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Benefits and risks of smart home technologies

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ABSTRACT

Smart homes are a priority area of strategic energy planning and national policy. The market adoption of smart home technologies (SHTs) relies on prospective users perceiving clear benefits with acceptable levels of risk. This paper characterises the perceived benefits and risks of SHTs from multiple perspectives.

A representative national survey of UK homeowners (n=1025) finds prospective users have positive perceptions of the multiple functionality of SHTs including energy management. Ceding autonomy and independence in the home for increased technological control are the main perceived risks. An additional survey of actual SHT users (n=42) participating in a smart home field trial identifies the key role of early adopters in lowering perceived SHT risks for the mass market. Content analysis of SHT marketing material (n=62) finds the SHT industry are insufficiently emphasising measures to build consumer confidence on data security and privacy.

Policymakers can play an important role in mitigating perceived risks, and supporting the energy-management potential of a smart-home future. Policy measures to support SHT market development include design and operating standards, guidelines on data and privacy, quality control, and *in situ* research programmes. Policy experiences with domestic energy efficiency technologies and with national smart meter roll-outs offer useful precedents.

1. Introduction

Smart homes are one of the EU's 10 priority action areas in its Strategic Energy Technology Plan: "*Create technologies and services for smart homes that provide smart solutions to energy consumers*". Behind this strategic policy objective lies *"the Commission's vision for the electricity market [which] aims to deliver a new deal for consumers, smart homes and network, data management and protection"* (EC, 2015). A wide range of publicly-funded projects across the EU are designed to engage consumers in this vision (Gangale et al., 2013). Underlying the EU's strategic goals for a smart home future are clear assumptions that households seek a more active role in the energy system. The Commission argues that *"Communities and individual citizens are eager to manage energy consumption …"* (EC, 2015; EESC, 2015). From this policy perspective, smart homes are enabling technologies to meet a latent demand by households for home energy control and management. As such smart homes are seen as an integral part of a future energy efficient system, helping to reduce overall demand as well as alleviating supply constraints during periods of peak load (Lewis, 2012; Firth et al., 2013). As in the EU, widespread diffusion of smart homes in the UK has already been anticipated in policy documents (DECC, 2009; HMG, 2009) and is seen as an important 'building block' of the smart grid (DECC-OFGEM, 2011). Smart home experts agree that "*climate change and energy policy will drive UK smart home market development*" (Balta-Ozkan et al., 2013a).

Smart home technologies (SHTs) comprise sensors, monitors, interfaces, appliances and devices networked together to enable automation as well as localised and remote control of the domestic environment (Cook, 2012). Controllable appliances and devices include heating and hot water systems (boilers, radiators), lighting, windows, curtains, garage doors, fridges, TVs, and washing machines (Robles and Kim, 2010). Sensors and monitors detect environmental factors including temperature, light, motion, and humidity. Control functionality is provided by software on computing devices (smartphones, tablets, laptops, PCs) or through dedicated hardware interfaces (e.g., wall-mounted controls). These different SHTs are networked, usually wirelessly, using standardised communication protocols. The diversity of available SHTs means the smart home has many possible configurations and by implication, 'smartness' (Aldrich, 2003). In this paper,

*Abbreviations:*SHTs, smart home technologies

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'smart homes' is used as a generic descriptor for the introduction of enhanced monitoring and control functionality into homes.

SHTs are increasingly on sale both off-the-shelf and with professional installation. Examples available in the UK include British Gas' HIVE system for controlling heating and hot water systems, and RWE's SmartHome system for heating, appliances and lighting. The global market for smart appliances (including fridges, washing machines, tumble dryers, dishwashers and ovens) is projected to grow 650-fold from $40 m in 2012 to $26bn in 2019 (IEA, 2013). Global consumer research carried out in seven countries worldwide, including the UK & Germany, suggests a high level of market support (GfK, 2015). Over half the consumers surveyed expressed a general interest in smart homes, and 50% believe SHTs will have an impact on their lives over the next few years (GfK, 2016). Market forecasts project over half a million households in Germany will have smart appliances or devices by 2019, driven by widespread adoption of smart phones (Harms, 2015).

However, actual levels of uptake of SHTs are still low, and smart product sales are dominated by internet-connected TVs (Harms, 2015). Market growth will ultimately depend on prospective users clearly perceiving potential benefits with acceptable levels of risk. In terms of benefits, SHTs can provide not just enhanced energy management, but also improved security and security, enhanced leisure and entertainment services, and extended personal independence through healthcare provision and assisted living (Chan et al., 2009; Nyborg and Røpke 2011).

Communicating these benefits alone is insufficient. SHT developers are already recognising the challenge of gaining the trust and confidence of prospective users (Harms, 2015). Market research has found the most significant barrier to adoption is upfront cost, followed by lack of awareness and privacy concerns (GfK, 2016). Several studies have examined prospective users' concerns about SHTs in more depth using small samples in technology demonstration labs, deliberative workshops, or focus groups (Paetz et al., 2012; Balta-Ozkan et al., 2013a, 2014). These studies have confirmed interest in the energy management potential of smart homes, but have also identified potential market barriers to adoption including cost, privacy, security, reliability, and the interoperability of different technologies. Privacy and trust-related issues have delayed or halted smart-meter rollouts (AlAbdulkarim and Lukszo, 2011; Hoenkamp et al., 2011). Similar issues may arise with data collected by internet-enabled SHTs within the home (Cavoukian et al., 2010; Balta-Ozkan et al., 2013b). A wider set of sociotechnical concerns with SHTs includes an increased dependence on technology, electricity networks or outside experts, and the proliferation of non-essential luxuries inducing laziness in domestic life (Balta-Ozkan et al., 2013b).

This suggests prospective users are more circumspect about SHTs than policymakers. Market analysis finds that "*market players, industry and retailers need to collaborate to create awareness of smart homes and to communicate the features, but especially, the benefits of these systems*" (Harms, 2015). Early adopters attracted by the novelty of SHTs are particularly important for differentiated marketing and sales strategies (Moore, 2002). Early adopters 'seed' market growth by trialling and testing innovations and communicating their benefits and functionality to the more risk-averse majority of consumers (Rogers, 2003). The profile of potential early adopters willing to take greater risks in being the first movers to adopt SHTs is largely unknown. Yet policies to support SHTs need to be particularly sensitive to early adopters' distinctive characteristics (Egmond et al., 2006).

Three important questions characterise the potential market for SHTs and shape the smart home policy environment:

Q1. How do prospective users perceive the *specific benefits* and *risks* of SHTs?

Q2. Do *early adopters* have distinctive perceptions of SHTs?

Q3. Is industry marketing of SHTs *aligned* with the perceptions of prospective users?

This paper answers each of these questions by analysing three new data sources: a national market survey of prospective SHT users (n=1025); an early adopter survey of SHT field trial participants (n=45); content analysis of SHT industry marketing material (n=62). The two surveys were conducted in the UK, a major consumer market into which smart meters are currently being rolled out, and SHTs are becoming commercially available. The content analysis of industry marketing material focused on the SHT industry active in EU markets, with a subsample of smaller UK-focused companies.

This paper makes novel contributions to the important policy challenge of enabling smart technology diffusion into homes throughout the UK and Europe. First, perceived benefits and risks of SHTs are comprehensively assessed, providing a strong evidence base for policy to address areas of consumer concern while reinforcing SHTs' potential contribution to energy system objectives. Second, the characteristics of SHT early adopters are distinguished, enabling targeted policy to help initiate market growth. Third, inconsistencies between industry, prospective users, and policymakers' vision for smart homes are identified, pointing to critical areas in which policy leadership can shape the development of the SHT market. These policy implications are addressed in detail in the concluding section. This follows an explanation of data collection methodology and sampling, and then the presentation of key results and analysis.

