

Simply tell me how—On Trustworthiness and Technology Acceptance of Attribute-Based Credentials

Rachel Crowder
Newcastle University
Newcastle upon Tyne, United
Kingdom

George Price
Newcastle University
Newcastle upon Tyne, United
Kingdom

Thomas Groß
Newcastle University
Newcastle upon Tyne, United
Kingdom

ABSTRACT

Attribute-Based Credential Systems (ACS) have been long proposed as privacy-preserving means of attribute-based authentication, yet neither been considered particularly usable nor found wide-spread adoption, to date. To establish what variables drive the adoption of ACS as a usable security and privacy technology, we investigated how intrinsic and presentation properties impact their perceived trustworthiness and behavioral intent to adopt them. We conducted two confirmatory, fractional-factorial, between-subject, random-controlled trials with a total UK-representative sample of $N = 812$ participants. Each participant inspected one of 24 variants of Anonymous Credential System Web site, which encoded a combination of three intrinsic factors (provider, usage, benefits) and three presentation factors (simplicity, presence of people, level of available support). Participants stated their privacy and faith-in-technology subjective norms before the trial. After having completed the Web site inspection, they reported on the perceived trustworthiness, the technology adoption readiness, and their behavioral intention to follow through. We established a robust covariance-based structural equation model of the perceived trustworthiness and technology acceptance, showing that communicating facilitating conditions as well as demonstrating results drive the overall acceptance and behavioral intent. Of the manipulated causal variables, communicating with simplicity and on the everyday usage had the greatest and most consistently positive impact on the overall technology acceptance. After earlier correlational empirical research on ACS technology acceptance, ours is the first research showing cause-effect relations in a structural latent factor model with substantial sample size.

KEYWORDS

attribute-based credentials, anonymous credential systems, perceived trustworthiness, technology acceptance

1 INTRODUCTION

Attribute-Based Credential Systems (ACS) and Anonymous Credential Systems as a specialization offer a great potential for the privacy protection of users in a wide range of scenarios. They have received attention from industry behemoths, such as IBM and Microsoft with their respective Identity Mixer (IDEMIX) and U-Prove implementations. They found some adoption in, for instance, in the IRMA Card [21, 52] of Radboud University or the collaboration between Microsoft Research and Signal, headed for deployment in the Signal client [16]. However, in the global scheme of things, ACS failed to reach broad adoption.

The complex technical and socio-economic challenges and herculean task of building a sustainable and thriving ACS eco system

notwithstanding, it remains an open question whether users would actually widely adopt ACS granted their availability. Furthermore, it is an open question what human factors would consistently drive such an adoption.

Prior empirical correlational research by Benenson et al. [4] with $N = 30$ university students from Patras supports that ACS technology adoption could be modelled with the Technology Acceptance Model (TAM 2.0). Similarly, recent work by Harborth and Pape [31] showed that a TAM-inspired PLS path model with $N = 141$ users could fit the adoption of the mix-network JonDoNym quite well. Even though the latter result is not on ACS themselves, its model is instructive vis-à-vis of the ACS analysis of Benenson et al. [4].

Still, to this date, we are missing a robust structural latent variable model for the perceived trustworthiness and technology acceptance of Attribute-Based Credential Systems. Prior research having only been correlational, no research to date has established actual cause-effect relations which factors would drive ACS adoption. As the given models were focused on modest extensions of core TAM, we were missing important factors such as facilitating conditions for perceived trustworthiness or results demonstrability for technology acceptance.

Aims. We ask the research question what makes a sound latent-variable model of ACS technology acceptance. We further ask which intrinsic properties of an ACS or its provider and which presentation properties of its delivery channel will impact perceived trustworthiness and eventual technology acceptance.

Our Contributions. (i) We report the first large-scale study with $N = 812$ participants representative of the UK population to establish a robust model of perceived trustworthiness and technology acceptance of Attribute-Based Credential Systems. (ii) This study is the first to establish a cause-and-effect random controlled trial with systematic manipulation of independent variables influencing perceived trustworthiness and technology adoption in a between-subjects fractional-factorial design. (iii) We offer the first confirmatory latent-variable covariance-based structural equation model (CB-SEM) of these factors, the first model to include attitudes and subjective norms as covariates as well as facilitating conditions and results demonstrability as antecedents.

2 BACKGROUND

This work investigates human factors in relation to Attribute-Based Credential Systems (ACS), using the Technology Acceptance Model (TAM) and measures of perceived trustworthiness. We introduce these areas in turn.

2.1 Attribute-Based Credential Systems

Originally conceptualized by David Chaum [17], Attribute-Based Credential Systems (ACS) bear the promise of offering authentication without identification. We especially focus on Anonymous Credential Schemes as one form with strong privacy-preserving properties. One strand of development starting from Brands' construction [9] became the ACS Microsoft U-Prove. Another based on one of the first breakthrough constructions by Camenisch and Lysyanskaya [13] was developed into the IBM Identity Mixer (IDEMIX) ACS [15]. The latter was subsequently extended with methods for revocation [12], efficient attribute encoding [11], and smart card enablement [6], all technical advancements towards the adoption in government-certified identity cards and passports. Later advancements were made in elliptic-curve instantiations [14, 47]

More recent advancements include the development of the IRMA Card [21, 52], a smart card version of ACS with selective disclosure as well as the ACS deployment for Signal to achieve privacy-preserving authentication of Signal groups [16]. Furthermore, ACS were expanded to model graph signatures [26], relational anonymous credential schemes [48, 49] and confidentiality-preserving security assurance [25], for which the nomology in this paper likely also holds.

2.2 Technology Acceptance Model

Originally developed by Davis [19, 20] as an adaptation of the Theory of Reasoned Action (TRA), the Technology Acceptance Model (TAM) offers a framework to explain computer usage behavior. It has a considerable history of scrutiny [36, 39, 46]. It has been extended with a range of antecedents such as subjective norms and results demonstrability in TAM 2.0 [50] as well as with constructs for trust and risk [42]. It was further extended to the Extended Unified Theory of Acceptance and Use of Technology (UTAUT2) [51], which was in turn used as a foundation for perceived trustworthiness scales.

TAM and its variants have been used and extended for the modeling of a range of privacy-enhancing technologies, such as Attribute-Based Credential Systems [4] and Mix-Networks [31], which we shall examine in related works.

2.3 Measuring Perceived Trustworthiness

The Cambridge Dictionary defined trustworthiness as “the quality or fact of being able to be trusted.” We investigated a range of options to measure perceived trustworthiness, especially with the context of online and computer systems. The investigated instruments are largely from the areas of marketing and e-commerce.

In our investigation, we found a distinction between a perceived trustworthiness of provider (of a service or an artifact) and the perceived trustworthiness of a system (or artifact).

In terms of Perceived Provider Trustworthiness, Lee and Turban [35] focused on trust in online merchants, distinguishing between merchant properties, medium properties and contextual properties. Gefen [24] considered different dimensions of trust and trustworthiness for electronic commerce. Büttner and Göritz [10] discussed measures of trust for online shops. Their scale includes ability, benevolence, integrity, and predictability, the former three having been used by Lee and Turban and Gefen, as well.

For Perceived System Trustworthiness on the other hand, Corritore et al. [18] investigated the perceived trustworthiness of Web sites, and considered as constructs honesty and reputation and risk. Bart et al. [3] considered Web sites, evaluating factors such as privacy and security or absence of errors as antecedents of trust.

In a separate line of work, McKnight et al. [40] investigated trust in specific technologies, including general faith in technology and trusting stance, which we adopted to measure covariates.

Alalwan et al. [1] extended the UTAUT2 with notions of trust, which used a trust scale by Gefen. Due to the affinity to the Technology Acceptance Model, this scale was one of the foundations of our measurements of perceived trustworthiness.

2.4 Measuring Privacy Concern

There exist a range of instruments measuring privacy concern, well documented for instance by Preibusch [43]. For this study, we chose Internet Users Information Privacy Concern (IUIPC) [38] as the privacy concern instrument. IUIPC has received scrutiny in terms of its validity and reliability [27]. While the instrument was reported to show good pedigree in terms of content validity, there were weaknesses found wrt. the reliability of the subscales control and awareness, which led to the proposal of an eight-item brief scale called IUIPC-8 [28].

2.5 Modelling Non-Normal, Ordinal Data

In a reflective measurement model, the indicators are endogenous, that is, caused by the latent factors. Standard maximum likelihood (ML) estimation assumes the multivariate normality for the joint population distribution of the endogenous variables, given the exogenous variables [33, 34]. This can only hold for continuous variables. Consequently, analyzing ordinal data, such as obtained from Likert scales from self-report instruments introduced above, with ML estimation may yield inaccurate results [22] and the community has discussed a range of appropriate alternatives [8]. To make the point, Liddell and Kruschke [37] illustrated misrepresentations that can occur when ordinal data is analyzed in metric models.

To establish accurate models on non-normal, ordinal data, we turn to diagonally weighted least square estimation with robust standard errors and a mean- and variance adjusted test statistic (WLSMV). In general, WLSMV models are more complex to comprehend, because they operate on a probit-estimation and thresholds for choosing a level on an indicator. They also require a greater sample size than ML models. Furthermore, Shi et al. [45] cautioned that the RMSEA fit index could be inaccurate especially for larger models with more than $p = 20$ covariance observations. They advocated SRMR as a fit estimate that stays accurate especially with a larger sample size ($N \geq 500$). We will take these considerations into account in our global fit evaluation.

3 RELATED WORKS

There are two main related works to consider for the perceived trustworthiness and technology acceptance of Attribute-Based Credential Systems (ACS).

