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PREFERENCE INCONSISTENCY IN MULTIDISCIPLINARY DESIGN DECISION MAKING

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ABSTRACT
Research from behavioral psychology and experimental economics asserts that individuals construct preferences on a case-by-case basis when called to make a decision. A common, implicit assumption in engineering design is that user preferences exist a priori. Thus, preference elicitation methods used in design decision making can lead to preference inconsistencies across elicitation scenarios. This paper offers a framework for understanding preference inconsistencies, within and across individual users. We give examples of three components of this new framework: comparative, internal, and external inconsistencies across users. The examples demonstrate the impact of inconsistent preference construction on common engineering and marketing design methods, including discrete choice analysis, modeling stated vs. revealed preferences, and the Kano method and thus QFD. Exploring and explaining preference inconsistencies produces new understandings of the relationship between user and product.

Keywords: customer preference; preference construction; context effect; utility theory; multidisciplinary design; decision making; Kano; discrete choice analysis; conjoint analysis; preference model

1. INTRODUCTION
A common, implicit assumption in engineering design is that user preferences exist a priori: preferences exist as a "database" in the users' mind which they query when making product-related decisions. While designers cannot directly access such a database, they can create models derived from it. For example, utility methods for estimating preferences are sometimes used as if such a database exists and has a particular structure. Products are then designed and optimized using these measurable user preference models. Research in behavioral psychology over the past thirty years has challenged this view of user preferences, finding instead that people construct preferences as needed on a case-by-case basis in response to the decision at hand. The phenomenon is referred to as preference construction [1]. Such research has shown violation of the utility theory assumptions, such as rationality, and that preferences can change in response to question phrasing. In certain decision scenarios with a choice between two outcomes, question phrasing has triggered shifts in preference from one option to the other, termed a preference reversal [1]. Survey design plays a large role in preference outcome, and important decisions of juries and doctors are prone to inconsistencies based on the context in which their preferences are elicited [2, 3]. As multidisciplinary design increasingly integrates engineering models with models from other disciplines, including marketing, sensitivity to the limitations of models is increasingly warranted, so that better design insights can be gained.

Preference construction theory has yet to be incorporated into the preference elicitation models and methods used in engineering design. Within the preference elicitation tools that product designers currently use, preference construction can lead to preference inconsistency. It is important to emphasize that preference inconsistency is symptomatic of two or more

different preference constructions, and, in order to identify a preference inconsistency, at least two measurements of customer preference must be performed using separate preference elicitation methods. This paper suggests a new framework for understanding preference inconsistencies and gives three examples of different preference inconsistencies important in engineering design. The examples also serve to demonstrate the research potential of incorporating preference construction theory into engineering design research.

We begin by introducing a new conceptual framework that helps categorize the research in construction of preferences from other fields, and subsequently allows us to apply this research within engineering design. We define two general types of preference inconsistency. The first is *within-user inconsistency*, in which a user may construct preferences with dependence on, for example, mood or amount of time available to interact with the preference elicitation tool. This type of inconsistency manifests, for example, in measured properties of error and/or variance in consumer preference models. The second type is the *across-user inconsistency*, wherein a group of users are all inconsistent in their preferences in a similar and explainable manner. This type of inconsistency manifests in the estimated parameters of the model, and may also contribute to within-user inconsistency. Note that this is different from preference heterogeneity, in which model parameters account for differences in preferences between users or groups of users. To further explain the concept, we define three different types of across-user inconsistency that are useful in engineering design work: comparative, external, and internal.

We define a *comparative inconsistency* as an inconsistency identified by comparison of preference constructions from different groups of users in response to very similar preference elicitation procedures. It is termed comparative because it requires comparisons of preferences between sets of users.

We define an *external inconsistency* as occurring when a group of users exhibits a mismatch between stated preferences in a preference elicitation procedure and revealed preferences gathered from purchase history. It is termed external because it requires the examination of preferences determined outside of the preference elicitation process to identify the inconsistency.

We define *internal inconsistency* as occurring when a preference structure determined for a group of users in one part of a preference elicitation procedure fails to explain or is contradictory to the preference behavior demonstrated separately by the same group of users in another part of the preference elicitation procedure. It is termed an internal inconsistency because it is identified by examining results of one preference elicitation procedure, e.g., a survey, without using outside information, such as different versions of the same elicitation procedure or purchase information.

The paper offers one example each of our categorizations of comparative, external, and internal inconsistencies. Each example comes from a different form of preference elicitation: Kano category classification, capturing the voice of the customer in Quality Function Deployment; discrete choice survey analysis, with small manipulations in survey formulation causing large inconsistencies in preference; and a combination approach, where discrete choice survey analysis, buy/not buy scenarios, and past purchase information are all used to demonstrate inconsistency in preference construction. In all three examples, inconsistent preference construction does not serve to discredit the method at hand, but instead adds increased insight to design knowledge. The first example shows that consumers perceive a strong relationship between 'quilting' and absorbency in paper towels. In a previous publication, the approach was generalized to a methodology that detects the "sentinel/crux" attribute relationship in products [4]. The second example demonstrates that a large market potential for eco-friendly paper towels could be created through the activation of a particular preference construction for a group of users. The third example suggests it is more difficult for people to consistently imagine necessity than it is for people to consistently imagine delight.