2. Methodology and data

This section provides details of the different datasets used in the analysis, the data collection instruments and sampling procedures, and the sample characteristics of each dataset. SPSS version 22 was used for all the survey data analysis; Microsoft Excel was used for the content analysis of industry marketing material.

2.1. National survey

A survey instrument was developed by the research team to measure prospective users' perceptions of the benefits, risks, and design attributes of SHTs, as well as general issues of consumer confidence in SHTs.

The survey instrument was structured in two parts. Part One contained socio-demographic questions (respondent age, respondent gender, household size, household income, home tenure) and a basic question on smart home awareness used to screen respondents. The screening question was included to minimise hypothetical response biases from homeowners with no prior knowledge about SHTs. The screening question was "*Do you know what 'smart home technologies are?*". Response options ranged from "*no idea*", "*vague idea*", "*general idea*", "*good idea*" to "*already have some installed*". Respondents answering "*no idea*" were screened out and did not continue the survey. All other respondents passed the screening question and moved on to Part Two.

Part Two of the survey began with an open-ended question asking respondents to provide a few words "*that first come to mind when you think about 'smart home technologies'?*". Respondents were then asked about the information channels through which they had found about SHTs (6 response options). The remainder of Part Two comprised detailed questions measuring perceptions of SHTs. Perceptions were measured on a 5 point Likert scale (from 1=strong disagree to 5=strongly agree) with an additional "don't know" response option. Questions measuring prospective users' perceptions were ordered as follows:

- the main *purposes* of SHTs (9 response options);
- the potential *benefits* of SHTs (12 response options);
- the relevance of SHTs for specific domestic *activities* (8 response options);
- the *design* features of SHTs (7 response options);

- the *control* of SHTs (7 response options);
- the potential *risks* of SHTs (12 response options).

All survey questions were developed, iteratively tested and refined for clarity and comprehensibility prior to implementation. No background information was provided to respondents at the beginning of the survey to minimise priming effects on responses. The order of response options within each block of questions was randomised to minimise potential ordering effects on responses (Choi and Pak, 2005). The full survey instrument is provided in the Supplementary material. The survey data are also publically available via the UK Data Service's ReShare data repository (collections 852366 & 852367).

The survey was implemented online by a market research company, SSI (Survey Sampling International). SSI scripted an online version of the survey instrument using their proprietary software. Once checked by the research team, SSI sent unique person-specific links to the survey to individuals in their respondent panel who have agreed previously to take part in survey research in exchange for incentives. The sampling frame for this study comprised: (i) homeowners, (ii) in the UK, (iii) over the age of 18. Survey responses were collected online by SSI from 18 September to 14 October 2015 until the minimum target sample size of 1000 was exceeded. The average survey completion time was just under 7 min. Further details on the sampling procedure is provided in the Supplementary material.

The sample pre-screening comprised n=1150 respondents (Table 1). A total of n=125 respondents with "*no idea*" about SHTs were screened out (10.7% of pre-screening sample). This means that the final sample post-screening slightly over represents homeowners familiar with SHTs. The final sample post-screening comprised n=1025 respondents (Table 2).

Respondents were grouped according to their levels of prior knowledge: low, medium, high (including respondents who already have some SHTs installed) (see Table 1). The high, medium, low prior knowledge groups are proxies for the early adopter, early majority, and late majority market segments which have different propensities towards the adoption of new technologies (Rogers, 2003). Similar segmentation based on prior knowledge has been used in the UK's consumer engagement plan for the smart meter roll-out (SMCDB, 2013).

In this study, the subsample of respondents with high prior knowledge of SHTs are of particular interest. This subsample is labelled and analysed as 'potential early adopters of SHTs' (n=385). This subsample is drawn from the full sample of respondents to the national survey which is labelled and analysed as 'prospective users of SHTs' (n=1025). 'Potential early adopters' are therefore a subset (i.e., not independent) of 'prospective users' (see Table 2).

Table 1
Prospective users' prior knowledge of smart home technologies.

Do you know what 'smart home technologies' are?			
Response options	**Pre-screening**	**Post-screening (final sample)**	**Groups based on prior knowledge**
No idea	10.7%		
Vague idea	21.8%	24.4%	Low prior knowledge (=late majority)
General idea	34.0%	38.0%	Medium prior knowledge (=early majority)
Good idea	29.7%	33.3%	High prior knowledge (=early adopters)
Already have some installed	3.8%	4.3%	
	n=1150	n=1025	

2.2. Early adopter survey

Participants in a smart home field trial were surveyed to measure perceptions of SHTs from a small sample of actual early adopters (n=45). The field trial ran from 2013 to 2015 in Loughborough, UK (Kane et al., 2015). Twenty participating households voluntarily signed up to have advanced heating controls and other SHTs installed in their homes, prior to these SHTs being widely commercially available in the UK. As such, this sample is considered to comprise *actual* early adopters. Through their informed consent to participate in the field trial, participants were aware of the general characteristics of SHTs. However, the survey was implemented before any SHTs were actually installed. Up to this point the research team running the field trial (including the authors of this article) had been careful to frame information about SHTs in generic terms and to minimise possible priming effects on respondents' perceptions of SHTs benefits and risks. The survey was implemented in May – August 2014 (at least two weeks prior to SHTs being installed in participants' homes).

The survey instrument was identical to that used in the national survey with three exceptions: (1) no screening questions were included; (2) an additional block of questions on the design of SHT interfaces was included; (3) the block of questions on SHT risks was excluded to avoid unduly raising concerns among households about to have SHTs installed.

Surveys were distributed to members of the 20 households participating in the field trial. These households spanned a range of household types including single occupancy, dual-income families with children, and retired couples. A total of 45 household members from 18 households provided responses to the survey. Respondents ranged in age from ten to seventy-four, and were drawn from professions that included students, carers, IT consultants and those not currently in paid work (see Supplementary material for further details on sample and recruitment). Table 2 (right hand column) summarises the sample characteristics. Unlike the national survey with one adult respondent per household, multiple respondents including children were sampled from the same households in the early adopter survey.

2.3. Industry marketing material

Marketing material from companies active in the smart home market was systematically analysed using content analysis. Content analysis is a widely used method for characterising texts, documents, and other published material through simple quantitative descriptors such as the frequency of occurrence of a defined set of 'codes'. The codes are linked to specific words, phrases or meanings of the textual content. Recent applications in the energy domain include content analyses of online marketing by green electricity providers (Herbes and Ramme, 2014), of images associated with different forms of energy production (O'Neill et al., 2013), and of the underlying dimensions of energy-related behaviours (Boudet et al., 2016).

To analyse industry marketing material on SHTs, a comprehensive set of codes were developed under three themes: design and function; users; control and management. Each of these themes comprises multiple codes capturing more specific and discrete issues (see Supplementary material for full coding template). Each of these issues had previously been identified in a literature review of research on smart homes and their prospective users (Wilson et al., 2015). The set of codes therefore provided a systematic basis for analysing the content of industry marketing material on SHTs.

A wide range of companies active in the smart home market were sampled from a list of participants at a major smart home industry conference, supplemented by web searches for UK-based companies. For each company, marketing materials were identified that related either to specific SHTs or to more general smart home visions. Materials included print, web, and video publications. The final sample comprised 62 companies (see Supplementary materials for details of

Table 2
Sample characteristics.