Perceived Trustworthiness & Technology Acceptance of ACS. First, Beneson et al. [4] investigated the perceived trustworthiness and technology acceptance of ACS after a preliminary examination of

the subject [5]. They issued ACS smart card to distributed systems students of Patras University and received $N = 30$ observations from their questionnaires.

In terms of research design, Benenson et al. [4] specified a new TAM model and diligently offered the reliability statistics for the new instruments. They distinguished primary and secondary task in keeping with the observation in usable security that those are processed differently. We follow their lead in this respect.

Benenson et al. included risk and trust in their instruments, similar to Pavlou's extension of TAM [42], however only used a single item for these two constructs. We perceived single-item constructs as unreliable and fraught with statistical perils (e.g., needing to be considered ordinal and not interval scale) and, thereby, opted for more comprehensive scales. Benenson et al. also included items on situation awareness that are not found in the different versions of TAM. We also observed that the items on perceived anonymity and usefulness of the secondary task seem rather similar, which might challenge their validity.

Benenson et al. concluded that "the sample size (30 participants) is prohibitively small for deeper statistical analysis such as multiple regressions or structural equation modeling;" we agree to this commendably cautious assessment. Hence, their study only included a preliminary—yet instructive—correlation analysis.

Trustworthiness and Technology Acceptance of JonDoNym. Second, Harborth and Pape [31] established a partial least square structural equation model (PLS-SEM) with SmartPLS on a sample of JonDoNym¹ users. JonDoNym is not an ACS, but a mix-net service which was founded on the Java Anon Proxy (JAP).

Harborth and Pape established a structural equation on $N = 141$ questionnaire responses from anonymous users. Following the guidance by Hair et al. [29, 30], we note that PLS path modeling focuses on maximizing the variance explained and on theory development. The competing covariance-based SEM (CB-SEM) is more appropriate for confirmatory research. Even though PLS-SEM has been frequently criticized in the field, a number of researchers came eloquently to its defence [30, 44]. As a considerable advantage, we point out that PLS-SEM is generally non-parametric and robust in face of distribution problems. It can typically also cope with smaller sample sizes than CB-SEM, *ceteris paribus*.

We noticed in this research that the users seem to have been anonymous and that no demographics were provided. While this raises the obvious question of the characteristics of the sample, there is a subtler point that anonymous users may not be distinguished as unique and that, therefore, the independence of observations may have been jeopardized.

4 AIMS

4.1 ACS Trustworthiness & Acceptance

Our first line of inquiry is a sound model of ACS trustworthiness and technology acceptance. Here, we aim at fitting a theoretically founded model on the different relations impacting ACS technology acceptance.

RQ 1 (ACS TRUSTWORTHINESS & ACCEPTANCE). *We aim at establishing and confirming a robust structural latent variable model of the perceived trustworthiness and technology acceptance of ACS.*

We aim at a structural equation model based upon the Technology Acceptance Model (TAM 2.0) [50] and the empirical research by Benenson et al. [4]. Figure 1 illustrates the overall planned structure. The corresponding hypotheses are yielded by the underlying theory and not by establishing experimental cause-and-effect relations.

Hypotheses. For brevity, we only name the alternative hypotheses and have it understood that the corresponding null hypotheses can be derived canonically.

H_1 : Privacy Concerns yield a positive impact on the Intention to Use an ACS.

H_2 : Faith in Technology yields a positive impact on the Intention to Use an ACS.

H_3, H_4 : Privacy Concerns have a positive impact on Primary Usefulness and Privacy Usefulness, respectively.

H_5, H_6 : Faith in Technology has a positive impact on Primary Usefulness and Privacy Usefulness, respectively.

H_7 : Facilitating Conditions impact Perceived Trustworthiness positively.

H_8 : Facilitating Conditions impact Ease of Use positively.

H_9, H_{10} : Results Demonstrability has a positive impact on Primary Usefulness and Privacy Usefulness, respectively.

H_{11} : Results Demonstrability impacts Ease of Use positively.

H_{12}, H_{13} : Perceived Trustworthiness has a positive impact on Primary Usefulness and Privacy Usefulness, respectively.

H_{14}, H_{15} : Ease of Use has a positive impact on Primary Usefulness and Privacy Usefulness, respectively.

H_{16} / H_{17} : Primary Usefulness as well as Privacy Usefulness yield a positive impact on Intention to Use.

H_{18} : Ease of Use impacts the Intention to Use positively.

H_{19} : The Intention to Use impacts the Behavior to download positively.

We call the relations between Usefulness, Ease of Use, Intention to Use, governed by Hypotheses H_{14} – H_{18} , the *Core Technology Acceptance Model*.

4.2 Impact of ACS Properties

Our second line of inquiry is the cause-effect impact of intrinsic and presentation properties of an ACS on its perceived trustworthiness and technology acceptance.

RQ 2 (IMPACT OF ACS PROPERTIES). *We investigate to what extent*
 (i) *intrinsic properties of a scheme and its provider, as well as*
 (ii) *the overall presentation and perception of the offering*
impact the perceived trustworthiness, overall technology acceptance
and behavioral intention to follow through with an installation.

The corresponding hypotheses model true cause-effect relations established by experimental manipulations.

Hypotheses. Again, we only name the alternative hypotheses, the prefix *C* indicating a cause-and-effect hypothesis. All hypotheses operate on the perceived trustworthiness and the antecedents of the core technology acceptance model. Note that, therefore, each

¹<https://anonymous-proxy-servers.net>

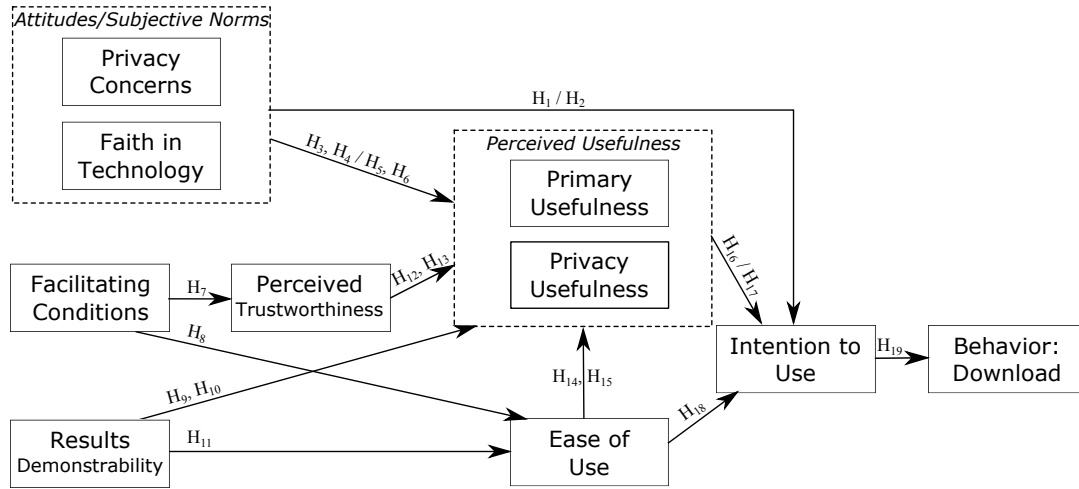


Figure 1: Aimed at structural equation model based.

Note: slash denotes different antecedents; comma denotes different consequences.

hypothesis is a compound hypothesis yielding multiple statistical hypotheses operating on low-level variables.

Intrinsic Properties.

- $H_{C,1}$: The provider of an ACS impacts its perceived trustworthiness and acceptance.
- $H_{C,2}$: The benefits of an ACS yield an impact in that user benefits have a more positively effect than privacy benefits.
- $H_{C,3}$: The usage of an ACS makes a difference in that everyday use has a more positively effect that tech usage.

Presentation Properties.

- $H_{C,4}$: Simplicity of the textual content has a positive impact on perceived trustworthiness and acceptance.
- $H_{C,5}$: The presence of people has a positive impact on perceived trustworthiness and acceptance.
- $H_{C,6}$: The available support makes a difference on perceived trustworthiness and acceptance in that more support options yield a more positive outcome.

5 METHOD

This work was pre-registered in the Open Science Framework². For reproducibility, results, graphs and tables were computed from the datasets with the R package knitr. All test statistics are evaluated at a significance level of $\alpha = .05$. Statistical inferences are designed to be two-tailed and multiple-comparison corrected.

We hosted two experiments as part of this study, one on intrinsic properties, the other on presentation properties. The two experiments were created as a fractional factorial design, that is, each experiment is a factorial design of its own manipulations, and uses the default levels of the variables of its sister experiment as fixed values. The experiment on presentation properties of Attribute-Based Credential Systems set the provider to none.

5.1 Ethics

The studies followed the ethical guidelines of the institution and received ethical approval.

Participants entered the study under informed consent and could leave the survey at any point. Participants had the opportunity to contact the principal investigator to ask further questions.

Participants were paid at slightly greater rate than required by Prolific Academic for the expected completion time of the questionnaire: £4. Participants could only enter the survey once.

5.2 Sample

Sampling Process. We set the target population as residents of the United Kingdom. As survey population, we chose the UK residents registered on the platform Prolific Academic, the sampling frame consisting of the corresponding user list as of August 2019. Both experiments were independently sampled, with participants registered for one experiment being excluded from the other, thereby maintaining independence of observations. The sampling was conducted with a representative distribution by age, gender and ethnicity, with replacement in the case of participants not completing the full survey. Overall, the sampling process was a judgment sampling, in which participants matching the age/gender/ethnicity constraints self-selected to participate.

Sample Size. The sample size was determined with an *a priori* power analysis. We planned for a range of analyses with the ultimate goal of covariance-based structural equation modelling (CB-SEM). Using a comparable study design by Benenson et al. [4] as guidance (with 8 variables), we computed an *a priori* sample size of 553 cases for Structural Equation Modeling. For a greater model with 14 latent variable and 53 measurement variables, we found *a priori* that a sample of 840 would offer us a sensitivity of an effect size of 0.16 at 80% power. Consequently, designed the study to have an overall sample size of 420 and were to be merged into one sample with 840 cases for SEM.