2. LITERATURE REVIEW

2.1 Behavioral Psychology, Economics, and Marketing

Researchers have repeatedly used context effects, a particular type of across-user comparative preference inconsistency, to discredit theories and assumptions of psychology and economic behavior. For excellent literature reviews, refer to Slovic, who cites over forty papers on the subject, and Kagel and Roth's *Handbook of Experimental Economics*, which devotes several chapters to related work from a variety of fields [1,5]. The phenomenon of preference reversal has been well-documented with the help of context effects, observed when different phrasings of a choice question are shown to result in different experimental outcomes. If a user appeals to an internal database through a query, then the same preference should emerge independent from particular contextual variables. The finding that different choices result from manipulations of context is taken as evidence that users do not query a database but rather construct their preferences.

A classic example is that "it is possible to construct pairs of lotteries with the property that many people, when asked at what price they would be willing to sell (or buy) the lotteries, put a higher price on one, but when asked to choose which they would prefer to participate in, choose the other" [5]. Display effects, such as horizontal *vs.* vertical positioning of choice sets have also been demonstrated [5]. In multiple choice surveys, such as discrete choice, it has been found that "how one feels about an attribute level (say, 35 mpg) depends critically on the competing levels of the other alternatives (say, 30 or 40 mpg)" and "continuous attributes are biased upward compared with categorical attributes" [6].

The experimental economics community has demonstrated that willingness to pay, and thus utility theory, is contingent upon different context effects and preference constructions. Tversky and Kahneman employed context effects to discredit

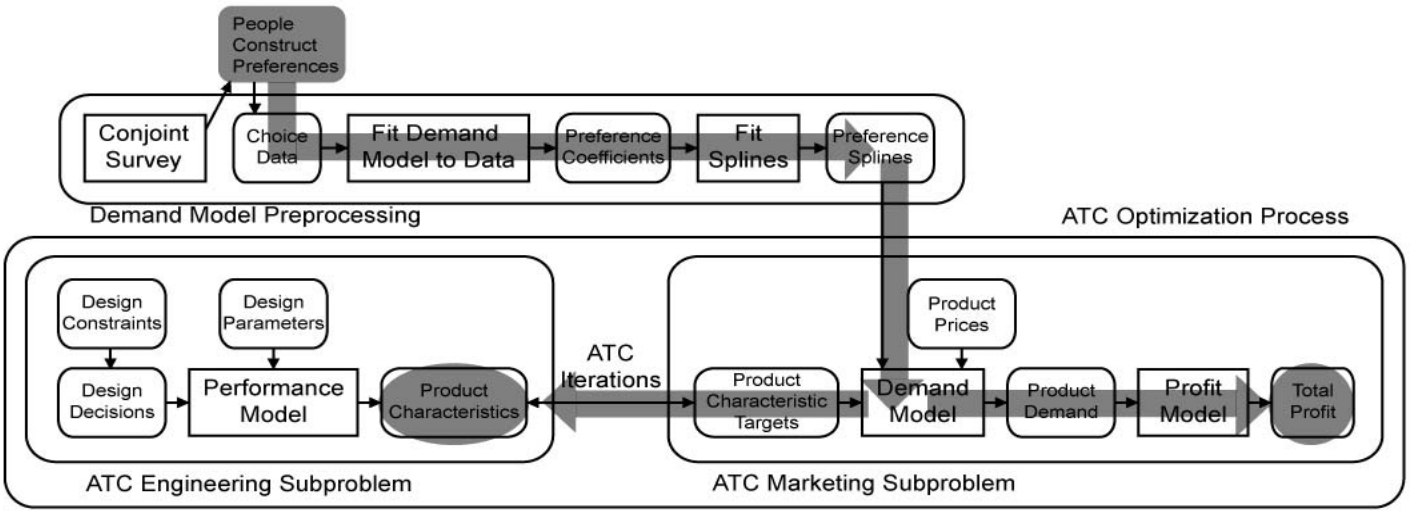

Figure 1: Propagation of preference construction through Michalek's engineering/marketing ATC Formulation

