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Information Technology Product Bundling in the Presence of Complementarities, Quality Uncertainty, and Network Effects: An Agent-Based Approach

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INFORMATION TECHNOLOGY PRODUCT BUNDLING IN THE PRESENCE OF COMPLEMENTARITIES, QUALITY UNCERTAINTY, AND NETWORK EFFECTS: AN AGENT-BASED APPROACH

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Abstract

Bundling of information technology products and services is prevalent in markets for information goods, telecommunication services, computer hardware, and software goods. However, factors affecting consumers' choice of IT product bundles, and the resultant impacts to markets, have not been clearly documented in the information systems literature. In this paper, we develop agent-based simulation models to examine the effects of bundle component quality uncertainty (in either the focal or supplement components), bundle component complementarity (complementary or noncomplementary bundles), and network effects (global market shares or local social network interaction effects) on agents' choices of product bundles. In addition, we also examine different effects of agents' risk preferences (risk-aversion, risk-neutrality, and risk-seeking) on their choices of product bundles. Finally, we differentiate the impact of network effects and agents' risk preferences on bundle choices depending on two types of agent preferences for bundle attributes: homogeneous or heterogeneous preferences. Our findings indicate that global market share network effects have a significant influence on risk-averse and risk-neutral agents' choice of different product bundles. Market share network effects do not seem to have much influence on bundle choices among risk-seeking agents. Interestingly, our simulation results also indicate that social network interaction effects on a local scale have greater effects on bundle choices of risk-averse and risk-neutral agents, compared to the market share network effect. Our overall results also indicate that agents have the highest preference for complementary product bundles with a good, certain quality focal item than for other types of product bundles. From our research findings, implications for research and practice are presented.

Keywords: Product bundling, quality uncertainty, network effects, agent-based modeling

Introduction

Product bundling of information technology products is increasingly prevalent in markets for information goods on the Internet, computer hardware, and software goods (Bakos and Brynjolfsson 1999, 2000; Drake 2000). Examples of such a product strategy

in the marketing and distribution of IT products include the bundling of Internet Explorer with Microsoft Windows Operating System, Application Service Providers' (ASP) bundled provision of software and network access, and the tied-in sale of PCs with Internet access subscription services. Firms' decisions on product bundling and distribution have important, although at times controversial, impacts on social welfare, market competition, and concentration (e.g., Microsoft's case with Internet Explorer). Similarly, individuals' judgment and choice of IT product bundles have crucial effects on market demand of bundles. However, factors affecting individuals' choice of IT product bundles and their corresponding impacts have not been clearly documented in the information systems literature.

The dominant stream of past research in product bundling has been in terms of providing economic analyses and managerial rationales of bundling (e.g., Dansby and Conrad 1984; Venkatesh and Mahajan 1993). Furthermore, scant attention has been paid to investigating individual preferences and buyer behavior with respect to product bundles. In particular, the IS and consumer behavior literature in product and price bundling have not examined the effects of product quality uncertainty (in focal and supplement components), bundle component complementarity, and market network effects or externalities on individual choices of bundles. Specifically, with respect to IT product bundles, we seek to answer these research questions:

- Do individuals' choice of product bundles depend on whether the focal or supplement bundle item is complementary or noncomplementary to each other?
- Do individuals' choice of product bundles depend on the presence of product quality uncertainty in either the focal or supplement bundle component?
- Do individuals' choice of bundles depend on the presence of market share or social interaction network effects (information cascades)?

Drawing from the research literature on product bundling (Harlam et al. 1995; Yadav 1994; Yadav and Monroe 1993), individual decision-making (Loewenstein 2001), prospect theory (Kahneman and Tversky 1979), mental accounting (Thaler 1985), reason-based choices (Shafir et al. 1993; Simonson 1989), and network effects or externalities (Brynjolfsson and Kemerer 1996), we formulate research hypotheses and an individual-level bundle choice model to evaluate the answers to our research questions. To test these hypotheses, we design and conduct an agent-based simulation experiment to study individual choices of IT product bundles.

Research on the above-proposed issues has important implications for research and practice in the domain of product and brand extensions (Aaker and Keller 1990) and the bundling of digital information products such as information goods, music, and video content on the Internet (Bakos and Brynjolfsson 1999, 2000). On electronic markets of the Internet, more often than not, consumers tend to be uncertain of the quality of digital goods they are evaluating since these goods are essentially experience goods and merchant reputations are not readily discernable (Klein 1998). Similarly, when individuals and firms face decisions of technology adoption of new IT product categories such as enterprise resource planning (ERP) application bundles, ASP service and product bundles, and handheld Personal Digital Assistants (PDA), they are often uncertain of the market adoption potential of new IT standards or products, product quality, and reputation of firms in such nascent markets. Therefore, depending on perceived product quality uncertainty and product complementarity relationships between focal and supplement bundle items, and associated network effects in markets, individuals often judge product bundles differently and make dissimilar purchase decisions. Findings from this research would provide insights into how merchants can devise improved strategies for product and brand extensions, and also help IT goods providers take into account how individuals valuate and choose IT product bundles in devising business models for information goods and IT products.

Theoretical Background and Research Hypotheses

Complementary and Noncomplementary Product Bundles

Bundling occurs when two or more products are jointly sold or marketed, usually at a price different from the sum of their individual prices. In multiproduct bundling, the functional compatibility or complementarity of bundle components can vary in markets. Complementary product bundles are those in which the individual components function as a system (e.g., a computer and operating system), while noncomplementary bundles are those in which the bundle components are not functionally related (e.g., a printer and cellular phone). In complementary bundles, consumers purchase a system of products that enhance the functionality of each other (Estelami 1999). Complementarity can be based on dimensions such as matching usage, timing, image, distribution, and derived demand (Simonin and Ruth 1995).

Past research in economics and marketing has shown that consumers gain incremental value when specific combinations of products are bundled together rather than sold separately (Dansby and Conrad 1984). Thus, bundle price premiums are more prevalent in complex product categories such as IT goods where complementary bundles provide added value by reducing consumer cognitive efforts to use the products effectively (Estelami 1999). Consequently, consumers have higher purchase intentions and choice probability for bundles of complementary products rather than for noncomplementary bundles (Gaeth et al. 1990; Harlam et al. 1995).

