



Measuring the adoption and discontinuance of low carbon digitally-enabled innovations: Exploring repeat survey quality

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ABSTRACT

Innovations for carbon emission reduction require broad adoption, but initially attract a limited user base. Repeated surveys inform product and service adoption and discontinuance dynamics, yet statistical analyses may yield misleading results due to potentially overestimated question quality. Our examination of responses to a single question focusing on 16 low-carbon digital consumer innovations investigates their reliability in a 2019–2020 repeated survey. Notably, our investigation indicates that questions related to novel digital innovations, particularly services in contrast to physical products, tend to exhibit diminished reliability. Additionally, quantifying discontinuance presents greater challenges than measuring adoption. Therefore, results regarding the types of products or services adopted and discontinued may be affected by measurement error of responses. This study provides valuable insights for stakeholders interested in comprehending adoption and discontinuance dynamics through survey methodologies.

1. Introduction

New digital products and services are available across different domains of daily life transforming the consumer landscape. Digitally-enabled innovations in mobility, food provision, domestic living, and energy supply have the potential to help reduce carbon emissions in several ways. For example, by substituting for physical movement, accessing services instead of owning physical goods, exchanging physical goods and reducing waste through peer-to-peer networks, controlling and managing energy demand through the internet of things and integrating consumption activity into supply networks to support efficient system functioning (Wilson et al., 2020).

When new innovations are introduced, they require time to takeoff and diffuse (Golder and Tellis, 1997). Several new digital products and services with low carbon potential are slowly increasing their market presence, such as e-bikes (D'Almeida et al., 2021; Zhou et al., 2023), shared taxis services (Leich and Bischoff, 2019), peer-to-peer (P2P) car-sharing schemes (Valor, 2020), and digital hubs for local food (Sgroi and Marino, 2022). However, many remain adopted by only a small proportion of the population (i.e. suffer from innovation resistance) (Chadwick et al., 2022; Huang et al., 2021; Talwar et al., 2020). To help meet net zero targets, a greater portion of the population will be

required to adopt such innovations, especially those substituting incumbent high carbon emitting products, services and behaviors (Li and Wang, 2022; Wang et al., 2022; Zhou et al., 2023). Even if adoption of these newer low carbon innovations occurs, their adoption is not always sustained. The discontinuance of innovations can be intricate as consumers might experiment with them, pause usage, and later use them again (suspension), or choose not to continue using them at all, essentially disadopting the innovations (Lehmann and Parker, 2017). It is therefore crucial that research studying adoption processes also consider post adoption to provide insights and recommendations for public policy makers, companies and society (Vrain et al., 2022).

Many studies investigating innovation diffusion use interviews or surveys (Tellis et al., 2009; Wang et al., 2023). However, there is evidence that how a question is formulated can alter the outcome of the answers obtained (e.g., Saris and Revilla, 2016). This can lead to large amounts of measurement error, causing the results obtained in scientific research to be compromised. In fact, although this error is well known, and correcting for it can be essential to obtain reliable results from question-based analyses, very few researchers attempt to do so (Saris and Revilla, 2016). Correcting for measurement error may seem complicated, but can be simple if the quality (the reliability and validity) of questions is known.

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When the reliability of the measure is low, it will affect the results of repeated surveys leading to inaccurate or inconsistent results across them (Bach, 2021). In some cases, conducting tests to measure the reliability of responses could report misleading satisfactory results. For example, the chi-square test (or Kappa Cohen test) can be used to reject the null hypothesis that main survey and repeat survey respondents are independent (Brennan and Prediger, 1981). In other words, that there is inter-wave reliability. Yet, these tests may provide dubious results when studying the diffusion and discontinuance of new products (or services)¹ because the proportion of adopters and discontinuers of each current/new product may be very small in very large samples. Therefore, understanding about consumer adoption of new digitally-based innovations and discontinuance of unsustainable products may be challenged if we do not know the quality of the questions. This paper addresses the following research questions:

- Which method can be used to improve the reliability and validity of responses regarding the adoption and discontinuance of products?
- What type of products and consumer adoption and discontinuance behaviors are more difficult to measure to obtain a high-quality response?
- To what extent does the quality of responses vary among different types of products and behaviors, including incumbent versus new innovations, adoption versus discontinuance, and physical products (P) versus digitally-based services (S)?

Public and private R&D investment in green technologies constitutes a mere 4% of global expenditures while postponing action will lead to increased transition costs (Blanchard et al., 2023). This underscores the compelling necessity for innovative approaches to grasp the shift from high-to low-carbon consumer products and services (Wilson et al., 2020). Our work primarily focuses on evaluating measurement quality using a questionnaire applied to an extensive range of products (Vrain et al., 2022). This questionnaire enables us to gauge response reliability across various scenarios, such as product adoption or discontinuance, the introduction of new digitally-based products, established market offerings, and both services and physical products. Overall, this study helps to develop improved surveys that can capture more accurate data on the dynamics of discontinuance, and thus contributes to the design of more effective policies promoting sustainable behaviors. In the following sections, we first review the literature measuring adoption and discontinuance with repeated surveys, and explain the survey design process which involves theoretical validation, concept differentiation and transforming assertions into answer requests. Then, we develop hypotheses in line with our research questions. We then describe the method used to test the reliability and validity of survey questions for different types of innovations, present the results and discuss the main findings of the work, limitations and future avenues of research conducting surveys that could help understand the adoption and discontinuance of disrupting and incumbent low-high carbon innovations.