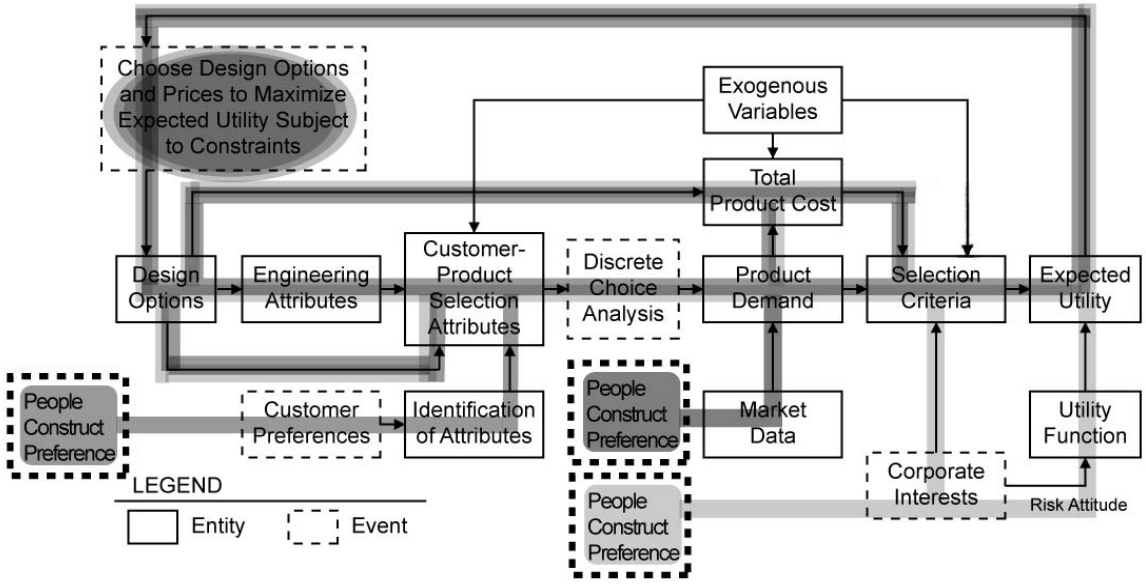

Figure 2: Propagation of preference construction through Wassenaar *et al.*'s decision-based-design flow chart

rational choice behavior modeling [5, 7]. The experimental economics community has documented violations of both "description invariance" and "procedure invariance," which claim that despite different representations and elicitation procedures, the same choice problem should always result in the same preferences. Camerer an experimental economist, explains: "Invariance violations are especially troublesome for utility theories… The most famous violations of description invariance are "framing effects." Reversals of preference are induced by changes in the reference points… the most pressing question is whether framing effects are systematic and predictable. The evidence is mixed" [5].

2.2 Decision-Based-Design

Within-user preference inconsistency, which can manifest as preference model variance, has been addressed previously by Luo et. al., and Besharati et. al.[8, 9], They use robust design to address the variance of consumer preference parameters in an interdisciplinary marketing/engineering design optimization. As many engineering design frameworks accept variance in parameters, within-user inconsistency can be dealt with in this fashion. This approach cannot address across-user inconsistencies, as these inconsistencies manifest not necessarily in model variance, but instead in model parameters, with potential implications in variance and error terms as well. This will be demonstrated in the discrete choice analysis example in Section 3.

Pullman et. al. notice the effects of across-user inconsistency, without noting it as such, in their comparison of preferences elicited from QFD and conjoint analysis, stating that optimal products designed using the two different preference elicitation processes varied on important features. They claim the difference stems from "what customers say they want and what managers think will best satisfy customer needs," which is another way of stating that managers are attempting to compensate for preference inconsistencies between point of evaluation, purchase and use [10].

The effects of across-user preference construction are highlighted in the grey overshadow of two design methodology frameworks proposed by Michalek and Wassenaar illustrated in Figures 1 and 2 [11, 12]. These figures serve to demonstrate how preference inconsistencies become involved in and propagate through design processes. Michalek's framework only takes one measurement of customer preference, so inconsistencies will not be identified or addressed. Wassenaar's generalized framework includes three sources of preference construction, and these constructs will interact in the framework. In this framework, there is potential for the identification of external inconsistencies with modifications to the framework, for example by comparing collected customer preferences and existing market data.

Designers also experience preference construction in their design decisions. In deciding between conflicting preferences, preference structure inconsistencies may lead to different products. Preference construction research has shown that rewording questions can change indifference points between two alternatives, and can change preference for one alternative over another, impacting design decisions that use the hypothetical equivalents/inequivalents approach [13]. See et al. state that "a designer's stated preferences may result in intransitive preference structures." This a typical result of the context effect experiments mentioned previously. It may seem viable to combat intransitivity or dampen preference inconsistency by asking designers to explain their preferences, but this leads to confirmation bias and bolstering, in which people reconstruct their preference structures after making a decision in order to substantiate their choice [14, 15]. Kulok and Lewis develop a method to correct for this within-user (in this case, within-designer) preference inconsistency without, necessarily, input from the designer [16]. Interestingly, Gurnani and Lewis found that relaxing the assumption of rationality by introducing error into a model of designer decisions (the construction of preferences) leads to convergence and optimality in decentralized design [17].

Survey used in Sections 3 and 4:

Components of a 217-respondent survey on paper towels are used to demonstrate comparative and external inconsistencies. The six-part survey was administered by Luth Research [18] via the internet. Respondents received one dollar for participating. The survey was designed and the results were analyzed using Sawtooth Software [19]. The survey structure is summarized in Table 1. Results from Part I were presented at ICED2007 and are summarized in Section 3 to demonstrate a comparative inconsistency [4]. This paper and [4] were written in tandem. This paper serves to define a framework of preference inconsistencies and discuss illustrative examples, while [4] concentrates on introducing a new methodology based on the identification of comparative preference inconsistency. Results from Parts II, IV, and V are analyzed in Section 4 as new contributions and an example of external inconsistency.