In addition, research in prospect theory (Kahneman and Tversky 1979) and mental accounting (Thaler 1985) suggest that consumers may have more positive product evaluations for bundles consisting of complementary components. Prospect theory puts forward the importance of gain versus loss framing in evaluating the prospect outcomes. In price bundling, it is found that when price information is integrated into a package price while price discount information is specified separately in components, individuals tend to have more favorable evaluations of the bundled offer (Johnson et al. 1999). Thus, we posit that when consumers are presented with a bundle of complementary items, they perceive this bundle type as providing more gains, as opposed to a noncomplementary one that tend to be perceived as loss-incurring.

Research on reason-based choices finds that in choice behavior under preference uncertainty, individuals prefer the alternative supported by the best reasons (Shafir et al. 1993; Simonson 1989). It is typical that complementary bundles dominate noncomplementary ones, and the choice of complementary bundles is easier to justify than that of noncomplementary ones. Thus, we expect that consumers have a higher purchase intention of complementary bundles compared to noncomplementary bundles (see Bundles 1 and 2 in Table 1).

Table 1. Types of IT Product Bundles in Agent-Based Simulation

Bundle Type	Complementarity Level	Focal Item	Supplementary Item
Bundle 1	Complementary	Quality Certain	Quality Uncertain
Bundle 2	Complementary	Quality Uncertain	Quality Certain
Bundle 3	Noncomplementary	Quality Certain	Quality Uncertain
Bundle 4	Noncomplementary	Quality Uncertain	Quality Certain

Quality Uncertainty in Focal and Supplement Bundle Components

Gaeth et al. (1990) and Simonin and Ruth (1995) make the distinction between the focal product and the supplement component in the bundle. Gaeth et al. find that consumer evaluations of bundled products are consistent with an averaging model of the information integration theory (Anderson 1981), whereby bundle component ratings are balanced or averaged into an overall evaluation. Simonin and Ruth propose that a bundle with an existing brand-name product has less quality uncertainty and an individual is likely to have existing preferences and attitudes toward the existing brand. Thus, a product bundle with an existing brand-name product as the focal item is more likely to gain consumer attention and confidence of product quality based on familiarity and liking of the existing brand (Aaker and Keller 1990). Similarly, brand extensions are preferred when a brand is perceived as high quality and consumers perceive the new product extension to be relatively similar and related to the family brand (Aaker and Keller 1990; Gaeth et al. 1990).

Consumers evaluate product bundles using an anchoring and adjustment heuristic. They tend to anchor on the focal component in the bundle to assess quality, and then adjust their initial evaluations by taking into account less important components (Tversky and Kahneman 1974; Yadav 1994). This phenomenon is consistent with Kahneman and Tversky's (1979) prospect theory in that individuals are averse to losses and their responses to losses are more extreme than the responses to gains. Therefore, if the product quality of the focal bundle component is uncertain, rather than that of the supplement item, consumers tend to perceive more potential losses or risks in purchasing such a bundle (see Bundles 2 and 4 in Table 1). The anchoring and adjustment heuristic (Yadav 1994), coupled with the theories of reason-based choices (Shafir et al. 1993) suggest that the selection of complementary bundles with only quality uncertainty in the supplement component dominates and is easier to justify than noncomplementary bundles with quality uncertainty in the focal item (see Bundles 1 and 4 in Table 1).

Network Effects

In marketing IT products, firms often try to leverage demand-side economies of scale, or network effects. In industry sectors such as IT and telecommunications, the direct benefit a consumer obtains from adopting a new product depends on the size of the installed base. Direct network effects thus can be understood as positive consumption externalities, and can be modeled as a function of the number of users of the product. Classic examples for markets with direct network effects are the telephone or fax networks, in which each user's benefit from joining the network increases with the size of the network. Economic literature on network effects is extensive. Seminal work on network effects and systems competition includes Katz and Shapiro (1986, 1995) and Farrel and Saloner (1986). Empirical studies that study network effects include Saloner and Shepard (1995), who analyze the adoption of ATM machines in the banking industry, and Gandal (1994) and Brynjolfsson and Kemerer (1996), who use hedonic price regressions to test for the presence of network externalities in markets for computer spreadsheets.

Agent-Based Modeling

Agent-based modeling has been used to simulate ecosystems, markets, and social systems in different fields in social sciences such as economics and social psychology (e.g., Carley 2002; Miller 1998). Agent-based simulation is characterized by the "existence of many agents who interact with each other" and the "emergent properties of an agent-based model are from the result of bottom-up processes" (Axelrod 1997). Agent-based simulation is useful in situations where contribution of the individual behaviors to the collective behaviors cannot be explained in a deductive manner and the focus of agent-based modeling studies is to examine and provide explanations for interesting emergent phenomena in the population.

Agent-based simulation is considered to be appropriate for this study due to several reasons. First, it is difficult to determine the level of risk aversion in human subjects in an experimental setting. Second, agent-based simulation allows us to uncover collective behavior based on setting attributes at the individual level, since we can vary different bundle attributes and parameters easily to test the effect of complementarities, quality uncertainties, and network effects in each simulation run. Third, in experiments regarding product choice, it is important that the subjects be familiar with the product properties (e.g., brands, features). However, it is difficult for researchers to discern human subjects who are not truly familiar with the products in experiments or surveys. Finally, studying network effects over time is ideal for agent-based modeling. Specifically, it allows us to study the influence of one agent's choice on other agents' choices and the potential nonlinearity in terms of their effects on choice outcomes over time.

Individual Demand Model of Product Bundle Choices

As past research has shown, individuals may evaluate the worth of a product differently when it is in a bundle than when it is not. Explicitly bundling two or more products together in a bundle is likely to influence the context in which individuals evaluate those product items because it will literally force individuals to evaluate them in the context of one another. In the information systems and marketing literature, there are multiple dependent variables that constitute an individual's evaluation of a product bundle. Typically, these variables include choice, purchase intention, perceived savings, willingness to pay, and likelihood of recommending a product to others (Harlam et al. 1995; Gaeth et al. 1990; Johnson et al. 1999; Simonin and Ruth 1995; Yadav and Monroe 1993).

