Working Paper Series

SIMSEG/ACM
A Simulation Environment for Artificial Consumer Markets

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Working Paper No. 79
March, 2001

Working Paper Series

March, 2001

SFB
'Adaptive Information Systems and Modelling in Economics and Management Science'

Vienna University of Economics
and Business Administration
Augasse 2–6, 1090 Wien, Austria

in cooperation with
University of Vienna
Vienna University of Technology

http://www.wu-wien.ac.at/am

This piece of research was supported by the Austrian Science Foundation (FWF) under grant SFB#010 ('Adaptive Information Systems and Modelling in Economics and Management Science').

SIMSEG/ACM
A Simulation Environment for Artificial Consumer Markets

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March 19, 2001

Abstract

The ACM-Artificial Consumer Market is part of the integrated simulation endeavor named the "Artificial Economy". Complementing and extending the concepts developed in the SIMSEG simulation environment of Working Paper No. 60 this report proceeds in two steps. (1) it outlines the basic constructs and consumer behavior phenomena implemented in the ACM in a nontechnical manner. (2) it elaborates the formal structure and relationships in full detail. The ACM was never headed for mimicking any real consumer market. However, it is ambitious enough to capture a number of behavioral mechanisms that are deemed crucial for exposing the Artificial Firms' analytical and strategic agents to a challenging artificial marketplace.

1 Purpose of the Artificial Consumer Market as a simulation environment

The Artificial Consumer Market (ACM) is part of an Artificial Economy (AE) project headed for exploring the consequences of economic agents' learning behaviors that gradually increase in complexity. On the macro level there are only three basic classes of agents: artificial firms, artificial investors, and artificial consumers. On the micro level the artificial firms (AF) consist of four types of internal managerial agents: production, finance, and marketing units coordinated by a corporate agent. While each business management sub-discipline has elaborated fairly intricate models for studying decision processes within their particular application domain, there is little evidence of hypothesizing on the meta level [Otruba, 1981]. The computer simulations in the AE should allow for analyzing the effects resulting from the competitive or collaborative interactions between agent populations with different degrees of smartness. The AE provides the framework for examining the fitness and efficiency of various analytical and strategy-building decision tools under the regime of experimentally controllable conditions.

Experimentation within the AE first explores the domain-specific factors such as the properties of the consumer market and the consequences of the marketing strategies, while the AFs neither differ in terms of production experience and cost functions nor with regard to access to financial resources and interest rates. Once the intra-domain cause-effect relationships are sufficiently understood, an inter-domain experimental design may take place. In order to integrate financial decisions, a corporate finance agent receives estimates

* In addition to the two individuals who happen to co-author this report a lot more research collaborators from among the SFB's Research Initiatives 1,2,3,5, and 6 have contributed to SIMSEG/ACM in some way or another.

of revenue and cost time series and makes plans with regard to investment and financing R&D, production and market operation.

It is not the purpose of the Artificial Consumer Market (ACM) to mimic any 'real' consumer population. Rather it aims at constructing an artificial environment at the marketing front end of the Artificial Firm that puts the AFs under challenge to function and survive as learning organizations. Therefore, the ACM duplicates only a selected number of *typical* properties of consumer markets that are deemed crucial in rewarding harmonized strategies of the marketing and production departments and in penalizing uncoordinated action of the AF agents [Natter et al., forthcoming].

2 Conceptualizing the ACM: A nontechnical overview

2.1 Extensions compared to SIMSEG 1.0

The SIMSEG results (SIMulation environment for market SEGmentation and positioning) gained in 1997-2000 need various modifications for interfacing with the Artificial Firm explicitly and convincingly. SIMSEG contributes two modules to the AE: (1) the Artificial Consumer Market (ACM) and (2) analytical and strategic marketing agents of the Artificial Firms (AFs) including recent methodology for conjoint analysis [Frühwirth-Schnatter and Otter, 1999] and perceptions-based market segmentation [Mazanec and Strasser, 2000; Buchta et al., 2000]. The initial versions of both modules [Baier and Mazanec, 1999] were limited to reactive consumer agents and a marketing agent who pursues an externally determined objective with a consistent and invariable segmentation/positioning strategy. Consumer preferences — as usual in economics — were predetermined and fixed. Thus 'learning' on the part of the consumer was restricted to accumulating product knowledge on the level of perceived attributes owing to the firms' market communication.

The new ACM simulation environment as implemented in SIMSEG 2.0 introduces the refinements needed to comply with contemporary consumer theory and structural equation models of buyer behavior [Howard and Sheth, 1969; Engel. Kollat and Blackwell, 1973; Howard, 1977; Mazanec, 1978; Kroeber-Riel, 1980; Bagozzi, 1986; Myers, 1996]. Particularly, it distinguishes between the brand attributes (which are only observable to the AFs as binary yes/no reactions) and the underlying latent attitude dimensions. This leads to a multi-level system for the different 'languages' of advertising and consumers expressing their everyday experience, the consumers' choice criteria rooted in long-term memory, and the jargon of the R&D engineers in the AF. The ACM models the brand perceptions on three levels: latent attitudinal dimensions, verbal response generating probabilities and (redundant sets of) observable indicators of the latent dimensions. The consumers' acquire product comprehension by being exposed to market communication about (modifications of) brand attributes. These bundles of perceived attributes are indicative of a set of unobservable latent attitude dimensions. Thus, the consumers preserve a condensed brand profile in a latent attitude space, which is imperfectly retrieved by the AFs owing to the consumers' limited ability to express their brand evaluations. This is a very realistic setting that puts the AFs under pressure to explore the attitude space by trial and error. The degree of ambiguity of the brand attribute indicators is systematically adjustable. It may be subject to experimentation with 'would-be worlds' [Troitzsch, 1999] confronting the AFs with an either easily decodable or a rather fuzzy consumer response. Discovering the type of a 'learning organization' that is more likely to survive under these challenges is an intriguing research question for the entire AE project. Observing the cause-effect relationships put forward by (loosely versus strongly) coordinated action of the production and advertising agents is unique in the AE concept and cannot be pursued in a 'marketing-only' model.

The Artificial Consumer Markets-Artificial Firm interface tackles this problem by providing a link between the latent attitudinal dimensions and the technical features, which is unknown to the AF. Both the AF's product improvement program and market communication influences the consumers' brand perceptions, attitudes and choices. Both the product features detected during consumption and the advertising stimuli are input to the consumer's sensory, perceptual and evaluative systems. As consumers dislike to persist with an inconsistent attitudinal system they have to settle to a 'compromise' post-choice attitude. Reconciling and weighting the technology-induced and the advertising-caused positions in attitude space also allows for simulating 'technology-driven' vs. 'market-driven' environments. Production/technology

and marketing/promotion set mutual restrictions and reinforce or dampen each other. The brand perceptions and choice model makes a distinction between the consumers' (directly unobservable) abstract product comprehension ('long-term memory') and the observable consumer and advertising vocabulary. The attributes of the observational language ('short-term memory') are subject to communicative persuasion and periodically measured in consumer surveys. Advertising-induced changes in the strength of belief regarding a brand possessing a particular attribute are nonlinearly fed back into the long-term memory.

To sum up the following conceptual extensions characterize the ACM as implemented in SIMSEG 2.0:

- According to the tradition of product positioning theory the consumers' brand perceptions and evaluations (attitudes) are modeled as points in a latent space, which is unknown to the competing firms and can only be figured out by processing observable attribute assignments. Thus SIMSEG 2.0 differentiates between the consumers' redundant and fuzzy manner of talking about a particular product class and the managers' and product engineers' condensed 'expert' language. Brand perceptions are initialized in a segment-specific manner.

- Preferences are incorporated into the brand space as 'ideal points'; unlike conventional ideal-point models, however, SIMSEG 2.0 employs a modified unidirectional model to allow for irrelevant attitude dimensions without having to distinguish between desired and undesirable dimensions. The preferences are segment-specific and not necessarily linked to the consumer perceptions of rivalling brands.

- The consumers' 'cognitive algebra' comprises compensatory as well as noncompensatory choice rules. Consumers in the ACM follow simple rules requiring very modest assumptions about the consumers' information processing and attitude formation. These rules are operative on the disaggregate level and characterize what economists may term a boundedly rational being. It is imperative that the ACM does not imply just one built-in decision mechanism but allows for a variety of rules and consumer heterogeneity in terms of decision styles.

- The ACM consumers develop pre-choice and post-choice attitudes towards the competing brands. They form consideration sets of acceptable brands based on the expectations aroused by advertising and on their personal preferences. They make random decisions in case of several brands being equally attractive and equally priced.

- Attitude change depends on confronting the brands' technology induced evaluation with the perceptual profile aroused by advertising. Consumers who purchase a brand contribute to disseminating the product comprehension and the knowledge about the brand's technological quality. The technological properties are not part of the consumer language and never experienced individually and isolated from each other. Rather the consumers experience them 'holistically' by building a technology induced attitude, which may diverge from the expectations mediated by advertising.

- Market communication happens through media advertising and through word-of-mouth. Advertising carries nontechnical persuasive information. According to what is known from communication research word-of-mouth fulfills a double function. The communicator's (opinion leader's) relays function guarantees that knowledge about the brands' technical properties gets disseminated. At the same time the communicators influence the recipients' decision making by reporting their valuing of the brands' performance. This is achieved by spreading their personal (dis)satisfaction experience.

- The (dis)satisfaction experienced after buying a brand governs the consumer's intention to repurchase, the propensity to spread word-of-mouth messages, and the persuasibility regarding future advertising. A consumer who finds his expectations fulfilled is likely to develop loyalty. In SIMSEG 2.0 this is equivalent to keeping a brand in one's evoked set of purchasing alternatives despite one or more competing brands becoming more attractive. A disappointed consumer may (temporarily) ban the brand from his consideration set of buying alternatives; then it is disregarded irrespective of its advertising pressure. Disappointment nourishes the consumers' reactance to persuasive advertising. Personal communication is more likely to occur for more extreme (dis)satisfaction levels. Exaggerated advertising claims and unfulfilled promises thus feed dissonant information into personal communication channels and also provoke dissonance of the non-buyers receiving such messages.

- A number of sensitivity parameters governs the depth and accuracy of the consumers' information processing and cognitive effort. These parameters capture the influence of the involvement in the product class [Kroeber-Riel, 1980, p. 315]. There is no separate variable for brand involvement [Mühlbacher, 1988]. The involvement is consumer-specific to allow for experimental settings with different involvement segments.

2.2 The ACM macro structure

Figure 1 highlights the macro structure. It assists in describing the ACM dynamics and the data flow between the levels of latent constructs and observable indicators.

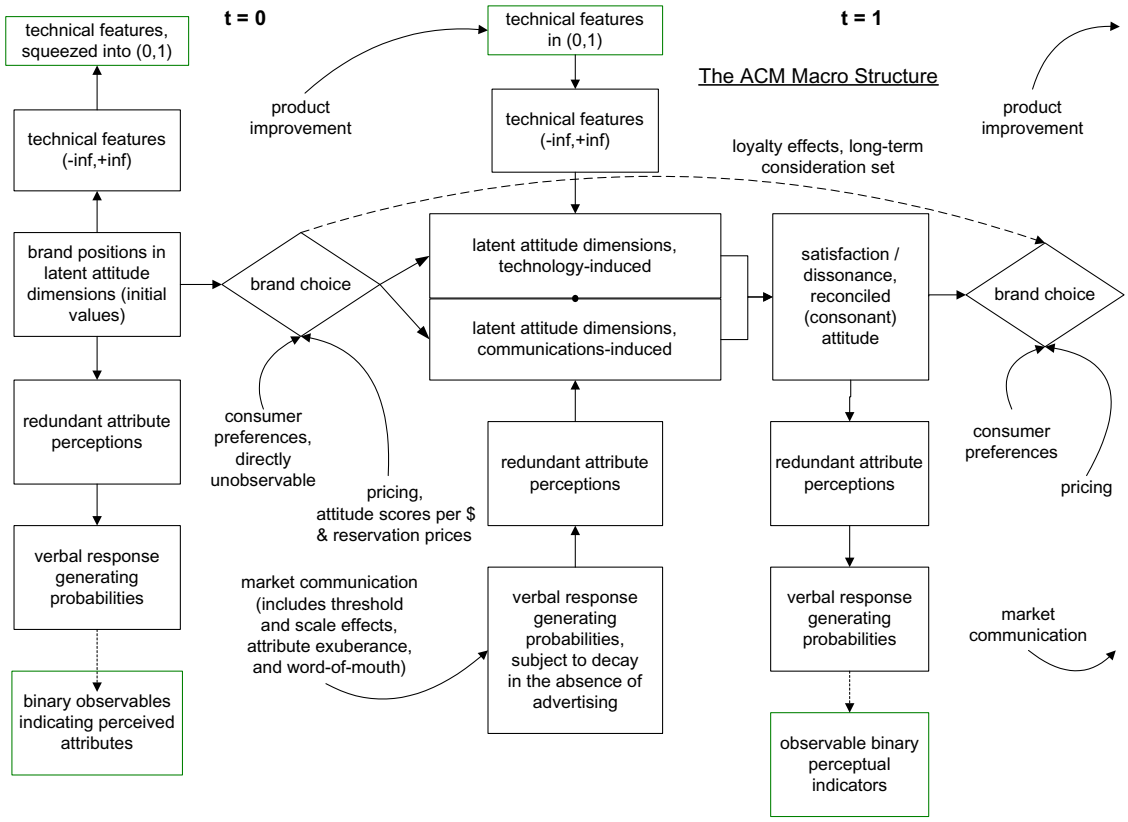

Figure 1: ACM macro structure

It is important to generate starting values of the ACM according to a scenario determined by the experimental design. Many experiments require an 'equal opportunities' scenario, where no brand/firm benefits from some in-built competitive advantage, but lives on its own analytical skills and imaginative strategies. Another requirement is the tuning of the measurement models, as the ACMs should also differ with respect to the accessibility of the latent attitude dimensions. One market may exhibit a 'simple structure' in factor-analytic terminology, others may be rather obscure in terms of the perception indicators available to the AFs. Hence a 'classic' factorization scheme comes to mind first. It expresses the observable product attributes as non-linear combinations of a small set of (attitudinal) factor scores. The loadings matrix introduces intercorrelations into the perceptual attributes (assuming orthogonal factors and uncorrelated attitudinal dimensions, see Section 3.1). Thus, experimental variations of the empirical accessibility of the brand attitudes in the initial period may either set the values of the loadings matrix or define the desired intercorrelations of perceived attributes. Section 3.1 of the formal presentation suggests such a non-linear

mapping. Alternatively, a nonlinear mapping by means of some neural network architecture may be applied.

