials may increase the perceived utility of smart products by focusing on the additional functionalities and benefits offered, such as autonomy and time-savings.

5.2. Risk communication

As expected, our results found that risk communication from different sources impacted risk perception. The government, manufacturer, and large media coverage/story each contributed to a similar level of increase in perceived risk, and they each lowered the level of utility and risk tolerance to a similar degree. On the other hand, small media

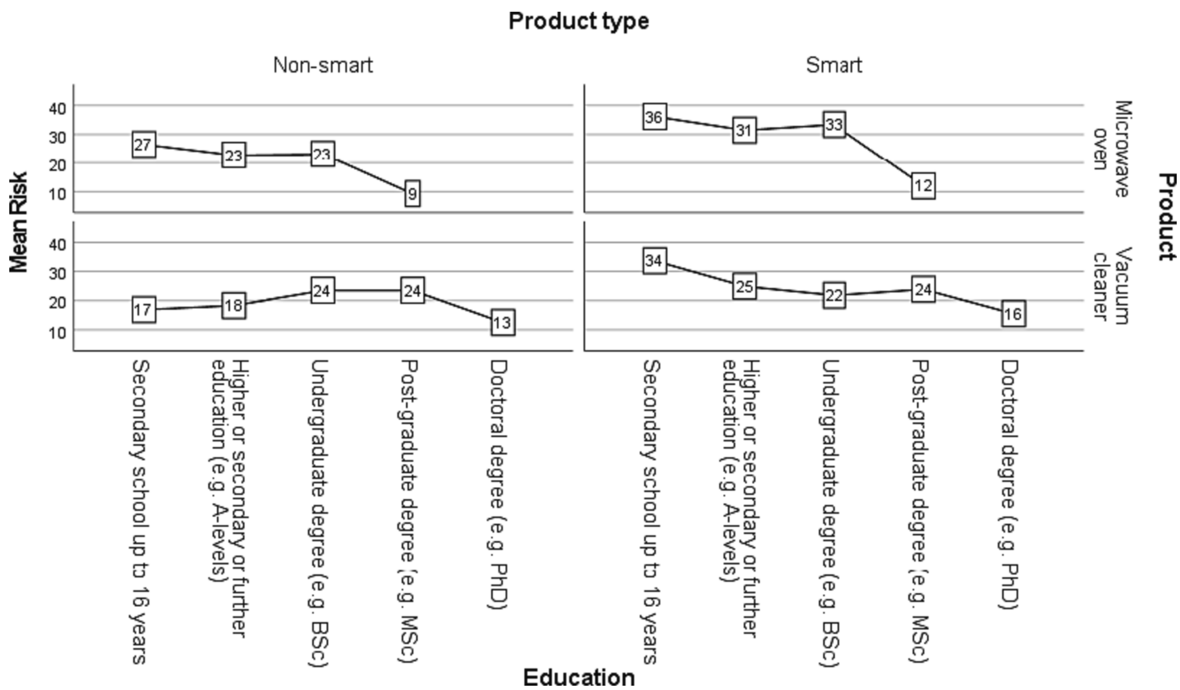

Fig. 10. Mean perceived risk vs Education level by Product and Product type.