Table 1: Overview of paper towel survey

Part I	Part II	Part III	Part IV	Part V	Part VI
Discrete Choice I 3 versions	Discrete Choice II 1 version	Rate Brand Perform-Ance	Past Purchase Info.	Buy/Not Buy Scenarios	Demo-graphics

3. COMPARATIVE INCONSISTENCY IN DISCRETE CHOICE ANALYSIS

In Part I, three different groups of approximately 70 users were given a discrete choice survey and chose between paper towels with the different attributes and levels as described in Table 2. An example question from survey Part I, version A, is shown in Figure 3. Group A took survey version A, which did not mention towel absorbency, softness, or strength. Group B took survey version B, which was slightly 'manipulated': absorbency, softness, and strength were mentioned as product attributes but with exactly the same "average" level of 2 out of 3 across all possible answers. Note that this "average" level information was identical across all profiles, all respondents, and all choice tasks. Group C took survey version C, in which absorbency, softness, and strength were presented with varying levels, like the other towel attributes: softness (rating of 1, 2, 3 out of 3), absorbency (rating of 1, 2, 3 out of 3), and strength (rating of 1, 2, 3 out of 3). Note that these rating scales were not purely ordinal, as the survey began with descriptions of each rating, i.e., "Absorbency: A rating of 1 out of 3 can absorb a 2.5 inch water spill (About the same size around as a tomato slice)." These rating descriptions were available as a pop-up window with every question.

A multinomial logit model (McFadden's Conditional Logit) was fit to each group's answers using Sawtooth CBCHB [20]. This model allows us to obtain estimates of preferences for each individual and relies on Bayesian estimation techniques [21]. The estimated parameters were normalized using the "full factorial marketplace normalization technique," an original method of the authors explained in more detail in [4], in order to compare the different models, because utility measurements cannot be compared directly across models due to scaling effects. In the full factorial market, part worth utilities are used to predict the choice share of every possible product (every combination of attribute/levels), assuming every possible product is available for selection. Full factorial choice shares are calculations of the utility of each product in the marketplace divided by the sum of utility of all possible products. While

Table 2: Attributes and Levels Present in Versions A, B, and C of survey Part I

Attribute	Strength	Softness	Absorbency	Quilting	Recycled Paper Content	Packaging	Pattern
Version *A* N=70				Quilted or Not Quilted	0, 30, 60, or 100%	1,2,or 3 Rolls	Patterned or Not Patterned
Version *B* N=73	2 out of 3	2 out of 3	2 out of 3	Quilted or Not Quilted	0, 30, 60, or 100%	1,2,or 3 Rolls	Patterned or Not Patterned
Version *C* N=74	1,2, or 3 out of 3	1,2, or 3 out of 3	1,2, or 3 out of 3	Quilted or Not Quilted	0, 30, 60, or 100%	1,2,or 3 Rolls	Patterned or Not Patterned

Figure 3: Example questions from survey Part I, versions A

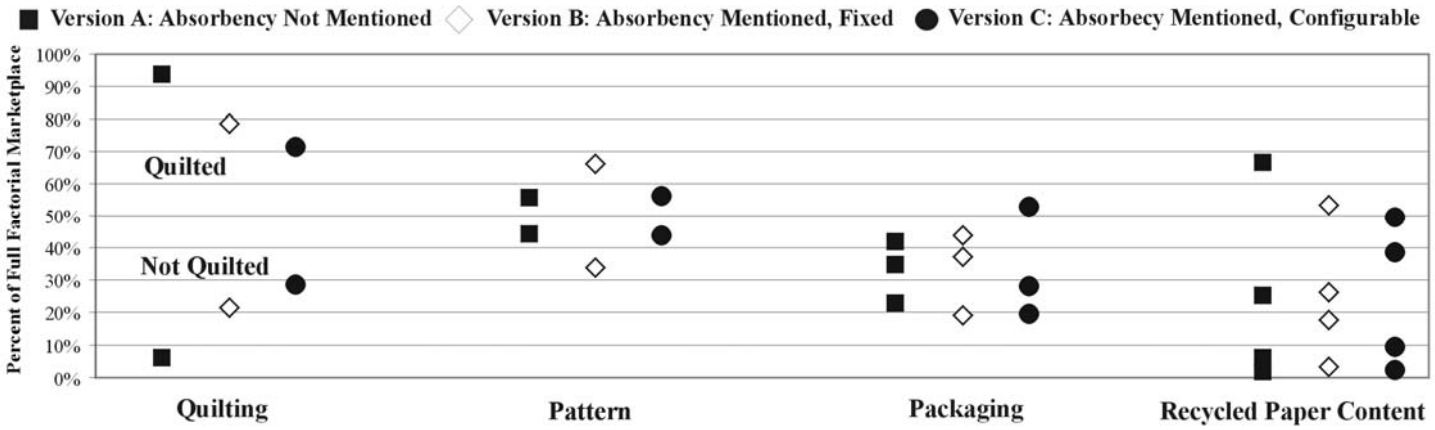

Figure 4: Aggregated Full Factorial Market Shares across survey versions

utility between separate model estimations cannot be compared, full factorial marketplace measures can. The full factorial marketplace includes all possible levels of all attributes in all possible combinations, thus avoiding related model artifact problems. Full factorial choice shares are aggregated across all products that contain a particular attribute/level, to create a measurement we term the *aggregated full factorial market share*. As with utility part worths, a higher aggregated full factorial market share means a higher preference, and a larger spread between aggregated market shares for the levels of one attribute means that attribute is more important in the choice decision than others.