Survey sample (and sample size):		National survey (full sample, n=1025)	National survey (subsample with high prior knowledge, n=385)	Early adopter survey (n=45)
Referred to in the text as:		***prospective users of SHTs***	***potential early adopters of SHTs***	***actual early adopters of SHTs***
Respondent age	under 35	18.7%	27.1%	26.6%
	35–44	18.0%	22.1%	17.8%
	45–54	20.1%	20.6%	15.6%
	55–64	19.3%	14.8%	20.0%
	over 64	23.8%	15.4%	20.0%
Respondent gender	male	49.3%	61.6%	48.9%
	female	50.7%	38.4%	51.1%
Household size	1	17.5%	13.5%	5.6%
	2	42.6%	34.3%	44.4%
	3	17.5%	20.8%	16.7%
	4	17.2%	22.3%	27.8%
	5 or more	5.3%	9.1%	5.6%
Household income	under £25,000	24.1%	19.5%	not known
	£25,000 – £40,000	35.4%	30.1%	
	over £40,000	34.2%	45.5%	
	prefer not to say	6.2%	4.9%	

the sample and methodology).

The characteristics of the companies sampled are summarised in the upper half of Fig. 1, and the characteristics of the marketing material sampled in the lower half of Fig. 1. Characteristics are non-exclusive, so the totals per pie chart in Fig. 1 can exceed 62.

The majority of companies were EU-based but active in multiple markets. The majority of material analysed was text or video on company websites (n=46) as well as brochures (n=10). The material was much more likely to be a sales pitch advertising specific SHTs available in the market (n=52) than a broader vision of a smart home future (n=12). Marketing material was targeted at other businesses and at prospective users (households) in roughly equal proportions.

The sample of companies and marketing material is not designed to be representative. However it does cover different types of material from a wide range of companies active in smart home markets. We tested for associations between principal region of operation and coding results and found no associations (see Supplementary materials for details). In other words, for our sample, the principal markets in which sampled companies were active do not affect the content of material analysed.

3. Results and discussion

3.1. Prospective users of SHTs

The national survey characterised how prospective users perceived

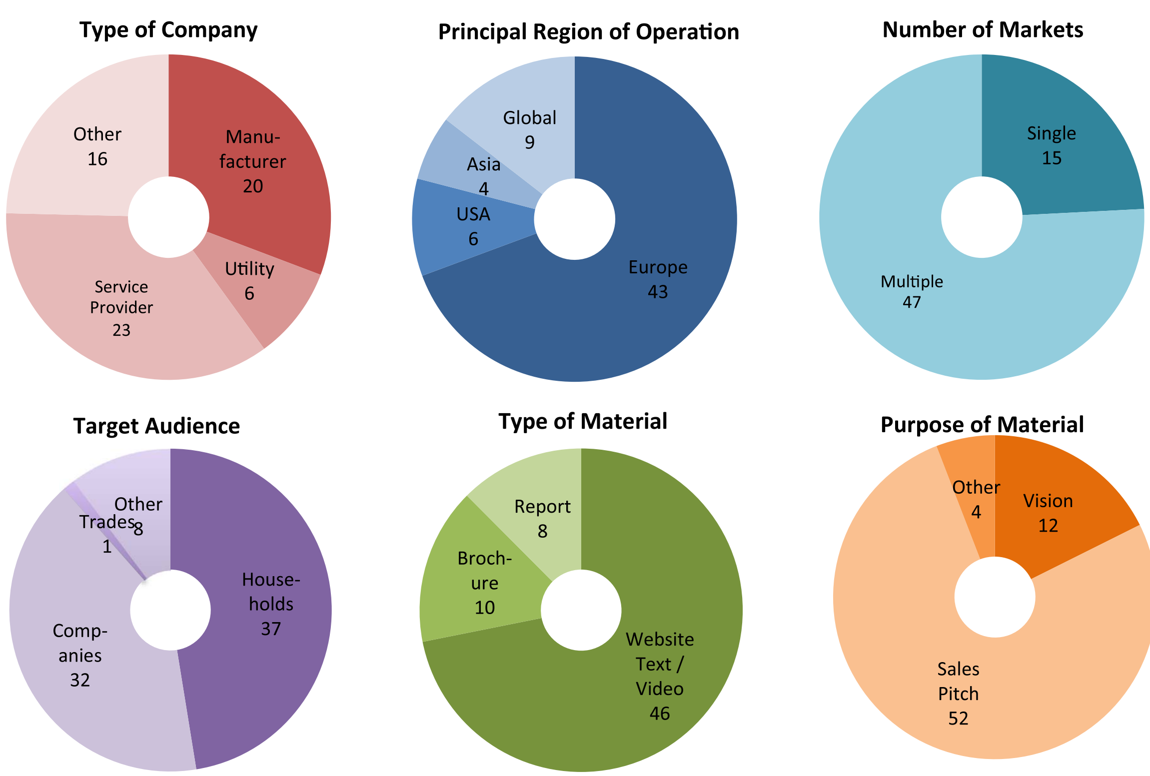

Fig. 1. Sample characteristics of industry marketing material. Notes: Upper three pies show characteristics of companies; lower three pies show characteristics of marketing material. Totals that are greater than n=62 are due to non-exclusive characteristics.

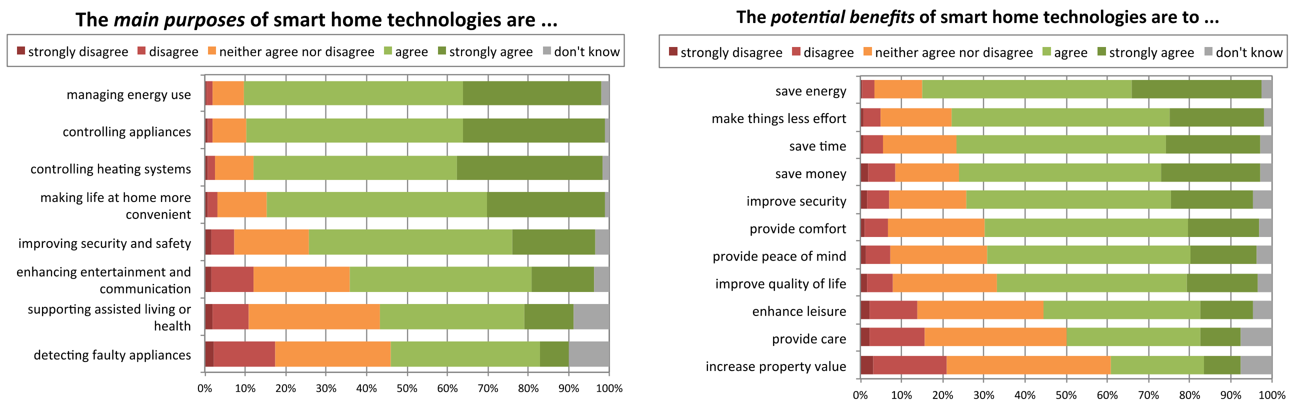

Fig. 2. Prospective users' perceptions of the purpose & benefits of smart home technologies.

benefits and risks of SHTs. Survey respondents clearly perceive the *main purpose* of SHTs to be controlling energy, heating and appliances (Fig. 2, left panel). Over 86% of respondents agreed or strongly agreed with these three response options. The smart home is dominantly seen through an energy management lens. The purpose of the smart home in making life at home more convenient (83% agree or strong agree), providing security (71%), and enhancing entertainment and communication (60%) are also clearly perceived (see Supplementary material for full results).