2. Theory development

The theoretical development in this study comprises three key elements: measuring adoption and discontinuance of innovations using repeated surveys, designing survey measurements and the development of hypotheses.

2.1. Measuring adoption and discontinuance of innovations with repeated surveys

While research has extensively examined factors influencing the

¹ A product is a tangible good, service, or idea offered to meet customer needs. It can be a physical item, service, or intangible offering.

diffusion of new products and services (Mazzarol and Rebound, 2020; Peres et al., 2010; Rogers, 2004), less attention has been given to post-adoption discontinuance measurement (Cruz-Cárdenas and Arévalo-Chávez, 2018; Laukkanen, 2016; Midgley and Dowling, 1993). Many consumers reject new products after trying them (Klonglan et al., 1971), and the distinction between discontinuing new and incumbent products is often neglected (Lehmann and Parker, 2017; Palacios Fenech and Longford, 2014). In many cases, it's unclear whether disenchantment and/or substitution causes discontinuance for new or incumbent products (Cottrell et al., 2021; Prins et al., 2009).

Moreover, using aggregate sales or penetration data sets is particularly difficult for measuring how many people in a social system have decided to use or discontinue a new/incumbent product again without measuring its use in different periods. For instance, when a disruptive substitute product is introduced, a phenomenon referred to as hidden discontinuance occurs (Palacios-Fenech and Tellis, 2016). During this period, the existing product quietly undergoes discontinuance, although this is not immediately evident in its overall adoption rate. With the introduction of multiple substitute products, complexity increases, giving rise to a greater diversity of consumer segments. Some may switch to the new product, in alignment with disruption theory (Christensen et al., 2013), or opt to use both products simultaneously, but others may delay their decision to adopt the new product (leapfroggers) (Chandrasekaran et al., 2022). While there have been some survey attempts to investigate discontinuance (Kislev and Kislev, 2020; Laukkanen, 2016), the utilization of repeated studies is still very limited compared to the use of longitudinal studies focused to investigate adoption of new products (Papagiannidis et al., 2015; Papazoglou and Spanos, 2018). Nevertheless, with the pressing demand for a more profound understanding of these critical disruptive dynamics to mitigate the environmental impact of current product and service consumption, the adoption of repeated and longitudinal studies to investigate discontinuance emerges as exceptionally beneficial (Vrain et al., 2022). Unfortunately, surveys in such studies can encounter response quality issues due to survey design.

2.2. Designing survey measurements

Question reliability measures consistency of a measurement, while validity assesses if results truly reflect what they aim to measure. Combining reliability and validity determines measurement quality (Krosnick, 2018; Saris and Andrews, 2004). To create a high-quality question, it is necessary that the question actually measures the concept of interest, i.e., that it is theoretically valid. To do this, a simple three-step procedure can be used (Saris and Gallhofer, 2014). The *first step* is theoretical and consists of differentiating between concepts by intuition and concepts by postulation (Blalock, 1968). For concepts by intuition, the question asked is obviously measuring the concept of interest. For example, "How satisfied are you with your new product?" However, it becomes a concept by postulation when asking about satisfaction of the product, and also about a specific benefit of the new product that affects satisfaction, such as the fact that it is environmentally friendly. In this case, different indicators will measure a more complex concept (i.e. overall satisfaction and environmentally friendly satisfaction). In short, a shortcut is not recommended to measure a complex concept. For example, asking about satisfaction because it is environmentally friendly would not be useful to measure at the same time as overall satisfaction (i.e. How satisfied are you with your new product because it is environmentally friendly?). Note that although the procedure is more direct when asking questions based on intuition compared to those based on postulation, errors are often made where what is asked is not exactly what is to be measured. Asking questions based on postulation generally will require asking more questions. Then, the relationship between the variables to be measured and the answers obtained will be very weak.

The *second step* is to decide what concept you want to measure, be it an evaluation, a feeling, a norm, a preference, or anything else, and what

the object is, and apply a production rule based on linguistic knowledge (Saris and Gallhofer, 2007).