Figure 4 shows the aggregated full factorial market shares for the attributes and levels of quilting, pattern, packaging, and recycled paper content across the three groups. Group A, which knew nothing about the towels' absorbency, had a high preference for quilted paper towels. Absorbency was included as average across all choices for Group B, and their preference for quilting was significantly less. For Group C, which saw varying levels of absorbency in their available towel choices, quilting approaches the importance of the more trivial attributes of pattern and packaging. This difference in preference structure between versions A and B is particularly interesting because these versions shared exactly the same choice options.

Figure 5 shows the estimated part worths for quilting in more detail, with standard error bars. If Besharati et al.'s [9] integrated marketing and design robust optimization approach had been used with version A of this survey, it would have found that quilting was an important attribute in the design of the paper towel, but not so for versions B and C. Since the across-user preference inconsistency affects the parameter and potentially also variance and error, their approach would lead to different robust optima dependent on the construction of preferences.

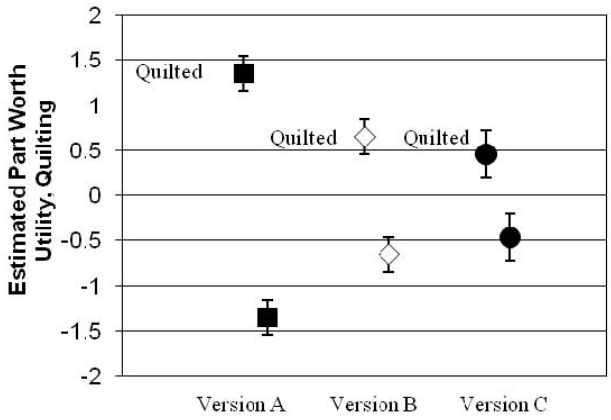

Figure 5: Preference for quilted over not quilted

A main effects analysis was also performed using Sawtooth's SMRT 'Counts' interface [22]. The independent variables were the attributes, and the dependent variable was choice. In version A, Recycled Paper Content and Quilting were significant predictors of choice ($p<.01$). Pattern and Packaging were not significant predictors of choice. In version B, Recycled Paper Content and Quilting were significant predictors of choice ($p<.01$). Pattern and Packaging were not significant predictors of choice. In version C, Strength, Softness, Absorbency, and Recycled Paper Content were significant predictors of choice ($p<.01$). Quilting was not a significant predictor of choice, nor was Packaging or Pattern. As an indication that respondents evaluated the attributes as independent from each other, no significant interaction effects were found between attributes in any survey version. In other words, no combination of any two attributes was a significant predictor of choice.

Complex attributes of high importance to the user we term *crux* attributes, while other attributes associated with the crux ones we term *sentine*l. A methodology for rigorously identifying this crux/sentinel relationship is given in [4]. Identifying this relationship helps designers to understand how users evaluate products and construct preferences. In the above example, quilting serves as a sentinel for the crux attribute of absorbency. Surveys that miss crux attributes will give inconsistent preferences for sentinel attributes, when compared to preferences modeled from surveys that include both crux and sentinel attributes.

4. EXTERNAL INCONSISTENCY IN ECO-DESIGN

An eco-friendly product purchase requires users to make a complex attribute trade-off between public good (preserving the environment) and private good (sacrifice in price or performance, or both). Preference construction for eco-friendly products is prone to external inconsistency between preferences gathered in the design process and preferences exhibited in the marketplace. Three preference construction phenomena can account for these construction inconsistencies. *Social desirability bias* (SDB) is a propensity for people to answer a survey in accordance with an accepted social norm, in the case of eco-design, advancing the public good rather than the private good [23]. *Embedding* occurs when, for example, users state that they are willing to pay a fifty-cent premium for a recyclable yogurt container in a survey on yogurt, when, in fact, the user is only willing to add fifty cents to their entire weekly shopping bill to purchase eco-friendly goods [24]. In other words, such premiums do not necessarily scale for an individual's multiple purchases. *Pseudo-sacredness* occurs when the individual's values for the environment are manifested as 'sacred' in preference elicitation, i.e. they will not trade them for other desirable qualities; but in another context, their eco-values are traded-off [25].

The following research is based on the assumption that people perceive a link between recycled paper content and eco-friendly paper towels. The survey used in this research and presented in Table 1 avoided directly evaluating the strength of this link in order to minimize respondent "priming" for thinking about the environment during the survey. The survey purposefully never mentions the word "environment," as this could strengthen social desirability bias. We also could not ask respondents for the relative importance of recycled paper content as compared to other attributes in eco-friendly paper towels at the end of the survey, as the large amount of exposure to this attribute during the survey would bias their answers. Instead, we rely on inference and past findings to support this assumption. With respect to the perceived importance recycled paper content versus other potential eco-friendly attributes: respondents did not care as much about packaging in their product choices as they did about recycled paper content in Section 3. Previous choice analysis research on toilet paper found that the average respondent was not willing to pay more for unbleached paper alone, but was willing to pay more for recycled paper alone [23]. With respect to the perceived importance of buying products made from recycled materials versus other eco-friendly actions: refer to chapter eight of an excellent compilation of polls on environmental issues by Guber, which states that environmentalists and non-environmentalists alike are more likely to "buy products made from recycled materials whenever possible" than "buy a product because the label or advertising said it was environmentally safe or biodegradable" or "avoid purchasing products made by a company that pollutes the environment" [26]. Other relevant references are also provided by Guber.