² https://osf.io/w39bv/?view_only=199b1119d7134e6cb2f50109361a89bd

5.3 Assignment

Both experiments were designed as random-controlled trials. In both experiments, we used a simple random assignment to allocate participants to their conditions. The randomness was generated with a Javascript pseudo-random number generator.

During an experiment run, the assignment was blinded to the experimenters as well as the participants. We facilitated this blinding by segregating the experimental environments by conditions, that is, offering a separate survey as well as a separate Web page embedding the corresponding manipulations for each condition. Experimenters were able to see the conditions assigned to participants in the final dataset.

5.4 Operationalization

5.4.1 Measurement Instruments. We adapted a range of standard questionnaires for the topic of Attribute-Based Credential Systems as target technologies. The overall purpose was to measure system trustworthiness and technology acceptance contextualized by privacy concerns and general faith in technology. Specifically, we selected the following instruments for the following purposes:

Privacy concerns (IUIPC-10) [38] Elicits the long-term privacy concerns of users in the dimensions control (ctrl), awareness (aware) and collection (collect). We selected it as a covariate, informing technology adoption wrt. privacy usefulness.

Faith in Technology (FIT) [40] Elicits long-term attitudes on using technology and general trusting stance. We selected FIT as a covariate informing primary usefulness.

System Trustworthiness (ST) [40] Elicits perceived trustworthiness in a particular technology, with a range of sub-scales. (i) Social influence (si) elicits a subjective norm in the form perceived social pressure to engage or not to engage in a behavior. (ii) Facilitating conditions (fc) models the available resources, knowledge and support engage with the technology to be trusted. (iii) Performance Expectancy measures the expectation that the technology will be useful, which we used as primary usefulness (primuse) in the Technology Acceptance Model (TAM 2.0). (iv) Perceived Trustworthiness (trust) elicits to what extent participants are willing to trust the technology. (v) Behavioral Intention models is identical to the behavioral intention used in TAM 2.0.

Technology Acceptance Model (TAM 2.0) [50] Models to what extent users are willing to adopt a given technology. (i) Results Demonstrability (results) models whether participants find the results apparent and easily communicable. (ii) Primary Usefulness (primuse) measures the expectation that the technology will be useful in general, adapted from ST Performance Expectancy. (iii) Privacy Usefulness (privuse) elicits whether participants find the technology useful to support their privacy. (iv) Behavioral Intention (bi) models the intent to use the technology, which is identical to the behavioral intention used in ST.

Table 1 contains an overview of the measurement variables with their operationalization in these instruments.

Instrument Evaluation. As we have adapted existing questionnaires in their wording to match them to the application area of

Attribute-Based Credential System, we diligently evaluated the final instruments for their validity and reliability.

Overall, the instruments used yielded considerable validity and reliability metrics. For the TAM Results Demonstrability construct, we found that one item (rTAR4) was inconsistent with the rest of the construct and chose to eliminate this item, with no ill effect on the reliability of the measurement of the construct. We removed the Social influence (si) subscale, because of excessively great indicator correlation. With regards to behavioral intention, we removed STBI3 due to great correlation with STBI1.

We noticed that two IUIPC sub-scales (ctrl and aware) yielded low internal consistency ω as discussed in earlier work. We chose to retain these constructs to keep privacy concerns in the model.

5.4.2 Manipulations. We developed a Web site about a new Attribute-Based Credential System (ACS), in which different pieces of content could be changed easily. In that, we enabled the manipulation of ACS intrinsic properties—their provider, usage and claimed benefits—and ACS presentation properties—simplicity of the content in terms of readability, presence of people and level of support. The intrinsic properties were changed in the core content, the presentation properties also in the Web design elements around the core content. These manipulations were to some extent influenced by the work of Egger et al. [23] on affective design of e-commerce user interfaces and design features that yield perceived trustworthiness. Figure 2 illustrates the manipulated pieces of content in the example of a single Web page. We controlled the possible confounder of readability with Flesch’s Reading Ease, crafting the text fragments such that they are similar in readability even if they differed in content.

Intrinsic Properties.

- (i) provider: intrinsic properties of the provider, manipulated by which provider is being used, incl. a description of the organization in an about section. Four levels (with three binomial dummy variables):
 1. gov: the UK government ($d_{\text{gov}} = 1$),
 2. company: IBM (an internationally operating company which predominately developed Attribute-Based Credential Systems in the past) ($d_{\text{company}} = 1$),
 3. uni: a nationally known university (anonymized for submission) in the UK ($d_{\text{uni}} = 1$).
 4. none: no provider is named, a condition reserved for the presentation trial ($d_{\text{gov}} = 0$ & $d_{\text{company}} = 0$ & $d_{\text{uni}} = 0$).
- (ii) benefits: intrinsic benefits of an Attribute-Based Credential System, with two levels:
 1. privacy: general benefits for privacy and data protection (benefits = 0)
 2. user: benefits specific for a user’s life (benefits = 1),
- (iii) usage: description of how the system is used intrinsically, with two levels:
 1. tech: Usage described in terms of the processes and procedures of the technology (usage = 0),
 2. everyday: Usage described in terms of every-day use of the system (usage = 1).

We define as reference category: university-privacy-tech.

Table 1: Final Operationalization of Measurement Variables (MVs)

	Instrument	Sub-Scale	Variable	Items
Privacy concerns	IUIPC-10 [38]	Control Awareness Collection	ctrl aware collect	ctrl1, ctrl2, ctrl3, awa1, awa2, awa3 coll1, coll2, coll3, coll4
Faith in Technology	McKnight [40]	Faith Trusting Stance	fit ts	MKF1, MKF2, MKF3, MKF4 MKTS1, MKTS2, MKTS3
System Trustworthiness (ST) [40]		Social Influence Facilitating Conditions Perceived Trustworthiness	si fc trust	STSH, STSH2, STSH3 STFC1, STFC2, STFC3, STFC4 STT1, STT2, STT3, STT4, STT5, STT6
Technology Acceptance Model [50]	TAM 2.0	Results Demonstrability Primary Usefulness := Performance Expectancy (ST) Privacy Usefulness Ease of Use Behavioral Intention (TS)	results primuse privuse ease bi	TAR1, TAR2, TAR3, TAR4 STPE1, STPE2, STPE3, STPE4 TAU1, TAU2, TAU3, TAU4, TAE1, TAE2, TAE3, TAE4 STB11, STB12, STB13 , STB14

Note: rVAR = reverse-coded variable VAR; VAR = variable VAR removed after reliability analysis.

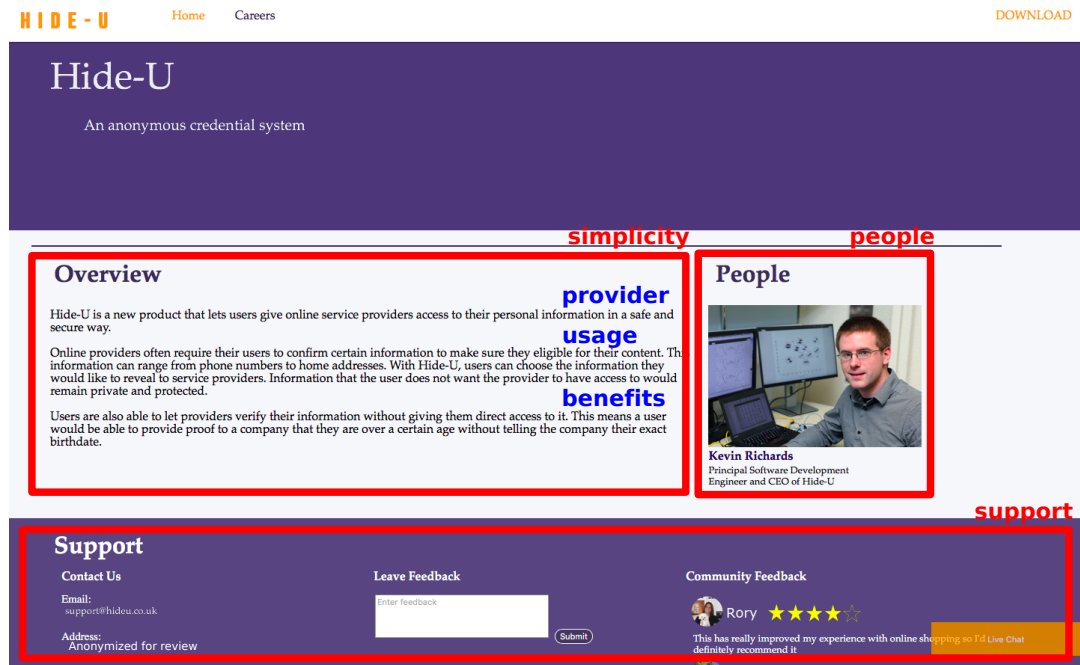


Figure 2: Overview of the interventions placed on the ACS Web site. Note: Intrinsic variables are depicted in blue; presentation variables in red. The example site displays the condition: provider=none, usage=everyday, benefits=user, simplicity=simple, people=photo, support=fullsupport of the presentation study.

Presentation Properties.