To answer our research questions, we focus on a critical measure of individual-level consumer behavior: choice of product bundle. From our literature review, we posit the following hypotheses linking product bundle complementarity and bundle component quality uncertainty:

> ***H1***: Complementary product bundles will have a higher choice probability, compared to noncomplementary product bundles.
>
> ***H2***: Product bundles with only quality uncertainty in the supplement component will have a higher choice probability, compared to product bundles with only quality uncertainty in the focal component.

To model agents' choice of different bundle types, we specify an individual-level demand model of agents' choice for bundle types using the multinomial logit demand specification. Suppressing a subscript for time t and with the parameters as defined in Table 2, agent i's utility for product bundle j is modeled as a function of bundle components' quality (which reflects product attributes such as price and durability), complementarity, and bundle market share:

Table 2. Multinomial Logit Choice Model Parameters and Values for Results Reported

Parameters	Values
Focal item value weight w_F	Equal monetary value of focal item and supplement item: 0.5
Supplement item value weight w_S	Equal monetary value of focal item and supplement item: 0.5
Coefficient for focal item quality β_{Fi}	Draw from normal distribution (mean 0.8, std deviation 0.3)
Coefficient for supplement item quality β_{Si}	Draw from normal distribution (mean 0.5, std deviation 0.3)
Coefficient for complementarity γ_i	Draw from normal distribution (mean 0.8, std deviation 0.3)
Coefficient for market share λ_i	Draw from normal distribution (mean 0.8, std deviation 0.3)
Quality of focal item QF_{ij} Quality of supplement item QS_{ij}	*High Quality* (*Low Dispersion*): Draw from normal distribution (mean 10, std deviation 1) *Low Quality* (*High Dispersion*): Draw from normal distribution (mean 2, std deviation 15)
Bundle complementarity C_{ij}	*High Complementarity*: Draw from normal distribution (mean 10, std deviation 1) *Low Complementarity:* Draw from normal distribution (mean 2, std deviation 15)
Bundle market share M_j	Market share of last period. Equals 0 for first time period.
Extreme value type 1 error ε_{ij}	Draw from exponential distribution with mean 0.3

$$U_{ij} = w_F \beta_{Fi} QF_{ij}{}^{p} + w_S \beta_{Si} QS_{ij}{}^{p} + \gamma_i C_{ij}{}^{p} + \lambda_i M_j{}^{p} + \varepsilon_{ij} \quad (1)$$

Therefore, as shown by McFadden (1981), the probability of person i choosing bundle j (amongst a choice set of K bundles) is given by:

$$\Pr(\text{Bundle } j) = \frac{Exp(U_{ij})}{\sum_{k=1}^{K} Exp(U_{ik})} \quad (2)$$

In this bundle demand specification, it is assumed that the agent chooses the bundle with the highest utility and this choice is indicated by the probabilistic choice share equation in equation (2). Product bundles in agents' choice set are assumed to be substitutes for each other. Agents choose only a single unit of bundle, which is typically the case in IT durable goods purchases.

Research Methodology

Agent-Based Modeling Approach

Overview of Simulation Experiment

We developed two simulation models using an agent-based simulation package—SWARM (**www.swarm.org**). The first model, as described in the previous section, is an utility-maximization, multinomial logit choice model which models agents' bundle choices as a function of the utilities derived from each product bundle. Specifically, each agent chooses a bundle that maximizes its utility as a function of observed and unobserved bundle attributes. The second model is a rule-based model which models agents' choices as a function of heuristic rules determined from the behavioral marketing and decision-making literature reviewed in the prior section. The rule-based model is used as a benchmark comparison for the utility-maximization choice model so as to ascertain that the utility functions specified are tenable and realistic.

In our simulation experiment, we study agents' choices of product bundles under different conditions of *network effects* and *agents' preferences* for bundle item quality and complementarity. Specifically, we investigate three types of network effects: no

network effect, market share effect, or social network interaction effect. Similarly, we consider two types of agent preferences for bundle item quality and complementarity: homogeneous or heterogeneous. Thus, we utilize a six-cell factorial design for our simulation examining the impacts of network effects and agents' preferences on individual agent choice and overall market shares of bundle types across time. Table 3 lists all of the treatment conditions for network effects and agents' preferences. For each treatment, 10 simulation runs are generated with 1,000 iterations in each run.

Table 3. Treatment Conditions for Network Effects and Agent Preferences

Treatment Type	Network Effects
Condition 1	No networking effect
Condition 2	Market shares effect
Condition 3	Social network interaction effect

Treatment Type	Agent Preferences
Condition 1	Homogeneous preferences
Condition 2	Heterogeneous preferences

We specifically examine bundles that are composed of pairs of products, with one as the focal item and the other as the supplement item. The monetary value of both the focal and supplement items are assumed to be equal. We manipulate *bundle component complementarity* (complementary/noncomplementary), and *quality uncertainty* (focal/supplement component). It is assumed that these two aspects of bundle attributes are agents' subjective evaluations and thus may differ across agents. We focus on examining product bundles composed of either a *good* quality (high quality evaluation with low dispersion) focal component and an uncertain quality (low quality evaluation with high dispersion) supplement item, or an unknown quality focal component and a good quality supplement item (see Table 2). In theory and practice, these two cases of product bundle quality uncertainty are the most interesting and important to analyze. As such, there are four types of bundles studied. Table 1 lists all of the quality uncertainty and complementarity properties of the focal and supplement items in each bundle type.

In both simulation models, there are a total of 384 agents in the agent economy, with 128 each of risk-seeking, risk-adverse, and risk-neutral agents. Each agent makes a decision of which bundle to choose in each time period. Depending on the experimental treatment under consideration, the choice decision is based on quality uncertainties, complementarity of the focal and supplement item, market share of bundle in the last period, and the bundle choices of other agents in the same social network.