The ACM macro structure in Figure 1 originates from combining a factor-analytic model (which is very ordinary in product positioning theory) with a simple probabilistic independence model for generating the binary observables. As an extension, a latent-variable threshold model [Long 1997; Fahrmeir and Tutz, 1997] may be employed that allows for experimenting with group-specific or individual threshold parameters. The consequence is that the product attributes are not measured on pseudo-interval rating scales. They get squashed into probabilities, which lead to either affirmative or negative consumer response in terms of yes-no statements (see Section 3.3). The loadings matrix determines the distinctness of the consumers' attitudinal system. By setting their values the experimenter may create a product class where the attitudinal dimensions are easy or hard to recognize by the AFs. (Later, in an advanced stage of AE experimentation the loadings matrix may be subject to adaptation, when, e.g., the consumers establish more clear-cut evaluative dimensions as their product comprehension increases.)

For the initial period it is imperative to set out with a scenario that conforms precisely with the experimental design. As mentioned above this will most frequently be a setting, where no brand or firm outperforms the other AFs because of implicit competitive advantages. The AFs product improvement and promotional spending decisions in the initial period change the brands' positions in the consumers' latent attitude space. The mass communication via media advertising uses non-expert, unprecise and emotionally loaded vocabulary. Through this language filter the AFs initiate changes of the brand positions in attitude space. If an advertising claim loses its sustained media support, the probabilities (beliefs) decay and the strengths of the perceived brand attributes decrease drastically (see Section 3.2).

Product variations and changes in the brands' technical features become known to the buyers and to those consumers receiving messages from buyers through personal communication. The consumers do not directly recognize these technical features, which are defined in production expert language. But they make a technology-based evaluation resulting in a technology induced attitude. The technical features are linked to the consumers' latent attitude space via a non-linear transformation held constant during a series of simulation cycles but unknown to the AFs (see Section 3.1). They have to figure out how technology influences the consumers' product evaluation as best they can. By sorting, filtering, and weighting all these evaluative materials ('reconciling') the consumers arrive at a post-purchase and/or post-communication attitude. Again it is reflected by the brand's position in the latent attitude space. And again, it is not directly observable, but has to be measured by verbal (or pictorial) indicators. In compliance with standard psychometric modeling the necessary strength of belief must grow exponentially for generating unity values on the measurement level with near-certainty.

2.3 Set theory, brand choice, (dis)satisfaction and adaptive preferences

In earlier versions of the simulation environment the consumers followed a cognitive algebra that allowed for three different rules of brand choice: compensatory, and non-compensatory conjunctive or disjunctive. Product perceptions and preferred attributes were involved in the consumers' utility calculus; product knowledge was subject to learning, preferences were fixed. Also the consumers did not have a memory of their brand choices made in past periods. Refinements regarding the role of preferences in the consumers' brand choice decisions are now implemented for Version 2.0. It is straightforward to introduce variable preferences dependent on adaptive aspiration levels. While the 'learning of preferences' is still a largely unexplored notion in traditional economics [Brenner, 1999, p. 117] the Artificial Consumer Market functions more realistically as far as these perceptual and preferential dynamics are concerned. Preferences are portrayed in the latent attitude space as 'ideal points' (see Sections 3.1 and 3.4 for details). A consumer's ideal point for a product class indicates the combination of his desired levels of each attitude dimension. This is equivalent to an aspiration level that varies according to the consumer's product knowledge and experience. An unrealistically high aspiration level cannot be maintained without continuing disappointment. A modest aspiration level easily fulfilled by an average purchase alternative is likely to rise as consumers learn to acquire better value for money.

Any combined marketing-production model benefits from the numerous studies that have been conducted in (service) quality research. Most of the empirical studies were inspired by the SERVQUAL model [Parasuraman, Zeithaml and Berry, 1985, 1988; Zeithaml and Berry, 1988]. Irrespective of all the

critical comments, which are rightly brought forward against the SERVQUAL concept, it has its merits as far as it triggered off a lively discussion about the construct of 'perceived (service) quality'. One of the lessons seems to be that a construct 'perceived quality' separate from the construct of attitude toward products or services is highly superfluous [Mazanec, 1997]. However, the discussion clarified the views about 'transaction-specific' versus long-term attitudes and reiterated the need for focusing on attitudinal (pre and post-choice) dynamics. The conceptualization of 'perceived quality' as a discrepancy between expectations and experiences (expectancy-disconfirmation approach) raised a number of criticisms, mainly from the measurement point of view. A 'performance-only' concept [cf. SERVPERF as propagated by Cronin and Taylor, 1992] seems to be clearly preferable in perceived quality field research. In a simulation environment like the ACM the experimenter need not care about the consumers' ability of correctly remembering their pre-purchase expectations after acquiring consumption experience. He is in control of modeling brand expectations and performance independently of when and how often they are measured. While perceived quality may be dispensable, the (dis)satisfaction construct is not. The ACM consumers pursue the expectancy-disconfirmation paradigm (Cardozo, 1965; Oliver and DeSarbo, 1988) by deriving (dis)satisfaction from (un)fulfilled product claims. The dynamic aspects of (dis)satisfaction are consistent with equity theory (Oliver and Swan, 1989a,b) regarding the adaptation of consumers' aspiration levels to the market reality (Trommsdorff, 1998). The gradual adaptation of expectations characterizes a smoothly evolving marketplace (Johnson, Anderson and Fornell, 1995). For achieving structural breaks in a simulation run exogenous shocks leading to a disruption in the consumers' preferences are admissible in the ACM.

Actually, the concept of (dis)satisfaction plays a central role in the SIMSEG consumer model. It is the key factor for conducting the joint ACM and AF simulation experiments. The brand positions in the (latent) attitude space are governed by the competitors' communicative and technological actions and the consumers' reactions. The AFs are put under pressure to coordinate and harmonize their market communications and product improvement decisions, as two different organizational units are in charge of these processes. The AFs may conduct a 'perceived quality' or a satisfaction study where they try to measure the gap between expectations and performance. The ACM provides this information about consumer (dis)satisfaction in a very realistic manner. It is worded in the consumers' fuzzy language the same way their latent brand attitudes are reflected by a redundant set of observable indicators for perceived attributes. A composite (unidimensional) measure of (dis)satisfaction complements this set of attribute-specific indicators.

The consumers on the artificial market experience product (dis)satisfaction when the technical/functional product features (fail to) match the advertising claims. Hence they build up loyalty, or suffer from dissonance. Consumer theory never makes generalizable propositions on a measurement level higher than ordinal. For the simulation experiments a more precise specification is required to implement relationships such as 'the higher the amount of dissatisfaction the lower the probability of repurchase'. It is of paramount importance, however, to realize that a theory-driven gain in precision always excels an arbitrary parameterization. For incorporating the consequences of brand (dis)satisfaction the SIMSEG model takes recourse to elementary 'set theory'. The concept of consideration sets with its numerous variants originates from Howard and Sheth's concept of the 'evoked set' (1969), the individual consumer's group of purchasing alternatives comprising not more than 5 to 7 product brands. In the sequel consumer research invented a variety of 'sets' [see the whole zoo of awareness, inert, inapt, consideration, or choice set concepts explained by Crompton, 1992 or Goodall, 1991].

Hauser and Wernerfelt [1990] summarize results on the "consideration set phenomenon" and admit that it "is critical to the predictive ability of quantitative models" (p. 393f.). The SIMSEG artificial consumers resemble their real counterparts in forming brand sets according to their stage in the purchase-repurchase cycle. The consumers on the ACM do not keep records of their intrinsic brand choice probabilities. Rather than bookkeeping they like to follow very simple decision rules (see Section 3.4). They build consideration sets of equally attractive buying alternatives that exceed their aspiration levels in terms of (price weighted) brand attribute dimensions. A second filter works in absolute terms, as consumers discard a brand surpassing their reservation price for the product class. Consumption experience, either self-made or mediated through word-of-mouth, changes the consumers' composition of consideration sets. Thus learning effects are responsible for two dynamic phenomena: They lead consumers (1) to (temporarily) barring a brand from their consideration sets where it does not come up to the expectations solicited by advertising; or, (2)

they make consumers maintain a high-performing brand in their sets even when competing brands advertise more attractive brand profiles. Fairly elaborate learning regimes for the consumer agents in the AE such as SIMSEG-adjusted components of Thomas Brenner's 'Variation-Imitation-Decision' (VID) model [1999, pp. 71–89] have been adopted. In Version 2.0 the consumers communicate with each other about their brand usage experience and also exhibit imitative behavior by recognizing other peoples judgments of product quality.

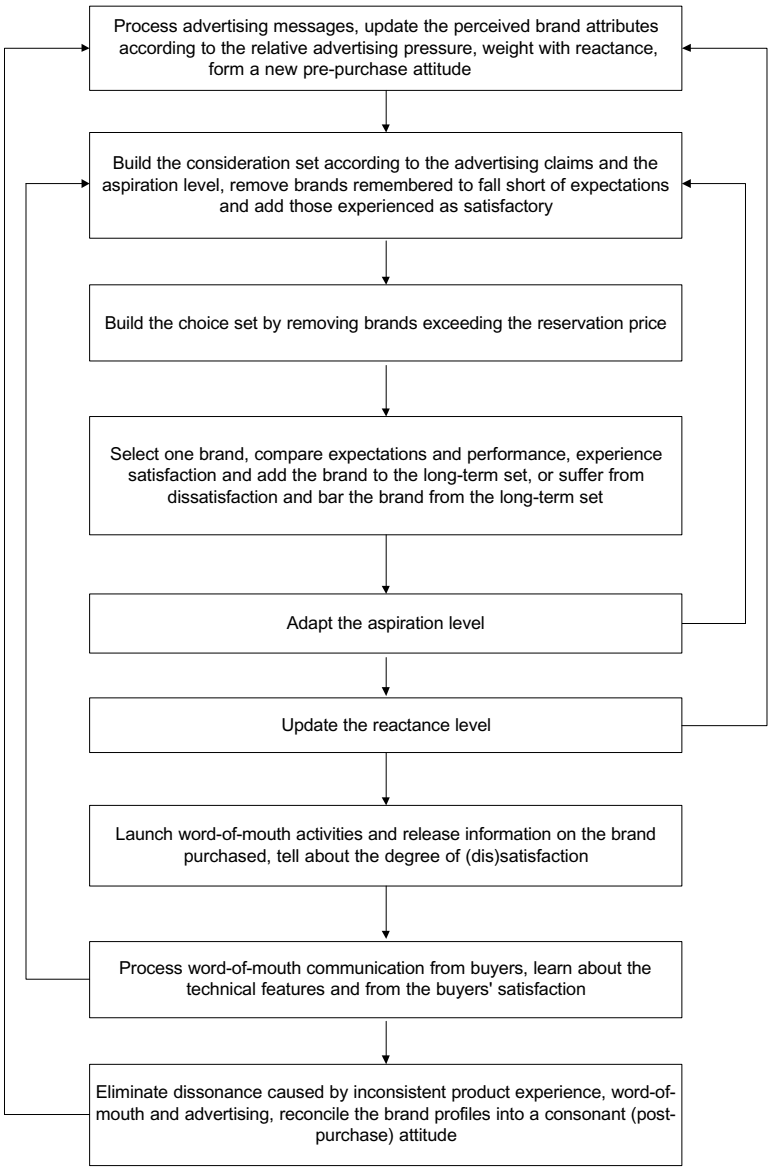

Figure 2: Communication, learning and decision-making on the ACM

2.4 The ACM micro structure: Tracing the individual consumer

The ACM microstructure is easily apprehensible on the disaggregate level of purchasing and consumption by watching an individual consumer's trajectory through these processes. Figure 2 highlights the stages in

the consumer's decision making. Particularly, it indicates the feedback loops which govern the adaptive behavior of the consumers on the ACM. The loops are 'intra-personal', such as aspiration level adaptation or accumulating reactance against persuasive advertising, or 'inter-personal' such as spreading word-of-mouth messages to fellow consumers. In a realistic set-up of an ACM the AFs are facing the rationality restrictions imposed on the consumer's brand choice. Satisficing behavior instead of utility maximization prevails in the brand evaluation stage and ties are broken up by random selection on the disaggregate level of the individual consumer. In the post-choice evaluation, however, the consumers are relentless in comparing expectations and actual brand performance. In this stage they also reward over-fulfillment of advertising promises. This is consistent with the global objective of the Artificial Economy project. If one aims at analyzing the AF's policies of developing a coordinated approach to corporate planning, the consumers on the ACM should be particularly sensitive to a misfit in the AF's technology-marketing policies.

It has been emphasized previously that it is the authors' ambition to conceive the ACM as parsimonious as possible and to avoid unnecessary simulation parameters. To accommodate all the empirical phenomena itemized in Figure 2 several modification are applied to the standard ideal-point model [cf. Myers, 1996; Hruschka, 1996]. The consumers decide on the brands to enter their consideration sets according to a modified version of the ideal-point model, named the *Unidirectional Ideal-Point Model with threshold* (see Figures 3 and 4). The UIPM combines a spatial approach for representing attitudes with aspiration level learning.