In the *third step* the assertions can be transformed into requests for answers (Saris, 2012). Once this procedure is done, the quality of the questions can be estimated using a software. In addition, many decisions will have to be made without empirical evidence because every survey is different. An alternative is to conduct a pretest but is costly and takes time (Presser and Blair, 1994). To complicate matters further, the target audiences will have different skills and cultures. A good question is the same question in different cultures, and will be very relevant to capture cultural differences in product adoption and discontinuance and consumer tendencies to adopt new environmentally sustainable products or discontinue high emitting incumbent products (Claudy et al., 2015; Steenkamp et al., 1999). Furthermore, it's important to recognize that responses may not always be stable due to many of our human cognitive limitations. These large number of limitations, which include all kind of biases and heuristics in perception, information processing, and limited memory can influence how individuals perceive, evaluate, and ultimately remember about products. For example, questions about the past are particularly prone to errors owing to memory constraints (Öztaş Ayhan and İşiksal, 2005).

In the following section, we outline the hypotheses that support our belief that responses to questions about novel digital innovations, especially services as opposed to physical products, are often less reliable. Furthermore, we assert that quantifying discontinuance is more challenging than measuring adoption. These hypotheses are grounded in the idea that human cognitive limitations can shape how respondents can complete questionnaires, guided by their interactions with products and services. This, in turn, may also hinge on the unique characteristics of the product and the stage within their adoption or discontinuation process.

2.3. Hypotheses development

Understanding new digital products is challenging as consumers need to construct entirely new knowledge structures (Moreau et al., 2001) and grasp and remember unfamiliar new attributes (Mantonakis et al., 2008). Consequently, questions about these products can be more confusing than those about established products, potentially leading to a lower quality of responses. Therefore, we propose the following hypothesis:

H1. The quality of responses to questions about established products will exceed to that of responses about new digital products.

On the other hand, the adoption process typically exhibits greater clarity and visibility compared to the discontinuance process (Chandrasekaran et al., 2022). Discerning between product discontinuance, prior discontinuance, partial or intermittent cessation due to replacement and/or disenchantment, and iterative transitions to competitor products within the same category constitutes an exceptionally intricate challenge (Prins et al., 2009; Rogers, 2004; Ng, 2023). For this reason, it can be posited that, for both incumbent and novel innovations, respondents may exhibit reduced consistency when questioned about discontinuance.

H2. Response quality concerning adoption will exceed that of responses about discontinuance across all types of innovations.

While the discontinuance process is already considerably more intricate than the adoption of physical products (Jacoby et al., 1977), the dynamics become even more convoluted when dealing with digital services, as evident in attrition (Libai et al., 2009). In contrast, despite shifting consumer dynamics and the growing prominence of self-extension in the digital realm (Belk, 2013), physical products continue to elicit stronger attachments (Peck and Luangrath, 2023). This is attributed to the intangible and transient nature of services, posing challenges in establishing enduring tangible value, as observed in studies like Atasoy et al. (2018). Consequently, we hypothesize that

differentiating between “currently using” and “used in the past” may be more feasible for physical products, such as electric bicycles, than for new digitally-based services, such as shared taxis or P2P car sharing.

H3. The quality of responses concerning the adoption and discontinuance of new physical products (P) is anticipated to exceed the quality of responses related to new digitally-based services (S).

3. Methods

An online repeated measures survey was administered in the UK by a market research company (Dynata) in two waves (2019 and 2020). A sample of 1116 nationally representative respondents (based on age, gender and household income) was used to investigate low-carbon digitally-enabled products and services to understand consumer adoption or discontinuance dynamics. Vrain et al. (2022) provide further details on survey methodology, whilst both full survey instruments, sampling method and data quality checks are accessible in Data Availability.

Vrain et al. (2022)'s study aimed to measure product and service usage in a repeated survey by asking individuals “have you ever had a [new digitally-enabled product]” or “have you ever used a [digital service]”. It could be wrongly assumed that participants will respond reliably across repeated surveys because the types of products are described with clarity and because the difference between the use options of each product is also very clear (Vrain et al., 2022). Providing the following four response options - 1) yes, currently; 2) yes, in the past; 3) no, but I've heard of them; and 4) no, I have never heard of them, raises potential issues with the data collected. For example, the options - 1) yes, currently and 2) yes, in the past - could lead to misinterpretation. To enhance clarity, consider the following question: “Have you ever shared a ride (either as a driver or as a passenger)?” In this case, both options can be chosen by an adopter who currently uses the service, and option two can be chosen by an adopter, as well as by a discontinuer, who may have discontinued use due to a negative experience, as noted by Rogers (2004). This ambiguity in responses poses a challenge for accurately assessing adoption and discontinuance. Similar considerations apply to the use of identical question and response options, as presented in Table 1, which were utilized in the survey examined to measure the adoption and discontinuance of 16 new digitally-enabled products and services across transport, food, home, and energy. The selected innovations in four domains are presented in Table 1, along with the questions used: seven for transport – car clubs, P2P car sharing, ride-sharing, shared taxi, mobility-as-a-service, electric bike, and e-bike - three for food – digital food hubs, meal kit delivery service, and 11th hour food apps, three for housing – smart heating system, smart lighting, and smart home appliances, and three for energy – electricity generation with storage, electricity peer-to-peer, and electric vehicle-to-grid. This survey also investigated the adoption dynamics of three incumbent products and behaviors: 1) car with a petrol or diesel engine; 2) a big food shop in a supermarket and 3) an electricity generation system at home. Note that some innovations are digitally-based services (i.e. apps), and others, are new physical products with digital technology (i.e. electric vehicle-to-grid) (Wilson et al., 2020).

