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Software Bundling for Competitive Advantage: Vendor Strategies and Public Policy Implications*

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As an engineered product, a software package has multiple dimensions that must be designed judiciously to enhance its competitive viability. Functionality, reliability and price are three such common dimensions. However, many software products are sold as bundles of individual components and the competitive impact of bundling has received less attention in the research literature. In this paper, we examine the implications of software vendors using bundling as an element of competitive strategy. A game theoretic model of the actions of an incumbent and a new entrant is developed and the impact on vendor and consumer welfare is analyzed. Numerical experiments with the model show that (i) increasing bundle size is an effective strategy for the incumbent to increase its payoff at the cost of the entrant's payoff and consumer surplus, especially when the entrant's quality is low (ii) in the presence of bundling, the entrant can still increase its own payoff and consumer surplus at the cost of the incumbent's payoff, by increasing product quality up to the level that best segments market demand with the incumbent and (iii) an increase in bundle size by the incumbent, or an increase in quality by the entrant, can both result in an increase of total surplus. Similar results are observed in a related case where the entrant offers free software bundles. Our results provide insights into how software vendors may strategically use bundling and quality as additional product dimensions in order to stay competitive in the market. These results also inform the competing vendors of the impact of bundling related public policy actions on their respective payoffs.

Keywords : **Software Bundling, Game Theory, Oligopoly Competition, Quality, Pricing**

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Ⅰ. Introduction

As an engineered product, a software package has multiple dimensions that need to be designed judiciously in order to be attractive to consumers in a competitive marketplace. Common technical dimensions that come to mind are functionality, hardware requirements, reliability and compatibility. Another dimension of the product-price-is also important. When designing their products, for the consumer market, software vendors obviously have these dimensions in mind. However, software products have another dimension which can affect the competitive dynamics. This dimension is *bundling*-where two or more distinct products are sold as one combined package at a single price [Stremersch and Tellis 2002; Varian 1999]. MS Office is an obvious example but many others exist. From a buyer's standpoint, bundles represent the collective value of the individual components plus any synergies that may arise from integration within the bundle. In addition, as more components are packaged into one bundle, demand uncertainty decreases for the vendor. Bundling offers an additional avenue for vendors to differentiate themselves and add value to their offerings making it an added element of competitive strategy. This motivates us to examine the economic impact of bundling on software vendors and consumers of their products in a competitive setting, to determine who benefits and under what conditions. The results offer insights to software vendors as they develop their products and competitive strategies.

The practice of bundling can be seen in different settings such as textbooks, contracts, healthcare coverage and even mortgages and has also become popular with vendors in the software industry. *Microsoft Office* has established market leadership after a long period of competition with *Corel Office* and *Lotus Office*, but recently we see some competition with newly emerging bundles such as *Star Office* and *Open Office*. The competition of ERP packages is another example. In the early period of ERP offering, firms tried to offer differentiated set of applications. However, as competition increased and mergers and acquisitions of competing firms occurred, the offerings of ERP applications became similar with competing bundles of similar applications. Competing bundles often have similar graphical user interfaces and standardization of file formats that make it easier to exchange documents among them. These characteristics lower the switching costs for consumers and intensify competition among vendors. The recent and rapid growth of the open-source community and advances in platform-free application development have added a new twist, one in which incumbents compete against a free product with similar characteristics.

Two types of bundling have been recognized as is discussed in the literature review in section 2, although the boundary between them is sometimes fuzzy. One is ***centric bundling***, where secondary components or promotional software applications are attached to one central offering. For example, the Windows operating systems is often bundled with a group of software components including games, media players, Internet Explorer, firewalls, and the like. Symantec's *Norton Utility* package is another example, where *Norton AntiVirus* is the centric offering and *pcANYWHERE, Norton GoBack*, and the like are attached to add value. The second type is ***non-centric bundling***, where comparably sophisticated applications are packaged together in an integrated manner without any one component being the central offering. Office suites such as *Microsoft, Corel, Lotus, Star*, and *Open Office* are representative examples of non-centric offerings, where word processor, spreadsheet, presentation, database management system, and additional software applications are bundled together. Similarly, *Microsoft Works* comes with Word, Streets and Trips, Money, Picture It! Photo, Encarta Encyclopedia, and so forth. *TheOpenCD* project (theopencd.org) offers a file that users can freely download and burn a CD. The file includes dozens of applications in separate menus: Office and Design, Internet and Communication, Multimedia and Games, and Utilities and Others.

Bundling applications in the centric case has two effects. Obviously, the add-ons can enhance the value of the central offering. However, the central offering can also make the add-on components more acceptable compared to similar components from competitors which are being offered standalone. In other words one may choose to buy antivirus package A over antivirus package B, even though the latter is better, just because A comes bundled with a central component of value, while B does not. Centric bundling is often a major issue in antitrust disputes where monopolists who offer bundles are sued by competitors or the government. The implications of centric case upon competition have been well explored in both the information systems literature and legal cases. In this paper, therefore, we focus on competition between non-centric software bundles because that variant has received less attention in the literature even though it has been practiced by the software industry for some time.