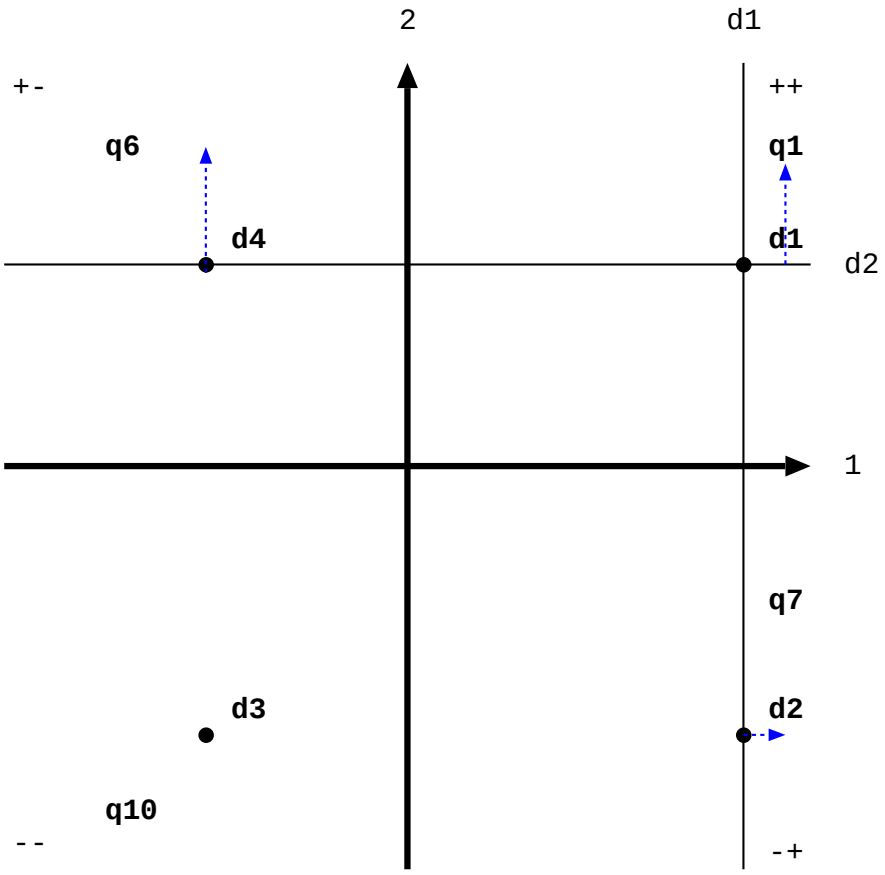

Figure 3: Unidirectional ideal-point model with threshold $d_1 = d_2 = 0$ (city-block metric)

Imagine two (price weighted) attribute dimensions d_1 and d_2 in a latent attitude space with a city-block metric. The attitude scores increase from left to right and from bottom to top. Focus on the right upper quadrant first, indicated by $++$. The ideal point $\mathbf{d}_1$ denotes an individual or group-specific aspiration level thus introducing preferences into the brand space. Contrary to the conventional ideal-point model there are no

spherical, elliptical or diamond-shaped iso-preference curves surrounding an ideal point. Over-fulfillment of the aspiration level neither increases nor decreases a brand's likelihood of entering the consideration set. This means that the consumers in the ACM are unaware of any product attributes exhibiting an inverse u-shaped utility function. They are more likely to accept a brand the more it approaches their aspiration levels 'from below'. Brands exceeding that level are equally welcome (unless over-priced) and induce the consumers to raise their aspirations.

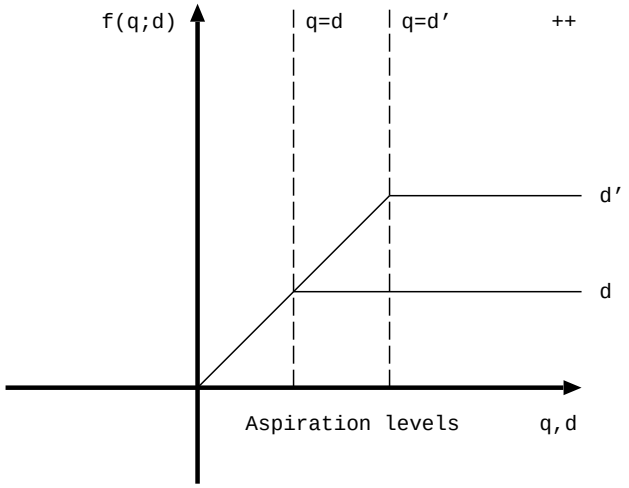

Figure 4: Moving along an attitude dimension

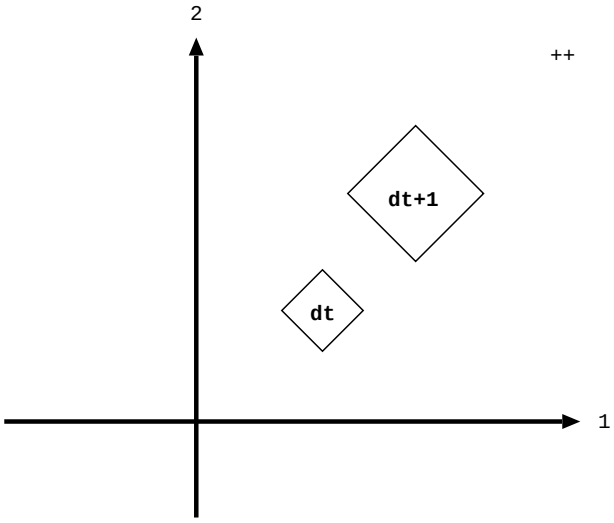

Figure 5: Visualizing the aspiration level in the 'n-directional' ideal-point model (city-block metric)

Figure 4 shows how the attractiveness of a brand develops moving along an attitude dimension. It stays meaningless before it crosses the irrelevance-relevance threshold and then gains more and more strength of belief until it reaches the aspiration level needed for being considered an attractive buying alternative. Unidirectionality is not an illegal simplification. It captures one of several SIMSEG features that may be interpreted as criteria of bounded rationality. Any product attribute can be reformulated to comply with this simple cognitive algebra. (If you like your tea (beer) neither lukewarm nor boiling (frozen) you look for claims promising 'adequate temperature' that will move your expectations closer to your aspiration level.) Unidirectionality is in conformity with the measurement model of binary indicators for the latent attitude

dimensions. To assume a realistic usage of binary attributes, the 'zero' answer should be able to capture the composite meaning of 'does not fit' and 'irrelevant'. If a consumer rates a brand and more indicators of an attitude dimension get unity values, the brand's position shifts toward positive infinity. Somewhere in this shift the aspiration level ought to become relevant for determining the consumer's preferences where the origin of the attitude space is a natural threshold.

In principle, an adaptive aspiration level may also be introduced into the conventional, i.e. 'n-directional', ideal-point model. If the attitude space exhibits a city-block metric the aspiration level does no longer collapse into the ideal point. Instead, it surrounds the ideal point in a diamond-shaped iso-preference curve (see Figure 5). The brands inside the 'diamond' area are equally eligible for consideration. This results in two separate dynamic effects: (1) the shifting of the ideal point $\mathbf{d}_t \rightarrow \mathbf{d}_{t+1}$ when expectations rise, and (2) the changing of the 'satisficing threshold' when tolerance grows or shrinks.

In Figure 3 brand $\mathbf{q}_1$ will enter the consideration set of a consumer pursuing an aspiration level (ideal point) $\mathbf{d}_1$ in the $++$ quadrant. Because of the dimension relevance threshold at zero (origin of the coordinate system) the situation is different in the other three quadrants. For a consumer with an aspiration level $\mathbf{d}_3$ neither of the two dimensions is relevant for his brand preferences. For a person characterized by $\mathbf{d}_2$ in the second and $\mathbf{d}_4$ in the fourth quadrant only one of either d_1 or d_2 influences the consideration set. Movements along the relevant dimensions (see the arrows for the most preferred brands) change the consumer's willingness to consider this brand. As one brand at least exceeds any of the aspirations consumers will learn to raise their expectations.

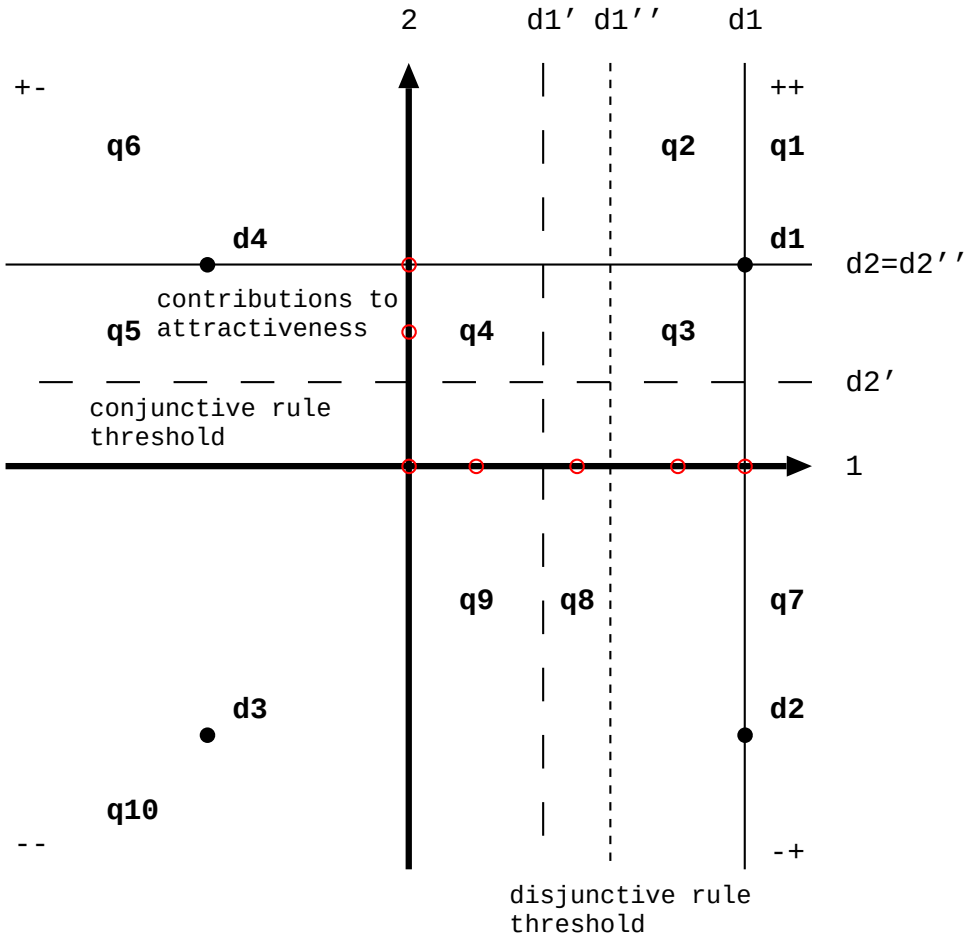

Figure 6: Noncompensatory schemes in the unidirectional ideal-point model (city-block metric)

The UIPM follows a compensatory approach. However, there is ample empirical evidence [Bettman, Luce and Payne, 1998] that suggests to relax the rather strong assumption of a fully compensatory scheme. The brand's excellent position in one attitudinal dimension may offset poor performance in another dimension once it has passed the relevance threshold. In the consideration stage, however, over-fulfillment by exceeding the aspiration level in one dimension does not further contribute to make the brand enter the set of acceptable buying alternatives or to compensate for partial failure in another dimension. A random choice occurs if the acceptable brands also charge identical prices below the consumer's reservation price. The consumer's inability or unwillingness to make meticulous judgments in the pre-choice stage is one concrete aspect of the operationalization of 'bounded rationality'. In the post-purchase stage the consumption experience enforces a higher level of awareness for the brand attributes including the evaluative dimensions that may have been ignored or neglected previously. A larger amount of cognitive effort is subjectively justified. Consumer learning in the post-choice phase benefits from a richer and more reliable input than just advertising or word-of-mouth.

Noncompensatory choice rules are needed to achieve a realistic mixture of decision styles in the consumer population. Figure 6 demonstrates how a conjunctive or a disjunctive decision rule [Hruschka, 1996; Roberts and Lilien, 1993] conforms with the aspiration level concept. An additional satisfaction threshold is needed to implement these rules. Under the conjunctive regime the consumer expects an acceptable brand to offer a (modest) minimum performance in each relevant (i.e. with aspiration > 0) evaluative dimension. The disjunctive rule decider requests a (fairly high) performance in at least one relevant dimension. Thus the 'ideal point' marks the consumer's preferences and sets the aspiration target; the satisfaction threshold controls the brands' entrance into the consideration set. In his post-purchase reasoning the noncompensatory consumer is likely to increase his cognitive effort. The satisficing principle is welcome to facilitate choice. Once the choice has been made much more factual knowledge assists in readjusting what may be desired (aspiration level) and what is satisfactory for becoming a new choice alternative. Both, aspiration level and satisficing threshold, are subject to learning with a nice option of convergence when the brand comprehension and the consumers' capability of discriminating among brands evolve.

The following composition of consideration sets result from the aspiration levels together with the UIPM, conjunctive and disjunctive decision styles in Figure 6:

Ideal point	UIPM	conjunctive	disjunctive
$\mathbf{d}_1$	$\mathbf{q}_1$	$\mathbf{q}_1, \mathbf{q}_2, \mathbf{q}_3$	$\mathbf{q}_1, \mathbf{q}_2, \mathbf{q}_3, \mathbf{q}_6, \mathbf{q}_7$
$\mathbf{d}_2$	$\mathbf{q}_1, \mathbf{q}_7$	$\mathbf{q}_1, \mathbf{q}_2, \mathbf{q}_3, \mathbf{q}_7, \mathbf{q}_8$	$\mathbf{q}_1, \mathbf{q}_2, \mathbf{q}_3, \mathbf{q}_7$
$\mathbf{d}_3$	all	all	all
$\mathbf{d}_4$	$\mathbf{q}_1, \mathbf{q}_2, \mathbf{q}_6$	$\mathbf{q}_1, \mathbf{q}_2, \mathbf{q}_3, \mathbf{q}_4, \mathbf{q}_5, \mathbf{q}_6$	$\mathbf{q}_1, \mathbf{q}_2, \mathbf{q}_6$

Table 1: Composition of consideration sets by decision styles.

3 Formal outline of the ACM

In this section we present a formalized view of the simulation environment, on the one hand by discussing the assumptions and constructs of the ACM, and on the other, by giving proper interface definitions and an overview of the model's calibration needs. Although the latter is closely linked to the definition of market scenarios, we defer such a discussion to future work. Let us start with an overview of the 'technical' assumptions of the ACM (Figure 7 may illustrate):

- In a simulation the set of consumers and the set of firms participating in the market is constant.
- The firms operate on a single product class given a fixed technological environment, in the sense that there is a bound to product improvement.
- *Market time* is thought of as synchronization points for information exchange, as well as periods of information processing. A *period* is divided into (consecutive) steps of information processing (see the arrows connecting the model components).