Table 2 shows the number of respondents who chose each response option to the questions regarding adoption status in both 2019 (main survey) and 2020 (repeat survey). Those that selected 1) *yes, currently* are coded as 'adopters', and those that are coded as 'discontinuers' selected 2) *yes, in the past*. The rest of the respondents are coded as non-adopters under 'heard' - 3) *no, but I've heard of them*, and 'not heard' - 4) *no, I have never heard of them*, in the case of new products. For incumbent products, option 4) was not available to respondents and the response option 'never', is coded under 'heard'.

Then, we compute the tables between the answers received in the main and in the repeat survey for each product. That is, we create contingency tables that compare the answers received in the main

Table 1
Questions to measure adoption of low carbon digital innovations.

Type	Example	Question
T1	S Zipcar	Have you ever been a member of a car club?
T2	S Turo	Have you ever done P2P car-sharing? (either by providing a car or by using someone else's car)
T3	S Liftshare	Have you ever done ride-sharing? (either as a driver or a passenger)
T4	S UberPool	Have you ever used a shared taxi?
T5	S Whim	Have you ever used mobility-as-a-service?
T6	P Nissan Leaf	Have you or your household ever had an electric vehicle?
T7	P Jump	Have you ever had an e-bike?
F1	S Open Food Network	Have you ever used digital hubs for local food?
F2	S Hello Fresh	Have you ever used a meal kit delivery service?
F3	S Too Good to Go	Have you ever used 11th hour food apps?
H1	P Nest	Have you ever had a smart heating system at home?
H2	P Philips Hue	Have you ever had any smart lighting at home?
H3	P Samsung Smart Fridge	Have you ever had any smart home appliances?
E1	P Tesla Powerwall	Have you ever had any electricity generation with storage at home?
E2	S Brooklyn Microgrid	Have you ever traded electricity peer-to-peer?
E3	P DriveElectric V2G	Have you ever used electric vehicle-to-grid at home?
T0	P	Have you or your household ever had a car with a petrol or diesel engine?
F0	S	Have you or your household ever done a big food shop in a supermarket (either in store or online) to stock up on food in advance of when it's needed?
E0	P	Have you ever had an electricity generation system at home?

Adapted from Wilson et al., 2020. Type: Product (P) or Service (S). Transport (T), Food(F), Home (H) and Energy (E).

survey conducted in 2019 and the repeat survey conducted in 2020. These tables are created for each product being studied. By comparing the responses between the main and repeat surveys, we can observe any changes in responses over time for each product. They are displayed in Tables A1 and A2 in Appendix A. Then, we conducted chi-square tests of independence on the full sample of respondents for the question that

Table 2
Main and repeat survey data.

	Main Survey				NA ^b	Repeat Survey				
	Adopters	Discontinuers	Heard ^a	Not Heard		Adopters	Discontinuers	Heard ^a	Not Heard	NA ^b
T1	18	35	621	442	0	18	24	666	408	0
T2	1	13	477	624	1	1	16	526	571	2
T3	15	71	718	312	0	7	55	777	276	1
T4	14	60	443	599	0	4	72	488	550	2
T5	2	4	112	997	1	2	2	124	984	4
T6	12	18	21	1065	0	17	13	1062	23	1
T7	29	29	892	165	1	37	18	991	68	2
F1	5	9	112	987	3	3	9	181	922	1
F2	17	84	909	105	1	27	84	926	78	1
F3	10	11	159	934	2	6	12	204	892	2
H1	105	10	947	54	0	132	9	918	57	0
H2	78	7	915	116	0	94	13	914	95	0
H3	44	2	962	107	1	50	11	982	72	1
E1	22	9	654	425	6	19	7	666	421	3
E2	0	1	147	965	3	0	2	156	958	0
E3	1	2	246	861	6	0	2	270	843	1
T0	949	72	95	-	0	930	88	98	-	0
F0	960	122	34	-	0	905	128	83	-	0
E0	86	17	1013	-	0	76	19	1021	-	0

Adopted: 1) yes, currently; **Discontinued:** 2) yes, in the past; **Heard:** 3) no, but I've heard of them; and **Not Heard:** 4) no, I have never heard of them.

^a Never for Mainstream (T0,E0,F0)

^b NA is not available

classifies adoption status (i.e. adopters, discontinuers, non-adopters). We also select only those respondents that replied being adopters or discontinuers in the main sample to conduct the tests (Table 3). We applied the Chi-square test because it was previously applied to reject the null hypothesis that adopters, discontinuers and non-adopters are not associated between the two surveys: main and repeat (Vrain et al., 2022). The chi-square test allows us to compare the responses from the main survey and the repeat survey. However, due to the limited number of adopters and discontinuers in the two surveys, the chi-square test may not have sufficient statistical properties to detect any potential lack of association between these groups of interest because the sample size for

Table 3
Chi-Square tests of independence.