- (i) simplicity: simplicity of the language used to convey the usage and benefits of the ACS controlled by readability metrics. Two levels:
 1. complex: employs language being complex, that is, a low readability in terms of Flesch Reading Ease (or correspondingly a high reading grade level) (simplicity = 0),
 2. simple: employs simple language, that is, a high readability in terms of Flesch Reading Ease (and low reading grade level) (simplicity = 1).
- (ii) people: presentation of the ACS with a photo of a person to relate to or not, with two levels:
 1. nophoto: a photo of a person to relate to is absent (people = 0).
 2. photo: a (stock) photo representing a leading developer is displayed next to the content (people = 1),
- (iii) support: presentation of different levels of support opportunities on the Web site. Three levels (with two binomial dummy variables):

1. fullsupport: support information containing contact information (e-mail and chat) as well as a user feedback system ($d_fullsupport = 1$),
2. contact: support information contains contact information only (e-mail and chat) ($d_contact = 1$),
3. nosupport: no support-related cues are given ($d_fullsupport = 0$ & $d_contact = 0$).

We define as *reference categories*: complex-nophoto-nosupport.

5.4.3 Manipulation and Attention Checks. We integrated three kinds of manipulation checks in the survey:

1. Factual manipulation checks, asking participants questions about facts of the inspected Web pages, such as, the color of the download button, or presence of manipulations, such as, the presence/absence of a photo as indicated by the condition.
2. Impact manipulation checks, debriefing self-report of the participants how much they perceived a particular aspect of the Web page influenced them.
3. Instructional Manipulation Checks (IMCs) [41], instructions to select a particular option as confirmation of sustained attention. We pre-registered the plan to remove observations of participants who failed more than one attention check (IMC).

5.5 Procedure

As overall procedure, participants were asked to visit a Web site on Attribute-Based Credential Systems and evaluate their properties. The condition, that is, the combination of realizations of manipulated independent variables, was embedded in the Web site the participants were directed to.

The participants proceeded as follows:

- (1) First, the participants filled in questionnaires their demographics and on trait-like co-variables, such as IUIPC and general Faith and Trust in Technology.
- (2) Second, participants were directed to a web site and asked to spend 10 minutes to read the Web site and form an opinion on the described Attribute-Based Credential System (ACS).
- (3) Third, the participants were asked factual questions on the Web site appearance to check that they indeed completed the task. (In Figure 3 this step is shown with the other manipulation checks to save space)
- (4) Fourth, the participants answered questionnaires on their impressions of the system, incl. on reliability, system trustworthiness, and technology acceptance, as well as their behavioral intention to use such a system.
- (5) Throughout the questionnaire, the participants answered instructional manipulation checks (IMCs) that served as attention checks and re-confirmation to pay attention for the participants.
- (6) Finally, in the debriefing, the participants reported how much they felt different aspects of the Web site contributed to their decisions, were offered an opportunity to give qualitative comments and finally reconfirm their download action with a code.

Figure 3 illustrates this procedure in a nutshell.

Table 2: SEM Modelling Phases

Model	Description
1. Measurement	Reflective measurement of latent variables (LVs) by the measurement variables (MVs, indicators); no regression equations.
2. Correlational	Path model incorporating the measurement model <u>plus</u> regression equations according to statistical hypotheses from aims establishing ACS Trustworthiness and Acceptance (§4.1; Figure 1).
3. Causal	Path model incorporating the correlational model <u>plus</u> regression equations on dichotomous variables modelling the experiment conditions and, thereby, the causal impact of intrinsic and presentation properties (§4.2).

5.6 Structural Equation Model

The nomological network is theoretically founded on the Technology Acceptance Model (TAM 2.0) [50]. It is empirically substantiated taking into account the correlation analysis of Benenson et al. [4]. We depicted the nomology designed for this study in Figure 1.

As summarized in Table 2, we establish the structural equation model in three steps. 1. The *measurement model* is constructed by setting the measurement variables (MVs) defined in the operationalization of Table 1 as reflective measurements of the corresponding latent variables. 2. The *correlational path model* is based on the theoretical nomology proposed in Section 4, incorporating the variables primary usefulness (primuse), privacy usefulness (privuse), and ease of use (ease) forming the core of TAM. Results demonstrability (results) and facilitating conditions (fc) act as major antecedents. 3. The *causal path model* is built by adding causal variables as single-item variables and encoded as binomial dummy variables for multinomial variables. They model the conditions of the experiments. We incorporated them as regression antecedents for perceived trustworthiness (trust), primary usefulness (primuse), privacy usefulness (privuse), and ease of use (ease). This model also incorporates the download behavior as endogenous dichotomous variable and consequence of behavioral intention.

5.6.1 Modelling Approach. We followed a modelling approach that embeds the Two-Step Modelling approach proposed by Anderson and Gerling [2] and advocated by Kline [34]. We base the SEMs on a Weighted Least Square estimation with mean and variance correction (WLSMV) to account for the ordinal, non-normal data [8], evaluating the fit with the robust CFI and TLI, a robust RMSEA and SRMR.³ We compare nested models with the likelihood-ratio test (LRT) on the equal-fit hypothesis. For unnested models, we compare the cn_{05} , that is, the critical N for the χ^2 test at .95 confidence [7], in addition to other fit indices.

In our variant, we proceed according to three steps outlined in Table 2.

³We followed David A. Kenny's recommendation [32] that for models with $N > 400$ cases, the χ^2 test will be almost always statistically significant, and de-emphasized this test. Further, we are aware that RMSEA may be less reliable than usually expected in WLSMV estimation and focus on the more robust SRMR [45].

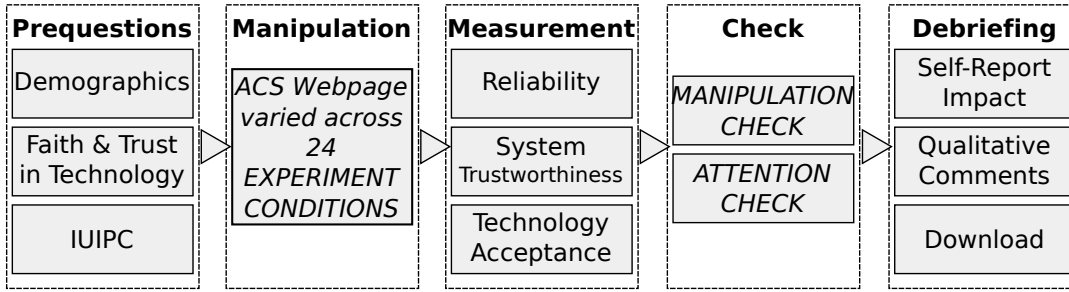


Figure 3: Overview of the experimental procedure.

- (1) We started with the theoretical model informed by general TAM 2.0 [50] and the model proposed by Benenson et al. [4]
- (2) We computed univariate histograms and density diagrams for the inputs to diagnose distribution problems as well as covariance/correlation matrices to indicate variables with risk of substantial multicollinearity. In this process, we identified variables that need additional consideration in the final model.
- (3) We evaluated the measurement model first (Table 2, Step 1.), that is, computed a confirmatory factor analysis (CFA) model that only included the exogenous and endogenous latent variables (LVs) for the desired constructs and their indicator/measurement variables (MVs). In that, we established general fit, the significance of all reflective MV-LV relations, as well as factor loadings and the reliability in terms internal consistency.
- (4) Based on this analysis, we diagnosed faults in the measurement model and underlying questionnaires, deriving a refined measurement model.
- (5) We added the predicted regression equations to the measurement model to build the correlational model (Table 2, Step 2.). We tested with a χ^2 likelihood ratio test (LRT) that the improvement of the more complex correlational model over the simpler measurement model is statistically significant. We then expanded the correlational model with direct paths from the attitudes and subjective norms to the behavioral intention. We tested this expansion, in turn, with an LRT.
- (6) Once convinced that the correlational model is a good fit, we expanded it by dichotomous variables designating the conditions of the experiments, forming the causal model (Table 2, Step 3.). We tested the statistical significance of incorporating the direct paths on attitudes and subjective norms with an LRT.

6 RESULTS

6.1 Sample

The initial sample consisted of 940 participants, 473 from the study on intrinsic properties, 467 from the study on presentation properties. Cases were removed from the sample without replacement based on two criteria: (i) The participant did not complete the full survey; (ii) The participant failed more than one attention check, as pre-registered. Table 3 shows the refinement to the final sample

Table 3: Sample Refinement

Phase	Intrinsic		Presentation		Total
	Excluded	Size	Excluded	Size	
Starting Sample		473		467	940
Incomplete	58	415	34	433	848
Duplicate	25	390	0	433	823
FailedAC > 1	36	379	0	433	812
Final Sample					812

Table 4: Demographics of the final sample

	Overall
N	812
Gender (%)	
Male	391 (48.2)
Female	414 (51.0)
Rather not say	7 (0.9)
Age (%)	
18-24	133 (16.4)
25-34	215 (26.5)
35-44	167 (20.6)
45-54	115 (14.2)
55-64	141 (17.4)
65+	41 (5.0)

with a final $N = 812$. We provide its demographic characteristics in Table 4.

6.2 Measurement Model Evaluation

We first established a confirmatory factor analysis (CFA) of the measurement model, that is, of the indicator variables and latent variables considered. We established this CFA on the variables specified in operationalization Table 1.

We found that the measurement model showed a good global fit, documented in Table 5. We inspected the residuals for local fit and were satisfied. While we anticipated correlated residuals, based on observations on the questionnaire, we chose not to include those in the model *ad post facto*.

Table 5: Fit measures for the WLSMV-estimated CFA of the measurement model.

χ^2	df	p_{χ^2}	CFI	TFI	RMSEA	LL	UL	p_{rmsea}	SRMR
3501.88	879.00	< .001	0.97	0.97	0.06	0.06	0.06	< .001	0.05

Table 6 incorporates the WLSMV-estimated factor loadings of the measurement model. All loadings are estimated with high confidence and a p -value of $p < .001$. In terms of reliability, the factors ctrl and aware show the lowest internal consistency, with $\omega = 0.73$ and a signal-to-noise ratio ($S/N_\omega \leq 2.76$). Privacy usefulness (privuse yields the greatest internal consistency, with $\omega = 0.95$). Overall, we assess that the measurement model is valid and sufficiently reliable to continue our investigation with the correlational structural equation model.