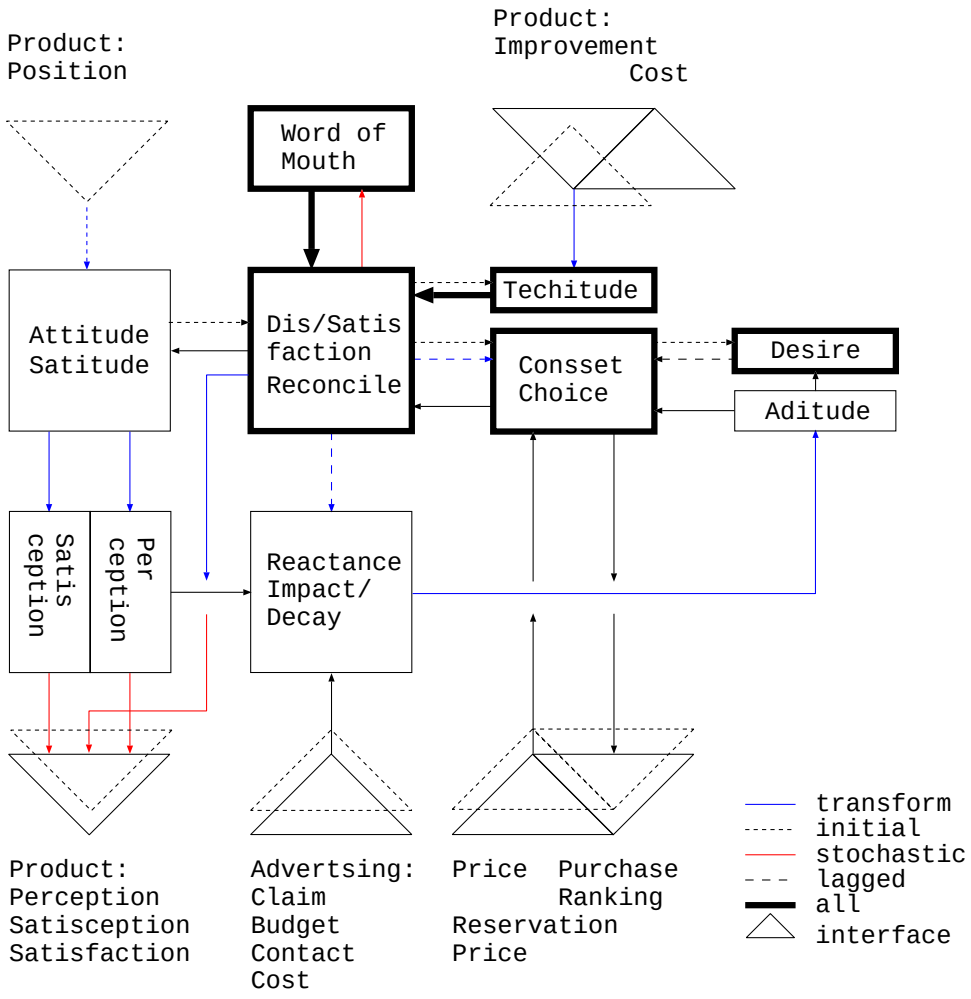

Figure 7: Information and decision flow of the market model.

- The firms are assumed to act on segments of consumers. A *segment* is targeted with exactly one product (brand), and the product is available only to the consumers of a segment. Alternatively, we may assume inseparable markets where all the products are visible and available for all the consumers. A *product* is a bundle of technical (feature), advertising (claim, budget), and price information (see the solid triangles pointing into the model).
- The term *brand*, in the sense of the name (identifier) of a product [cf. Kotler, 1986] is meant to represents the firm's long-term concept of a product, which we use synonymously with product. We assume a fixed set of brands and that each firm's set of brands is constant for a simulation.
- A consumer responds with the choice of exactly one product, and is periodically surveyed on the perceptions and evaluations of the products on the market (see the solid triangles pointing out of the model).
- A consumer adapts his desires, attitudes, feeling of (dis)satisfaction, and reactance to advertising, and own or communicated consumption experience, and may memorize past experience (see the boxes of the model and their connections).
- The model can be initialized by propagating initial product positions to the constructs on the interface level (see the dotted triangles and arrows). Further, a market-wide *reservation price* and a reference price for advertising and the production input factors must be set.

Figure 8 gives an example of a market structure under the assumption of separability: firm 1 has two brands which have the, e.g., same technical characteristics but are promoted differently. Firm 2 has one brand and demands the same price as firm 1 for brand 2. Further, its segment definition shows an overlap with the definition of firm 2 for brand 2, which leads to competition for consumers 3. If we drop the assumption of market separation the situation becomes different: depending on the claims selected for brands 1 and 2 firm 1 may be confronted with cannibalization effects. Similarly, there will be competition between brands 2 and 3 among all the price sensitive consumers. Nevertheless the firms can target the same segments as above but with different claims and/or prices in order to achieve a 'segmentation' of the consumers. Last but not least, it should be clear that separation can be model by the experimenter as well, via initial market 'conditions' and external influences on the desires of consumers. Thus we think the suggested framework is versatile enough for modeling a variety of interesting structural assumptions of ACMs.

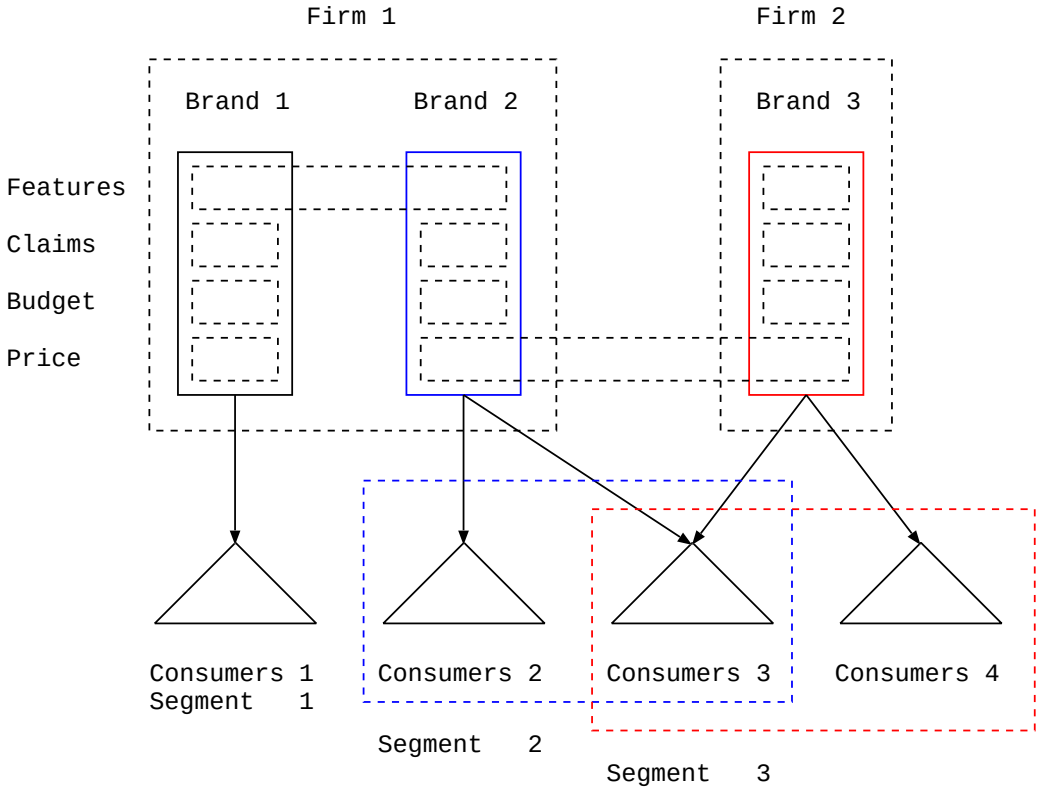

Figure 8: An example of a separable market.

In the following discussion we require an extensive notation: consumer, product and attribute indices will be used as one block, followed by comma separated step and time indices. Following common usage, vectors (scalars) will be in lowercase bold (normal) type, matrices in uppercase bold. In a matrix context vectors are always of 'column' type but for the scalar product of two vectors we use the 'dot' notation. Variables that denote memory constructs will have a bar to express that they are (exponential) time averages, and variables of the interface level will be set in a different type. For an overview of the parameters and variables of the model see Tables 4 and 5 in Section 3.7.

3.1 Attitude formation

Transformation: Initially, let us denote the following non-linear mapping from the reals to the unit interval as the *squashing function*, and assume in the context of vectors and matrices it is a function of their elements, i.e.

$$\varphi(x) := \frac{1}{1+\exp(-x)}, \quad x \in \mathbb{R}. \tag{1}$$

Note, we will also need the linear transformation $2\varphi(x) - 1$ to the interval $(-1, +1)$, which is equivalent to the hyperbolic tangent function. Further, we agree to denote the inverse function by $\varphi^{-1}(\cdot)$.

Basic Model: Let $\mathbf{q}_{ij,*,t} \in \mathbb{R}^L$, denote the ith consumer's *attitude* to product j (the position in the latent space of attitudes), in the $*$th step of attitude formation in period t, and $\mathbf{p}_{ij,*,t} \in (0,1)^K, K \geq L$ the consumer's (manifest) *perception* of the product. On the one hand, a consumer's perception changes in response to advertising, $\mathbf{p}_{ij,0,t} \rightarrow \mathbf{p}_{ij,1,t}$ (pre/post-advertising perception), and on the other, the attitude changes in response to product experience, $\mathbf{q}_{ij,0,t} \rightarrow \mathbf{q}_{ij,1,t}$ (pre/post-purchase/word-of mouth attitude). Attitudes and perceptions are related via the non-linear mappings:

$$\mathbf{q}_{ij,0,t} := \mathbf{A}_i \varphi^{-1}(\mathbf{p}_{ij,1,t}), \quad \mathbf{A}_i \in \mathbb{R}^{L \times K}, \tag{2}$$

$$\mathbf{p}_{ij,2,t} := \varphi(\mathbf{B}_i \mathbf{q}_{ij,1,t}), \quad \mathbf{B}_i \in \mathbb{R}^{K \times L}. \tag{3}$$

Thus, a product's position in attitude space is a (usually information reducing) projection of a consumer's perception, and vice versa. Note that the linear mappings are meant to differ at most between groups of consumers. Finally, attitude formation is 'embedded' in time by $\mathbf{p}_{ij,0,t+1} := \mathbf{p}_{ij,2,t}$, and we can summarize the cycle of the basic model by the following steps of information processing

$$\mathbf{p}_{ij,0,t} \rightarrow \mathbf{p}_{ij,1,t} \rightarrow \mathbf{q}_{ij,0,t} \rightarrow \mathbf{q}_{ij,1,t} \rightarrow \mathbf{p}_{ij,2,t} = \mathbf{p}_{ij,0,t+1}.$$

Let us assume $\mathbf{A}_i \mathbf{B}_i = \mathbf{E}$ (the $k \times k$ identity matrix). Obviously, this is a simplification of the unknown effect of information reduction: in fact, if we assert to know, say, $\mathbf{A}_i$ we would have to make a choice with respect to $\mathbf{B}_i$ each time the attitude changes. By the above assumption we hypothesize that the (transformed) perceptions live in a linear subspace, and if advertising tries to influence consumers 'out' of this space they 'reconcile' to the 'closest' perception in this subspace. The corresponding vector is known to be the orthogonal projection onto the subspace of $\mathbf{A}_i$[1], and following from above, this is the linear mapping $\mathbf{B}_i \mathbf{A}_i$. and, we see that the effect of advertising is just $\mathbf{B}_i \mathbf{A}_i (\varphi^{-1}(\mathbf{p}_{ij,1,t}) - \varphi^{-1}(\mathbf{p}_{ij,0,t}))$. Obviously, there is no effect if $\mathbf{p}_{ij,1,t}$ is orthogonal to the subspace. More general, the angle of this vector with its projection gives us a measure of the loss in effectiveness due to 'disorientation'. We conjecture the latter becomes more likely if $L \ll K$, and advertising does not bother to learn the consumers' perceptual redundancies.

Example: Let us explore the typical assumption of attribute redundancy. Initially we ask, what is the difference in departing either from $\mathbf{A}$, or $\mathbf{B}$. At first glance: 'none', but introducing factor analytic reasoning constrains the effects of advertising. First, observe, that (for random variables) $\mathrm{cov}(\varphi^{-1}(P)) = \mathbf{B}\,\mathrm{cov}(Q)\mathbf{B}'$, but for $\mathrm{cor}(\varphi^{-1}(P)) = \mathbf{B}\mathbf{B}'$ to hold (for uncorrelated Q), we have to constrain $\mathbf{B}$ to be (row) normalized. Second, let us assume two latent dimensions that are linked to two separate manifest dimensions each. Further assume a low level of so-called 'cross-talk' from the other two manifest dimensions:

$$\mathbf{B}_1 = \begin{pmatrix} 1.337 & -0.152 \\ 0.543 & 0.052 \\ -0.229 & 1.347 \\ 0.002 & 0.871 \end{pmatrix} \Leftarrow \mathbf{A}_1' = \begin{pmatrix} 0.64 & 0.06 \\ 0.27 & 0.07 \\ 0.01 & 0.52 \\ 0.08 & 0.35 \end{pmatrix}$$

We see that the differences in link strengths are preserved in $\mathbf{B}_1$, as well as in the orthogonal projection:

$$\mathbf{B}_1 \mathbf{A}_1 = \begin{pmatrix} 0.85 & 0.35 & -0.07 & 0.05 \\ 0.35 & 0.15 & 0.03 & 0.06 \\ -0.07 & 0.03 & 0.70 & 0.45 \\ 0.05 & 0.06 & 0.45 & 0.31 \end{pmatrix},$$

We see that the 'crosstalk' does not really play a role — advertising only the, say, first two dimensions, has a negligible effect on the other attitudinal dimension, and vice versa. But note this is only ceteris paribus

[1] From the singular value decomposition $\mathbf{A} = \mathbf{LWM}$ we see that a perception is projected onto the coordinate system of the manifest space $\mathbf{M}$, the coordinates are weighted by $\mathbf{W}$, and then are projected onto the coordinate system of the latent space $\mathbf{L}$.

reasoning which ignores possible changes on the latent level (see below). Now, let us start from the latent level, and normalize $\mathbf{A}'_1$ to comply with the factor analytic constraint:

$$\mathbf{B}_2 = \begin{pmatrix} 0.996 & 0.093 \\ 0.968 & 0.251 \\ 0.019 & 1.000 \\ 0.223 & 0.975 \end{pmatrix} \Rightarrow \mathbf{A}'_2 = \begin{pmatrix} 0.534 & -0.105 \\ 0.494 & -0.016 \\ -0.145 & 0.536 \\ -0.029 & 0.490 \end{pmatrix}.$$

We see that, for a model with the intended redundancy structure, the factor analytic constraint imposes a limitation on the link strength, i.e. the 'indicating' links are nearly identical. Note that the correlative structure of the 'indicating' links is the same in both models but the 'cross-correlations' between the 'indicating' and the 'noisy' links are different in sign.

Techitude: A product's *technical features* (attributes) $\mathbb{p}_{j,t} \in (0,1)^{\bar{K}}$, are condensed into a position in attitude space in the same way as above. Let $\mathrm{c}_{ij,t} \in \{0,1\}$ denote if the product was chosen, and thus the information is available, and let us define the position as

$$\tilde{\mathbf{q}}_{ij,0,t} := \begin{cases} \tilde{\mathbf{A}}\varphi^{-1}(\mathbf{p}_{j,t}) \quad \tilde{\mathbf{A}} \in \mathbb{R}^{L\times\bar{K}} & : \quad \mathrm{c}_{ij,t} = 1 \\ \mathbf{q}_{ij,0,t} & : \quad \text{else} \end{cases}. \tag{4}$$

Note, the step index indicates the situation after purchase but before word-of-mouth communication. By the latter a consumer may obtain additional information (see Equation (34) in Section 3.5), but if he does not, his attitude is pre-defined to remain the same (see Equation (5)).