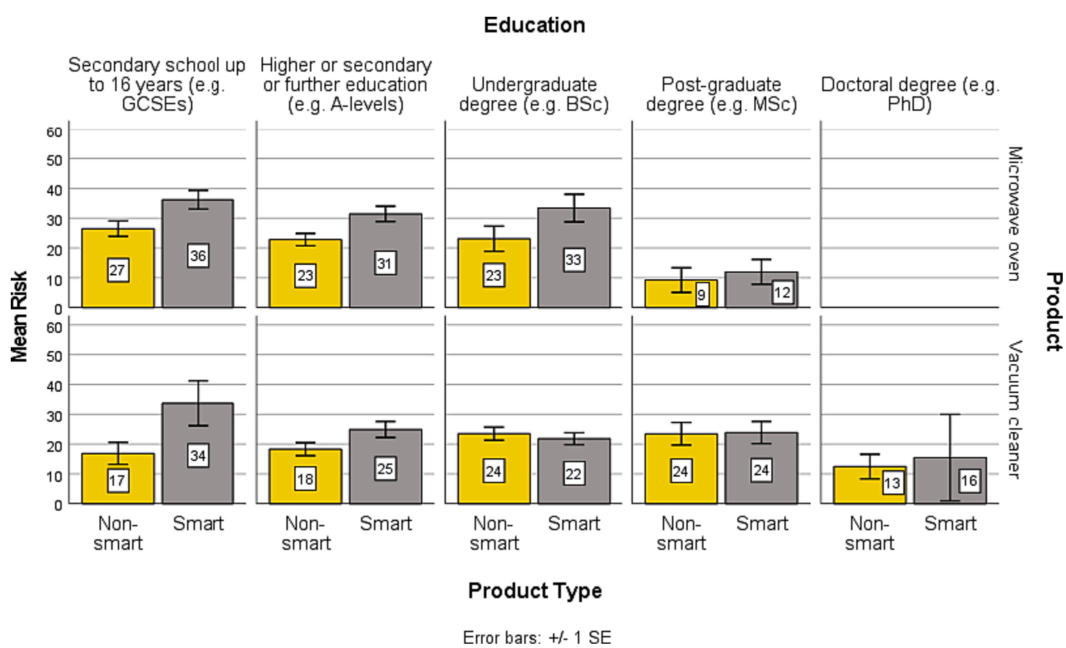

Fig. 11. Mean perceived risk for microwave oven and vacuum cleaner by Education Level.

coverage/story had the least impact on perceived risk, utility and risk tolerance. Our findings corroborate the results of the BN model and previous research (Fessenden-Raden et al., 1987; Koné & Mullet, 1994; Mazur & Lee, 1993; Morgan et al., 1985; Slovic, 1999; Wåhlberg & Sjöberg, 2000). These results have implications for risk communicators – identifying which source of risk communication significantly influences risk perception means that risk communication strategies can be tailored to increase awareness of risk and hazards associated with products.

Unsurprisingly, we found that large media coverage had a greater impact on risk perception when compared to small media coverage, hence confirming previous research (Mazur, 1981, 1990; Mazur and Lee, 1993; Wåhlberg and Sjöberg, 2000; Wiegman and Gutteling, 1995). These results have implications for risk communicators – identifying the amount of media coverage that significantly influences risk perception means that risk communication strategies can be tailored to increase awareness of risks and hazards associated with products. Also, providing the public with frequent, accurate and complete information about risks can ensure that the effect of risk communication on the public's risk perception is maintained (Mazur, 1981, 1990; Wåhlberg and Sjöberg, 2000; Wiegman and Gutteling, 1995).

5.3. *Demographics*

Contrary to our expectations, we found no difference in the risk perception of smart and non-smart home appliances between men and women. This finding contradicts previous research suggesting that men tend to judge risks smaller when compared to women (Davidson and Freudenburg, 1996; Slovic, 1999; Barke et al., 1997). On the other hand, some research suggests that gender differences are not evident for all types of risk and are dependent on environment or context (Davidson & Freudenburg, 1996; Greenberg & Schneider, 1995; Hellesøy, Grønhaug, & Kvitastein, 1998; Hitchcock, 2001). For instance, Davidson and Freudenburg (1996) observed that gender differences are most evident for technologies that pose a risk of contamination, such as nuclear technology. Hence, our results and previous research highlight the need to understand the impact of contextual factors such as environment and socio-demographics on risk perception. This will allow better characterisation of gender differences and their impact on risk perception.

We found that higher educational level was associated with less perceived risk and so confirmed previous research (Sjöberg, 1998; Sjöberg and Drottz-Sjöberg, 2009; Slovic, 1999). This suggests that risk communication should be tailored for different subpopulations to effectively influence risk perception and behaviour. Also, product manufacturers may reduce perceived risk via product trials, demonstrations, focus group sessions and safety information.

5.4. Strengths and limitations of study

In this study, response bias and demand characteristics were minimised in several ways. We performed two experiments with different products and participants. Hence the findings in Experiment 1 are validated by Experiment 2. Also, in each experiment, we used between-subjects design whereby participants were randomly assigned a product type, risk information and media coverage scenario.

Although our work captured the perceived risk, utility (benefits) and risk tolerance of smart and non-smart home appliances, we recognise that the extent to which our results can be generalised for all home appliances is limited, especially since only two types of home appliances were investigated. Hence the results of this study may vary given other types of home appliances since the perception of risk, utility and risk tolerance is product dependent (Alhakami and Slovic, 1994; Rijsdijk and Hultink, 2009; Slovic, 1987, 1999; Fischer, 2017). In addition, our study did not include variables such as product price, which may well impact the perceived utility of the products.

5.5. Recommendations for further research

Further research should seek to examine the risk perception of other home appliances, especially since risk perception is product dependent (Alhakami and Slovic, 1994; Rijsdijk and Hultink, 2009; Slovic, 1987, 1999; Fischer, 2017). Examining other types of home appliances would allow for a better understanding of the differences in risk perception between different home appliances and their smart and non-smart versions. Also, further research should consider product price and willingness to pay (WTP) since they may impact the perceived utility of the products. Our ongoing work is addressing these specific limitations, and preliminary results are already available.