The potential benefits of SHTs for prospective users are clearly related to these purposes. Respondents perceive the *potential benefits* of SHTs to be saving energy, time, and money, as well as making domestic life less effortful (Fig. 2, right panel). Again, there is overall agreement for all response options with response means exceeding the midpoint of the response scales.

An additional question further probed perceptions of the potential benefits of SHTs by asking about the *domestic activities* most likely to be affected. Activities included cooking, cleaning, washing, leisure, socialising, or working. Responses were extremely similar overall. Respondents weakly agreed that all activities were of similar relevance, and were unable to distinguish particular aspects of domestic life that would be made more convenient, easy, or comfortable (see Supplementary material for full results).

Prospective users also perceive risks associated with SHTs (Fig. 3, left panel). However despite public and media attention on monitoring, privacy and data security issues with smart technologies in the home, much broader issues are of greater concern. Prospective users of SHTs more strongly perceive *potential risks* in the increasing dependence of domestic life on systems of technology provision (77% agree or strongly agree) and electricity networks (63%) (Fig. 3, left panel). The benefits of increased control over the domestic environment come at the expense of reduced autonomy and independence of the home from encompassing sociotechnical systems. A British person's smart home is no longer their castle.

However, respondents also considered that SHT designers, developers and providers can take a range of steps to ensure *consumer confidence* (Fig. 3, right panel). At least 80% of respondents agreed or strongly agreed with each of the six response options. SHTs should be designed to be reliable, easy to use, controllable, and easy to over-ride. The market applications of SHTs should guarantee privacy, confidentiality, and secure data storage. SHTs should also be provided by credible companies with resources to provide performance warranties.

The national survey included questions on the design and control of SHTs to understand how prospective users perceive SHTs affecting domestic life. Control over the domestic environment is the principal purpose of SHTs (Fig. 2), and how control is exercised and by whom depends on the design of SHT interfaces and devices. Respondents perceived their role as controllers of SHTs in both active and passive ways (Fig. 4, left panel). SHTs enable control *by* households, but also automate control *for* households, although always running in the background. Respondents similarly perceive SHTs both to be *always on* and active, and to operate *only when activated*. In both cases these apparently contradictory modalities of control and operation indicate the multiple ways in which SHTs can be configured. Prospective users have clear perceptions of how SHTs are controlled on a day-to-day basis: through a combination of pre-set scheduling, automated responses, and user inputs or adjustments; using multiple not single devices; and by multiple not single users (Fig. 4, right panel).

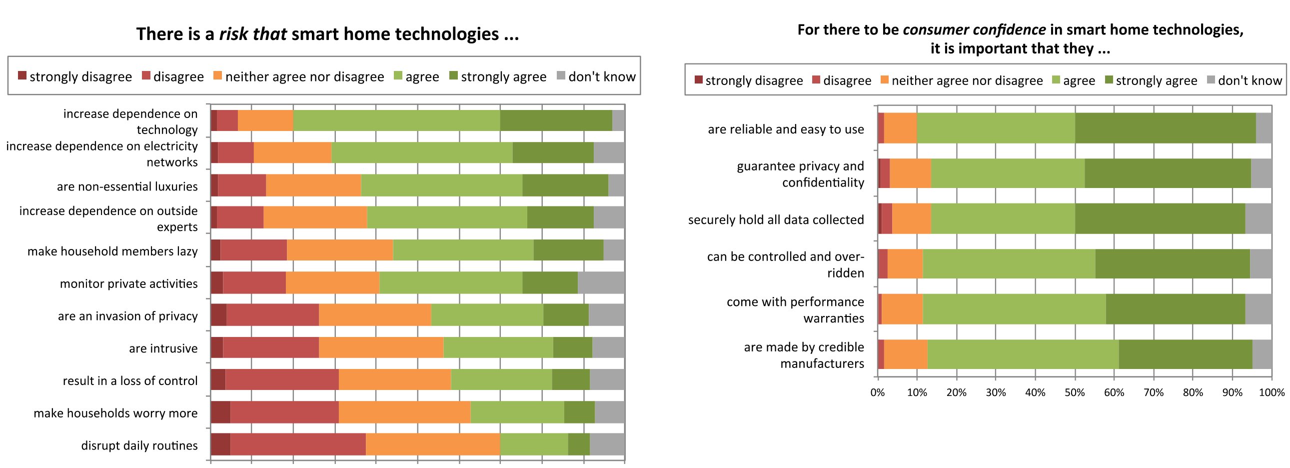

Fig. 3. Prospective users' perceptions of risks and confidence-building measures for smart home technologies.

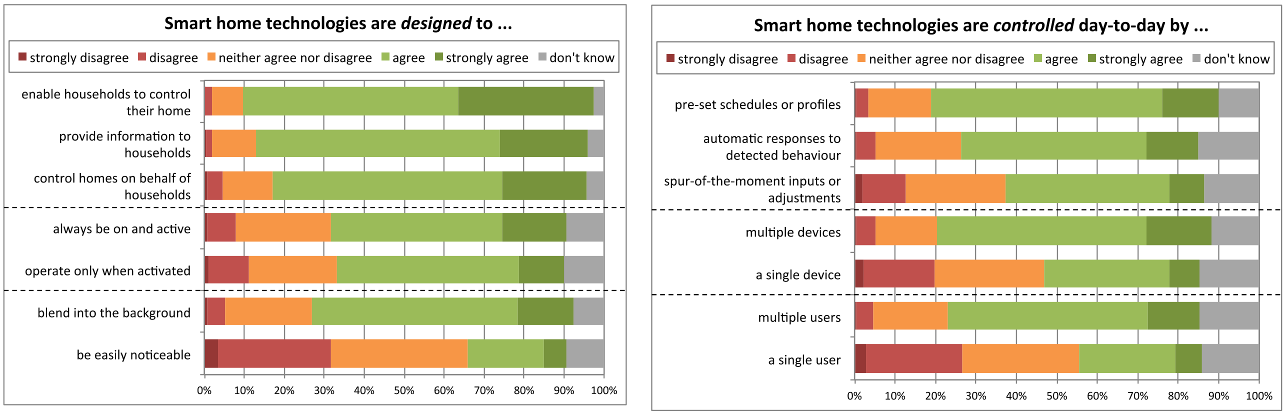

Fig. 4. Prospective users' perceptions of the design and control of smart home technologies.

3.2. Potential early adopters of SHTs

Prospective users with high prior knowledge of SHTs are indicative of a potential early adopter market segment. The characteristics of early adopters have been well characterised in the technology diffusion literature (Rogers, 2003). Relative to later adopter groups in the mass market, early adopters:

(H1). have higher prior awareness of an innovation;

(H2). are wealthier and have more diverse social networks;

(H3). actively seek information from a variety of sources;

(H4). are less susceptible to interpersonal influence;

(H5). perceive stronger benefits of adoption;

(H6). perceive risks of adoption to be more manageable.

Using high prior knowledge of SHTs (H1) as a proxy for potential early adopters allows the distinctive characteristics of this important market segment to be tested. Potential early adopters comprised 37.6% of the final sample (n=385, see Table 2).

Chi-squared tests showed high prior knowledge to be significantly associated with socioeconomic characteristics (Table 3). Specifically, respondents with high prior knowledge were significantly *more likely* to be younger, be male, live in larger households, and live in higher income households. These associations are broadly consistent with expectations for early adopters in general (H2), and with users of information and communication technologies more specifically (OECD, 2008). Larger households imply families with children (or elderly people) living at home, with potentially greater needs for control and convenience in home management.