Reconciliation: A consumer adjusts his current expectation (pre-purchase/post-advertising attitude) to new information on the performance of a product (either acquired directly by consumption (usage), or indirectly by word-of-mouth communication), but only on relevant attitudinal dimensions. Let us denote a consumer's current *aspiration level* on the lth dimension as $\bar{d}_{il,t} \in \mathbb{R}$, define zero to be the *threshold of relevance*, and the rate of adjustment as $\eta_{i1} \in (0,1]$ (depending on a consumer's involvement), and let us define the change in attitude as

$$q_{ijl,1,t} := \begin{cases} \eta_{i1}\tilde{q}_{ijl,1,t} + (1-\eta_{i1})q_{ijl,0,t} & : \quad \bar{d}_{il,t} > 0 \\ q_{ijl,0,t} & : \quad \text{else} \end{cases}. \tag{5}$$

Note, now the step index indicates the situation after word-of-mouth communication.

Desire: The consumers are assumed to adapt their aspiration levels $\bar{\mathbf{d}}_{i,t} \in \mathbb{R}^L$ to their current market induced desires which are as strong as 'reasonably possible'. Further there may be (temporary) external influences to change a desire $\mathbf{d}_{i,t} \in \mathbb{R}^L$. Let $\eta_{i4} \in [0,1]$ denote the rate of adaptation to the current desires (depending on involvement), $\mathbb{J}$ the set of products, and let us define the change in aspiration as

$$\bar{\mathbf{d}}_{i,t+1} := \eta_{i4} \max_{j\in\mathbb{J}}(\mathbf{q}_{ij,0,t}) + (1-\eta_{i4})(\bar{\mathbf{d}}_{i,t} + \mathbf{d}_{i,t}). \tag{6}$$

Note, the market induced desires are advertising biased. Thus, if we want to model a more 'consolidated' view of the market, as suggested in Section 2.4, we can use the 'reconciled' attitudes that include information obtained by word-of-mouth, i.e. $\tilde{\mathbf{q}}_{ij,1,t}$.

τ	$t=1$	$t=3$	$t=5$	$t=10$
0.9	0.1	0.271	0.410	0.651
0.8	0.2	0.488	0.672	0.893
0.7	0.3	0.657	0.832	0.972
0.6	0.4	0.784	0.922	0.994
0.5	0.5	0.875	0.969	0.999

Table 2: Exponential decay, $1-\tau^t$.

Remark: Table 2 illustrates the model of exponential decay: the columns show the loss (decay) of an initial level $z_0 \in \mathbb{R}$ after t periods (in percent), i.e. the model $z_t := z_0\tau^t$, with $\tau \in (0,1)$ the *persistence*,

and $z_0 - z_t = z_0(1-\tau^t)$. More general, an initial level is adjusted exponentially to a target level, $z_{t+1} := z_t\tau + z(1-\tau)$, to the effect that $\Delta_t = z - z_t = (z-z_0)\tau^t = \Delta_0\tau^t$ and $\Delta_0 - \Delta_t = \Delta_0(1-\tau^t)$ is the reduction in difference after t periods. Note that $\Delta_\infty := \lim_{t\to\infty}\Delta_t = 0$ and thus $z_\infty = z$, where $z = 0$ in the simple model.

For ease of notation, let us define the *threshold indicator* function, and assume that in the context of vectors and matrices it is a function of their elements, i.e.

$$\psi(x) := \left\{ \begin{array}{ccc} 1 & : & x > 0 \\ 0 & : & \text{else} \end{array} \right. , \quad x \in \mathbb{R}. \tag{7}$$

(Dis)satisfaction: We assume that the performance of a product is compared with the pre-purchase expectation, which leads to the overall feeling of *(dis)satisfaction*. Let us assume the intensity of this feeling depends on a consumers involvement $\eta_{i2} \in (0,1]$, and is subject to saturation effects, i.e.

$$s_{ij,0,t} := \left\{ \begin{array}{ccc} 2\varphi\left(\eta_{i2}\psi\left(\bar{\mathbf{d}}_t\right)\cdot\left(\tilde{\mathbf{q}}_{ij,0,t} - \mathbf{q}_{ij,0,t}\right)\right) - 1 & : & \mathrm{c}_{ij,t} = 1 \\ 0 & : & \text{else} \end{array} \right. . \tag{8}$$

Note, first if no information is available because the product was not chosen, $\mathrm{c}_{ij,t} = 0$, the feeling is 'neutral'. Second the differences in performance and expectation are noticed only on relevant attitudinal dimensions, and they are compensable. Third, we transform by the hyperbolic tangent function (see Equation (1)), because the feeling has a direction which entails specific responses. Finally, the step index indicates the situation before word-of-mouth communication.

The responses to the experience of (dis)satisfaction are threefold: first, past (current) experience can influence the current (future) choice process(es) to the effect of a different composition of the set of products considered (see Section 3.4), second, it determines the *reactance* to advertising which dampens the change in the perception of a product (see Section 3.2), and third it determines the propensity to communicate by word-of-mouth (see Section 3.5).

After word-of-mouth a consumer's feeling of (dis)satisfaction adopts the current intensity and direction if the intensity exceeds the remembered level, but otherwise the memory decays. Let $\eta_{i3} \in [0,1)$ denote the persistence of the memory (depending on involvement), and let us define the change in memory as

$$\bar{s}_{ij,t+1} := \left\{ \begin{array}{ccc} s_{ij,1,t} & : & |s_{ij,1,t}| > |\bar{s}_{ij,t}| \\ \bar{s}_{ij,t}\eta_{i3} & : & \text{else} \end{array} \right. . \tag{9}$$

Note, a consumer ignores a contradictory experience of lower intensity, but due to the memory decay he will not persist in a contradiction for long. Alternatively, asymmetric conditions for involvement dependent adjustments could be considered, e.g., $-s_{ij,1,t} > (1-\eta_{i3})|\bar{s}_{ij,t}|$ would model a sensitivity to dissatisfaction which is the higher the higher the involvement (persistence).

Reactance: The arousal of reactance is confined to the feeling of dissatisfaction but a consumer attempts to avoid contradictions, i.e.

$$r_{ij,t+1} := |\min(0, \min(s_{ij,1,t}, \bar{s}_{ij,t}))|. \tag{10}$$

Satitude: Let us assume that the experience of (dis)satisfaction with a product is also measurable in the space of perceptions — that corresponds to expectation-performance indicators based on the disconfirmation approach to perceived quality measurement (see Section 3.3). Thus we assume that attitudinal differences are processed (projected) in the same way as attitudes, but on irrelevant dimensions a consumer's feeling is either 'neutral' or 'irrelevant'. Let us define the perceived (latent) (dis)satisfaction as

$$\begin{array}{rcl} \grave{\mathbf{p}}_{ij,t} & := & 2\varphi(\mathbf{B}_i\grave{\mathbf{q}}_{ij,t}) - \mathbf{1}, \\ \grave{q}_{ijl,t} & := & \left\{ \begin{array}{ccc} \tilde{q}_{ijl,1,t} - q_{ijl,0,t} & : & \bar{d}_{ijl,t} > 0 \\ 0 & : & \text{else} \end{array} \right. . \end{array} \tag{11}$$

Note, the transformation is the same as in Equation (8). For convenience we may refer to the perceived (intensity of) (dis)satisfaction as a *satisception*.

Example: Figure 9 illustrates the relationship between perceptions and (dis)satisfaction intensities. Assume a single manifest/latent dimension, then the line denoted by q shows $p \mapsto q$ for a range $p \in$

$(0.05, 0.095)$. For the intensities $|s|$ (along the x-axis) assume that the value of q for $p = 0.05$ is the origin of the absolute value of the (total) attitudinal difference (see Equation (8)), and that the latter increases along the y-axis. There are lines for different choices of the parameter $\eta_2 \in \{0.5, 0.7, 1\}$. We can infer that, given the same spacing $p_2 - p_1 = \Delta$ on the perceptions scale, the intensities would increase with the distance $|(1 - \Delta)/2 - p_1|$. Note, in a respective plot this would be a u-shaped line. Nevertheless, if we assume $\Delta(p) = (1 - p)m$, where $m > 0$, and ignore memory effects we will observe an intensity of, e.g., dissatisfaction increasing with p. We can interpret this as follows (see the next section): the same advertising impact is followed by the higher an intensity of dissatisfaction in a later period the higher the current belief p, if the technical performance remains the same (as the attitude corresponding with the initial belief). Note that reactance dampens the effect, and will itself be the stronger the stronger the belief.

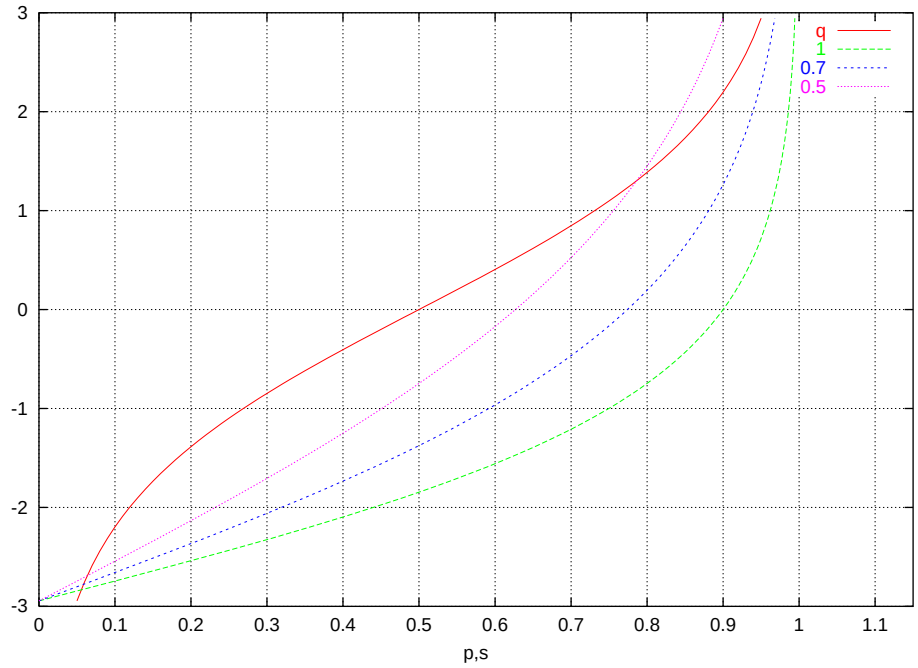

Figure 9: The intensity of (dis)satisfaction for different levels of involvement (see Equation (8)).

3.2 Dynamics of perceptions

Let us discuss the manifest level of the model of attitude formation in this section. Technical features and perceived attributes, were introduced to live on the interval $(0, 1)$. This is on the one hand a convenience for modeling technical improvement, and on the other, in the case of advertising, a necessity (see below). Further, we can postulate parsimonious measurement models, if we interpret these variables as probabilities (see the next section).

Response: In response to advertising consumers change their beliefs (perceptions), but such change is subject to saturation effects, and therefore we need bounded variables. In the following we will use the subscripts introduced in the previous section with equal meaning. Let $m_{ijk,t} \in (-1, 1)$ denote the *impact* of the kth claim for the jth product on the ith consumer, ϑ_0 the persistence of belief in the case of a zero or negative impact, and let us define the change in belief as

$$p_{ijk,1,t} := \begin{cases} p_{ijk,0,t} + (1 - p_{ijk,0,t})(1 - r_{ij,t})m_{ijk,t} & : \quad m_{ijk,t} > 0 \\ p_{ijk,0,t}\vartheta_0 & : \quad \text{else} \end{cases} . \tag{12}$$

Note, first, in case of dissatisfaction advertising is met with scepticism, i.e. the impact is dampened by reactance (see Equation (10)). Second, the impact is proportional to the current gap (unused potential) of belief $1 - p_{ijk,0,t}$, and therefore the stronger the lower the current belief. Conversely, the higher the current

belief the higher the loss in credibility: $-p_{ijk,0,t}(1-\vartheta_0)$. Finally, remember that the pre-advertising belief of the current period is just the post-word-of-mouth belief of the previous period, i.e. $p_{ijk,0,t} = p_{ijk,2,t-1}$.

Impact: We assume that the impact of advertising is decomposable and subject to saturation effects. On the one hand, let $\mathrm{b}_{j,t} \in \mathbb{R}_0^+$ be the advertising budget for product j, and $\mathrm{n}_{j,t}$ the number of consumers addressed with the same message (size of a segment). On the other let $\mathrm{m}_{jk,t} \in \{0,1\}$ indicate if the kth claim is contained in the jth message. Finally, let $\mathrm{s}_{ij,t} \in \{0,1\}$ denote if consumer i is addressed with the jth message, and remember the threshold indicator function $\psi(\cdot)$ from Equation (7). Note that replacing an index by a dot we use as a shorthand for summation. A claim's impact on consumer i depends on its *intensity* which is determined by a number of attention effects, and the responsiveness of a consumer (see Equation (14) below), i.e.

$$m_{ijk,t} := \phi\left(\mathrm{s}_{ij,t}\mathrm{m}_{jk,t}\left(\frac{1}{\max\left(1,\sum_{j'\in\mathbb{J}}\psi\left(\mathrm{s}_{ij',t}\mathrm{m}_{j'\cdot,t}\right)\right)}\right)^{\vartheta_1}\left(\frac{1}{\max(1,\mathrm{m}_{j\cdot,t})}\right)^{\vartheta_2}\right.$$
$$\left.\left(\frac{\max_{k'\in\mathbb{K}}(\sum_{j'\in\mathbb{J}}\mathrm{s}_{ij',t}\mathrm{m}_{j'k',t})}{\max(1,\mathrm{s}_{ij,t}\sum_{j'\in\mathbb{J}}\mathrm{s}_{ij',t}\mathrm{m}_{j'k,t})}\right)^{\vartheta_{i3}}\frac{\mathrm{b}_{j,t}}{\mathrm{n}_{j,t}^{\vartheta_4}\mathrm{b}_0};\vartheta_{i5}\right). \quad (13)$$

Note, first, the more messages compete for the attention of a consumer the less the effect of a message, where no claim at all (or a zero budget) does not qualify as a competing message. Second, the fewer claims a message contains the sharper its focus and consequently its effect. Third, the fewer messages that contain a claim the higher the focus on that claim. For the choice of parameters we suggest $0 \leq \vartheta_{i3} \ll \vartheta_1 < \vartheta_2 \leq 1$, where we think that modeling diversion of attention effects is mandatory. Fourth, the scale factor $\mathrm{b}_0 \in \mathbb{R}^+$ models the reference price (cost) of a contact per consumer, and it is assumed that the consumers of a segment are contacted with the same intensity (frequency). Fifth, the parameter $\vartheta_4 \in [0,1]$, models economies of scale effects that depend on the number of consumers addressed (with the same message). Finally, the impact of a claim depends on the responsiveness of a consumer, denoted by $\vartheta_{i5} \in (0,1]$.