6. Conclusion

The present study examined consumers' perceived risk, utility and risk tolerance of smart and non-smart home appliances and how they are impacted by risk communication. The results of this study show that consumers perceive smart versions of home appliances as riskier, less useful and are less tolerant of their risks when compared to non-smart versions. Hence, product manufacturers should aim to reduce the perceived risk associated with smart products via product trials and demonstrations.

Identifying which risk communication has a significant impact on risk perception is key to developing effective risk communication strategies. Our findings show that risk communication from the government, manufacturer, and media increases consumers' perceived risk and decreases their perceived utility and risk tolerance of smart and non-smart home appliances. However, small media coverage/story had the least impact on perceived risk, utility and risk tolerance. Hence this study's results validate the results of the BN fragment used for modelling consumer risk perception (see Fig. 1).

Finally, our findings also show that men and women judge risk the same, and higher education is associated with lower perceived risk. Hence while there is no great need to tailor risk communication differently for men and women, it should be tailored to the needs of different subpopulations. Also, product manufacturers may reduce perceived risk by conducting focus group sessions, product trials and providing additional safety information.

CRediT authorship contribution statement

Joshua L. Hunte: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Martin Neil:** Writing – review & editing, Supervision, Resources, Methodology, Formal analysis, Conceptualization. **Norman E. Fenton:** Writing – review & editing, Validation, Supervision, Resources, Methodology, Formal analysis, Conceptualization. **Magda Osman:** Writing – review & editing, Validation, Resources, Methodology, Conceptualization. **Christos Bechlivanidis:** Writing – review & editing, Validation, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Norman Fenton and Martin Neil are Directors of Agena Ltd.

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Appendix A

This section presents the Bayesian network (BN) model, variables, and node probability tables (NPTs) for comparing two population means and distributions. The Bayesian approach includes the following steps:

1. Learn the population mean and variance from the sample mean and sample variance for each population using the BN model shown in Figure 12. This model uses the following theorem to learn the population distribution:

$$Sample\ variance = Chisquared(n-1) \times variance/(n-1)$$

Where n is the sample size. See Table 7 for node probability tables (NPTs).

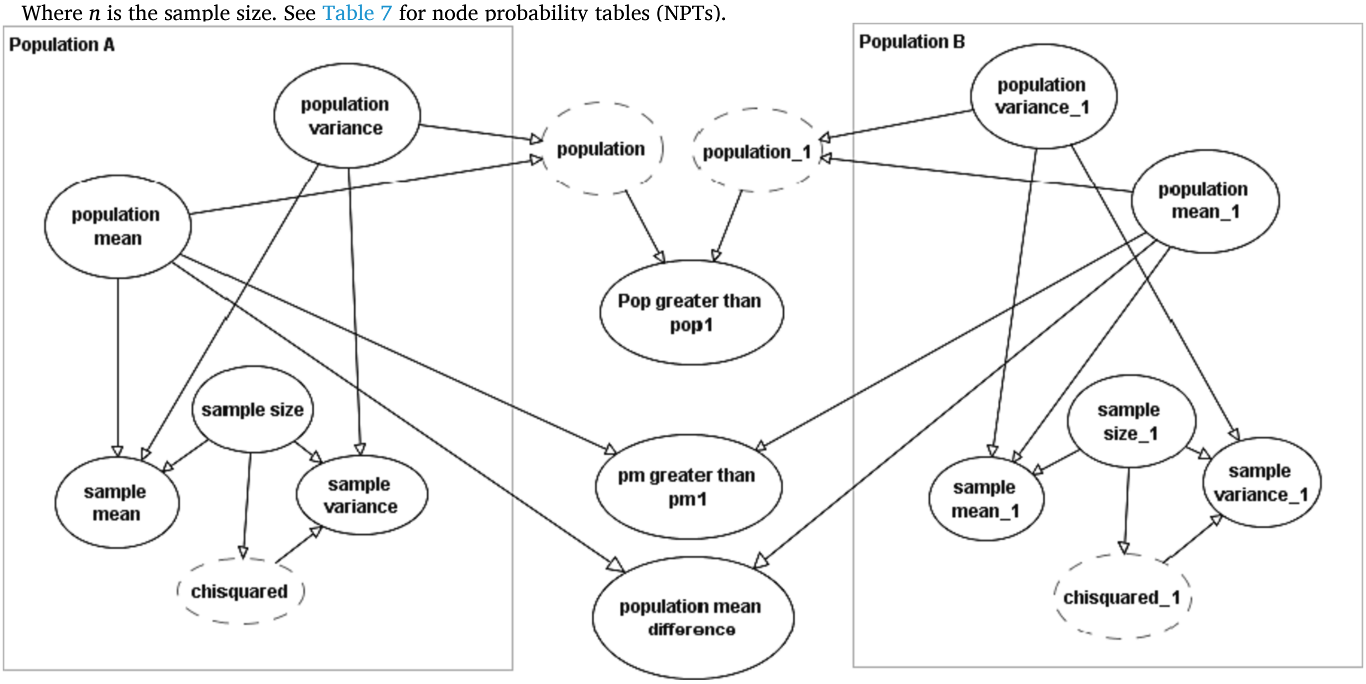

Fig. 12. BN model used for two means hypothesis test

2. Determine the difference between the two populations by estimating the difference in the population means and distributions using the nodes *pop greater than pop1*, *pm greater than pm1,* and *population mean difference*.