Risk Preferences and Agent Preferences for Bundle Item Quality and Complementarity

In our agent economy, we assume that there are three types of agents with different risk preferences: *risk-adverse*, *risk-seeking*, or *risk-neutral*. Different types of risk preference are modeled using different specifications of utility functions: concave (risk-adverse), convex (risk-seeking), or linear (risk-neutral) functions. Similarly, in line with prior marketing and economic literature in choice modeling (e.g., Chintagunta et al. 1991), we assume that agent preferences for bundle item quality, complementarity, and last period market share can be either *homogeneous* or *heterogeneous*. In the homogeneous case, agents' preferences are assumed to be identical in the population, and thus the bundle attribute parameters β_F, β_S, γ, λ are identical for all agents. In the heterogeneous case, we adopt a continuous heterogeneity specification such that the bundle attribute parameters $\beta_F i$, β_{Si}, γ_i, λ_i in the agent population are drawn from a univariate normal distribution. This constitutes a random coefficients multinomial logit choice model.

To be specific, in the homogeneous agent preferences condition, agent i's utility function for product bundle j is modeled as:

$$U_{ij} = w_F \beta_F QF_{ij}{}^p + w_S \beta_S QS_{ij}{}^p + \gamma C_{ij}{}^p + \lambda M_j{}^p + \varepsilon_{ij} \quad (3)$$

When agent preferences are heterogeneous, the bundle attribute parameters are agent-specific and drawn from a normal distribution. Agent i's utility for bundle j is modeled as:

$$U_{ij} = w_F \beta_{Fi} QF_{ij}{}^p + w_S \beta_{Si} QS_{ij}{}^p + \gamma_i C_{ij}{}^p + \lambda_i M_j{}^p + \varepsilon_{ij} \quad (4)$$

where $p = 1/3$ for risk-averse agents; $p = 3$ for risk-seeking agents; $p = 1$ for risk-neutral agents. These settings of p values conform to economic theories of convex and concave utilities for various risk preferences. Since bundle item quality and complementarity are assumed to be agents' subjective evaluations of each bundle type, QF_{ij}, QS_{ij}, and C_{ij} are specific to each agent i.

Network Effects

We study three types of network effects in our agent economy: *no network effect*, *market share effect*, or *social network interaction effect*. With no network effect affecting agents' bundle choices, the first treatment condition is such that agents' decision are based solely on observed and unobserved bundle attributes in each time period. With the market share network effect in the second condition, an agent's bundle choice influences and is influenced by choices of other agents because the agent's choice exerts a positive externality in the agent economy. This is because an agent's utility for a bundle type increases with the number of agents choosing the same bundle type in the last period of the global agent economy. We implement this condition by incorporating the market share of each bundle in the last period into the agent utility functions.

With the social network interaction effect in the third treatment condition, agents' bundle choices are influenced by interactions with *acquaintances* within a defined social network on a local scale in the agent economy. Specifically, each agent is randomly assigned 10 other agents as acquaintances at the start of each simulation run. These 10 acquaintances are deemed as the agent's social network in the agent economy and are fixed throughout the simulation run. In each time period of a run, an agent's bundle choice can be influenced by its acquaintances' choices such that if it finds that more than 50 percent of its acquaintances choose a particular bundle, the agent will always choose this same dominant bundle in its social network. In this way, an agent's choice of a bundle type is adaptive over time periods in a local sense within the agent economy.

Table 2 reports all of the treatment condition parameters for network effects and agent preferences for bundle attributes, and their associated values for results shown in this paper. Values set for treatment conditions and agent preference parameters are guided by qualitative research in which surveys of consumer choices of bundles were conducted (Goh and Lee 2002).

Rule-Based Modeling Approach

The utility-maximization choice model in this paper is compared with a rule-based simulation model. We focus on several distinctive and conclusive results from our literature review to formulate rules for the rule-based model. First, research on reason-based choice has provided evidence that individuals prefer complementary bundles to noncomplementary bundles. In addition, several empirical studies also concluded that individuals have higher purchase intentions and higher willingness-to-pay for complementary product bundles compared to noncomplementary product bundles. Thus, Rule 1 is formulated as:

> ***Rule 1****: Complementary product bundles are preferred to noncomplementary ones.*

With regard to the quality uncertainty/certainty in focal and supplementary items in a bundle, past studies revealed that consumers usually anchor on the focal component in a bundle to assess the bundle's quality. Thus, the focal item's quality will be given higher weight or emphasis than the supplementary item's quality. Therefore, Rule 2 is formulated as:

> ***Rule 2:*** *Quality certainty in a focal item is preferred to that in a supplementary item.*

The rule-based model is then run with the same parameter values used in the utility-maximization choice model. In each experimental treatment condition, 10 runs are generated with each run consisting of 1,000 iterations.

Results and Discussion

Results of Utility-Maximization Choice Model

To recap, our research questions in this paper focus on analyzing whether individuals' choice of product bundles depends on bundle components' complementarity, quality uncertainty, and the presence of network effect in the market economy. For each iteration of a simulation run, we analyze the individual agent-level choice of bundle types and aggregate the market shares of all

Table 4. All Agents: Market Shares of All Product Bundle Types

		Homogeneous Preferences				Heterogeneous Preferences			
		All Agents				*All Agents*			
	Statistics	**Bundle 1**	**Bundle 2**	**Bundle 3**	**Bundle 4**	**Bundle 1**	**Bundle 2**	**Bundle 3**	**Bundle 4**
	Mean	39.456	26.750	21.529	12.266	39.493	28.006	21.078	11.423
No Network	*StdDev*	2.305	2.154	1.987	1.658	2.493	2.185	2.115	1.636
Effect	*2.5 Pct*	35.156	23.177	17.708	9.375	34.635	23.177	16.927	7.813
	97.5 Pct	44.271	30.990	25.781	15.885	44.271	31.771	25.781	14.844
	Mean	44.069	24.653	21.473	9.806	41.152	27.390	20.373	11.085
Market Share	*StdDev*	2.448	2.190	1.981	1.558	2.654	2.189	1.998	1.613
Effect	*2.5 Pct*	39.063	20.573	17.708	6.771	36.458	22.917	16.667	8.073
	97.5 Pct	48.958	28.906	25.000	13.021	46.615	31.771	24.479	14.583
Social	*Mean*	50.002	21.876	20.751	7.372	48.466	25.647	16.968	8.919
Network	*StdDev*	4.995	3.442	3.052	1.447	4.935	3.736	2.541	1.646
Interaction	*2.5 Pct*	40.885	15.104	15.104	4.948	39.063	19.271	12.240	5.990
Effect	*97.5 Pct*	59.896	28.646	27.083	10.417	58.594	32.552	22.396	11.979