Potential early adopters were significantly more likely to have found out about SHTs through all information channels with the exception of word of mouth (Table 4). This is also consistent with expectations for early adopters (H3 and H4). Later adopters who are less aware of new technologies are more likely to receive information through interpersonal networks and less likely to actively seek information through media or internet.

Kruskal-Wallis H tests were run to determine whether potential early adopters perceived stronger benefits and lower risks of SHTs compared to later adopting groups. Kruskal-Wallis is a nonparametric test of difference appropriate for use on ordinal Likert scale data (equivalent to one-way ANOVA for parametric data).

There were statistically significant differences ($p < .01$) between adopter groups on all eight response options for the *main purposes* for SHTs, and on all eleven response options for the *potential benefits* of SHTs (see Fig. 2). Post hoc pairwise comparisons were performed using the Dunn procedure with a Bonferroni correction for multiple comparisons. In all case except two, the early adopter group (high prior knowledge) had significantly stronger perceptions of the *main purposes* of SHTs and the *potential benefits* of SHTs than both the early majority and late majority groups (medium and low prior knowledge respectively). The two exceptions were 'controlling heating systems' and 'managing energy use' as *main purposes* of SHTs for which early adopters were significantly different from the late majority, but not the early majority (see Supplementary material for all test results).

Overall, there is good evidence that finding out more about SHTs significantly strengthens potential early adopters' positive perceptions of benefits. This is consistent with expectations for early adopters (H5).

Potential early adopters might be expected to perceive lower risks with SHTs as a corollary of perceiving stronger benefits. However this is generally not the case (see Supplementary material for all test results). There were only three cases in which the early adopter group perceived significantly lower risks: 'increase dependence on outside experts', 'result in a loss of control', 'are non-essential luxuries'. But in each of these three cases, early adopters were significantly different only from the late majority (low prior knowledge) but not from the early majority (medium prior knowledge).

Overall, there is only weak evidence that potential early adopters perceive they will be more able to independently configure and effectively use and control SHTs without relying on technical experts. This is partially consistent with expectations for early adopters (H6).

Table 3
Association between prior knowledge of smart home technologies and socioeconomic characteristics. Note: Columns do not sum to 100% as only one response option per socioeconomic characteristic is shown to illustrate key differences between full.

Socioeconomic characteristics	All prospective users (n=1025)	High prior knowledge group (n=385)	Association between prior knowledge and socioeconomic characteristics[a]	Socioeconomic characteristics of high prior knowledge group
Age (< 45)	36.7%	49.2%	χ^2=56.1, df=8, p < .01	young
Gender (male)	49.3%	61.6%	χ^2=48.5, df=2, p < .01	male
Household size (4 or more)	22.4%	31.4%	χ^2=51.2, df=8, p < .01	large households
Household income (> £40,000)	34.2%	45.5%	χ^2=39.9, df=6, p < .01	high income households

[a] Association was tested on disaggregated data between three prior knowledge groups and all socioeconomic response options.

Table 4
Information channels on smart home technologies for potential early adopters compared to all prospective users. Note: Columns do not sum to 100% as response options were non-exclusive.

How do you know about smart home technologies?			
Response options for common information channels	**All prospective users (n=1025)**	**High prior knowledge (n=385)**	**Association between prior knowledge and information channel**[a]
internet	62.2%	78.7%	χ^2=87.0, df=2, p < .01
TV, news or magazines	48.6%	53.5%	χ^2=17.6, df=2, p < .01
home or electrical stores	13.0%	22.6%	χ^2=51.1, df=2, p < .01
energy companies	30.5%	35.1%	χ^2=7.7, df=2, p < .05
word of mouth	34.0%	35.8%	χ^2=1.1, df=2, n.s.

[a] Association was tested on disaggregated data between three prior knowledge groups and all informational channel response options.

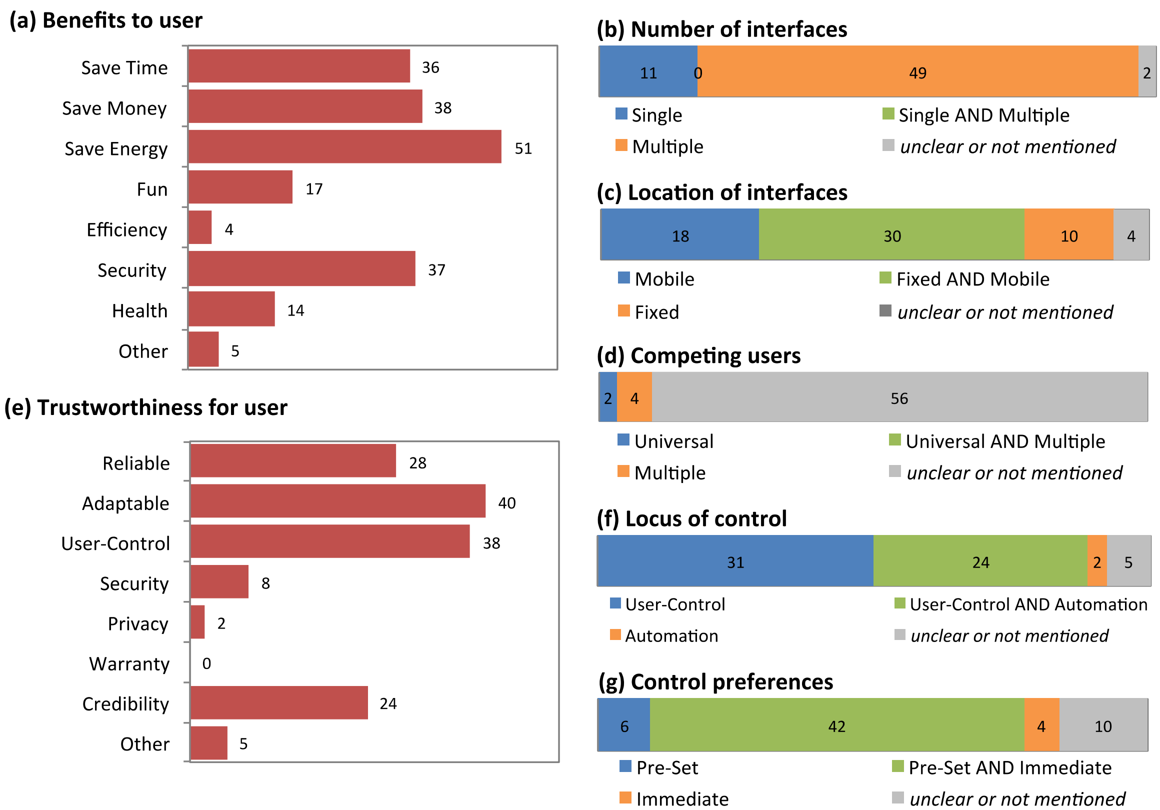

Fig. 5. Content of smart home marketing material. Notes: Bars show frequency of codes in sampled material; numbers per bar show frequency (n). Red bars in left panels (a,e) are for coding categories with multiple, non-exclusive codes (so total n > 62). Blue, green, orange bars in right panels (b,c,d,f,g) are for coding categories with bi-dimensional, exclusive codes (so total n=62). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.3. Actual early adopters of SHTs

The early adopter survey measured perceived benefits and risks of SHTs in households committed to having SHTs installed in their homes before they became widely available commercially. Although a small sample, responses from these actual early adopters provide a useful reference point to compare against the potential early adopter group (with high prior knowledge) from the national survey. This also helps determine if the actual early adopters who volunteered to participate in the smart home field trial have similar perceptions to the broader population of potential SHT early adopters.