	All subjects				Adopters and Discontinuers			
	DF	N	Chi-square	P-value	DF	N	Chi-square	P-value
T1	9	1116	1050.26	0	3	53	26.59	0.00
T2	16	1116	194.34	0	2	14	2.69	0.26
T3	12	1116	216.00	0	3	86	5.83	0.12
T4	12	1116	204.72	0	2	74	0.35	0.84
T5	16	1116	387.89	0	2	6	3.00	0.22
T6	12	1116	516.13	0	3	30	17.40	0.00
T7	16	1116	620.68	0	2	58	20.88	0.00
F1	16	1116	651.96	0	3	14	2.70	0.44
F2	16	1116	586.36	0	3	101	14.95	0.00
F3	16	1116	385.44	0	3	21	4.91	0.18
H1	9	1116	510.64	0	3	115	19.79	0.00
H2	9	1116	568.28	0	3	85	11.67	0.01
H3	16	1116	275.33	0	3	46	2.97	0.40
E1	16	1116	669.65	0	3	31	10.78	0.01
E2	6	1116	143.70	0	2	3	3.00	0.22
E3	12	1116	425.64	0	2	1021	515.38	0.00
T0	4	1116	1218.30	0	2	1082	100.16	0.00
F0	4	1116	124.19	0	2	103	27.64	0.00
E0	4	1116	636.24	0	4	1116	636.24	0.01

All subjects (a): We can reject the Null Hypothesis that main survey and repeat survey respondents are independent. Also, with Kappa-Cohen tests.

Adopters and discontinuers (b): Adopters and discontinuers of the main sample are selected (i.e. T1: 53 adopters (n = 18) or discontinuers (n = 35) of the main sample). The same respondents for the repeat survey are tested with a Chi-Square to test independents between responses.

innovation adopters and discontinuers compared to non-adopters may be too small to provide a reliable indication of whether they are truly independent or related to each other. That is, when the sample size of the non-adopters is much larger compared to the sample size of adopters and discontinuers, it can dominate the statistical analysis and potentially mask any significant relationships or associations between the adopters and discontinuers.

Therefore, to further investigate the relationship between adopters and discontinuers across the two surveys, we calculated the probabilities that respondents would choose the same option (i.e. adopter or discontinuer) in both waves. This was done by dividing the number of cases where responses matched in Tables A1 and A2, which contain information about the number of cases where respondents' choices matched in terms of adoption status between the main and repeat surveys, by the total number of cases where respondents chose each option in each wave (i.e. main and repeat). We divided the number of cases where respondents' responses matched (same adoption status -see Tables A1 and A2) by the total number of cases where respondents chose each option in each wave (main and repeat surveys). This approach allowed us to examine the consistency of respondents' choices across the two surveys and gain a better understanding of whether adopters tended to remain adopters, discontinuers tended to remain discontinuers, or if there were changes in adoption status between the two surveys.

Then, we estimate the probability of respondents giving the same response (adopters or discontinuers) in both the main and repeat surveys for adopters and discontinuers. For each product, we measure the probabilities for the main survey, repeat survey, and both surveys combined. The mean (average) and standard deviation (SD) of these probabilities are calculated separately for new products and incumbent products. Based on these probabilities for each product we test the hypotheses relating to the type of product (H1-H3). For this, we applied the Wilcoxon test comparing the coincidence probabilities of the products in which we are interested. The test statistics and p-values offer insights into the statistical significance of the comparisons. Finally, we examine the challenges posed by results in understanding the dynamics of discontinuance using repeated surveys in the context of energy transition, how to formulate questions that could eventually improve that quality of the survey and further research recommendations.

4. Results

The results section is divided into two parts: one focuses on Chi-Square Tests, and the other discusses the outcomes of the hypotheses.

4.1. Chi-square tests

Applying a Chi-square test to the full sample (n = 1116) we reject the null hypothesis that the main survey and the repeat survey respondents are independent. Therefore, we could mistakenly assume that there are no intra-individual differences between the two waves (Vrain et al., 2022). However, to further investigate this relationship, we conducted a separate analysis by focusing only on the adopters and discontinuers (i.e. referring to Table 3: T1: 53 adopters, n = 18 or discontinuers, n = 35). That is, excluding non-adopters. The results of this analysis revealed that for several categories, namely P2P car-sharing (T2), ride-sharing (T3), shared taxi (T4), electric vehicle (T5), digital hubs for local food (F1), 11th hour food apps (F3), smart home appliances (H3), and electric vehicle-to-grid at home (E3), we could not reject the null hypothesis. This indicates that there is no significant relationship between the responses of the selected adopters and discontinuers in the main and repeat surveys for these specific categories (Table 3). It is worth noting that we were unable to perform the Chi-square test for trading electricity peer-to-peer (E2) due to the limited number of cases, as there was only one respondent in this category (see Table A2). These findings highlight the importance of considering specific subgroups, such as adopters and discontinuers, when examining the relationship between respondents'

Table 4

Probability of same response in both surveys of Adopters and Discontinuers.