6.3 Correlational Model

As second step, we evaluated the correlational path model, which incorporates the measurement model established in Section 6.2 and adds regression equations modelling the hypothesized relations introduced in Section 4. This more complex model yielded a statistically significant improvement over the measurement model, $\chi^2(23) = 430.138, p < .001$. This already gave us confidence in the validity of the correlational model.

We established the correlational model itself in two steps: by first computing a model without the direct paths between attitudes and subjective norms to behavioral intention, that is, excluding the test of H_1 and H_2 , and then adding these paths in model building. The hypothesized model including the paths modelling hypotheses H_1 and H_2 fits statistically significantly better than the indirect model: We rejected the equal-fit hypothesis, $\chi^2(5) = 78.199, p < .001$.

We depict the resulting structural path model in Figure 4. We evaluate the global fit of the correlational model in Table 7, showing a decent fit. The scaled RMSEA of 0.066 indicates potentially troublesome residuals. On the other hand, the SRMR of 0.0546934 considered robust for the WLSMV estimation is defensible.

6.3.1 ACS Trustworthiness & Acceptance. We report selected regression coefficients in Table 8 and discuss their consequences in the following paragraphs.

Let us first consider the structural equation model on perceived trustworthiness and technology acceptance, that is, hypotheses H_1 thru H_{18} from Section 4.1. Figure 5 gives an overview of which hypotheses were retained, while Table 8 includes the corresponding near-significant or significant regression coefficients.

6.3.2 Core Technology Acceptance Model. As expected in core TAM, Primary Usefulness, Privacy Usefulness all impact behavioral intention positively. We thereby reject the null hypotheses corresponding to H_{16} and H_{17} . Regarding H_{18} , the impact of ease of use on behavioral intention is statistically significant in the model without direct attitude/subjective-norm paths, but not so in the model with them. Ease of Use has a statistically significant effect on both kinds of Usefulness. Hence, we reject the null hypotheses corresponding to H_{14} and H_{15} .

6.3.3 TAM Antecedents. Perceived Trustworthiness has a statistically significant impact on both forms of Usefulness. Hence we reject the null hypotheses corresponding to H_{12} and H_{13} .

Results Demonstrability has a statistically significantly positive impact on both forms of Usefulness as well as Ease of Use. We thereby reject the null hypotheses corresponding to H_9 , H_{10} and H_{11} .

Facilitating Conditions statistically significantly yielded a positive change in Perceived Trustworthiness and Ease of Use. We reject the null hypotheses corresponding to H_7 and H_8 .

6.3.4 Attitudes & Subjective Norms. We consider privacy concern first and present a comparison of the situation in indirect and direct modelling in Table 9. First, we observe that control and awareness have contradicting impact on their consequences. While ctrl impacts both forms of usefulness negatively, aware impacts them positively. The impact of collection is comparatively small. We could not unequivocally reject the null hypotheses corresponding to the hypotheses (H_1, H_3, H_4) on impact of privacy concerns (IUIPC control, awareness, and collection) on either Usefulness or Intention to Use. In the comparison between indirect and direct modelling, the direct effects of ctrl, aware and collect on behavioral intention negate the indirect effects through the perceived usefulness.

We find a similar situation with faith in technology (fit) and trusting stance (ts). Here, faith technology has a positive impact on usefulness and trusting stance a negative impact on usefulness. Likewise, the direct paths to behavioral intention negate these effects.

6.3.5 Mediation Analysis. We conduct a mediation analysis on the effects of privacy concern in Table 9. The table compares the standardized coefficients β of privacy concern factors with respect to their direct, indirect and total effect on behavioral intention. The left-side model, called “indirect” only incorporates the indirect effects of privacy concern through perceived usefulness. The right-side model, called “direct” incorporates a direct path from privacy concern factors to behavioral intention. Of the two models, the direct model is a statistically significantly better fit, $\chi^2(5) = 78.199, p < .001$. Consulting the table, we observe an inconsistent mediation, in which the direct effect contradicts the indirect effect mediated through perceived usefulness. The direct effects have a greater absolute magnitude than the sum of the indirect effects.

6.4 Causal Model

We compared the model with only indirect paths between attitudes and subjective norms to behavioral intention (excluding the test of H_1 and H_2) to the model including direct paths. We found that the model with direct paths improved the global fit statistically significantly, $\chi^2(5) = 83.791, p < .001$. We show the global fit of the WLSMV-estimated causal path model in Table 10. The causal

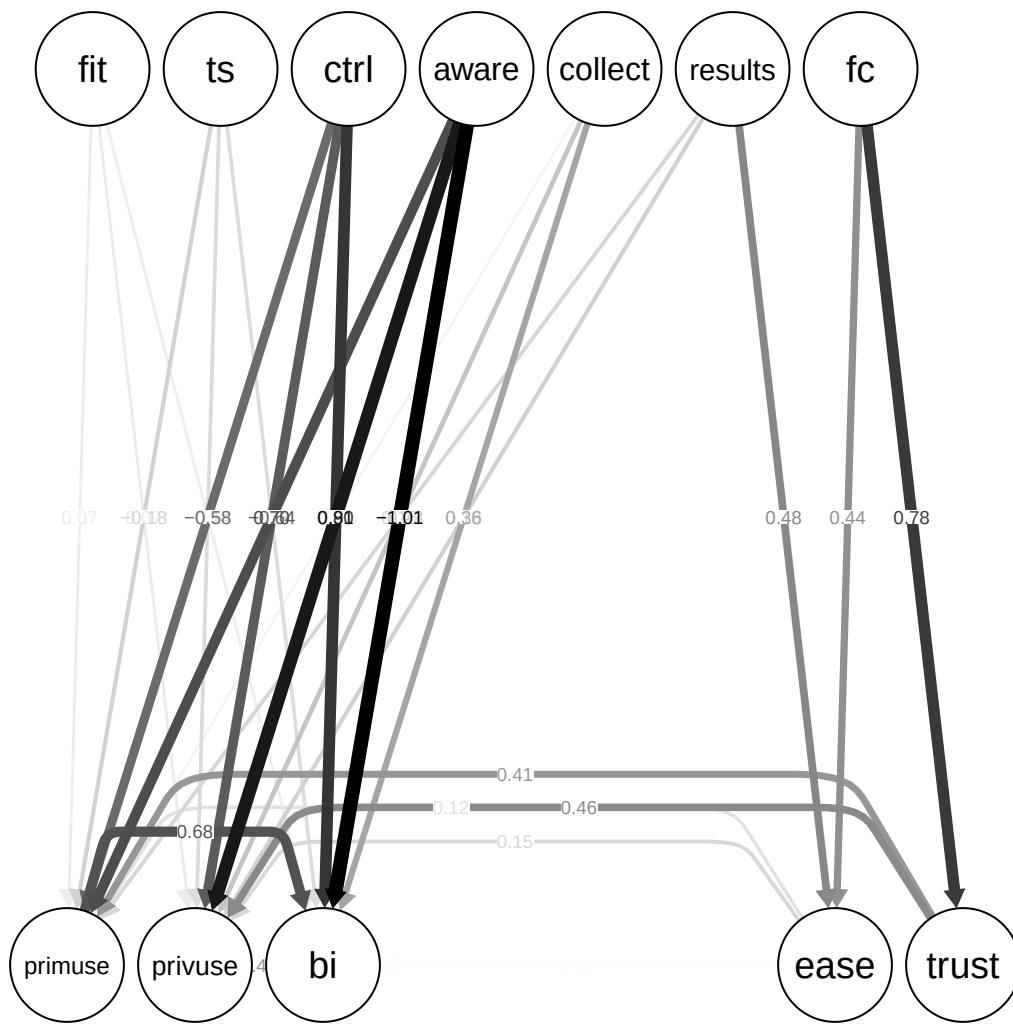


Figure 4: Correlational SEM model restricted to latent variables (standardized coefficients).

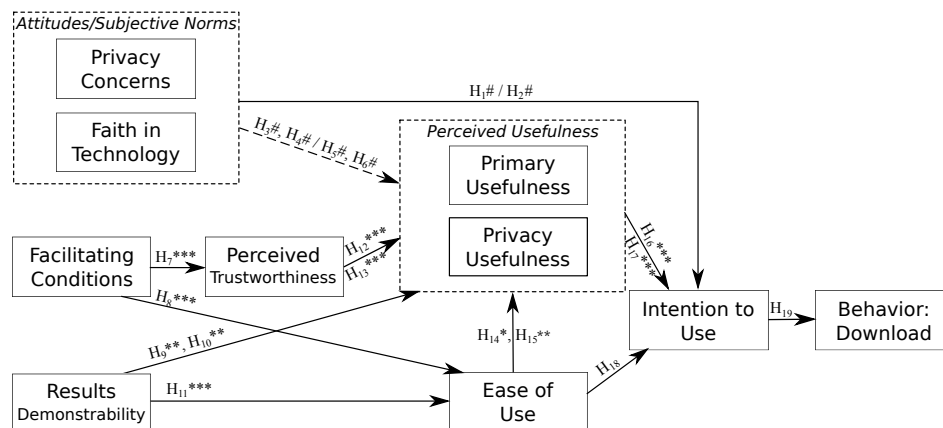


Figure 5: Results on hypothesis testing.

Note: slash denotes different antecedents; comma denotes different consequences; #: contradicting effects; *: $p < .05$, **: $p < .01$, ***: $p < .001$.

Table 6: Factor loadings of the WLSMV-estimated CFA of the measurement model.