Mann-Whitney U tests were run to determine whether actual and potential early adopters had similar perceptions of SHTs. Mann-Whitney is a nonparametric test of difference appropriate for use on ordinal Likert scale data (equivalent to t-tests for parametric data). Differences were tested on all the response options related to the *main purposes* of SHTs and to *consumer confidence* in SHTs. (Perceptions of the *potential risks* of SHTs were not measured in the actual early adopter survey).

For the *main purposes* of SHTs, there were no statistically significant differences between actual and potential early adopters, with two exceptions: 'enhancing entertainment and communication', U=4396, z=−3.75, p < .001, for which actual early adopters' responses were significantly lower; and 'managing energy use', U=5886, z=−2.59, p < .01, for which actual early adopters' responses were significantly higher (see Supplementary material for all test results).

For *consumer confidence* in SHTs, there were no statistically significant differences between actual and potential early adopters, with two exceptions: 'reliable and easy to use', U=5431, z=−2.91, p < .01; and 'come with performance warranties', U=5391, z=−2.04, p < .05. In both cases, the responses of actual early adopters were significantly higher than potential early adopters.

Overall, responses are very similar between actual early adopters (n=45, early adopter survey) and potential early adopters (n=385, subsample of national survey with high prior knowledge of SHTs). The few differences can be explained by the field trial setting in which actual early adopters' perceptions were measured. SHTs in the field trial related to heating, hot water, lighting and security. However 'smart'

Table 5
Mapping of SHT datasets onto research questions.

Data collection:		National survey		Early adopter survey	Companies at SHT conference +web search
Dataset (sample):		***prospective users***	***potential early adopters***	***actual early adopters***	***industry marketing material***
Q1a.	How do prospective users perceive the *specific benefits* [and risks] of SHTs?	X			
Q1b.	How do prospective users perceive the *specific* [benefits and] *risks* of SHTs?	X			
Q2.	Do *early adopters* have distinctive perceptions of SHTs?		X	X	
Q3.	Is industry marketing of SHTs *aligned* with the perceptions of prospective users?	X	X	X	X

TVs, linked to 'enhancing entertainment and communication', are by far the dominant SHT by sales (Harms, 2015). Actual early adopters also place more emphasis on certain measures for building consumer confidence. Uncertainties about technology performance and ease of use are likely sharpened in households about to have SHTs installed.

3.4. Industry marketing material

Alignment between prospective user perceptions and industry marketing is an important indication of shared and consistent expectations for the SHT market. The content analysis provides a systematic picture of how industry is representing the benefits, function, design, and use of SHTs to prospective users. In general this picture is similar across a range of different SHT companies.

Sampled marketing materials describe the main benefit of SHTs as helping households manage their energy use (Fig. 5a). SHTs are also commonly marketed as a means of improving household security (e.g., open door or window alerts, occupancy simulation), or as a means of enhancing leisure activities (e.g., scheduling entertainment and media services). This provides benefits to users through time savings, convenience, efficiency as well as entertainment. Improving health (e.g., physiological monitoring, communications with healthcare providers) is a niche market.

User interfaces are multiple rather than single (Fig. 5b), and are both fixed and mobile (Fig. 5c). Some interfaces might be wall-mounted or integrated into smart appliances, whereas others might be accessed through smart phone applications or standalone in-home displays. Although the marketing material recognises that homes are lived in by households and families, little attention is paid to how multiple SHT users may interact or to how conflicting preferences or settings may be resolved (Fig. 5d).

Measures to build consumer confidence in SHTs do not centre on privacy and security. Data security is only mentioned in 8 of the marketing materials from the sample of 62 companies (Fig. 5e). Only 5 of these 8 mentioned that data would be encrypted. Rather, industry marketing material seeks user trust and confidence by emphasising users being in control, and technologies being adaptable and reliable. Certain manufacturers also emphasise their credibility either through years of experience in the field of consumer electronics or through various design and technology awards.

Throughout the marketing material, user control of smart home technologies is a central concern (Fig. 5f). As Philips assure prospective users, "*your home is as individual as you and the way you live should be determined by you, not the system*". Both user control and automation are possible with 'set and forget' functionality in which users pre-set initial rules and conditions but can then step back allowing the technologies to take over. Despite a strong emphasis on pre-set scenes to account for regular routines, the marketing material also makes clear that users can always immediately over-ride a particular function (Fig. 5g). The ability to over-ride pre-sets is presented as essential for giving users a sense of 'control' over their SHTs while not imposing this as a requirement or burden. (See Supplementary materials for further analysis of SHT function and design in industry marketing).

There is strong overall coherence among industry market material on the communication of what SHTs should be able to do, and how they should be designed. SHTs are marketed as:

- being inconspicuous technologies running in the background, with only some of the interfaces being conspicuous within the home;
- allowing users to 'set and forget' their control preferences;
- focusing on enhancing lifestyles rather than delivering single, task-specific functions;
- being universally relevant to an all purpose audience rather than distinguishing specific types of users (with the exception of a specialised market niche for assisted living).

4. Conclusions and policy implications

Results from the three SHT datasets answer the three questions posed in the introduction (see Table 5). Each answer has important implications for the policy environment for smart homes.

4.1. How do prospective users perceive the specific benefits [and risks] of SHTs? (Q1a)

Prospective users have positive perceptions of SHTs aligned to their multiple functionality of managing energy use, controlling the domestic environment, and improving security. Prospective users perceive a clear value proposition centred on cost, control and convenience. This confirms a strong market potential for SHTs.

However, the impact on energy demand of SHTs once adopted is less clear. SHTs have many different and potentially competing benefits. SHTs help users to achieve both instrumental outcomes (e.g. saving energy, money or time, enhancing security or health) as well as hedonic goals (e.g. providing entertainment, having more fun). SHTs certainly enable energy management (e.g., control of heating and lighting systems by remote) but also facilitate energy consumption either by providing new services (e.g., pre-heating homes or running automated security routines while absent) or by intensifying existing services (e.g., audiovisual entertainment, internet connectivity). As well as being energy-consuming products themselves, SHTs may have the effect of entrenching ever more resource-intensive social conventions of comfort and convenience (Strengers, 2013). More generally, information and communication technologies impose additional and non-trivial loads of their own, both direct (e.g., plug) and indirect (e.g., server farms for cloud-based storage) (Koomey et al., 2013).

4.1.1. Policy implications

Energy intensification is a possible consequence of SHT-enabled control of the domestic environment. Energy intensification means that energy-intensive services may be consumed to a greater extent, over longer periods of time, or during peak periods when the grid faces supply constraints. Each of these conflicts with social or system management objectives to reduce energy demand or shift peak demand. The impact of SHTs on energy demand ultimately depends on how developers, manufacturers, and retailers design and market SHTs, and on how users configure and use them. For example, SHTs which include energy optimisation algorithms to reduce or shift demand, or to inform users if demand exceeds pre-set thresholds, may result in net demand reduction. SHTs which enable energy-intensive user preferences without algorithmic constraints may have the opposite effect.