	Adopters			Discontinuers		
	Main	Repeat	Both	Main	Repeat	Both
T1	0.72	0.72	0.52	0.50	0.34	0.17
T2	0.00	0.00	0.00	0.12	0.15	0.02
T3	0.29	0.13	0.04	0.35	0.27	0.09
T4	0.00	0.00	0.00	0.25	0.30	0.07
T5	0.50	0.50	0.25	0.00	0.00	0.00
T6	0.53	0.75	0.40	0.23	0.17	0.04
T7	0.54	0.69	0.37	0.39	0.24	0.09
F1	0.00	0.00	0.00	0.11	0.11	0.01
F2	0.26	0.41	0.11	0.49	0.49	0.24
F3	0.17	0.10	0.02	0.08	0.09	0.01
H1	0.61	0.77	0.47	0.00	0.00	0.00
H2	0.60	0.72	0.43	0.08	0.14	0.01
H3	0.34	0.39	0.13	0.00	0.00	0.00
E1	0.68	0.59	0.40	0.00	0.00	0.00
E2	NaN	NaN	NaN	0.00	0.00	0.00
E3	0.00	0.00	0.00	0.00	0.50	0.00
T0	0.98	0.96	0.94	0.59	0.72	0.42
F0	0.91	0.86	0.78	0.34	0.36	0.12
E0	0.76	0.67	0.51	0.26	0.29	0.08
New Product	0.35	0.38	0.21	0.16	0.17	0.05
Mean						
SD	0.27	0.32	0.20	0.18	0.17	0.07
Incumbent Product	0.88	0.83	0.74	0.40	0.46	0.21
Mean						
SD	0.11	0.15	0.22	0.17	0.23	0.19

Main and Repeat: Amount of coincidences/Number of cases on each wave; Both: Probability of Main * Probability of Repeat.

For example: Probability T3 (Main) = 2/(2 + 1 + 4) = 2/7 ≈ 0.29. See Table A1.

choices in different survey waves.

Table 4 presents the probabilities of intra-individual response consistency for product adoption and discontinuance in both surveys. The first column represents the probability of adopters giving the same response in the main survey, the second column represents the probability of adopters giving the same response in the repeat survey, and the third column represents the probability of adopters giving the same response in both surveys. Similarly, the last three columns represent the corresponding probabilities for discontinuers. The results show that, on average, the probability of having the same response for adopting a new product is 0.21 (SD = 0.20), while the probability of having the same response for discontinuing a new product is 0.05 (SD = 0.07). In contrast, for incumbent products, the average probability of having the same response for adopting an incumbent product is 0.74 (SD = 0.22), and of having the same response for discontinuing an incumbent product is 0.21 (SD = 0.19).

4.2. Hypotheses results

The Wilcoxon-test results presented in Table 5 confirm Hypotheses 1 and 2. The table provides the test statistic and p-value for each hypothesis.

Table 5

Wilcoxon tests.

Alternative	W	P-value
Incumbent Product or Behavior > New Product	159	0.00
New product Adopter > New Product Discontinuer	172	0.02
Incumbent Product or Behavior Adopter > Incumbent Product or Behavior Discontinuer	9	0.05
Incumbent Product or Behavior Adopter > New Product Adopter	44	0.01
Incumbent Product or Behavior Discontinuer > New Product Discontinuer	42	0.02
Physical New Product Discontinuer > Digital New Product Discontinuer	18.5	0.93
Physical New Product Adopter > Digital New Product Adopter	42.5	0.05

The reliability of responses regarding incumbent products is significantly higher compared to responses about new digitally-based products ($W = 159$, p -value < 0.01). Additionally, the reliability of responses for adoption is significantly higher than for discontinuance, both for new products ($W = 172$, p -value < 0.02) and incumbent products ($W = 9$, p -value < 0.05). Regarding Hypothesis 3, partial confirmation is found. The reliability of responses for adopting new physical products (P) is significantly higher compared to new digitally-based services (S) (P vs. S: $W = 42.5$, p -value < 0.05). However, for the discontinuance option of new products, the difference in reliability between physical products (P) and digitally-based services (S) is not statistically significant (P vs. S: $W = 18.5$, p -value > 0.93). These findings support the notion that responses related to incumbent products are more reliable than those concerning new digitally-based products. Additionally, the reliability of responses for product adoption tends to be higher than for product discontinuance. The partial confirmation of Hypothesis 3 suggests that the reliability of responses differs between adoption and discontinuance for new physical products and new digitally-based services. Fig. 1 visually represents the obtained results, offering clear validation of the hypotheses formulated in this research.