Responsiveness: The following function captures the idea of a thresholded and saturable response to a claim's intensity:

$$\phi(x;\vartheta) := \vartheta - \exp(-\vartheta x), \quad x \in \mathbb{R}_0^+, \vartheta \in (0,1]. \quad (14)$$

Note, first, that an increase in a claim's intensity, ceteris paribus by increasing the advertising budget, leads to a smaller increase in impact, $\frac{\partial\phi}{\partial x} = -\vartheta^2\exp(-\vartheta x) < 0$, but the proportions of two claims' intensities are smaller than their proportions of impacts if the latter are positive: $x_2/x_1 \leq \phi(x_2)/\phi(x_1), x_2 \geq x_1, \phi(x_1) \geq 0$. Second, the maximum impact is bounded by ϑ (saturation level), which at the same time determines the threshold of ineffective claim intensity. Note, there is a level of responsiveness, such that $\vartheta = \exp(-\vartheta) \approx 0.56714$ and a 'budget' per consumer equal the reference price (cost) has just zero impact (assume a single claim, a single product and no economies of scale effects).

Example: Figure 10 illustrates some choices of the responsiveness to advertising. The parameters were selected for a zero impact if the budget per consumer is just $1/2, 1, \ldots, 3$ times the reference price per contact. By definition the firms have to invest just more than that multiple to obtain an effect, but considerably more if their messages contain more than one claim and/or there are competing messages (products). On the other hand for large budgets the differences in impact will be low, and the message will be the really differentiating factor. To illustrate this, let us assume there are five products, advertised with a budget per consumer just equal the reference price per contact, and one to five claims per message which exhibit a triangular structure. Further, assume $\vartheta_1 = 1/2$, $\vartheta_2 = 2/3$, and $\vartheta_3 = 1/3$ (see Equation (13)). Let us first show the intensities, and second, the 'corresponding' impacts for a responsiveness of $\vartheta_5 = 2/3$ and alternative budgets of three times the reference price:

$$\mathbf{M} := \begin{pmatrix} 0.26 & -0.33 & -0.33 & -0.33 & -0.33 \\ 0.10 & 0.12 & -0.33 & -0.33 & -0.33 \\ 0.02 & 0.04 & 0.07 & -0.33 & -0.33 \\ -0.03 & -0.02 & 0.01 & 0.05 & -0.33 \\ -0.07 & -0.05 & -0.03 & 0.01 & 0.07 \end{pmatrix} \Leftarrow \begin{pmatrix} 0.45 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.28 & 0.30 & 0.00 & 0.00 & 0.00 \\ 0.21 & 0.23 & 0.25 & 0.00 & 0.00 \\ 0.18 & 0.19 & 0.21 & 0.24 & 0.00 \\ 0.15 & 0.16 & 0.18 & 0.21 & 0.26 \end{pmatrix}.$$

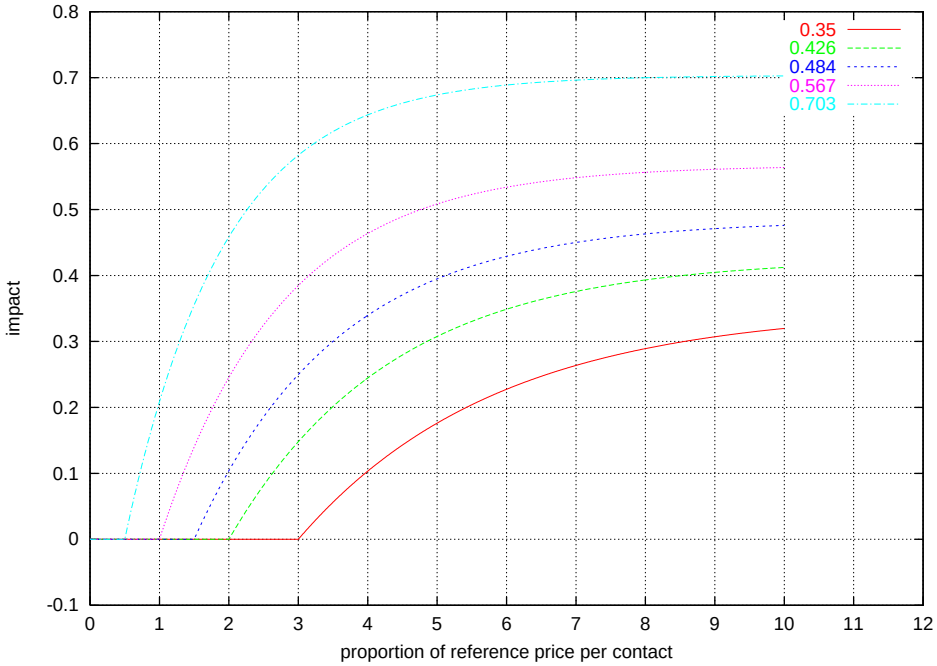

Figure 10: Advertising response for budgets that are a multiple of the reference price per contact, for different responsiveness parameters ϑ_5 (see Equation (14)).

Remark: Let us assume we have a model with a single latent dimension and two manifest dimensions, with $\mathbf{A} = (1/2, 1/2)$. Let us further assume a firm includes only one of the claims in its message and achieves a constant impact $0 < m < 1$. If we neglect reconciliation with product performance, we obtain the following model of the dynamics of perceptions:

$$p_{t+1} := \left(1 + \left(\frac{1 - p_t\vartheta_0}{p_t\vartheta_0}\,\frac{1 - p_t(1-m) - m}{p_t(1-m) + m}\right)^{\frac{1}{2}}\right)^{-1}.$$

Note, first, that the equal weighting of the manifest dimensions leads to the formation of equal belief, $p_t = p_{1,t} = p_{2,t}$. Second, the belief decays on the dimension not advertised, i.e. $0 < \vartheta_0 < 1$ of the current level is retained, whereas on the other the belief increases with m. Third, the effect of this message is that $p_\infty := \lim_{t\to\infty} p_t \in (0, 1)$, and $q_\infty \in (-\infty, +\infty)$. Thus, for any combination of decay and impact rates there is a finite level of the limit belief. Figure 11 shows the limit belief p_∞ as a function of the impact m for different values of the persistence ϑ_0. Observe, first, that $m = 1 - \vartheta_0 \Rightarrow p_\infty = 1/2$, i.e. if the impact equals the rate of decay the limit attitude is neutral, $q_\infty = 0$. Second, if $\vartheta_0 = 1/2 \Rightarrow p_\infty = m$, i.e. if half of the belief decays, the limit belief is identical to the impact rate.

Although the above model is a simplification we think it is typical: first, the firms may not guess the claims' redundancies correctly, second, advertising may not become effective due to blurred messages and competition, or miscalculated budgets, third, redundancies may be superseded by dimensional crosstalk (see Section 3.1). Nevertheless, product performance is the ultimate limiting (amplifying) factor that puts advertising claims into perspective, but meanwhile, until this information becomes available, they need not lead a consumer to unconstraint expectations.

We conclude this section by mentioning that a similar interpretation holds for the current level of a technical attribute (feature) $\mathrm{p}_{ij,t}$: there is an unused potential for improvement (of an existing technology) $1 - \mathrm{p}_{ij,t}$. Note, for an evolving or disruptive technology we suggest to model a continuous change or sudden structural breaks of the set of dimensions, but this is part of future work.

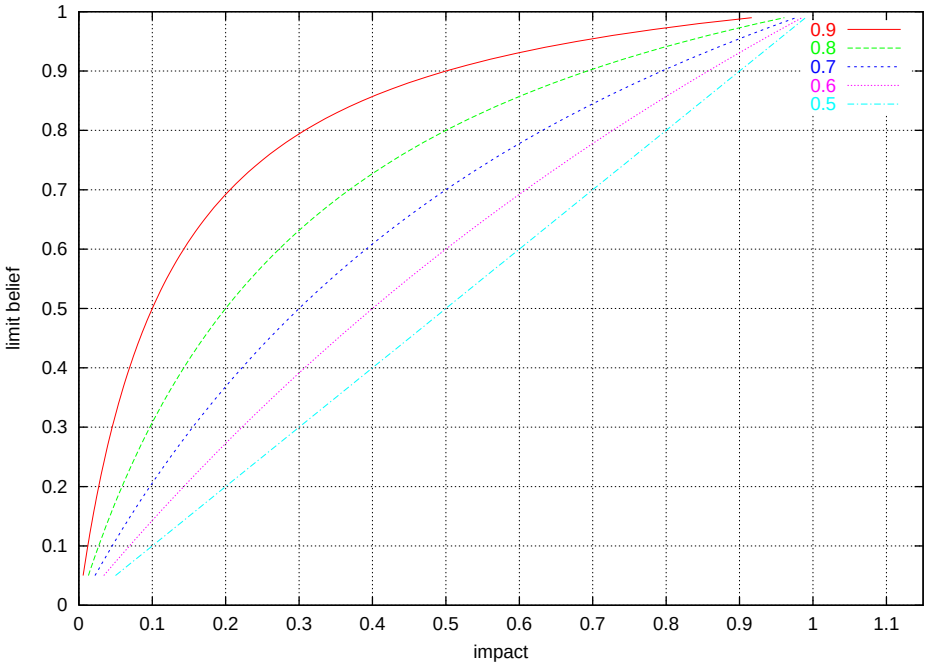

Figure 11: Limit advertising response to a single claim in a model with two equally important claims.

3.3 Measuring the state of a consumer

In this section we present a general concept for measuring the internal states of the consumers. Remember, we assume that a consumer is regularly surveyed on his perception of and (dis)satisfaction with a product, and that this information is available to the firms.

Perceptions: The strength of belief in product attributes is measured on a binary scale. Let $\mathfrak{x}_{ijk,t} \in \{0,1\}$ denote the ith consumer's stated belief, i.e. the agreement to the item describing the kth attribute of the jth product, and assume the variable $p_{ijk,2,t}$ is the probability to 'agree'. Thus, belief measurements are binomially distributed random variables:

$$\Pr(\mathrm{X}_{ijk,t} = 1) := p_{ijk,2,t}. \tag{15}$$

Note, according to the interpretation we suggest below, a zero (one) measurement can be thought of as indicating a 'low' ('high') belief, but given a single measurement this is 'pointless' information.

Satisfaction/Satisception: Similarly, the intensity and direction of the overall and attribute specific (dis)satisfaction of a consumer, is measured on a five-point bipolar scale. Let $\mathfrak{y}_{ij,t}, z_{ijk,t} \in \{-2,-1,0,1,2\}$ denote the ith consumer's stated overall (dis)satisfaction with product j, and with the product's kth attribute, respectively. Now, remembering the transformation according to Equation (1), let us return to the unit interval, i.e. $s'_{ij,1,t} := (1 + s_{ij,1,t})/2$ and $\grave{p}'_{ijk,t} := (1 + \grave{p}_{ijk,t})/2$, and assume we repeat a binary measurement with these probabilities four times and report the sum minus two as the scale values. Thus, (dis)satisfaction measurements are modeled as Bernoulli distributed random variables:

$$\Pr(\mathrm{Y}'_{ij,t} = z) := \mathrm{B}(s'_{ij,1,t}, 4), \tag{16}$$

$$\Pr(\mathrm{Z}'_{ijk,t} = z) := \mathrm{B}(\grave{p}'_{ijk,t}, 4), \tag{17}$$

where $z \in \{0,1,\ldots,4\}$, and the variables are transformed to $\mathfrak{y}_{ij,t} := \mathfrak{y}'_{ij,t} - 2$, and $z_{ijk,t} := z'_{ijk,t} - 2$, such that the scales are 'polarized' at zero. Remember, zero indicates a 'neutral', as well as an 'irrelevant' response (compare Equation (11)).

Example: Figure 12 illustrates the measurement of (dis)satisfaction on a bipolar scale. Note given a zero intensity 62.5 percent of the responses will be different from 'neutral' or 'irrelevant', but only 12.5 percent of the measurements will fall on the ends of the scale.

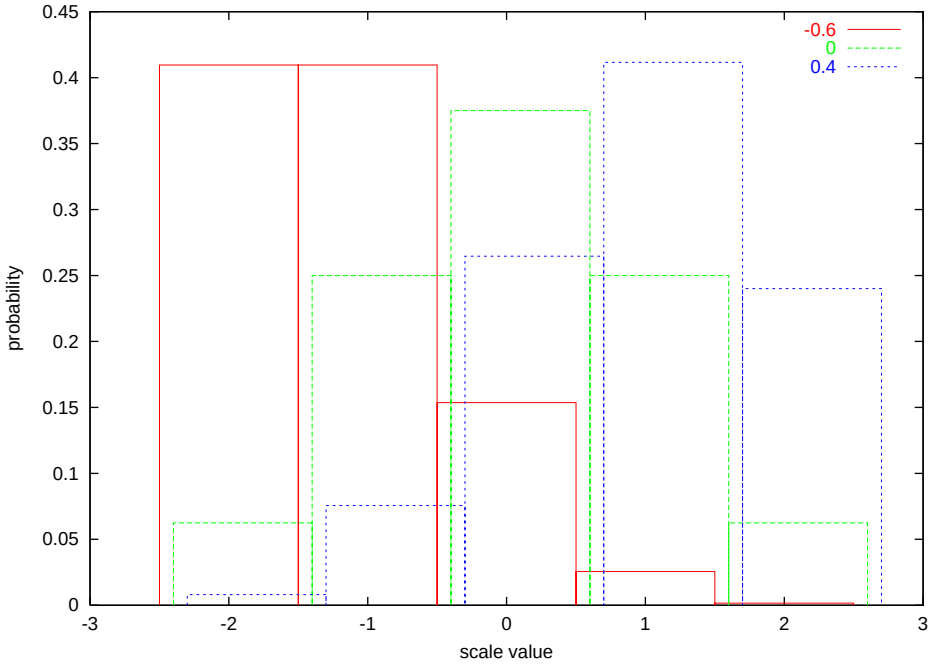

Figure 12: Distribution of scale values given different intensities of (dis)satisfaction.

3.4 Choice of a product

In the present section we discuss the process of consideration and choice set formation. We will assume one basic scheme, which can be varied by putting more emphasis on price or product 'quality'. The other modeling choice concerns different decision styles. Let us begin with the latter.