Table 5. Risk-Averse Agents: Market Shares of All Product Bundle Types

		Homogeneous Preferences				Heterogeneous Preferences			
		Risk-Averse Agents				*Risk-Averse Agents*			
	Statistics	**Bundle 1**	**Bundle 2**	**Bundle 3**	**Bundle 4**	**Bundle 1**	**Bundle 2**	**Bundle 3**	**Bundle 4**
	Mean	37.102	32.271	16.068	14.560	37.609	30.779	17.469	14.143
No Network	*StdDev*	4.350	4.118	3.031	2.937	4.278	4.086	3.627	3.032
Effect	*2.5 Pct*	28.906	25.000	10.156	8.594	29.688	22.656	10.938	8.594
	97.5 Pct	45.313	40.625	21.875	20.313	45.313	38.281	25.000	20.313
	Mean	45.740	25.333	18.370	10.557	39.414	29.667	17.398	13.521
Market Share	*StdDev*	4.618	4.064	3.548	2.609	4.538	3.873	3.353	3.075
Effect	*2.5 Pct*	36.719	17.188	11.719	6.250	31.250	22.656	10.156	8.594
	97.5 Pct	55.469	32.813	25.000	16.406	49.219	37.500	24.219	20.313
Social	*Mean*	52.081	21.852	17.120	8.948	46.768	27.768	14.461	11.003
Network	*StdDev*	5.962	4.431	4.182	2.647	6.338	5.173	3.274	2.821
Interaction	*2.5 Pct*	40.625	14.063	10.156	4.688	34.375	18.750	8.594	5.469
Effect	*97.5 Pct*	63.281	31.250	25.000	14.844	59.375	38.281	21.094	16.406

Table 6. Risk-Seeking Agents: Market Shares of All Product Bundle Types

		Homogeneous Preferences				Heterogeneous Preferences			
		Risk-Seeking Agents				Risk-Seeking Agents			
	Statistics	**Bundle 1**	**Bundle 2**	**Bundle 3**	**Bundle 4**	**Bundle 1**	**Bundle 2**	**Bundle 3**	**Bundle 4**
	Mean	43.779	15.555	32.120	8.547	41.987	22.021	29.216	6.776
No Network	*StdDev*	4.103	3.169	3.970	2.477	4.143	3.446	4.088	2.345
Effect	*2.5 Pct*	35.156	9.375	24.219	3.906	34.375	14.844	21.094	3.125
	97.5 Pct	51.563	22.656	40.625	14.063	50.781	28.125	36.719	11.719
	Mean	39.096	24.190	28.005	8.708	42.893	22.677	27.294	7.135
Market Share	*StdDev*	4.266	3.847	3.905	2.451	4.419	3.526	3.811	2.217
Effect	*2.5 Pct*	31.250	16.406	20.313	4.688	34.375	15.625	20.313	3.125
	97.5 Pct	47.656	32.031	35.938	13.281	52.344	28.906	35.938	11.719
Social	*Mean*	43.721	23.117	27.997	5.164	49.857	22.315	22.344	5.484
Network	*StdDev*	6.475	4.920	4.661	2.071	6.096	4.442	4.466	2.092
Interaction	*2.5 Pct*	30.469	12.500	18.750	1.563	38.281	13.281	13.281	2.344
Effect	*97.5 Pct*	57.031	34.375	35.938	10.156	63.281	32.813	31.250	10.156

Table 7. Risk-Neutral Agents: Market Shares of All Product Bundle Types

		Homogeneous Preferences				Heterogeneous Preferences			
		Risk-Neutral Agents				Risk-Neutral Agents			
	Statistics	**Bundle 1**	**Bundle 2**	**Bundle 3**	**Bundle 4**	**Bundle 1**	**Bundle 2**	**Bundle 3**	**Bundle 4**
	Mean	37.487	32.424	16.398	13.690	38.883	31.219	16.549	13.349
No Network	*StdDev*	4.245	3.790	3.381	3.091	4.348	3.652	3.298	3.013
Effect	*2.5 Pct*	28.906	25.781	10.156	7.813	29.688	24.219	10.156	7.813
	97.5 Pct	46.094	40.625	22.656	19.531	46.875	38.281	23.438	19.531
	Mean	47.370	24.435	18.044	10.151	41.148	29.826	16.427	12.599
Market Share	*StdDev*	4.282	3.749	3.253	2.577	4.420	3.721	3.177	3.084
Effect	*2.5 Pct*	39.063	17.188	12.500	5.469	32.031	21.875	10.938	6.250
	97.5 Pct	56.250	31.250	24.219	15.625	50.000	35.938	23.438	17.969
Social	*Mean*	54.203	20.659	17.135	8.003	48.773	26.857	14.099	10.271
Network	*StdDev*	5.976	4.165	3.916	2.451	6.232	4.970	3.313	2.978
Interaction	*2.5 Pct*	44.531	11.719	10.156	3.906	36.719	17.969	7.813	4.688
Effect	*97.5 Pct*	67.188	28.125	25.000	13.281	60.938	36.719	21.875	16.406

four bundle types examined. Similarly, across all 1,000 iterations of a simulation run and across all 10 runs of simulation, we compute the mean relative market shares of each bundle type. For all six experimental treatment conditions of network effects and agent preference types, we report the mean market shares of each bundle type in Tables 4 through 7.