Policymakers have intervened in the market roll-out of smart meters to support positive system outcomes. In the UK, the Department of Energy and Climate Change (DECC) was integral to an industry-wide effort to set design and operating standards, and offer in-home displays as an integral part of the smart meter installation process (DECC, 2014; DECC, 2015a). It is not yet known if these measures will effectively support energy demand reduction in households (Pullinger et al., 2014). However, analogous policy intervention should be considered to shape the design and use of SHTs, and so their potential contribution to system management objectives (Gann et al., 1999). First, clear policy guidelines can help ensure SHT hardware and software designs are compatible with smart meter-enabled communications from utilities during critical peak periods. This would enable SHT control algorithms to respond to supply constraints by shifting time-flexible domestic loads. Second, benchmark guidelines for energy optimisation or minimisation algorithms can steer industry to include design features in SHTs that mitigate the potential for energy intensification. Third, marketing and advertising standards can be used to ensure a clear message to prospective users that SHTs do not inevitably result in energy and cost savings. This would also create an incentive for the SHT industry to prioritise energy management functionality over ancillary SHT benefits.

4.2. *How do prospective users perceive the specific [benefits and] risks of SHTs? (Q1b)*

Prospective users' perceptions of data and privacy concerns with SHTs are not as prevalent nor salient as has been the case with smart meters. Smart meters have a less clear value proposition, and are rolled-out to households by energy utilities with low levels of consumer trust (Balta-Ozkan et al., 2013b). By comparison SHTs are voluntarily purchased as value-adding services from manufacturers of households' own choosing. However, there is market concern over ceding autonomy and independence in the home for increased technological control. Ensuring SHTs are controllable, reliable, and easy-to-use can help mitigate these perceived risks, and build consumer confidence.

4.2.1. *Policy implications*

Although consumer confidence measures fall largely to the SHT industry, policy can play a supportive role. From 2013–2015 in the UK, a market-based approach to energy efficient home renovations was introduced which included clear measures for quality control (Pettifor et al., 2015). Policymakers established a national system of independent certification of assessors, installers, and finance providers to ensure trustworthy, expert advice and practice.

An analogous quality control framework for SHTs would similarly help reduce perceived technology risks. SHTs for advanced home energy management typically require professional installers (electricians, gas engineers, plumbers) whose skills and knowledge will shape prospective users' experiences. Policymakers can play a coordinating or facilitative role with the SHT industry in developing transparent standards, best practice guidelines, or quality control procedures and rights of recourse for SHT installations.

The smart meter industry in the UK provides another precedent. Policymakers were instrumental in establishing Smart Energy GB (formerly the Smart Meter Central Delivery Board) as a well-resourced marketing and campaign body tasked with building consumer engagement with smart meters (SmartEnergyGB, 2015). The national smart meter rollout is a regulatory initiative, so this is not a direct analogy. Nevertheless, a concerted pan-industry initiative endorsed by policymakers to build confidence in SHTs would support market uptake.

4.3. *Do early adopters have distinctive perceptions of SHTs? (Q2)*

Potential early adopters of SHTs among UK homeowners are younger, wealthier, live in larger households, and actively seek more information on SHTs relative to all prospective users. However, the small sample of actual early adopters participating in the smart home field trial shows other household compositions and life stages (including retired couples) clearly form part of the early adopter market segment.

As early adopters acquire greater knowledge of SHTs, their positive perceptions of benefits are strengthened. This creates a virtuous cycle of reinforcing market demand. However, greater knowledge of SHTs does not significantly weaken early adopters' perceptions of risks. This emphasises the importance of measures to strength consumer confidence as SHTs become available commercially.

4.3.1. *Policy implications*

Risk mitigation measures during the initial commercialisation of SHTs is particularly important as the experiences of early adopters diffuse through social networks to reduce uncertainties perceived by later adopters in the mass market. The small sample of early adopters participating in the smart home field trial faced frequent, minor but cumulative issues with SHT installation and operation that risked undermining their confidence and use of the technologies (Hargreaves et al., 2015). As with the smart meter roll-out, SHT installers are an important 'trigger point' for informing or encouraging domestic energy practices with beneficial system outcomes (EST, 2010). From a policy perspective, this reinforces the importance of quality control measures and training to ensure SHT installation procedures are consistent with energy-management objectives.

SHT early adopters have socio-demographic characteristics which are similar to those of information communication and technologies more generally (OECD, 2008). A social risk is that SHTs extend the digital divide associated with ICTs further into homes. Later adopting market segments may include older households, lower income households, or geographically remote households (with poor internet access). This is particularly problematic if SHTs are enabling of health, quality of life or other social benefits. Policy initiatives to ensure universal broadband internet access have addressed the possible marginalisation of disadvantaged later adopters. Analogous policies could help avoid adverse distributional impacts of SHTs. As examples, grants, subsidies, or technical advice could be provided to vulnerable households to support adoption of SHTs for assisted living or for managing fuel poverty.

4.4. *Is industry marketing of SHTs aligned with the perceptions of prospective users? (Q3)*

Fig. 6 compares data on perceived benefits, control functionality, and consumer confidence in SHTs from the different user surveys as well as the industry marketing material. Different measures are used to represent the surveys (% of respondents in agreement) and the content analysis (% of marketing material mentioning a code). However these measures are broadly analogous. For marketing material to make explicit mention of a particular code is equivalent to an agreement that this code is a relevant and salient feature of SHTs. However, as the measures are not identical, the visual comparison in Fig. 6 of user