Factor	Indicator	Factor Loading				Standardized Solution				Reliability				
		λ	SE_{λ}	Z_{λ}	p_{λ}	β	SE_{β}	Z_{β}	p_{β}	R^2	AVE	α	ω	S/N_{ω}
fit	MKF1	1.00 ⁺				0.81	0.02	35.05	< .001	0.66	0.63	0.83	0.82	4.63
	MKF2	1.02	0.04	24.43	< .001	0.83	0.02	37.90	< .001	0.68				
	MKF3	0.97	0.04	21.94	< .001	0.78	0.02	32.12	< .001	0.61				
	MKF4	0.92	0.04	20.52	< .001	0.75	0.03	26.67	< .001	0.56				
ts	MKTS1	1.00 ⁺				0.90	0.01	73.09	< .001	0.82	0.78	0.87	0.90	8.67
	MKTS2	1.06	0.03	40.70	< .001	0.96	0.01	78.95	< .001	0.93				
	MKTS3	0.84	0.02	39.08	< .001	0.76	0.02	42.75	< .001	0.58				
ctrl	ctrl1	1.00 ⁺				0.79	0.03	30.02	< .001	0.62	0.54	0.65	0.73	2.76
	ctrl2	0.99	0.06	17.85	< .001	0.78	0.03	30.46	< .001	0.61				
	ctrl3	0.81	0.06	13.63	< .001	0.64	0.04	17.38	< .001	0.40				
aware	awa1	1.00 ⁺				0.82	0.03	27.64	< .001	0.67	0.62	0.66	0.73	2.70
	awa2	1.03	0.06	16.18	< .001	0.84	0.03	28.32	< .001	0.70				
collect	awa3	0.86	0.05	15.70	< .001	0.70	0.03	20.79	< .001	0.49				
	coll1	1.00 ⁺				0.82	0.01	61.96	< .001	0.68	0.73	0.89	0.89	8.45
	coll2	0.92	0.02	39.25	< .001	0.76	0.02	48.45	< .001	0.57				
primuse	coll3	1.15	0.02	56.36	< .001	0.95	0.01	128.34	< .001	0.90				
	coll4	1.06	0.02	61.20	< .001	0.88	0.01	88.81	< .001	0.77				
	STPE1	1.00 ⁺				0.91	0.01	73.64	< .001	0.83	0.79	0.90	0.92	11.93
	STPE2	0.95	0.02	56.72	< .001	0.87	0.01	82.70	< .001	0.75				
privuse	STPE3	0.97	0.02	58.04	< .001	0.88	0.01	95.98	< .001	0.78				
	STPE4	0.98	0.02	58.36	< .001	0.89	0.01	99.00	< .001	0.79				
	TAU1	1.00 ⁺				0.93	0.01	151.88	< .001	0.86	0.88	0.94	0.95	17.30
	TAU2	1.04	0.01	138.23	< .001	0.97	0.00	223.09	< .001	0.93				
ease	TAU3	1.03	0.01	140.53	< .001	0.95	0.00	205.54	< .001	0.91				
	TAU4	0.97	0.01	102.03	< .001	0.90	0.01	106.90	< .001	0.81				
	TAE1	1.00 ⁺				0.90	0.01	75.75	< .001	0.81	0.72	0.88	0.89	8.12
	TAE2	0.85	0.02	42.94	< .001	0.77	0.02	50.63	< .001	0.59				
bi	TAE3	0.97	0.02	50.76	< .001	0.87	0.01	71.99	< .001	0.76				
	TAE4	0.94	0.02	49.38	< .001	0.85	0.01	66.73	< .001	0.72				
	STB1	1.00 ⁺				0.95	0.01	189.61	< .001	0.91	0.86	0.93	0.93	13.56
	STB2	0.95	0.01	100.82	< .001	0.91	0.01	122.42	< .001	0.83				
results	STB4	0.96	0.01	103.36	< .001	0.92	0.01	126.51	< .001	0.84				
	TAR1	1.00 ⁺				0.86	0.01	65.62	< .001	0.74	0.69	0.84	0.85	5.51
	TAR2	0.88	0.02	40.69	< .001	0.76	0.02	49.45	< .001	0.58				
fc	TAR3	1.00	0.02	44.44	< .001	0.87	0.01	61.83	< .001	0.75				
	STFC1	1.00 ⁺				0.69	0.02	34.95	< .001	0.48	0.57	0.78	0.82	4.54
	STFC2	1.19	0.04	30.50	< .001	0.83	0.02	52.77	< .001	0.69				
	STFC3	1.14	0.04	25.46	< .001	0.79	0.02	38.96	< .001	0.63				
trust	STFC4	1.02	0.05	22.04	< .001	0.71	0.02	29.26	< .001	0.50				
	STT1	1.00 ⁺				0.97	0.00	202.29	< .001	0.93	0.70	0.90	0.91	10.13
	STT2	1.00	0.01	117.14	< .001	0.96	0.00	203.71	< .001	0.93				
	STT3	0.79	0.02	51.18	< .001	0.77	0.02	50.90	< .001	0.59				
	STT4	0.86	0.01	68.35	< .001	0.83	0.01	68.59	< .001	0.69				
	STT5	0.65	0.02	32.22	< .001	0.63	0.02	32.02	< .001	0.40				
	STT6	0.84	0.02	54.06	< .001	0.81	0.01	55.24	< .001	0.65				

Note: ⁺ fixed parameter; the standardized solution is STDALL**Table 7: Fit measures for the WLSMV-estimation of the correlational SEM.**

χ^2	df	p_{χ^2}	CFI	TFI	RMSEA	LL	UL	p_{rmsea}	SRMR
4034.26	897.00	< .001	0.96	0.96	0.07	0.06	0.07	< .001	0.05

model exhibits an excellent fit, better than the correlational model, evident in fulfilling the close-fit hypothesis.

We report that the regression coefficients of correlational and causal models are estimated to be essentially equal. The estimates reported in Table 8 still hold. Hence, the overall model stayed stable with the addition of the causal conditions. We continue to shed light on the impact of the causal conditions.

6.4.1 Impact of ACS Properties. As outlined in Section 4.2, we anticipated intrinsic and presentation properties experimentally manipulated to impact the antecedents of the core technology acceptance model. Table 11 shows the corresponding near-significant

and significant coefficients. We note that only the negative impact on perceived trustworthiness was statistically significant.

Intrinsic Properties. The intrinsic properties (provider, benefits and usage) were largely not statistically significant, apart from the provider being set to a company, which had a slight negative impact on primary usefulness. Hence, we failed to reject the null hypotheses corresponding to $H_{C,1}$, $H_{C,2}$ and $H_{C,3}$.

Presentation Properties. The presentation of the ACS (simplicity, people, support) made a considerable difference. While the presence of people did not show a statistically significant impact, failing to

Table 8: Regression coefficients of the correlational SEM.

Relation	<i>H</i>	<i>B</i>	<i>SE</i>	<i>p</i>	β
bi ~ ctrl***	<i>H</i> ₁	0.998	0.181	< .001	0.797
bi ~ aware***	<i>H</i> ₁	-1.223	0.213	< .001	-1.006
bi ~ collect***	<i>H</i> ₁	0.411	0.089	< .001	0.355
bi ~ fit	<i>H</i> ₂	-0.077	0.072	.289	-0.065
bi ~ ts*	<i>H</i> ₂	0.142	0.066	.031	0.135
primuse ~ ctrl***	<i>H</i> ₃	-0.700	0.128	< .001	-0.585
primuse ~ aware***	<i>H</i> ₃	0.819	0.149	< .001	0.704
primuse ~ collect	<i>H</i> ₃	-0.048	0.065	.455	-0.044
privuse ~ ctrl***	<i>H</i> ₄	-0.783	0.159	< .001	-0.645
privuse ~ aware***	<i>H</i> ₄	1.074	0.192	< .001	0.910
privuse ~ collect**	<i>H</i> ₄	-0.258	0.084	.002	-0.230
primuse ~ fit	<i>H</i> ₅	0.081	0.057	.156	0.072
primuse ~ ts***	<i>H</i> ₅	-0.178	0.054	< .001	-0.177
privuse ~ fit	<i>H</i> ₆	0.084	0.067	.209	0.074
privuse ~ ts*	<i>H</i> ₆	-0.143	0.060	.017	-0.140
trust ~ fc***	<i>H</i> ₇	1.201	0.047	< .001	0.782
ease ~ fc***	<i>H</i> ₈	0.627	0.061	< .001	0.438
primuse ~ results**	<i>H</i> ₉	0.167	0.062	.007	0.157
privuse ~ results**	<i>H</i> ₁₀	0.195	0.062	.002	0.181
ease ~ results***	<i>H</i> ₁₁	0.499	0.042	< .001	0.475
primuse ~ trust***	<i>H</i> ₁₂	0.391	0.035	< .001	0.414
privuse ~ trust***	<i>H</i> ₁₃	0.441	0.036	< .001	0.461
primuse ~ ease*	<i>H</i> ₁₄	0.120	0.060	.047	0.119
privuse ~ ease**	<i>H</i> ₁₅	0.159	0.050	.001	0.155
bi ~ primuse***	<i>H</i> ₁₆	0.713	0.051	< .001	0.682
bi ~ privuse***	<i>H</i> ₁₇	0.438	0.064	< .001	0.425
bi ~ ease	<i>H</i> ₁₈	0.009	0.055	.869	0.008

reject the null hypothesis corresponding to $H_{C,5}$, the other two interventions carried significant weight. In the support category it made statistically significant difference to have a contact option, affecting both trust and ease of use positively on the order of $\beta \approx 0.1$. Hence, we rejected the null hypothesis corresponding to $H_{C,6}$.