Subsequently, using the market choice shares of all bundle types for all agents, we conduct an ANOVA analysis to test if the aggregate choice shares of bundle types differ significantly across all network effect and agent preference type treatment conditions. In addition, we conduct an identical drilled-down analysis for risk-averse, risk-seeking, and risk-neutral agents' aggregate choice shares of bundle types. In the interest of brevity, we report that almost all (more than 98 percent) of bundle choice shares differ significantly ($p < 0.001$) across all treatment conditions of network effects and agent preference types, for all agents and the three types of agents with different risk preferences.[1] Figure 1 shows a graphical output of an ANOVA analysis for all agents across all treatment conditions. Our statistical analyses also show that our two research hypotheses are supported.

[1]Due to space constraints, we do not document the ANOVA analyses results in this paper. The authors can be contacted for these results if necessary.

We further discuss these results according to different network effects, differentiating agents' bundle choices in the case of either homogeneous (HM) or heterogeneous (HT) preference types.

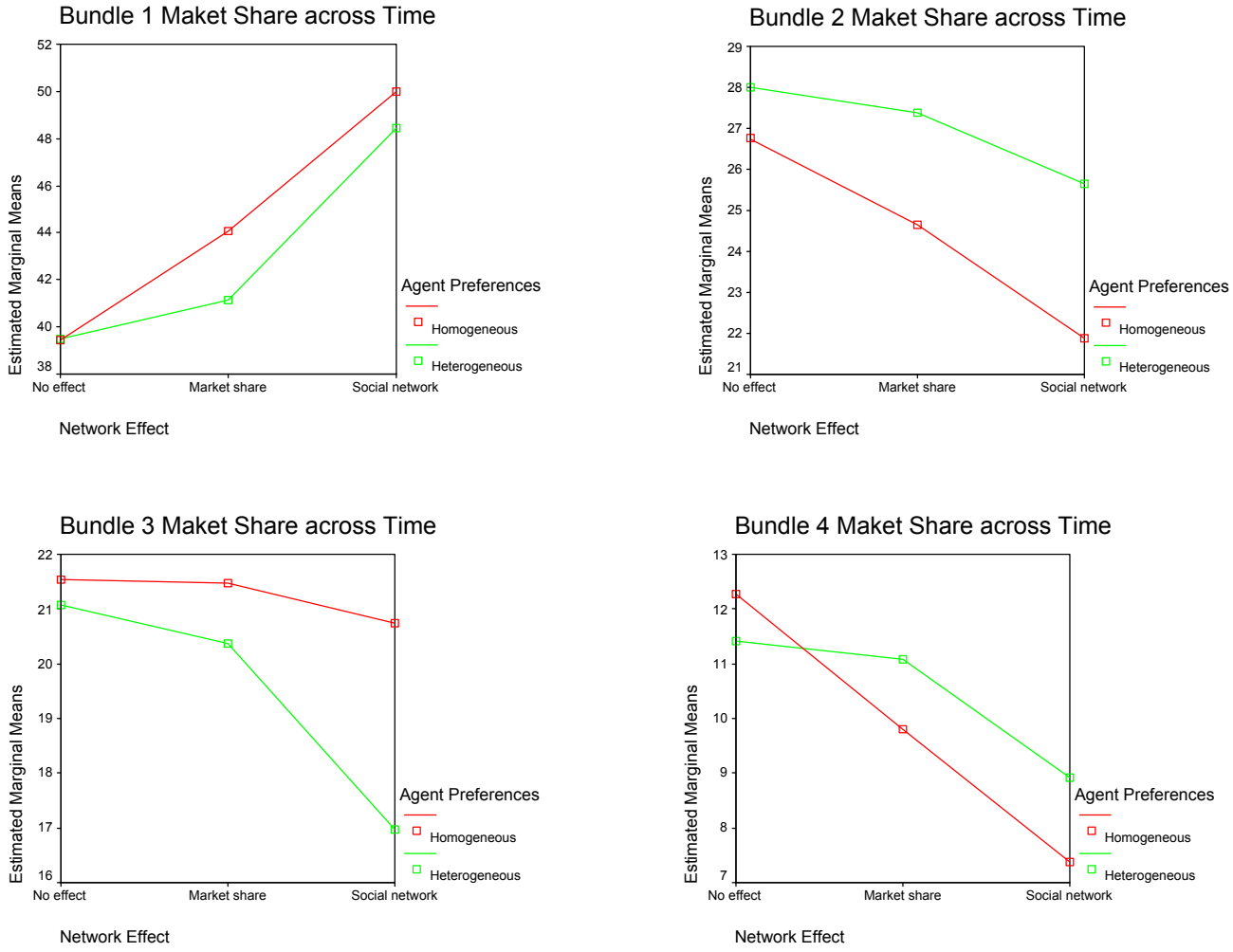
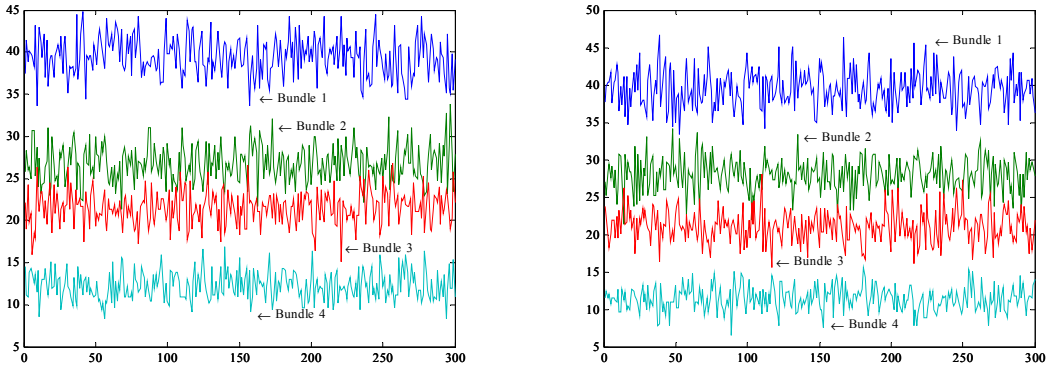