Utility: Under the *modified ideal point* decision rule the total attractiveness, or 'utility' of a product, is the sum of its contributions on the attitudinal dimensions, i.e.

$$u_{ij,t} := \mathbf{1} \cdot \max\left(0, \min\left(\mathbf{q}_{ij,0,t}, \bar{\mathbf{d}}_{i,t}\right)\right). \tag{18}$$

Note that a utility of zero would be ambiguous if a zero threshold of relevance could be 'fulfilled'. Although this is in fact only cosmetic, we have defined the threshold indicator function in this sense (see Equation (7)).

For a *conjunctive* decision rule we assume that the *satisfaction levels* are lower than the aspiration levels. Let $\beta_1 \in [0,1)$ denote the lowering factor, $\mathbf{1}$ a $l \times 1$ vector of ones, and let the utility indicate if there is not a single relevant dimension where the desired level is not satisfied, i.e.

$$u_{ij,t} := \psi\left(\mathbf{1} \cdot \bar{\mathbf{d}}_{i,t}\right) - \psi\left(\psi\left(\bar{\mathbf{d}}_{i,t}\right) \cdot \left(\mathbf{1} - \psi\left(\mathbf{q}_{ij,0,t} - \beta_1 \bar{\mathbf{d}}_{i,t}\right)\right)\right). \tag{19}$$

Note, if none of the dimensions is relevant there is nothing to indicate. This is in compliance with the first definition of utilities.

For a *disjunctive* decision rule we assume, again, a lowering of the aspiration levels, $\beta_1 \ll \beta_2 \leq 1$, but the consumers further concentrate on important dimensions, i.e. the satisfaction levels are defined as

$$d^*_{il,t} := \begin{cases} \beta_2 \max_{l' \in \mathbb{L}}(\bar{d}_{il',t}) & : \quad \bar{d}_{il,t} \geq \beta_2 \max_{l' \in \mathbb{L}}(\bar{d}_{il',t}) \\ 0 & : \quad \text{else} \end{cases}. \tag{20}$$

Now, let the 'utility' indicate if there is at least one relevant and important dimension where the desired level is satisfied, i.e.

$$u_{ij,t} := \psi\left(\psi\left(\mathbf{d}^*_{i,t}\right) \cdot \psi\left(\mathbf{q}_{ij,0,t} - \mathbf{d}^*_{i,t}\right)\right). \tag{21}$$

Note again, if none of the dimensions is important then nothing is to be indicated. Further, if there are no marked differences in the aspiration levels then all relevant dimensions will be considered important and thus 'satisfiable'.

Ranking: In the context of (initial) conjoint-measurements (product development) we need a preference ordering of the products instead of choice information. Let $\mathrm{o}_{ij,t} \in \{1, 2, \ldots, |\mathbb{J}|\}$ denote the rank number the ith consumer assigns to product j, and assume he arrives at such a number by comparing the utility of a product against all the others', i.e.

$$\mathrm{o}_{ij,t} := |\mathbb{J}| - \sum_{j' \in \mathbb{J} \setminus j} \psi(u_{ij,t} - u_{ij',t}). \tag{22}$$

Note, ties in the utilities are preserved, and as a consequence the rank numbers need not be contiguous. We think, this is an appropriate assumption given the possibility of noncompensatory evaluation styles.

Choice: Let us now present the basic scheme of consideration set formation. Initially, we may assume that a firm is able to exclude a consumer from the purchase of its own competing products (brands) which it offers to a different segment. Let $\iota \in \{0, 1\}$ indicate the assumption of market *separability*, remember that $\mathrm{s}_{ij,t}$ indicates the segment membership, and let us define the set of available products as

$$\mathbb{J}_{i,t} := \begin{cases} \{j : \mathrm{s}_{ij,t} = 1, j \in \mathbb{J}\} & : \quad \iota = 1 \\ \mathbb{J} & : \quad \text{else} \end{cases}. \tag{23}$$

We assume, a consumer makes a pre-selection among the alternatives by considering only the products that are priced below the consumer's reservation price, which we denote by w_{i0}, i.e.

$$\mathbb{J}_{i,0,t} := \{j : w_{ij,t} \leq w_{i0}, j \in \mathbb{J}_{i,t}\}. \tag{24}$$

Note if this result is in an empty set a consumer ignores the reservation price $\mathbb{J}_{i,0,t} = \mathbb{J}_{i,t}$. Next he excludes products that are remembered as highly dissatisfying in past periods (see Equation (9)). Let $\beta_{i3} \in [0, 1]$ be the threshold of relevance of the intensity of (dis)satisfaction[2], and define the reduced set as

$$\mathbb{J}_{i,1,t} := \mathbb{J} \setminus \{j : \bar{s}_{ij,t} < -\beta_{i3}, j \in \mathbb{J}_{i,0,t}\}. \tag{25}$$

Note, if this results in an empty set, a consumer is assumed to ignore the feeling of dissatisfaction $\mathbb{J}_{i,1,t} = \mathbb{J}_{i,0,t}$. Alternatively, he may 'trade' dissatisfaction against the violation of reservation price, if possible. Nevertheless, if the reservation price has the implicit interpretation of a consumer's budget constraint considering overpriced products is only a last resort, as assumed above. Next, the utilities from above come into play for further set reduction, i.e.

$$\mathbb{J}_{i,2,t} := \left\{ j : u_{ij,t} \geq \max_{j' \in \mathbb{J}_{i,1,t}} (u_{ij',t}), j \in \mathbb{J}_{i,1,t} \right\}. \tag{26}$$

Then the set is 'enlarged' by products that have been (told to be) highly satisfactory in the past, i.e.

$$\mathbb{J}_{i,3,t} := \mathbb{J}_{i,2,t} \cup \{j : \bar{s}_{ij,t} > \beta_{i3}, j \in \mathbb{J}_{i,0,t}\} \tag{27}$$

Note, the latter set we refer to as the *long term* consideration set because, in effect, these products do not take part in the utility based reduction step. Next, this set is reduced to the products with minimum price, where we denote by $w_{ij,t}$ the price demanded for product j, i.e.

$$\mathbb{J}_{i,4,t} := \left\{ j : w_{ij,t} \leq \min_{j' \in \mathbb{J}_{i,3,t}} (w_{ij',t}), j \in \mathbb{J}_{i,3,t} \right\}. \tag{28}$$

Finally, a consumer chooses, with probability $\frac{1}{|\mathbb{J}_{i,4,t}|}$, one among the products in the *choice set*. Remember, $\mathrm{c}_{ij,t} \in \{0, 1\}$ indicates if consumer i has chosen product j. For illustration of the utility maximizing (satisficing) step of set formation see Figure 6 and Table 1 in Section 2.4.

[2] Alternatively we may assume a stochastic decision, i.e. a product is excluded with probability $-\bar{s}_{ij,t}$. In this case the consumer may try 'again' even if the intensity of dissatisfaction is above a threshold.

In the case of a decision process based on price weighted utilities, the above scheme needs two modifications: first, we have to consider that the utilities of all the alternatives could be zero. Thus, let us define the price weighted utilities as follows

$$u'_{ij,t} := \begin{cases} \frac{u_{ij,t}}{w_{ij,t}} & : \quad \exists j' : u_{ij',t} > 0, j' \in \mathbb{J}_{i,1,t} \\ \frac{1}{w_{ij,t}} & : \quad \text{else} \end{cases} . \tag{29}$$

Second, we assume that a further reduction to minimum priced products is omitted. Figure 13 may illustrate the information flow of the two schemes of choice set formation.

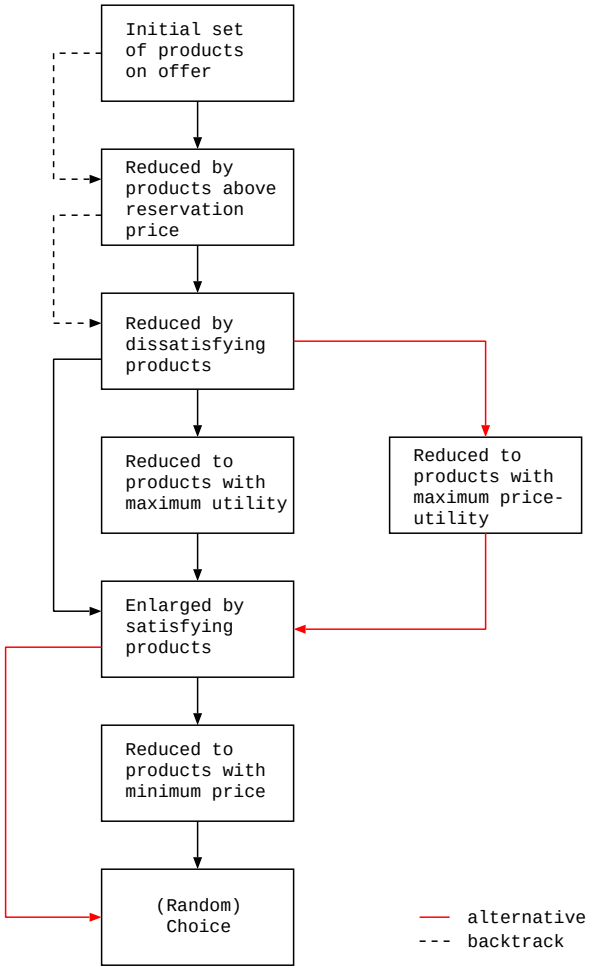

Figure 13: Information flow of consideration (choice) set formation.

Remark: In a model that assumes price weighting there is explicit leeway for pricing policies: assume utilities $u_1 \leq u_2$, then there exist prices $w_2 \geq w_1$, such that $\frac{u_1}{w_1} = \frac{u_2}{w_2}$. We see that for a product of inferior 'utility' a firm can only demand a lower price than for a product of superior 'utility', and vice versa. On the other hand, in the 'utility' based model of set formation (bad) product performance is not compensable by price. Thus, we have the option of modeling more quality versus more price oriented markets.

3.5 Word-of-mouth communication

In this section we discuss the modeling of word-of-mouth activities of consumers. We think this is an important part of the model, because it will be interesting to see the difference in market response if the consumers interact more or less frequently and thus the information base is different.

First, let the probability that consumer $i \in \mathbb{I}$ contacts consumer $i' \neq i$, which is indicated by the variable $h_{i,i'} \in \{0,1\}$, depend on $\kappa_i \in \{0,1,\ldots,|\mathbb{I}|-1\}$, the average number of contacts of a consumer, i.e.

$$\Pr(H_{i,i'}=1) := \frac{\kappa_i}{|\mathbb{I}|-1}. \tag{30}$$

Note that the probabilities are meant to differ at most between groups of consumers.

Second, we assume that the propensity to communicate about a product depends on the current intensity of (dis)satisfaction. Note that ignoring the direction is a simplification as negative experience generates a greater desire to communicate than a positive one. Let $v_{ij,t}, w_{ij,t} \in \{0,1\}$ denote the stochastic *communication indicators* of the sender and the recipient, respectively, where

$$\Pr(V_{ij,t}=1) := \begin{cases} |s_{ij,0,t}| & : \quad \mathrm{c}_{ij,t}=1 \\ 0 & : \quad \text{else} \end{cases}, \tag{31}$$

$$\Pr(W_{ij,t}=1) := \begin{cases} 0 & : \quad \mathrm{c}_{ij,t}=1 \\ 1 & : \quad \text{else} \end{cases}. \tag{32}$$

According to this definition a sender has nothing to say about a product he has not consumed (chosen), and only if a recipient currently has no consumption experience, he fills the gap with the information provided by a sender. Note, as a variant we may assume that the propensity of a recipient to 'fill in' is $1-|\bar{s}_{ij,t}|$, i.e. the more 'neutral' his feeling about a product the less prejudiced he is.

Third, the set of consumers from which consumer i receives information on the jth product is composed of the consumers he has a contact with, that communicate about the product, and from which he accepts the information, i.e.

$$\mathbb{I}_{ij,t} := \{i' : \max(h_{i,i'}, h_{i',i}) = v_{ij,t} = w_{ij,t} = 1, i' \in \mathbb{I} \setminus i\}. \tag{33}$$

Fourth, let us assume two effects of word-of-mouth communication: on the one hand the sender's (dis)-satisfaction intensities become known to the recipient, and on the other, the sender's technology induced position in attitude space. Finally, let us assume a simple averaging of the information obtained from multiple senders

$$\tilde{\mathbf{q}}_{ij,1,t} := \begin{cases} \tilde{\mathbf{q}}_{ij,0,t} & : \quad \mathrm{c}_{ij,t}=1 \vee \mathbb{I}_{ij,t}=\emptyset \\ \mathrm{avg}_{i' \in \mathbb{I}_{ij,t}}(\tilde{\mathbf{q}}_{i'j,0,t}) & : \quad \text{else} \end{cases}, \tag{34}$$

and

$$s_{ij,1,t} := \begin{cases} s_{ij,0,t} & : \quad \mathrm{c}_{ij,t}=1 \vee \mathbb{I}_{ij,t}=\emptyset \\ \mathrm{avg}_{i' \in \mathbb{I}_{ij,t}}(s_{i'j,0,t}) & : \quad \text{else} \end{cases}. \tag{35}$$

Remember from Section 3.1, if a consumer does not acquire new information on a product's technical characteristics, not even by word-of-mouth, he 'fills in' with his current attitude and his current experience of (dis)satisfaction is 'neutral'. Note, obviously we assume that the recipient, does not base the feeling of (dis)satisfaction on the communicated technical characteristics of a product but takes the view of the sender(s). We think this is a realistic assumption of the reinforcement effect of personal communication.

3.6 Setting of reference prices and costs

In this section we explore the 'calibration' of model constructs that are based on absolute scales, such as advertising budgets, and we make a few provisional assumptions about production costs. A discussion of the finance part must be deferred to future work.

Let us give a simple formula for choosing parameter settings related to the price levels on the consumer and input factor markets. Let $\rho \in [0,1]$ denote the share of marketing in a firms total cost (versus production) and let us choose a level for the reservation prices on the consumer market. If the firms' sales are

assumed to be equal, the reference price per contact b_0, the reference unit production cost a_0 and a firms starting capital k_0 are related to the reservation price as follows

$$\begin{array}{rcl} \mathrm{r}_0 & := & \frac{w_0}{2|\mathbb{J}|} \\ \mathrm{b}_0 & := & \rho \mathrm{r}_0 \\ \mathrm{a}_0 & := & (1-\rho)\mathrm{r}_0 \\ \mathrm{k}_0 & := & \mathrm{r}_0 |\mathbb{I}| \frac{T}{10} \end{array} . \tag{36}$$

Note, a firm's average revenue per consumer, r_0, is the 'average' reservation price per firm, and the starting capital is the average total revenue for a tenth of the total simulation time T, which we assume to be the initial stage of a market.