5. Discussion

The results reveal that it is easier to measure the adoption and discontinuance of incumbent products than of new digitally-based products. In addition, they demonstrate that it is more difficult to measure discontinuance than product adoption. The results also highlight that it is easier to measure the adoption status of new digitally-based physical products than the adoption status of new digitally-based services (see Table 5). Currently, with the responses obtained, the challenge for the researcher is to decipher whether the difference between the responses obtained in the two periods are due to changes in the treatment or are due to changes in reporting (Cernat & Sakshaug, 2021). Furthermore, the results show that by using contrasted statistical methods, such as Chi-Square tests, it can be assumed that the reliability and validity of the questions is higher than what is actually obtained by looking at the data carefully by estimating the probabilities that both waves are associated and respondents are consistent with their responses. Therefore, Chi-square statistical tests can be misleading when the proportions of new product adopters are too small, as shown in Tables 3 and 4

The inter-wave effects that may affect the validity and reliability of

the questions are large and very varied (Saris and Gallhofer, 2014). For example, the use of direct questions, the use of lines as a response mode, gradation, the use of frequencies or estimation of magnitudes have a positive effect on reliability and a small negative effect on validity (Saris and Gallhofer, 2007). In fact, as the number of decisions and the potential interactions between them is very high, it is not easy to evaluate the consequences of all these decisions on the quality of the question.

5.1. Understanding the discontinuance of products

The imperative replacement of incumbent high carbon-emitting products to expedite the energy transition, posing challenges for both humanity and the planet, demands a deeper grasp of discontinuance dynamics in both digitally-based and physical products (Vrain et al., 2022). The obtained results unveil two main challenges. First, the relatively low probability of consistent responses for discontinuing products suggests that in the rapidly evolving energy transition landscape, identifying the underlying reasons behind product discontinuance is a complex undertaking. The results indicate a significantly greater difficulty in measuring discontinuance compared to adoption through repeated and longitudinal surveys. Second, a new layer of complexity emerges when comparing physical products against digitally-based services across different types. Without a comprehensive understanding of why individuals discontinue various products, designing targeted interventions to foster sustained adoption of environmentally friendly alternatives may prove challenging. For example, without a better understanding of underlying emotions behind discontinuance, it may be more difficult to incentivize the replacement of unsustainable products (Valor et al., 2022). Hence, enhanced survey methods are essential to mitigate potential biases in reporting specific reasons for adopting and discontinuing products, with a focus on different product types.

5.2. Improving survey questions for measuring adoption and discontinuance

In this study, we were particularly interested in measuring whether people were currently using or had discontinued the use of a new product. When respondents answered the questions of interest, they were presented with three options: past, present, and future. The formulation of the question is clearly oriented to the past (i.e. have you

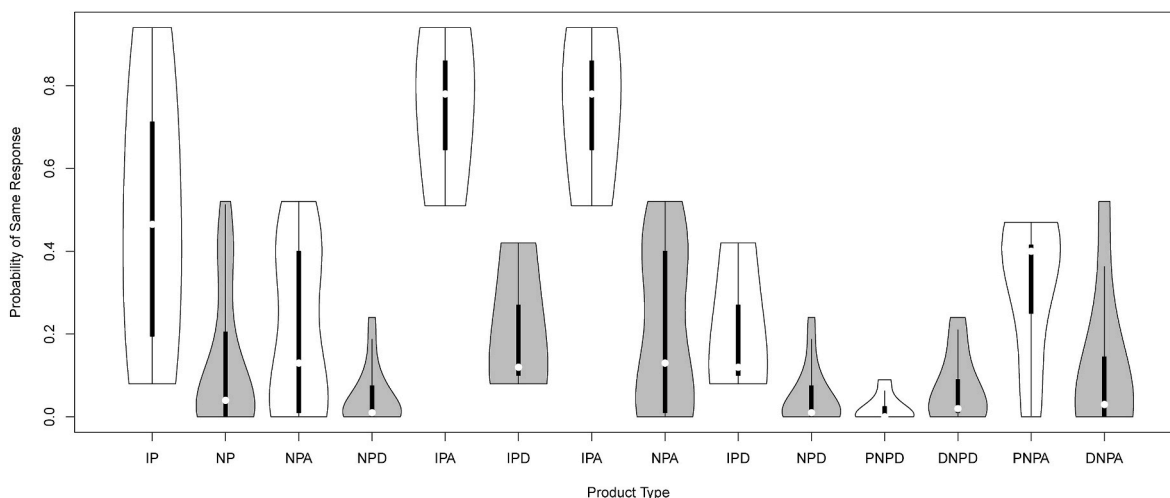


Fig. 1. Probability of Repeated Responses by Product Type
Abbreviations: IP: Incumbent Product or Behavior; NP: New Product; NPA: New product Adopter; NPD: New Product Discontinuer; IPA: Incumbent Product or Behavior Adopter; IPD: Incumbent Product or Behavior Discontinuer; IPD: Incumbent Product or Behavior Discontinuer; PNP: Physical New Product Discontinuer; DNP: Digital New Product Discontinuer; PNPA: Physical New Product Adopter; DNPA: Digital New Product Adopter. The results of the Wilcoxon-tests are presented in Table 5.

used this product?). However, the potential answers, four for digitally-based new products, and three for incumbent products, offer complex choices covering different time periods. For example, the answers: [1] yes, I currently use or [2] yes, in the past but not now, contain the present and the past at the same time.