1.1 Size and Quality of Bundles

When bundling is added to a vendor's strategy, competitive advantage depends on crafting an appropriate combination of price, quality and bundle size. In practice, competing software bundles usually do not vary greatly in bundle size. Moreover, that size is small. For instance, competing office-type bundles commonly include word processor, spreadsheet, presentation and, sometimes, personal database management software. Different explanations have been offered for this observation. Bakos and Brynjolfsson [1999] suggest that consumers have budget constraints and vendors may incur nonzero marginal costs in integrating an additional component. In fact, the marginal cost of adding components may increase with the size of the bundle, as each new module may need to integrate with a larger number of existing components. A factor that may contribute to the similarity of bundle sizes is that users have common expectations about the functionality of competing bundles. For office type bundles for example, functionalities such as word processing, spreadsheet and presentation are highly valued, but additional components like email clients and web publishing add comparatively less value to the bundle. <Table 1> illustrates this observation with specific examples. Microsoft Office bundles the favorite programs such as word processing and presentation and also charges the highest price.

<Table 1> Comparison of Office Products

	MS Office 2003 Professional Edition	Corel Word Perfect Office 11	Star Office 7	Open Office 1.1
Retail Price	\$329~499	\$29~450	\$79.95	Free
Word/Spreadsheet/Presentations	Y	Y	Y	Y
Database	Y	N	Y	Y

Competitors that produce Corel, Star, and Open Office do the same, but charge lower prices. All except one offer database management capabilities. In short, vendors will need to make a decision as to the appropriate value of bundle size.

The issue of bundle quality is more complex. ISO 8402 defines quality generally as "*the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs.*" ISO/IEC 9126 further defines 'characteristics' as functionality, reliability, usability, efficiency, maintainability and portability [Jung *et al.*, 2004]. Based on findings from the IT literature [Brynjolfsson and Kemerer, 1996] we conceptualize software bundle quality as the relative overall value perceived by customers. Brynsolfsson and Kemerer states,

"*the purchase price reflects only a relatively small portion of the total consumer expenditure; learning and conversion costs account for much of the remainder. This, in turn, helps to create strong network externalities, with theory suggesting a consumer preference for software that is perceived as a standard.*"

If a software bundle has lower learning and conversion costs than its competing product, then the software will be perceived as having higher quality. If strong network externalities exist, then also the software is more attractive than other products because of possible benefits such as (1) shared information from installed base of customers, leading to less learning cost and more usability (2) a larger market for complementary goods, (3) better compatibility and reliable integration, leading to less conversion cost (4) a thicker second-hand market [Farrell and Saloner, 1985; Katz and Shapiro, 1985; Westland, 1992; Whang, 1992].

1.2 Research Questions

To examine the implications of using bundling as an element of strategy, we construct a stylized game scenario consisting of one incumbent vendor, one new entrant and multiple customers. Although competing bundles are of similar sizes as noted earlier, they need not be identical in size. However, the competition of different size bundles has been well explored in the existing literature [Nalebuff, 2000; Dewan and Freimer, 2003]. In general, a bigger bundle size provides a competitive edge in this case. These models commonly assume identical and independent uniform distributions of the taste preferences of each component and find that bundling is more profitable and attractive when these values are aggregated with discounted prices lower than the sum of individual components.

Based on the theory, one firm offering lower size bundle in a duopoly situation would be at a disadvantage in capturing demand. Firms thus would offer the largest bundle size that consumers may reasonably expect. So the competition would lead to the same bundle size or different size bundles with the same essential components in which adding an additional component does not change the competitive outcomes.

In this idealized scenario however, to keep the model tractable we assume that the bundles of both vendors are of the same size. The specific research questions we pose here are (1) is a bundling strategy still effective in a vertically differentiated duopoly market[2] (2) how does an entrant's quality setting affect competition and (3) how should an incumbent firm compete with an entrant who offers an open/free bundle?

The remainder of the paper is organized as follows. Section 2 reviews the literature on software bundling and the game theoretic model of competition with bundling is introduced in Section 3. Analytical properties of the solution are presented to argue that a Nash equilibrium exists. However, even with simplifying assumptions, the model does not allow us to reach a closed form expression for the equilibrium solution. Hence, numerical experiments are conducted using the model. These results and their managerial implications are presented in section 4. Section 5 extends the base model to incorporate competition with a free bundle. Section 6 concludes the paper by discussing limitations and extensions.

2) "Vertically differentiated" means that the incumbent and entrant's bundle quality differ.

2. Literature Review

The information systems literature on bundling contains a variety of models which vary in their assumptions about decision-making structure and market characteristics. Interestingly, Geng *et al.* [2005] observed that "*the complexity involved in analyzing bundling has impeded researchers from obtaining general results* …" Bakos and Brynjolfsson [1999] considered a special case where a monopolist bundles together an infinite number of information goods. They found that the bundling strategy transfers consumer surplus to the seller's profit. In an extension of this work [Bakos and Brynjolfsson, 2000] they explored competition between multiple individual goods and one bundle, and between rival bundles. Their model assumed that two firms compete in selling n pairs of competing goods and that two goods in each pair are perfect substitutes with the same quality. They found that (i) when a bundle competes with unbundled multiple goods, bundling is a dominant strategy, and (ii) when competing with rival bundles, consumer surplus is higher, price is lower than in the monopolist case, and almost all consumers buy both bundles if the number of components in the bundles is very large. Geng *et al.* [2005] responded to these findings with the correction that pure bundling is optimal if the average value declines slowly without regard to any correlations among the valuations across bundled items.