Simplicity had the greatest impact on the model, statistically significantly affecting primary usefulness ($\beta = 0.115$) and ease of use ($\beta = 0.2$). We thereby rejected the null hypothesis corresponding to $H_{C,4}$.

7 DISCUSSION

7.1 Technology acceptance of ACS

Adoption of Attribute-Based Credential Systems (ACS) is well modeled with the extended Technology Acceptance Model (TAM 2.0). Taking into account the earlier work of Benenson et al. [4], we offer the first structural latent variable model from a large sample size with a sound WLSMV estimation for ordinal data. Perceived trustworthiness (trust) is a major predictor of Privacy Usefulness (privuse) and Primary Usefulness (primuse) with medium standardized effects.

7.2 Primary tasks trump privacy protection

We found that the primary usefulness trumped the privacy usefulness. This is not surprising and is a common belief in the community, that is, that the user's focus is on the primary task and not on the secondary task (here, privacy protection), phenomenon also observed by Benenson et al. [4]. However, once direct and indirect effects of privacy concern are accounted for, the ratio of effect of primary usefulness and privacy usefulness is only 3:2.

7.3 Demonstrable results and facilitating conditions are key drivers

Our structural model design took into account antecedents from system trustworthiness as well as TAM 2.0: facilitating conditions and results demonstrability. Facilitating conditions strongly impacted trust and ease of use. They model whether a user has the right resources and knowledge, compatible systems and help available. It stands to reason that these questions indeed need to be answered well to convince a user to adopt an ACS.

Similarly, TAM 2.0 results demonstrability, that is, whether the results are apparent to the user and whether the user is capable of explaining the results to others, yield considerable effects on ease of use as well as on privacy usefulness. Both results demonstrability and facilitating conditions had consistently positive effects as drivers of behavioral intention.

7.4 Focus on simplicity

Of the manipulated variables, simplicity has the most consistent positive effect: We found that choosing simple language in terms of readability had considerable significant positive effects on primary usefulness and ease of use. Hence, simple language would make users more likely to adopt the technology. The question arises to what extent the ACS can be presented in a simple fashion while still convincing users of their technical merits.

7.5 Lessons learned for the privacy paradox

Understanding how privacy concerns impact behavioral intention is crucial for the investigation of the privacy paradox. While earlier research already pointed out an attenuation effect in behavioral models due to middling reliability of prevalent privacy concern scales, we gain further insights from our model.

7.5.1 Inconsistent impact of IUIPC factors. We observed that the IUIPC factors control and awareness have contradicting effects on behavioral intention. While awareness increases the behavioral intention to use the ACS, control diminishes it. Awareness emphasizes that the user be aware and knowledgeable how information is used and that companies facilitate that by clearly disclosing how they handle information. Control on the other hand emphasizes the right to control and autonomy over decisions over the user's information. One may hypothesize that the conviction that the user has the right to control already yields less behavioral intention to adopt further privacy preserving technologies to enforce that control. With regards to the privacy paradox, the contradiction between impact of privacy antecedents on behavioral intention consequences offers an explanation why the privacy paradox occurs that has not been well researched previously.

7.5.2 Inconsistent mediation. Our analysis is the first to offer a mediation analysis of indirect and direct paths of privacy concern impacting behavioral intention. Here, we observed an inconsistent mediation for all privacy concern factors, that is, that direct effects and indirect effects have different signs. For example, control yields a positive effect through a direct path to behavioral intention, but negative indirect paths through usefulness.

Table 9: Privacy concern in indirect and direct modelling.

Relation	indirect				direct			
	B	SE	p	β	B_d	SE_d	p_d	β_d
primuse ~ ctrl	-0.314	0.069	< .001	-0.269	-0.700	0.128	< .001	-0.585
primuse ~ aware	0.340	0.078	< .001	0.303	0.819	0.149	< .001	0.704
primuse ~ collect	0.136	0.044	.002	0.123	-0.048	0.065	.455	-0.044
privuse ~ ctrl	-0.247	0.069	< .001	-0.208	-0.783	0.159	< .001	-0.645
privuse ~ aware	0.390	0.078	< .001	0.340	1.074	0.192	< .001	0.910
privuse ~ collect	-0.017	0.041	.677	-0.015	-0.258	0.084	.002	-0.230
bi ~ ctrl					0.998	0.181	< .001	0.797
bi ~ aware					-1.223	0.213	< .001	-1.006
bi ~ collect					0.411	0.089	< .001	0.355
Total Effect								
bi $\leftarrow$ ctrl				-0.206				0.124
bi $\leftarrow$ aware				0.256				-0.139
bi $\leftarrow$ collect				0.070				0.228

Table 10: Fit measures for WLSMV-estimation of the causal SEM.

χ^2	df	p_{χ^2}	CFI	TFI	RMSEA	LL	UL	p_{rmsea}	SRMR
3965.99	1319.00	< .001	0.97	0.98	0.05	0.05	0.05	.590	0.05

Table 11: Selected coefficients of the causal SEM, $p < .15$.

Relation	H	B	SE	p	β
primuse ~ d_gov	$H_{C,1}$	-0.175	0.112	.118	-0.071
primuse ~ d_company*	$H_{C,1}$	-0.250	0.112	.025	-0.095
trust ~ benefits	$H_{C,2}$	-0.144	0.100	.150	-0.061
primuse ~ usage	$H_{C,3}$	-0.112	0.075	.134	-0.052
primuse ~ simplicity*	$H_{C,4}$	0.203	0.079	.010	0.096
ease ~ simplicity***	$H_{C,4}$	0.423	0.093	< .001	0.201
primuse ~ people	$H_{C,5}$	0.112	0.075	.132	0.054
trust ~ d_contact*	$H_{C,6}$	0.281	0.121	.020	0.103
ease ~ d_contact**	$H_{C,6}$	0.311	0.109	.004	0.120

7.6 Limitations

7.6.1 Ecological Validity. There are limitations to the ecological validity as the ACS Web pages used as stimuli were mock-ups. With respect to manipulating the provider, the Web sites did not use the provider’s logos or domains due to licensing and legal restrictions. Otherwise, they mimicked the look-and-feel of existing sites of providers on Attribute-Based Credential Systems.

In order to gain a large representative sample and to be able to manipulate aspects of the ACS Web site, we paid a price in terms of ecological validity. The study of Benenson et al. [4] was more hands-on in offering their students physical artifacts (smart cards, etc.), thereby yielding stronger ecological validity.

7.6.2 Generalizability. The large sample was representative for the UK, in terms of age, gender and ethnicity. Due how Prolific operates, the sampling process is judgment sampling with self-selection, rather than a random sampling process on UK residents. However, in contrast to prior work, this study was neither limited to university students [4] nor constrained to anonymous users without reported demographics [31], affording us greater generalizability than in any previous study.

7.6.3 Measurement of Privacy Concerns. As indicated in the background section and observed in earlier studies [27, 28], the measurement of privacy concern with IUIPC-10 only offered middling reliability. As a consequence, we face a low signal-to-noise ratio on the privacy concern measurement and an attenuation of its effects on other factors. While most of the relations could still be estimated with considerable certainty, we incurred lower certainty for smaller regression coefficients.

8 CONCLUSION

In having established the first comprehensive structural latent variable model for the trustworthiness and acceptance of Attribute-Based Credential System (ACS), we offer a sound foundation for research in user decision making on ACS. Our latent variable model is based on a large sample representative of the UK population in gender, age and ethnicity.

While our model confirms and expands on existing research on ACS trustworthiness and acceptance as well as re-confirms conventional wisdom that perceived primary-task usability typically trumps perceived privacy usability, we show new insights which factors drive the users decisions. In that, we are the first to include results demonstrability and facilitating conditions as key drivers and show that they yield a consistent, medium-large positive effect on the ultimate technology acceptance of ACS. Overall, our model constitutes a comprehensive nomological network that can be used for other privacy-enhancing technologies beyond the given use case of ACS.

Furthermore, having established the first truly causal-effect analysis of the impact of intrinsic and presentation properties, we can show that simplicity of content yields a consistently positive impact. While a support framework (e.g., support contact or forum) also yielded a positive impact: it benefited the perceived trustworthiness.

We can show that using simple language to instruct the user on facilitating conditions, that is, what knowledge and resources are

needed to run the ACS successfully, and on demonstrable results, that is, what the ACS does in day-to-day and how to convey that to others, will yield a considerable boost in technology acceptance.

Our work, finally, offers new insights into the study of the privacy paradox, the attitude-behavior dichotomy of privacy: we observed inconsistent effects of different privacy concern factors and an inconsistent mediation.