Survey Part V asks users what price they would pay for a paper towel with average strength, average softness, average absorbency, and 0% recycled paper content. Sixty out of 217 users stated that they would not buy the towel for any price due to lack of recycled paper content and/or concerns for the environment. However, 52 out of 60 of these respondents reported in Part IV buying a towel brand that has 0% recycled paper content the last time they went shopping. This conflict in preference is an external preference inconsistency. It can be partially explained by the fact that only 3 of the 52 users gave a correct rating of 0% recycled paper content for their brand of towel in Part III. We term these 52 users idealists, as they are both idealistic in their own preferences and the configurations of the products they purchase. To detect whether or not this idealists group would fall out statistically, we appeal to latent class methods that are especially suited to this investigation.

We fit a latent class multinomial mixture model to survey Part II, a discrete choice survey. This was a separate discrete choice survey than the one in survey Part I, with the same survey given to all respondents and featuring the following mixture of product attributes: softness (rating of 1, 2, 3 out of 3), absorbency (rating of 1, 2, 3 out of 3), and strength (rating of 1, 2, 3 out of 3), recycled paper content (0, 30, 60, 100%), and price ($1.29, $2.39, $3.49, $4.59).

Preferences for the attributes of price, recycled paper content, absorbency, softness, and strength were modeled as part worth utilities with a discrete mixture model (also referred to as a latent class multinomial logit model) [27, 28]. Out of 2, 3, 4, 5, 6, 7, and 8 group models, a class structure of 3 groups provided the best-fitting model. To determine which model was best, Consistent Akaike Information Criterion (CAIC) were compared between models, with Groups of 2 and 3 providing the lowest (and thus best) CAIC values [23]. Although the 3 group model had a slightly higher (1529.56) CAIC than the 2 group model (1484.54), we selected the 3 group model because: (1) the idealist group fell out statistically, as we had predicted, (2) the pooled standard error on the parameter estimates was significantly lower in the 3 group model than the 2 group model, and (3) the 3 group model "added" a large third group that was highly sensitive to absorbency measures, providing additional explanatory value to the model. As Sawtooth recommends for selecting the best model, "When choosing among solutions, one also has access to other information, such as their patterns of utilities and estimated group sizes" [23].

The estimated part worth utilities for attribute levels are shown in Figure 6, where the graphs have been visually normalized to compare the groups. This normalization is a legitimate technique, as utility comparisons on a numerical scale can only be made within groups, not between groups. For example, a price of $4.59 has a utility of -1.07 to the traders and -9.44 to the price-driven group. This does not mean that the traders get 8.37 more utility out of a $4.59 price than the price-driven group does. It can be concluded, though, that all three groups prefer a price of $3.49 to $4.59, as $3.49 has a higher utility in all groups. Standard errors will be included in a future publication. Figure 6 clearly illustrates a group of users, termed the "traders," who value recycled paper content as much as price in their decisions, and trade-off all attributes in their decisions. This group includes 48 of the 52 idealists. The idealists comprise 31% of the traders group, indicating an external inconsistency for the entire group's preferences.