As mentioned at the beginning of the formal outline we assume an environment with a fixed technology. This implies that the production costs should increase with product improvement, exponentially as the bounds of the technology are approached. In the following we suggest a provisional model of production costs which is intended to be replaced by a proper simulation of production. Let us assume an S-shaped function of the cost of a technical feature, which captures the bound on technology:

$$\omega(x;\mu,\sigma) := \sigma \ln\left(\frac{\mu + x(1-\mu)}{(1-x)\mu}\right), \quad x,\mu,\sigma \in (0,1). \tag{37}$$

Note, μ is a location parameter, such that x is transformed to the interval $(\mu, 1)$, and determines a shift such that $\omega(\cdot) \in (0, +\infty)$. Further we scale by σ. The result is illustrated in figure 14.

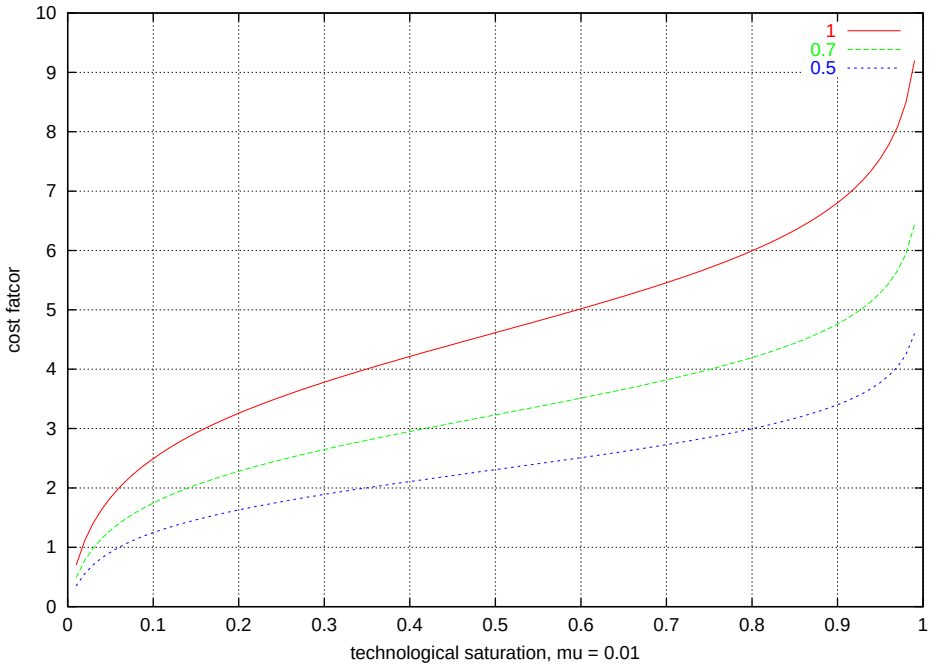

Figure 14: Cost functions modeling a saturation of technology.

Initially, we assume that the firms produce only the quantities they sell on the market, i.e. no costs arise for possible differences with planned quantities. Further, the initial cost of setting up a firm's production process can be neglected —we assume they reduce a firm's starting capital. Let us interpret the level of a technical feature as the intensity of a production factor and assume the variable cost of a product is the sum of the factor costs. Further, we want to model the cost incurred by changing a product, i.e. the set up costs for adapting the production process. Let us assume this cost depends on the sum of the changes in the factors' intensities, with weights $\lambda \in (0, 1]$. The jth product's variable cost $\nu_{j,t}$ and $\mathrm{f}_{j,t}$ its change cost are then defined as

$$\nu_{j,t} := \mathfrak{a}_0 \sum_{\bar{k}\in\bar{\mathbb{K}}} \omega(\mathfrak{p}_{j\bar{k},t}; \mu_{\bar{k}}, \sigma_{\bar{k}}), \tag{38}$$

$$\mathfrak{f}_{j,t} := \mathfrak{a}_0 \sum_{\bar{k}\in\bar{\mathbb{K}}} |\mathfrak{p}_{j\bar{k},t} - \mathfrak{p}_{j\bar{k},t-1}|^{\lambda}. \tag{39}$$

3.7 Interface definitions and simulation parameters

Table 3 shows the interface definition of the ACM. The first two blocks denote a firm's set of products (brands). The first block relates to decisions that are at the discretion of marketing (message, budget, and price). The second block the technical and cost characteristics. Note a specific product profile may be either the suggestion of production or marketing. If marketing suggests this does not imply that the profile is producible exactly as desired. Further, a 'suggestion' becomes producible in the following period. Production supplies marketing with information on the variable and fixed (change) costs of a product. The third block concerns the segment definition of a firm, i.e. which consumers are targeted with a product (brand). The fourth block pertains to the consumers' purchase decisions (choice) and their perception of and satisfaction with the products offered by the firms. According to our definitions at the beginning of the formal outline, the consumer, product (brand), attribute, and time indices are time-invariant for a simulation. Note this is a minimal definition that makes no assumptions about specific data-structures.

Name	Symbol	Consumer	Brand Product	Firm	Attribute	Time	Domain
Advertising Claim	$\mathfrak{m}$		x		x	x	$\{0,1\}$
Advertising Budget	$\mathfrak{b}$		x			x	$\mathbb{R}_0^+$
Price	w		x			x	$\mathbb{R}^+$
Technical Feature	$\mathfrak{p}$		x		x	x	$(0,1)$
Technical Change Cost	$\mathfrak{f}$		x			x	$\mathbb{R}_0^+$
Technical Variable Cost	ν		x			x	$\mathbb{R}^+$
Segment Definition	s	x	x	x		x	$\{0,1\}$
Choice	$\mathfrak{c}$	x	x			x	$\{0,1\}$
Preference Order	$\mathfrak{o}$	x	x			x	$\mathbb{N}^+$
Perception	$\mathfrak{x}$	x	x		x	x	$\{0,1\}$
Satisfaction	$\mathfrak{y}$	x	x			x	$\{-2,\ldots,2\}$
Satisception	z	x	x		x	x	$\{-2,\ldots,2\}$
Indices		i	j		$k,\tilde{k}$	t	

Table 3: ACM interface definitions.

The ACM project and the SIMSEG simulation environment attach high priority to the marketing strategy elements of market segmentation and product positioning. Consumer heterogeneity appears under two different formats: (1) as cross-sectional inter-personal heterogeneity causing segment-specific response and behavior, and, (2) as longitudinal intra-personal variation resulting from individual consumption histories and learning. Introducing heterogeneity in an experimentally controlled manner implies systematic initial parameter settings. The experimenters set segment-specific fixed values, or static distributions, or dynamic distributions with time-dependent means and/or variances. Note the latter is planned for future versions of SIMSEG.

Table 4 gives a tentative list of the SIMSEG parameters and experimental factors required to launch a simulation run. It gives a brief explanation of the parameters' function and feasible value ranges where applicable. In future work we will explore the possibilities of modeling stylized consumer types, i.e. if they might be reduced to a few meta-parameters and their 'calibrating' functions. Involvement as one such meta-construct was already mentioned in the present discussion.

#	Symbol	*Market setting:*	*Ranges*
(1)	I	the number of consumers	≥ 100
(2)		the number of firms	4 – 6
(3)	J	the number of brands	4 – 10
(4)	$\tilde{K}$	the number of technical attributes/features/dimensions	5 – 15
(5)	K	number of perceptual attributes/dimensions	5 – 15
(6)	L	number of attitudinal dimensions	2 – 5
(7)	$\tilde{a}_{l\tilde{k}}$	the technology - attitude links	[-1, 1]
		the number of indicating links per latent dimension	3 – 5
(8)	a_{ilk}, b_{ikl}	the (group specific) advertising - attitude - perception links	[-1, 1]
		the number of indicating links per latent dimension	3 – 5
(9)		the initial range of attitudes	[-2, 2]
		the initial number of attitudinal positions	4 – 7
(10)		the initial range of aspiration levels	[-3, 3]
		the initial number of aspirational positions	4 – 7
(11)	w_0	the reference reservation price	> 0
	$\mathfrak{b}_0$	the reference contact price	> 0
	$\mathfrak{a}_0$	the reference cost of production	> 0
(12)	ι	the separability of a market; the availability of a product	{0,1}
(13)	κ_i	the (group specific) average number of contacts per consumer (word-of-mouth activity	≥ 0
		Simulation parameters:	
(14)	T	the number of simulation periods (biweekly)	25 – 100
		the number of simulation runs (replications)	≥ 10
		Choice rules and adaptation:	
(15)		a consumer's decision style: compensatory, noncompensatory	{0, 1}
		a consumer's decision type: quality versus price oriented	{0, 1}
(16)	β_1, β_2	the consumers' satisfaction thresholds: amount of under-performance tolerated	[0, 1]
(17)	β_{i3}	a consumer's threshold of relevance of (dis)satisfaction	[0, 1]
(18)	η_{i1}	a consumer's rate of adaptation to technology induced attitudes	[0, 1]
(19)	η_{i2}	a consumer's sensitivity to (dis)satisfaction	[0, 1]
(20)	η_{i3}	a consumer's persistence of (dis)satisfaction	[0, 0.9]
(21)	η_{i4}	a consumer's rate of adaptation to market induced desires	[0, 0.5]
(22)	w_{i0}	a consumer's reservation price	> 0
		Advertising response parameters:	
(23)	ϑ_0	the consumers' persistence of belief: the level carried over given ineffective (or neglected) claims	[0.6, 0.9]
(24)	ϑ_1	the consumers' attention: the less impact the more firms compete for the attention of a consumer	[0.3, 1.0]
(25)	ϑ_2	the consumers' focus: the less impact the more claims a firm packs into its message	[0.3, 1.0]
(26)	ϑ_{i3}	a consumer's selectivity: the more impact the less firms 'use' a claim	[0.3, 1.0]
(27)	ϑ_4	economies of scale effects achieved for addressing larger market segments	[0.5, 1.0]
(28)	ϑ_{i5}	a consumer's responsiveness to advertising	[0.4, 0.8]

Table 4: ACM simulation parameters.

Symbol	*Indices*	*Domain*
i	the index of a consumer	$\mathbb{N}^+$
j	the index of a product	$\mathbb{N}^+$
k	the index of a perceptual attribute of a product, a dimension of the manifest space of perceptions and advertising claims	$\mathbb{N}^+$
$\tilde{k}$	the index of a technical attribute (feature) of a product	$\mathbb{N}^+$
l	the index of a dimension in the latent space of attitudes (aspirations, dis/satisfactions)	$\mathbb{N}^+$
t	the index of a period (time)	$\mathbb{N}_0^+$
	Endogenous variables	
$q_{ijl,*,t}$	the dimension specific attitude to a product of a consumer, before choice or after word-of-mouth communication	$\mathbb{R}$
$\tilde{q}_{ijl,*,t}$	the dimension specific technology induced attitude to a product of a consumer (performance), after choice or after word-of-mouth communication	$\mathbb{R}$
$\bar{d}_{il,t}$	the dimension specific aspiration (desire) of a consumer	$\mathbb{R}$
$d^*_{il,t}$	the dimension specific aspiration of a consumer given a disjunctive decision style	$\mathbb{R}$
$s_{ij,*,t}$	the overall (dis)satisfaction with a product of a consumer, after choice or after word-of-mouth communication	$(-1,1)$
$\bar{s}_{ij,t}$	the memory of the overall (dis)satisfaction with a product of a consumer	$(-1,1)$
$r_{ij,t}$	the reactance to advertising for a product of a consumer	$(0,1)$
$\dot{q}_{ijl,t}$	the dimension specific (latent) (dis)satisfaction of a consumer with a product	$\mathbb{R}$
$p_{ijk,*,t}$	the belief in an attribute of a product of a consumer (perception), before or after advertising, or after attitude formation	$(0,1)$
$\dot{p}_{ijk,t}$	the perceived (manifest) (dis)satisfaction with an attribute of a product of a consumer	$(0,1)$
	Exogenous variables	
$\mathrm{d}_{il,t}$	the external influence on the dimension specific aspiration of a consumer	$\mathbb{R}$
$\mathrm{p}_{j\tilde{k},t}$	level of a technical attribute (feature) of a product, intensity of a production factor	$(0,1)$
$\mathrm{m}_{jk,t}$	the advertising claim used for a product	$\{0,1\}$
$\mathrm{b}_{j,t}$	the advertising budget allocated to a product	$\mathbb{R}_0^+$
$\mathrm{w}_{j,t}$	the price demanded for a product	$\mathbb{R}^+$
$\mathrm{v}_{j,t}$	the variable production cost of a product	$\mathbb{R}^+$
$\mathrm{f}_{j,t}$	the fixed cost of changing the technical characteristics of a product	$\mathbb{R}_0^+$
$\mathrm{s}_{ij,t}$	the target consumer of a product; the product available for a consumer	$\{0,1\}$
	Observable variables	
$\mathrm{c}_{ij,t}$	the choice of a product by a consumer	$\{0,1\}$
$\mathrm{o}_{ij,t}$	the ranking of a product by a consumer	$\mathbb{N}^+$
$\mathrm{x}_{ijk,t}$	the belief in an attribute of a product stated by a consumer	$\{0,1\}$
$\mathrm{y}_{ij,t}$	the overall (dis)satisfaction with a product stated by a consumer	$\{-2,\ldots,2\}$
$z_{ijk,t}$	the (dis)satisfaction with an attribute of a product stated by a consumer	$\{-2,\ldots,2\}$

Table 5: ACM simulation variables.

4 Looking ahead: Introducing intentional marketing strategy agents

The development of the marketing agents of the AFs leads from exogenous fixed-objective, repetitive, single-period strategies to purposeful behavior where the 'marketing management' ameliorates its heuristic rules and decision criteria through experience. Within each AF the marketing agent interacts with the production and finance agents according to the coordination scheme enforced by the corporate agent. The type of interaction is an experimental factor that ranges from (a) hierarchically imposed corporate goals and side conditions (e.g. budget limits set by the finance agent and approved by the corporate agent) to (b) sequential processing (e.g. production/R&D accepts or rejects modifications desired by marketing) and further to (c) bargaining behavior (e.g. seeking a common optimum under the incentive scheme provided by the corporate agent).

The next step in agent technology relates to 'social agents' [Brassel, Möhring, Schuhmacher and Troitzsch, 1997], who form expectations of how the other marketing agents in the simulation environment may figure out the world. In the Artificial Consumer Market part of the AE this does not require highly sophisticated imagination, as the AFs watch the overt market conduct of their competitors. (Advertising budgets, consumer prices and the technical features of the products are known for each competitor's brand.) However, the lower level effects of the reactive and/or intentional agents' behaviors have to be properly understood, before it is admissible to let agents adapt their own expectations by trying to anticipate the other agents' strategies and actions.

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