Figure 1. All Agents: Market Shares of Bundles across Experimental Treatments

No Network Effect

In the base experimental condition where network effects do not influence agents' choices of bundle types in the agent economy, the simulation results revealed that in the entire agent economy, all agents on average predominantly choose Bundle 1 (39.5 percent choice share for both HM and HT preferences), followed by Bundle 2 (26.8 percent HM, 28 percent HT shares), Bundle 3 (21.5 percent HM, 21.1 percent HT shares), and Bundle 4 (12.3 percent HM, 11.4 percent HT shares). This relative order of market choice shares for each bundle type is similarly replicated in the case of risk-averse and risk-neutral agents in the agent economy when there is no network effect of bundle types in the market. In contrast for risk-seeking agents, in the absence of any network effect, these agents predominantly choose Bundle 1 (43.8 percent HM, 41.9 percent HT shares), followed by Bundle 3 (32.1 percent HM, 29.2 percent HT shares), Bundle 2 (15.6 percent HM, 22 percent HT shares), and Bundle 4 (8.5 percent HM, 6.8 percent HT shares). Thus, the relative order of choice shares for risk-seeking agents is switched between Bundle 2 and Bundle 3, compared to that of risk-averse and risk-neutral agents. Comparing bundle choice shares for all agents in the market, we find that under the HM agent preference conditions, mean choice shares of Bundles 1, 3, and 4 are equal or higher than those in the HT agent preference conditions (see Figure 1). This generally conforms to *a priori* expectation because under the HT agent preference treatments, agents have heterogeneous preferences and thus would be more likely to have varied choices among the

four bundles types. This would imply that the mean choice shares among bundles would be more diffuse. Figure 2 shows the all-agents trace plots of market shares for each bundle type over time in the absence of network effect.



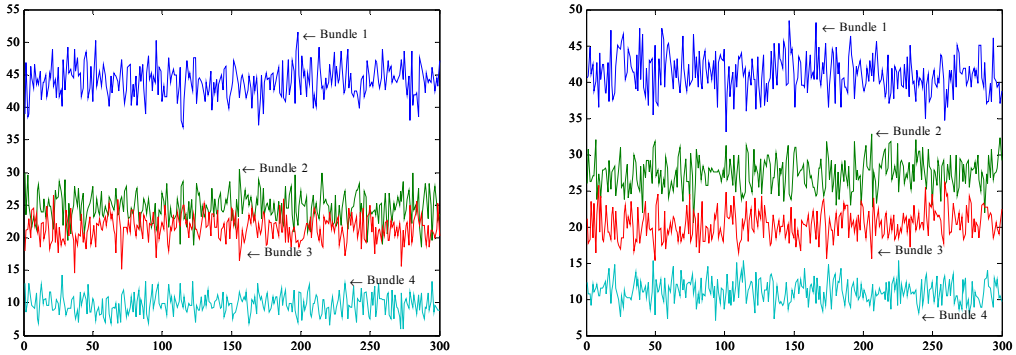
Homogeneous Preferences Heterogeneous Preferences

Figure 2. All Agents, No Network Effect: Market Shares of Bundles Across Time

The above results show that in the absence of network effects, risk-averse and risk-neutral agents predominantly prefer to choose product bundles composed of complementary component items, as opposed to the condition of no quality uncertainty in the focal bundle item. Therefore, the overriding bundle choice attribute for risk-averse and risk-neutral agents seems to be bundle complementarity, rather than quality uncertainty in either the focal or supplement item. In contrast, the results for risk-seeking agents suggest that these agents are willing to forego bundle item complementarity, such that they can be induced to choose noncomplementary bundles if the bundle item quality in the focal item is sufficiently high.

Market Share Network Effect

In the second experimental condition where global market share network effects influence agents' choices of bundle types, the simulation results revealed that for all agents in the market, there is significant increase in the average choice share of the most popular bundle type, Bundle 1, compared to the case when no network effect is present (39.5 percent HM to 44.1 percent HM, 39.5 percent HT to 41.2 percent HT). This significant gravitation of agents' bundle choice toward Bundle 1 is found in both the treatment conditions of HM and HT agent preferences. From Figure 1, it is evident that for both HM and HT treatments, the majority of all agents' switch their choice shares of Bundles 2 and 4 to Bundle 1 in the presence of market share effect in the economy since the choice share declines of Bundles 2 and 4 are the steepest while the share decline of Bundle 3 is only moderate. Figure 3 shows the all-agents trace plots of market shares for each bundle type over time in the presence of market share network effect..



Homogeneous Preferences Heterogeneous Preferences

Figure 3. All Agents, Market Share Network Effect: Market Shares of Bundles Across Time

Upon drilling down the bundle choice share analyses for agents of different risk preferences, we find that the overall choice share results for all agents in the presence of network effect in the economy are predominantly influenced by bundle choices of risk-averse and risk-neutral agents. These risk-averse and risk-neutral agents are significantly influenced by bundle network effects such that they would predominantly choose Bundle 1, the most popular bundle type, as opposed to Bundles 2 and 4 especially (see Tables 5 and 7). In contrast, for the risk-seeking agents, they are less influenced by market share network effect in the economy, since the choice share of Bundle 1 (the dominant choice) does not significantly increase or decrease compared to the case when there is no network effect present (see Table 6, 43.8 percent HM to 39.1 percent HM, 41.9 percent HT to 42.9 percent HT). In fact, in the presence of market share network effect, choice shares of risk-seeking agents seem to be more diffused across all bundle types for both HM and HT treatments.

The above results suggest that in the presence of market share network effects, risk-averse and risk-neutral agents prefer to choose the dominant bundle type in the economy. Similar to the no network effect case, the prevailing bundle choice attribute under the consideration of risk-averse and risk-neutral agents is bundle complementarity. Among the risk-averse and risk-neutral agents who switched their bundle choices to Bundle 1 from other bundle types, most risk-averse and risk-neutral agents are more than willing to forego bundle types with quality uncertainty in the focal item (i.e., Bundles 2 and 4) and instead choose a bundle type with prevailing market share in the economy (i.e., Bundle 1). In contrast, for risk-seeking agents in the case of market share network effects, they are willing to hold their ground with respect to bundle choices made in the case with no network effect. Thus, choice shares of all bundle types remain mostly unchanged compared the no network effect treatment (especially in the HT treatments). In general, our results concur with most empirical studies on direct and indirect network effects in economics and marketing in that consumer choices of IT product bundles can be influenced significantly by network effects in the economy. In contrast, we are able to distill our findings according to various types of network effects and agents with different risk preferences.