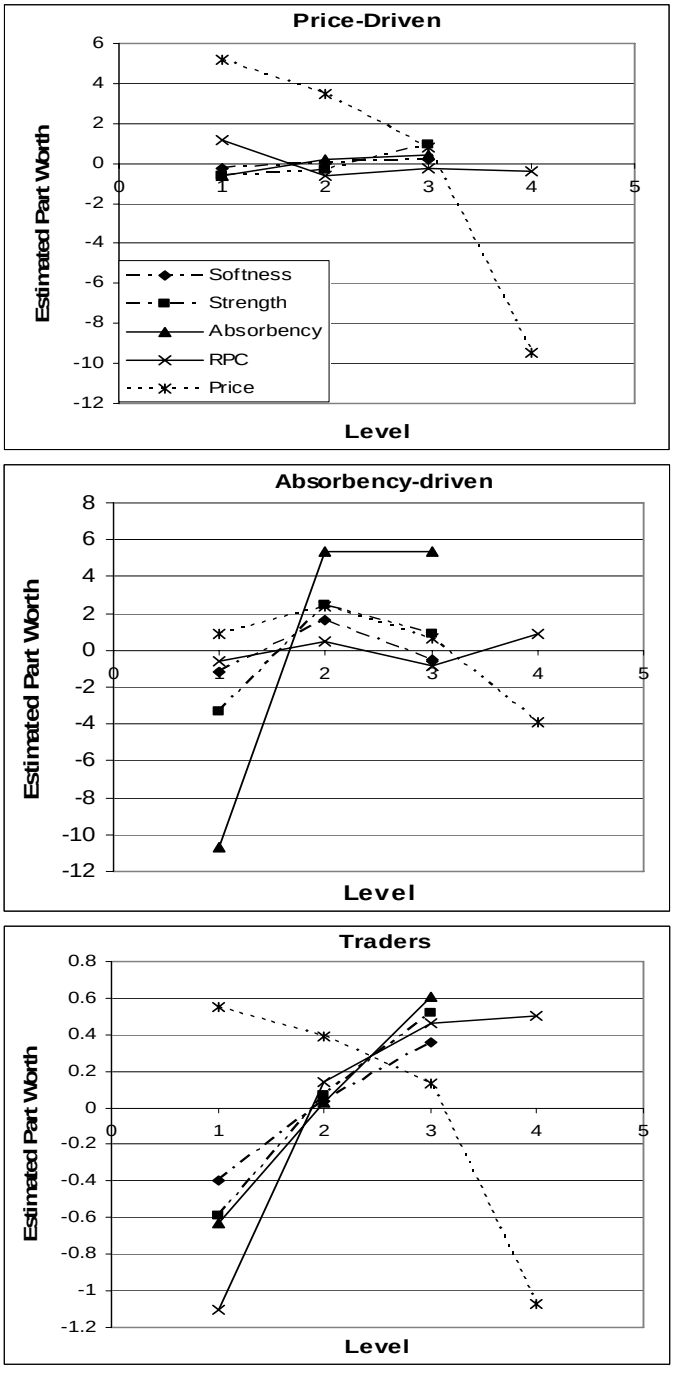

Figure 6: Latent class part worth estimations for Price-driven (52 respondents), Traders (120 respondents), and Absorbency-driven (45 respondents) groups

This external inconsistency represents a large market share opportunity for eco-friendly paper towels with the "activation" of the stated preferences of the idealists. This could perhaps be accomplished by educating idealists as to the recycled paper content of the paper towels they currently buy as well as eco-friendly alternatives. Preference inconsistencies for eco-friendly product attributes can be addressed proactively in design, for example, by including design details to "activate" consumers to construct a set of preferences that lead to a large market share shift. Preference inconsistency can also be addressed reactively, by designing an eco-friendly paper towel that is preferred in the market over a variety of preference constructions. A new methodology for proactive and reactive incorporation of an inconsistent preference model in a design optimization framework will be discussed in a future article.

The study here also highlights the intricacies of using revealed (market) preference data to assess preference for products that do not yet exist or are unknown to the survey respondents. While such data can be helpful for identifying preference inconsistencies, they can create unnecessary limitations on design possibilities. For example, in this study, assessing only revealed preferences would have neither distinguished three different types of paper-towel users nor indicated the potential market share change with user education.

5. INTERNAL INCOSISTENCY IN THE KANO METHOD

A survey conducted to investigate the effectiveness of the Kano method [29] revealed internal preference inconsistencies in which related questions in the survey were answered in an inconsistent manner for 24% of respondents. Other conclusions from the survey have been presented elsewhere [30]. The web-based survey investigated preferences for electric toothbrushes, studying the product attributes: variety of vibration speeds, brush head replacement indicator, recyclable brush heads, low battery indicator, automatic overcharge protection, and drip catch. The 80 respondents, all students at the University of Michigan, were educated to the meaning of the Kano categories of must-be, one-dimensional, delighting, and indifferent, and then were asked to classify the product attributes into these categories and provide written rationale for their classifications. Must-be and delighting attributes were explained to respondents as follows:

If a product feature is "Must-be," it means the lack of this feature would definitely cause you dissatisfaction, and probably make the product not as useful to you. However, unlike a One-dimensional feature, extra design effort spent on improving a Must-be product feature would not make much difference to you – it just needs to be included and functioning normally.

If a product feature is "Delighting," it means that the feature provides extra product satisfaction for you when it is present, but the product still does its job perfectly well when the feature is absent.

Respondents' classifications and written explanations for these classifications were examined by independent judges who identified incorrect classifications (39), classification explanations that mentioned other attributes (51), and classifications that mentioned other customers (32). To identify incorrect classifications, the two independent judges were given the same descriptions of the attributes that the respondents read, and asked to use these descriptions to identify respondent classification and written explanation pairs that *clearly* indicated that the respondent had misclassified the attribute. The judges had 90% agreement in independently indentifying all three types of problematic classifications, and discussed discrepancies to come to 100% agreement. Reviewers of this paper were particularly concerned with the removal of attributes due to incorrect classification, so it should be noted that only 4 must-be and 8 delighting classifications were removed for this reason, and, as previously mentioned, these removals were due to obvious flaws in classification rational as assessed by independent judges.

Problematic classifications were removed from subsequent analysis. Once the data was cleaned, survey respondents had provided 90 must-be classifications and 181 delighting classifications. A later part of the survey revisited attributes previously classified as must-be and delighting. First, the survey presented a description of a basic toothbrush that included none of the attributes previously mentioned, and told respondents it cost $40.00. Then, the survey presented users with a toothbrush description that included all attributes *except* those they previously classified as must-be (the "no-must-be toothbrush"), and on a separate webpage gave another description that included all attributes *except* those they classified as delighting (the "no-delighting toothbrush"). The survey asked respondents two questions about each scenario: would they consider buying the no-must-be/no-delighter toothbrush and, if they would, to specify the price they would pay. If they would not consider buying the toothbrush, the survey asked them to explain why.