In the possible answers for digitally-based new products given in the survey we also found the following options: [3] no, but I've heard of X [4] no, I've never heard of X. While these options may not appear to be so problematic because they refer to the past period, and may even be a way to obtain information about product awareness in the sample, they can be misleading. They are misleading because different concepts of intuition are measured. The three concepts of intuition are 1) current use, 2) past use and 3) awareness. That is, the questions do not seem to be as problematic as the possible answers. While the questions seem to measure a concept of intuition, the answers become concepts of postulation, and the answers do not measure exactly what is to be measured.

To enhance the reliability and validity of the request for answers, a potential approach is to simplify the answers. If additional information is desired, supplementary questions can be incorporated. For questions pertaining to past adoption or discontinuance, they should ideally be answerable with a simple "yes" or "no" response. If the objective is to explore whether the product will be used again in the future, a question aimed at estimating the probability that a product will be used again could be asked. An alternative way to know if a product has been discontinued is to use a statement: *I have stopped using this product*, with a yes/no answer, or a five-item Likert scale answer (Revilla et al., 2014). Instead of using agree-disagree Likert scales, which may compromise the quality of answer requests, an alternative approach could involve inquiring about the expected frequency of product usage. For example, participants could be asked about the number of times they use the product annually. Moreover, when measuring product awareness, it is advisable to address this aspect separately. These recommendations are particularly relevant at a time when many familiar products are likely to be phased out due to climate-related considerations (Guiltinan, 2010; Nishijima et al., 2019). As incumbent products vanish, new alternatives must be introduced to meet the needs previously fulfilled by these products (Helm and Little, 2022). However, the majority of new product introductions ultimately fail to attain significant market share (Crawford, 1977). These insights are also valuable for policymakers, enabling them to promote the faster adoption of resource-efficient products and prevent potential anti-competitive practices by incumbents, such as erecting barriers to entry that hinder the uptake of new innovations (Libai et al., 2009). Consequently, measuring discontinuance, both for new and complex products like those based on digital technologies, as well as for incumbent products, holds particular relevance for researchers, businesses, and public authorities in our current era of disruption.

5.3. Study limitations and future research recommendations

A limitation of this study is the lack of control for the potential impact of the Covid-19 pandemic, which occurred during the year between the main and repeat surveys. This significant disruptive event may have altered the salience and recall of information among respondents.

Accurate measurement of discontinuance dynamics through surveys is crucial for policymakers to promote the adoption of resource-efficient products (Libai et al., 2009). Deeper understanding of discontinuance dynamics opens up new research opportunities in two critical areas to reduce carbon emissions: 1) product competition and substitution dynamics for developing effective environmentally-friendly marketing strategies, including price adjustments, advertising tactics, and distribution strategies to align with increasing sustainable consumer preferences; and 2) exploring the unaddressed multiple factors (i.e. emotions) that affect discontinuance for different types of consumers and products. Addressing these two research directions will advance theories and

practical implications in the field.

Future research should prioritize improving the measurement of product adoption and discontinuance through concise questionnaires, alternative response formats, and pretests (Cernat & Sakshaug, 2021; Saris and Revilla, 2016). Longitudinal and cross-cultural investigations can provide valuable insights into behavioral variations, while exploring underlying mechanisms and technological advancements can enhance understanding. It is crucial to reduce sources of error and establish more reliable measures on the discontinuance of products in the presence of new product introductions, particularly when conducting studies across diverse cultural contexts (Steenkamp et al., 1999).

6. Conclusion

This study provides valuable insights into the measurement and dynamics of product adoption and discontinuance in the context of low carbon digitally-enabled products. The analysis highlights the challenges and complexities associated with survey question design, response options, and capturing intra-individual responses across survey waves. It reveals that the reliability and validity of measurements can be influenced by various factors, such as the type of product. The findings underscore the crucial role of carefully and precisely designing survey instruments in understanding consumer behavior with digital products and services – both in adoption and discontinuance. They align with the urgent need to understand better how to promote sustainability by discontinuing harmful products and identifying factors influencing green adoption. By addressing these methodological and theoretical gaps, researchers, practitioners, and policymakers can gain deeper insights into consumer decision-making processes and develop more effective strategies for product management and market interventions for low carbon digital innovations.

CRedit authorship contribution statement

Javier Palacios-Fenech: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing, Resources, Validation. **Emilie Vrain:** Investigation, Resources, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The two online survey datasets related to this article are available at ReShare (part of the UK Data Archive). Main survey is available at <https://reshare.ukdataservice.ac.uk/854723/>, and repeat survey is available at <https://reshare.ukdataservice.ac.uk/855005/>.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jclepro.2024.140311>.

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