Social Network Interaction Effect

In the third experimental condition where local social network interaction effects influence agents' choices of bundle types, the simulation results show that for all agents in the market, there is significant increase in the average choice share of the most popular bundle type, Bundle 1, compared to the case when no network effect is present (39.5 percent HM to 50.1 percent HM, 39.5 percent HT to 48.5 percent HT). This significant herding effect of agents' choices in the direction of Bundle 1 is found in both the treatment conditions of HM and HT agent preferences. From Figure 1 and Table 4, we see that for the HM treatments, a majority of all agents switch their choice shares of Bundles 2 and 4 to Bundle 1 in the presence of social network effect since the choice share declines of Bundles 2 and 4 are relatively steep compared to that of Bundle 3. However, unlike the market share network effect, for the HT treatments, most agents switch their choice shares of Bundles 2, 3, and 4 to Bundle 1 in the presence of social network effect. The choice share declines of Bundles 2, 3, and 4 are equally steep. In general, we note that the choice share increase of Bundle 1 under local social network effect is significantly larger than that with global market share network effect in the agent economy. Figure 4 shows the all-agents trace plots of market shares for each bundle type over time in the presence of social network interaction effect..

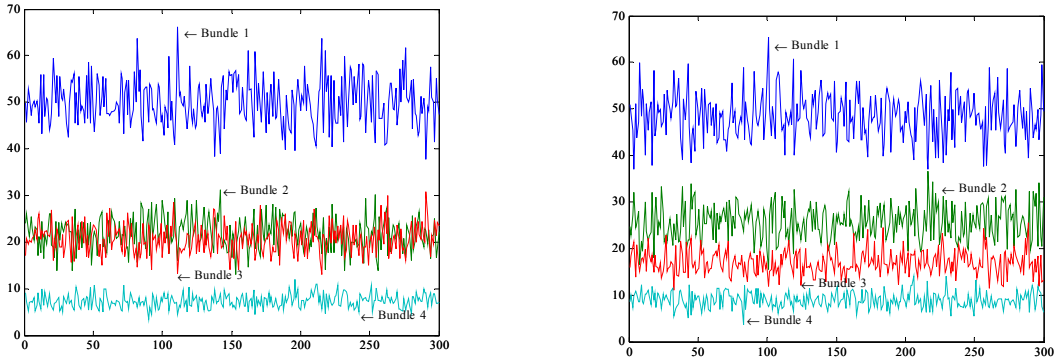


Figure 4. All Agents, Social Network Interaction Effect: Market Shares of Bundles Across Time

Analyzing the bundle choice shares of agents with different risk preferences, we find that the overall choice share results for all agents in the presence of social network interaction effect are predominantly influenced by bundle choices of risk-averse and risk-neutral agents. As in the case of market share network effects, these risk-averse and risk-neutral agents would predominantly choose Bundle 1, the most popular bundle type if it is the preferred choice of acquaintances within the same social network, as opposed to Bundles 2, 3, or 4 (see Tables 5 and 7). In contrast, risk-seeking agents are less influenced by social network interaction effect in the HM treatment, since the choice share of Bundle 1 (the dominant choice) does not change significantly compared to the case when there is no network effect present (see Table 6, 43.8 percent HM to 43.7 percent HM).

These results indicate that the agents' choices of bundles appear to be influenced more by interactions with acquaintances in the same social network than the global market share conditions. A possible explanation is that risk-averse and risk-seeking agents would want to reduce their bundle choice risks by seeking opinions from acquaintances from the same social network, but the risk-seeking agents are more concerned with maximizing its utility and have lower regard for opinions from acquaintances. These results have important implications for ne shopping on the Internet, since there is an abundance of products ratings and reviews in online communities that influence consumers' product purchasing decisions. In addition, these results imply that smaller-scale marketing techniques such as viral marketing may have higher impacts than national marketing campaigns such as TV advertisements which target consumers globally to capture product market shares.

Results of Rule-Based Model

Our simulation findings from the rule-based validation model reveal that agents' choices of bundles in this model are generally in line with those predicted under the utility-maximization choice model elaborated earlier. In particular, we find that the rank orderings of market shares of bundle types are almost identical in both the choice model and the rule-based model. In brief, the general conclusions from this model validation exercise are, across all agent preferences and network effects treatments, risk-averse and risk-neutral agents predominantly choose Bundle 1, followed by Bundles 2, 3, and 4 in descending order of choice shares. For risk-seeking agents, they generally prefer Bundle 1, followed by Bundles 3, 2, and 4 in descending order of choice shares. Thus, similarities in bundle choice share rankings indicates that the choice model reaches comparable findings with those of the rule-based model.

Conclusion

Bundling of IT products and services is prevalent in markets for information goods, telecommunication services, computer hardware, and software goods. However, factors affecting consumers' choice of IT product bundles and the resultant impacts to the markets have not been clearly documented in the IS literature. In this paper, we develop agent-based simulation models to examine the effects of bundle component quality uncertainty (in both the focal and supplement components), bundle component complementarity (complementary or noncomplementary bundles), and network effects (global market shares or local social network interaction effects) on agents' choice of product bundles. In addition, we also examine different effects of agents' risk preferences (risk-averse, risk-neutral, and risk-seeking) on their choices of product bundles. Our findings indicate that global market share network effects have a significant influence on risk-averse and risk-neutral agents' choice of different product bundles. Market share network effects do not seem to have much influence on bundle choices among risk-seeking agents. However, our simulation results also indicate that social network interaction effects on a local scale have greater effects on bundle choices of risk-averse and risk-neutral agents, compared to the market share network effect. Our overall results also indicate that agents have the highest preference for complementary product bundles with a good, certain quality focal item than for other types of product bundles. Extensions to this research may involve modeling direct network effects as a function of distance between agents, and modeling indirect network effects as a function of agents' adoption of unbundled complementary or noncomplementary bundle items.

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