If a user would not consider buying a toothbrush and specifically mentioned lack of an attribute in explaining unwillingness to purchase, this attribute was labeled as a "dealbreaker." If a user would consider purchasing the toothbrush, all attributes *not* included in the scenario were labeled as "negotiable." By examining responses and explanations from users willing to purchase the no-must-be toothbrush, 19 respondents were identified with at least one negotiable must-be attribute, providing a total of 29 must-be negotiable classifications, or 32% of must-be classifications (N=90). One might expect that these 19 users' displeasure could alternatively manifest as a large discount in the price they would quote for the toothbrush lacking their must-be attribute(s). This was not a clear response, as the average will-to-pay for the no-must-be toothbrush was $39.37, almost exactly the same price as for the basic toothbrush, with a standard deviation of $13.46.

The same question and evaluation procedure was repeated for the no-delighting-toothbrush, with 161 out of 181 delighting attributes receiving a negotiable status. Only three

delighting attribute classifications were identified as dealbreakers. The average purchase price for the no-delighting-toothbrush was $41.30 with a standard deviation of $10.99. Table 3 summarizes these findings. Note that a classification of "Unknown" is given to any attribute (1) not included in a no-must-be/no-delighter scenario that a respondent would not purchase and (2) the respondent did not specifically mention this missing attribute in their written explanation as to why they did not purchase the scenario. Some Unknown classifications, therefore, may be "silent" Dealbreakers.

Table 3: Negotiable and Dealbreaking Attributes

Attribute	Must-be	Delighting
Cleaned Total	90	181
Dealbreakers	29	3
Negotiable	29	161
Unknown	32	17

Recall that respondents' explanations for must-be and delighting attribute classifications were checked by independent judges for consistency with the descriptions mentioned previously and that instances of deviation from these descriptions were indentified and removed. A negotiable must-be attribute represents a preference inconsistency: in one preference construction, people claim the attribute *must be*, or *needs* to be included and functioning normally, while in another, they would buy the product without it. Nineteen respondents (24%) exhibited this inconsistency. Congruously, a dealbreaker delighting attribute also represents a preference inconsistency, but this inconsistency was found only in one respondent's answers. This difficulty in consistently imagining necessity versus ease of consistently imagining delight must be kept in mind when eliciting needs and preferences from users. In an optimization framework, this shift in preference from dealbreaker to negotiable (e.g., from non-compensatory to compensatory) would indicate a fundamental change in the problem formulation, in which a parameter (possibly a bound in an active constraint) could change to a variable depending on how preferences were elicited.

6. CONCLUSION

Here, we presented three demonstrations of how the construction of preferences manifests in product design methods. The quantitative identification of crux/sentinel attribute relationships will be helpful to designers, as keeping certain sentinel attributes in products, even if they become superfluous through design advancements, may be beneficial to user preference, at least until users adapt to the new design. As designers, it is important to keep in mind that if a user thinks a relationship exists between product attributes, then this thought will most likely influence their preferences until proven otherwise through education or experience. The highly inconsistent construction of preferences with respect to eco-friendly paper towels serves to highlight the potential market gains that could appear if, during product choice in the marketplace, careful design could trigger a set of favorable preferences over another less favorable set. The identification of negotiable must-be attributes suggests that stated customer "needs" should be taken as a starting point for building a set of required attributes in a product, rather than defining criteria. The user's of ease of consistently imagining delight versus difficulty of consistently imagining necessity may have far-reaching impacts on design research.

Early research in the behavioral sciences used preference construction to test and often disprove existing theories. For example, early psychology research in preference construction mainly disproved theories that relied on the formation of consistent and logical preferences. Later research began to aggregate such work into generalizations that explained interesting behavioral traits, the beginning of this movement marked by the publication of prospect theory by Kahneman and Tversky[7]. Current behavioral psychology and marketing research involving construction of preferences has made a variety of positive contributions to the decision theory community, helping psychologists and marketers understand how people make decisions and assessments.

The engineering design community has also explored preference structures in formal models that increasingly integrate user preferences in demand models with engineering functionality models in multidisciplinary product optimization. This model-based approach will be more effective with better understanding of the different ways in which preference construction manifests itself in such models. Different effects of preference construction, like social desirability bias and embedding, discovered in other research communities, can be brought into the design process and utilized to develop better models and better understanding of user attitudes towards products. The preference inconsistency examples provided above are not introduced for the purposes of invalidating the design methods in which they appear. Rather, they are intended to highlight that preference inconsistencies can provide additional insight for product design: gaining understanding of the user's ability to assess their own needs and preferences, learning about a customer's perceived associations between product attributes and the manner in which they evaluate product functionality, and increasing the sophistication of a linked engineering and marketing design process to access new market share for eco-friendly products. In a control metaphor, preferences elicited from any given procedure will contain both signal and noise, and deeper understanding of preference construction will allow the designer to distinguish the signal from the noise.

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