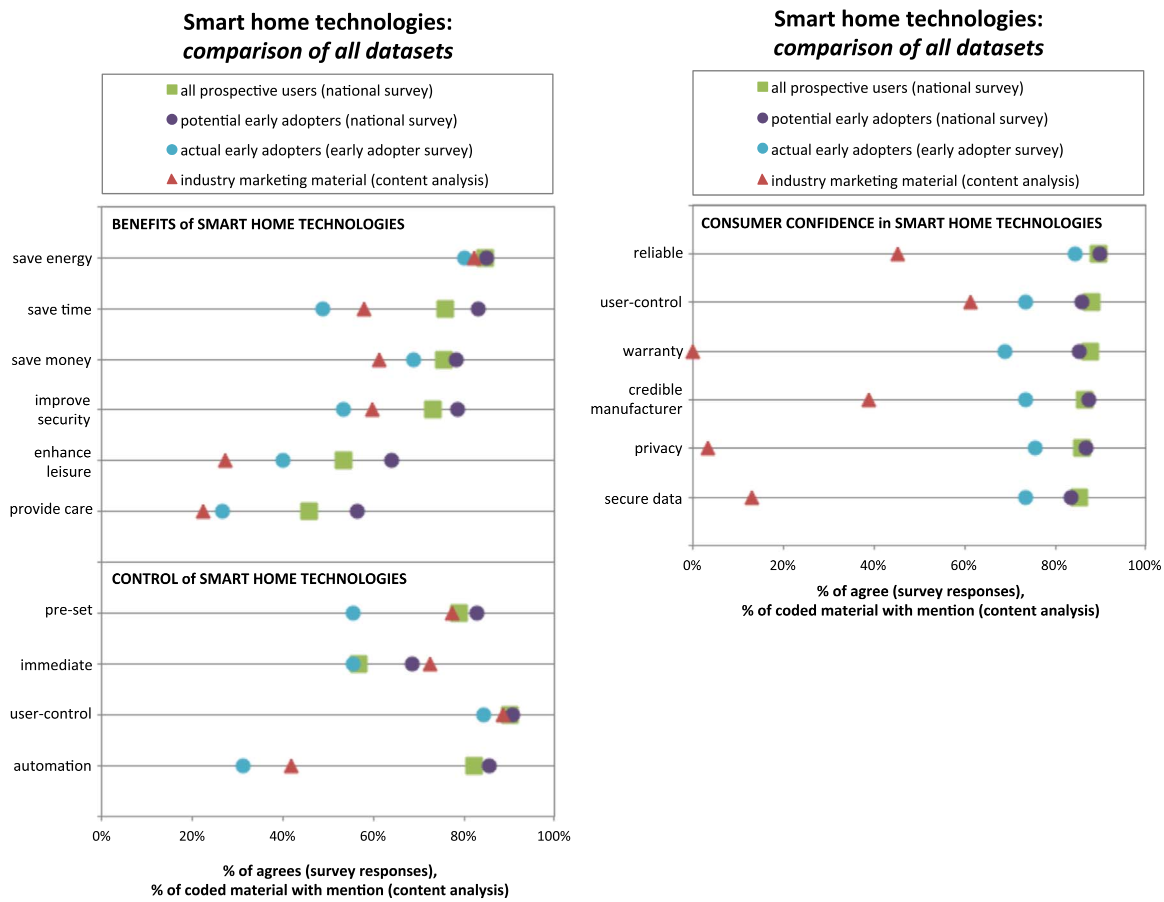

Fig. 6. Comparison of all datasets on smart home technology benefits and control (left panel), and consumer confidence (right panel). Notes: data from national survey (prospective users and potential early adopter market segment), early adopter survey, and content analysis of industry marketing material. Survey data show % of respondents in agreement (agree +strongly agree). Content analysis data shows % of marketing material mentioning code.

perceptions and industry marketing should be interpreted in terms of relative importance only.

There are four salient patterns in Fig. 6. First, potential early adopters see stronger benefits of SHTs but otherwise share similar perceptions of control functionality and consumer confidence with the full market of prospective users. Second, actual early adopters are more circumspect across the board with less strong perceptions of benefits and control functionality, but also risks. However the sample size of actual early adopters was small, and consisted of multiple members from each household with potentially different levels of prior knowledge and awareness.

Third, the industry marketing material is very clear on the energy-saving benefits of SHTs. This is consistent with user perceptions. The industry marketing material also emphasises other types of benefits, as well as SHT control functionality in a similar rank order to users (Fig. 6 left panel). One exception is that industry marketing material downplays automation in favour of active user control. This may be aimed at mitigating perceived sociotechnical risks of increasing dependence on technologies and experts, but may also potentially undermine the use of energy-management algorithms to reduce the potential for energy intensification.

Fourth, industry marketing clearly diverges from user perceptions in relation to consumer confidence (Fig. 6 right panel). There is a high demand for risk-mitigating measures from prospective users, including early adopters, but these are only weakly emphasised in industry marketing material.

4.4.1. Policy implications

Policymakers' vision for smart homes set out in Section 1 has two key elements: (i) empowered household users actively controlling their domestic environment to manage energy demand; (ii) aggregate system benefits through demand reduction, either overall or during peak periods. Both industry and prospective users agree on the first point: SHTs provide new control functionality with potential energy management benefits. However, agreement with the second point is less clear. Whether perceived benefits in each SHT-adopting home aggregate up into actual system management benefits depends on how control functionality is incorporated in practice into domestic life (Hargreaves et al., 2015). In this respect, policymakers' smart home vision is not consistently shared by users and industry. At the very least, there is significant uncertainty as to whether system management benefits are achievable.

Shared visions are important for guiding, legitimising, and reducing uncertainties with the development and diffusion of transformative innovations (Borup et al., 2006; OECD, 2015). Clear expectations shared by all principal actors can take on "*performative force*", stimulating and coordinating activity, and fostering investment (van Lente et al., 2013). The three principal actors in the SHT market are users, industry, and policymakers. Their visions for SHTs are largely convergent although industry needs to increase activity to build consumer confidence, supported by a clear regulatory framework and standards developed by policymakers.

However shared visions that do not fulfil expectations risk consumer backlash. There is clearly a risk that the energy-savings promise of SHTs is not borne out in practice. A comprehensive programme of research and monitoring of *in situ* SHT applications in early-adopter households is needed to understand how SHTs are used in practice to control the domestic environment (Wilson et al., 2015). This should include the extent to which energy-management algorithms can automate certain functions to avoid risks of energy intensification.

Policymakers can also engage prospective users in developing a shared vision for a smart energy future which is not in tension with other potential benefits of SHTs (Strengers, 2013). Users as 'energy citizens' rather than 'energy consumers' can pre-emptively address energy intensification risks through involvement in design processes or in deliberative spaces with industry and policy stakeholders. (Goulden et al., 2014; Schot et al., 2016).

Experiences with national smart meter roll-outs in EU member states raise another risk of consumer backlash associated with data security and privacy. Measures to address these risks were conspicuous by their absence in industry marketing material (Fig. 6 right panel). A systematic programme of consumer research and regulatory development has led to a clear and transparent framework governing data usage from smart meters (DECC, 2012; DECC 2015b, 2015a). In the absence of an equivalent regulatory framework in the consumer-led SHT market, technology developers need to make privacy and security more central to their smart home vision. Policymakers can help by developing best practice guidelines, by setting minimum requirements for data security, or by working with consumer rights organisations to raise the profile of this issue.

4.5. Limitations and final conclusions

There are important limitations to these insights on the potential SHT market. First, the survey data and content analysis of industry marketing provides a cross-sectional snapshot rather than a time-dependent trajectory of technological and market development. Second, it is not known if the marketing material adequately represent how companies are actually developing their technologies. Third, the quantitative data and analytical methods lack interpretive context (unlike interview-based approaches).

Nevertheless, the comparative analysis of three separate datasets to characterise the emerging smart home market provides a robust picture of user perceptions, industry marketing, and the extent to which both of these are consistent with policymakers' envisaged role for SHTs within smarter energy systems.

To conclude, although the market outlook for SHTs from both users and industry's perspective is positive, there are also important risks and issues that need addressing. Prospective users have positive perceptions of the multiple functionality of SHTs including managing energy use, controlling the domestic environment, and improving security. The value proposition for SHTs centres on cost, control and convenience. But although SHTs certainly enable energy management, they also facilitate energy consumption either by providing new services or by intensifying existing services. The impact of SHTs on energy demand ultimately depends on how they are designed and used.

Both prospective users and actual early adopters also express caution towards ceding autonomy and independence in the home for increased technological control. These broader sociotechnical risks are perceived more strongly than the privacy and data security concerns that have affected smart meter rollouts in the EU. The SHT industry can increase their efforts to help mitigate perceived risks by ensuring SHTs are controllable, reliable, and easy-to-use as measures for building consumer confidence. Confidence-building measures are particular important in the emerging SHT market to ensure that the strengthening positive experiences of early adopters are communicated through social networks to create a virtuous cycle of reinforcing market demand.

Policymakers can usefully intervene in SHT market development through design and operating standards, guidelines on data and privacy, support for industry-wide consumer confidence measures, quality control, and targeted *in situ* research programmes. Policy experiences with domestic energy efficiency technologies and with national smart meter roll-outs offer useful precedents.

To support positive system outcomes from widespread adoption of SHTs, policymakers can usefully intervene in SHT market development through design and operating standards, guidelines on data and privacy, support for industry-wide consumer confidence measures, quality control, and targeted *in situ* research programmes. Policy experiences with domestic energy efficiency technologies and with national smart meter roll-outs offer useful precedents.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2016.12.047.

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