Table 7
BN Variables and NPTs for BN model used for two means hypothesis test.

Variables	Abbrev.	Node Probability Tables
Sample size	*n*	Normal (0, 1000000)
Sample mean	*sm*	Normal (pm, pv/n)
Sample variance	*sv*	chisquared × pv/(n − 1.0)
Population mean	*pm*	Normal (0, 1000000)
Population variance	*pv*	Normal (0, 1000000)
Chisquared	*chisquared*	Chi Squared(n − 1.0)
Population	*pop*	Normal (pm, pv)
Population_1	*pop1*	Normal (pm_1, pv_1)
Pop greater than pop1	*popcomparison*	If (pop > pop_1, “True”, “False”)
PM greater than PM1	*pmcomparison*	If (pm > pm_1, “True”, “False”)
Population mean difference	*pm_difference*	pm − pm_1
Population variance_1	*pv_1*	Normal (0, 1000000)
Population mean_1	*pm_1*	Normal (0, 1000000)
Sample size_1	*n_1*	Normal (0, 1000000)
Sample mean_1	*sm_1*	Normal (pm_1, pv_1/n_1)
Sample variance_1	*sv_1*	chisquared1 × pv_1/(n_1 − 1.0)
Chisquared_1	*chisquared1*	Chi Squared(n_1 − 1.0)

The BN model shown in Figure 13 was used to investigate the interaction effects between gender, product, product type and risk communication source on perceived risk, utility and risk tolerance. The model NPTs was learnt from the study data.

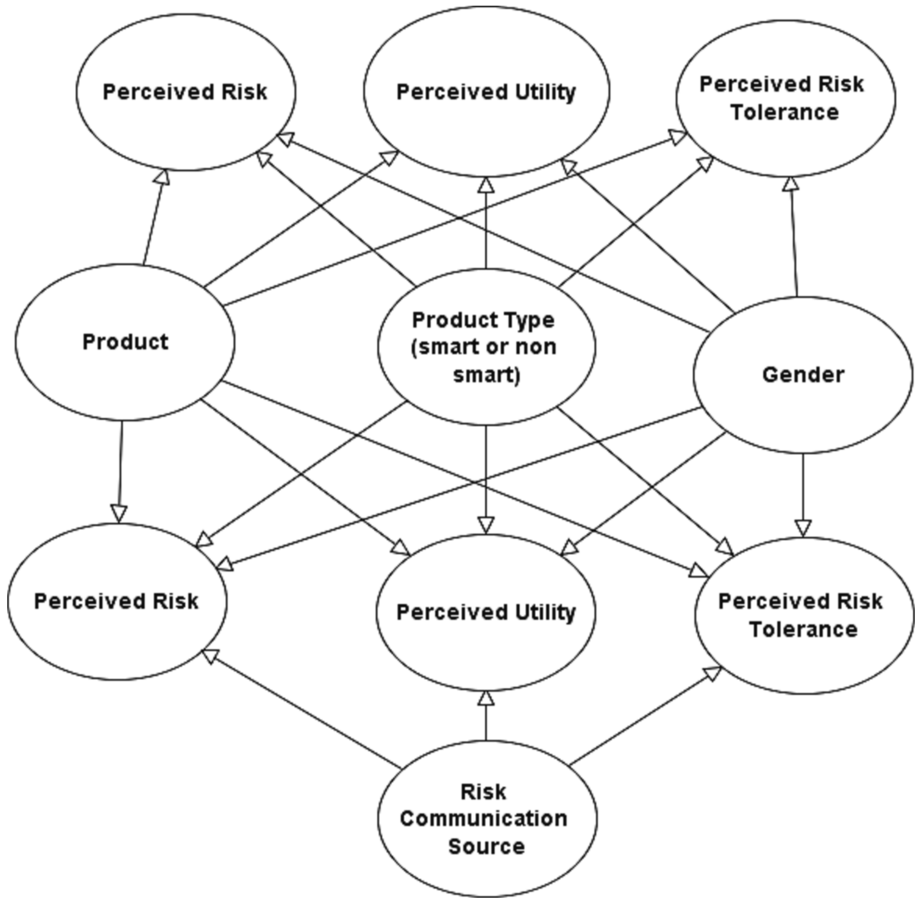

Fig. 13. BN model used to investigate interaction effects between variables

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