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REFERENCES

- [1] ALALWAN, A. A., DWIVEDI, Y. K., AND RANA, N. P. Factors influencing adoption of mobile banking by Jordanian bank customers: Extending utaut2 with trust. *International Journal of Information Management* 37, 3 (2017), 99–110.
- [2] ANDERSON, J. C., AND GERBING, D. W. Structural equation modeling in practice: A review and recommended two-step approach. *Psychological bulletin* 103, 3 (1988), 411.
- [3] BART, Y., SHANKAR, V., SULTAN, F., AND URBAN, G. L. Are the drivers and role of online trust the same for all web sites and consumers? a large-scale exploratory empirical study. *Journal of marketing* 69, 4 (2005), 133–152.
- [4] BENENSON, Z., GIRARD, A., AND KRONTRIS, I. User acceptance factors for anonymous credentials: An empirical investigation. In WEIS (2015).
- [5] BENENSON, Z., GIRARD, A., KRONTRIS, I., LIAGKOU, V., RANNENBERG, K., AND STAMATIOU, Y. User acceptance of privacy-abcs: an exploratory study. In *International Conference on Human Aspects of Information Security, Privacy, and Trust* (2014), Springer, pp. 375–386.
- [6] BICHSEL, P., CAMENISCH, J., GROSS, T., AND SHOUP, V. Anonymous credentials on a standard java card. In *Proceedings of the 16th ACM conference on Computer and communications security* (2009), pp. 600–610.
- [7] BOLLEN, K. A., AND LIANG, J. Some properties of hoelter’s CN. *Sociological Methods & Research* 16, 4 (1988), 492–503.
- [8] BOVAIRD, J. A., AND KOZIOI, N. A. Measurement models for ordered-categorical indicators. In *Handbook of Structural Equation Modeling*, R. H. Hoyle, Ed. The Guilford Press, 2012, pp. 495–511.
- [9] BRANDS, S. *Rethinking public key infrastructures and digital certificates: building in privacy*. Mit Press, 2000.
- [10] BÜTTNER, O. B., AND GÖRITZ, A. S. Perceived trustworthiness of online shops. *Journal of Consumer Behaviour: An International Research Review* 7, 1 (2008), 35–50.
- [11] CAMENISCH, J., AND GROSS, T. Efficient attributes for anonymous credentials. In *Proceedings of the 15th ACM conference on Computer and communications security* (2008), ACM, pp. 345–356.
- [12] CAMENISCH, J., AND LYSYANSKAYA, A. Dynamic accumulators and application to efficient revocation of anonymous credentials. In *Annual International Cryptology Conference* (2002), Springer, pp. 61–76.
- [13] CAMENISCH, J., AND LYSYANSKAYA, A. A signature scheme with efficient protocols. In *International Conference on Security in Communication Networks* (2002), Springer, pp. 268–289.
- [14] CAMENISCH, J., AND LYSYANSKAYA, A. Signature schemes and anonymous credentials from bilinear maps. In *Advances in Cryptology – CRYPTO 2004* (Berlin, Heidelberg, 2004), M. Franklin, Ed., Springer Berlin Heidelberg, pp. 56–72.
- [15] CAMENISCH, J., AND VAN HERREWEGHEN, E. Design and implementation of the idemix anonymous credential system. In *Proceedings of the 9th ACM conference on Computer and communications security* (2002), pp. 21–30.
- [16] CHASE, M., PERRIN, T., AND ZAVERUCHA, G. The signal private group system and anonymous credentials supporting efficient verifiable encryption. Tech. rep., Cryptology ePrint Archive, Report 2019/1416, 2019.
- [17] CHAUM, D. Security without identification: Transaction systems to make big brother obsolete. *Communications of the ACM* 28, 10 (1985), 1030–1044.
- [18] CORRITORE, C. L., MARBLE, R. P., WIEDENBECK, S., KRACHER, B., AND CHANDRAN, A. Measuring online trust of websites: Credibility, perceived ease of use, and risk. *AMCIS 2005 proceedings* (2005), 370.
- [19] DAVIS, F. D. *A technology acceptance model for empirically testing new end-user information systems: Theory and results*. PhD thesis, Massachusetts Institute of Technology, 1985.
- [20] DAVIS, F. D., BAGOZZI, R. P., AND WARSHAW, P. R. User acceptance of computer technology: a comparison of two theoretical models. *Management science* 35, 8 (1989), 982–1003.
- [21] DE LA PIEDRA, A., HOEPFMAN, J.-H., AND VULLERS, P. Towards a full-featured implementation of attribute based credentials on smart cards. In *International Conference on Cryptology and Network Security* (2014), Springer, pp. 270–289.
- [22] DISTEFANO, C. The impact of categorization with confirmatory factor analysis. *Structural equation modeling* 9, 3 (2002), 327–346.
- [23] EGGER, F. N., ET AL. Affective design of e-commerce user interfaces: How to maximise perceived trustworthiness. In *Proc. Intl. Conf. Affective Human Factors Design* (2001), Citeseer, pp. 317–324.
- [24] GEFEN, D. Reflections on the dimensions of trust and trustworthiness among online consumers. *ACM SIGMIS Database: the DATABASE for Advances in Information Systems* 33, 3 (2002), 38–53.
- [25] GROSS, T. Efficient certification and zero-knowledge proofs of knowledge on infrastructure topology graphs. In *Proceedings of the 6th Edition of the ACM Workshop on Cloud Computing Security* (New York, NY, USA, 2014), CCSW ’14, Association for Computing Machinery, pp. 69–80.
- [26] GROSS, T. Signatures and efficient proofs on committed graphs and NP-statements. In *Financial Cryptography and Data Security* (Berlin, Heidelberg, 2015), R. Böhme and T. Okamoto, Eds., Springer Berlin Heidelberg, pp. 293–314.
- [27] GROSS, T. Validity and reliability of the scale internet users’ information privacy concern (iuipe). *Proceedings of the Privacy-Enhancing Technologies Symposium (PoPETS) 2021*, 2 (2021), 235–258.
- [28] GROSS, T. Toward valid and reliable privacy concern scales: The example of iuipe-8. In *Human Factors in Privacy Research*, Springer Verlag, 2023.
- [29] HAIR JR, J. F., HULT, G. T. M., RINGLE, C., AND SARSTEDT, M. *A primer on partial least squares structural equation modeling (PLS-SEM)*. Sage publications, 2016.
- [30] HAIR JR, J. F., MATTHEWS, L. M., MATTHEWS, R. L., AND SARSTEDT, M. Pls-sem or cb-sem: updated guidelines on which method to use. *International Journal of Multivariate Data Analysis* 1, 2 (2017), 107–123.
- [31] HARBORTH, D., AND PAPE, S. Examining technology use factors of privacy-enhancing technologies: the role of perceived anonymity and trust. In *Twenty-fourth Americas Conference on Information Systems* (New Orleans, 2018).
- [32] KENNY, D. A. Measuring model fit. <http://davidakenny.net/cm/fit.htm>, Nov 2015.
- [33] KLINE, R. B. Assumptions in structural equation modeling. In *Handbook of Structural Equation Modeling*, R. H. Hoyle, Ed. The Guilford Press, 2012, pp. 111–125.
- [34] KLINE, R. B. *Principles and practice of structural equation modeling*, 4th ed. ed. The Guilford Press, 2015.
- [35] LEE, M. K., AND TURBAN, E. A trust model for consumer internet shopping. *International Journal of electronic commerce* 6, 1 (2001), 75–91.
- [36] LEE, Y., KOZAR, K. A., AND LARSEN, K. R. The technology acceptance model: Past, present, and future. *Communications of the Association for information systems* 12, 1 (2003), 50.
- [37] LIDDELL, T. M., AND KRUSCHKE, J. K. Analyzing ordinal data with metric models: What could possibly go wrong? *Journal of Experimental Social Psychology* 79 (2018), 328–348.
- [38] MALHOTRA, N. K., KIM, S. S., AND AGARWAL, J. Internet users’ information privacy concerns (IUPC): The construct, the scale, and a causal model. *Information systems research* 15, 4 (2004), 336–355.
- [39] MATHIESON, K. Predicting user intentions: comparing the technology acceptance model with the theory of planned behavior. *Information systems research* 2, 3 (1991), 173–191.
- [40] MCKNIGHT, D. H., CARTER, M., THATCHER, J. B., AND CLAY, P. F. Trust in a specific technology: An investigation of its components and measures. *ACM Transactions on Management Information Systems (TMIS)* 2, 2 (2011), 12.
- [41] OPPENHEIMER, D. M., MEYVIS, T., AND DAVIDENKO, N. Instructional manipulation checks: Detecting satisfying to increase statistical power. *Journal of Experimental Social Psychology* 45, 4 (2009), 867–872.
- [42] PAVLOU, P. A. Consumer acceptance of electronic commerce: Integrating trust and risk with the technology acceptance model. *International journal of electronic commerce* 7, 3 (2003), 101–134.
- [43] PREIBUSCH, S. Guide to measuring privacy concern: Review of survey and observational instruments. *International Journal of Human-Computer Studies* 71, 12 (2013), 1133–1143.
- [44] SARSTEDT, M., HAIR, J. F., RINGLE, C. M., THIELE, K. O., AND GUDERGAN, S. P. Estimation issues with pls and cbsem: Where the bias lies! *Journal of Business Research* 69, 10 (2016), 3998–4010.
- [45] SHI, D., MAYDEU-OLIVARES, A., AND ROSSEEL, Y. Assessing fit in ordinal factor analysis models: Srmr vs. rmsea. *Structural Equation Modeling: A Multidisciplinary Journal* 27, 1 (2020), 1–15.
- [46] SZAJNA, B. Empirical evaluation of the revised technology acceptance model. *Management science* 42, 1 (1996), 85–92.
- [47] TAN, S.-Y., AND GROSS, T. Monipoly—an expressive q -SDH-based anonymous attribute-based credential system. In *ASIACRYPT 2020* (May 2020).
- [48] TAN, S.-Y., AND GROSS, T. A relational credential system from q -sdh-based graph signatures. Cryptology ePrint Archive Report 2023/1181, IACR, 2023.
- [49] TAN, S.-Y., SFYRAKIS, I., AND GROSS, T. A q -sdh-based graph signature scheme on full-domain messages with efficient protocols. Cryptology ePrint Archive Report 2020/1403, IACR, 2020.
- [50] VENKATESH, V., AND DAVIS, F. D. A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management science* 46, 2

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- (2000), 186–204.
- [51] VENKATESH, V., THONG, J. Y., AND XU, X. Consumer acceptance and use of information technology: extending the unified theory of acceptance and use of technology. MIS quarterly (2012), 157–178.
- [52] VULLERS, P., AND ALPÁR, G. Efficient selective disclosure on smart cards using idemix. In IFIP Working Conference on Policies and Research in Identity Management (2013), Springer, pp. 53–67.