Lee [2000] analyzed non-centric bundling strategies in the base-supplemental goods market and found that bundling should increase social welfare unless the supplements are close substitutes. Nalebuff [2000, 2004] set up a bundling model in an oligopoly environment, where an incumbent offers two goods and an entrant offers only one of the two goods. All goods are of the same quality. The entrant's product is a perfect substitute and the incumbent cannot change prices after arrival of the new entry. The model shows how the incumbent's bundling strategy could deter the entry of a single software producer. Extending Nalebuff's framework, Dewan and Freimer [2003] investigated centric bundling where a single base software hosts a number of third party add-in products. The work found that bundling base software with add-in components increases profits if a high enough proportion of consumers value the add-in, and that consumer surplus and social welfare increase when bundling increases profit.

As can be seen from the preceding review, current literature on bundling assumes that the quality of competing bundles are the same and it also restricts analysis to situations where one bundle competes with separate individual products. Our model and numerical experimentation adds to the literature by examining a more realistic market setting where (a) bundles compete with one another, (b) bundle size is finite, not limited to two or infinite, and (b) quality of software bundles are vertically differentiated.

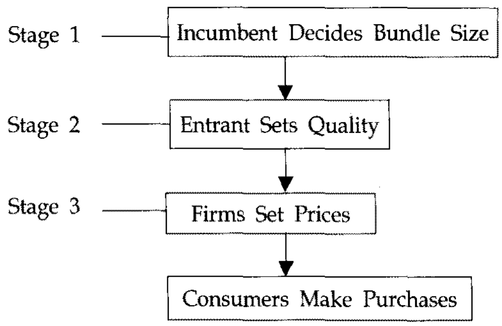
3. Basic Model of Competing Bundles

In our idealized environment, an incumbent competes against an entrant firm and each sells a bundle of software components, the bundle size being the same for both. The notation used in developing our model appears in <Table 2>.

<Table 2> Model Parameters and Decision Variables

Variables and Parameters	Representations
B	Number of components in a bundle
$\bar{B}$	Maximum number of components in a bundle
$i \in \{I, E\}$	index for Incumbent and Entrant
s_i	Quality of bundle i
P_i	Prices of Bundle i
p_i	average per component price of bundle i
R_i	Payoff for bundle i
n = 1, 2, 3, ⋯, N	Index on consumers
k = 1, 2, 3, ⋯, K	Index on software components in bundle
$\theta_{nk} \in [0,1]$	Taste parameter of consumer n for component k
$\bar{\theta}_{nB} = \frac{1}{B}\sum_{k=1}^{B}\theta_{nk}$	Customer n's average taste value across all components in a bundle of size B
U_n	Customer n's average utility per component for a bundle of size B
Q_i	Demand for bundle i
$F(\cdot)$	Cumulative distribution function of $\bar{\theta}_{nB}$
$f(\cdot)$	Probability density function of $\bar{\theta}_{nB}$

Competition between the incumbent and new entrant is conceptualized as a game that is played in three stages as illustrated in <Figure 1>. In the first stage of the game, the incumbent sets the number of components in its bundle to B, which is an integer between 1 and $\overline{B}$. $\overline{B}$ is a maximum bundle size as determined by multiple factors such as legal and technological constraints and consumer preferences.



<Figure 1> Game Structure

The incumbent and entrant's bundle quality differ and the former's bundle is assumed to have the higher quality. This assumption is based on the observation that quality reputations take time to percolate into the perceptions of customers and the entrant is at a disadvantage in this regard. It is possible for the entrant's quality to be higher although this scenario is less likely. We therefore do not consider this situation in our current analysis, but its implications are discussed in the concluding section. To simplify the analysis, we normalize the quality of the incumbent bundle, $s_I = 1$, while quality of the entrant bundle, s_E, can range between 0 and 1. In the second stage of the game, the entrant sets the quality of its bundle given the bundle size chosen by the incumbent. In the third stage, both firms compete in setting prices (p_I, p_E) for their bundles.

A brief discussion of the cost of quality is in order here. Even though we have conceptualized the mechanics of competition as a three stage game, clearly both the incumbent and entrant are developing their software suites in parallel. The entrant does not see the incumbent's product and then launch its development effort. Moreover, in software development efforts, the major cost component is that of skilled labor and these costs will be incurred by both entrant and incumbent well before this idealized game starts. It is true that after observing the incumbent's product, the entrant can adjust its own quality by controlling such activities as testing or not adding certain features in the product etc. Nevertheless, these adjustments do not represent the major component of development cost. In short, at the time the entrant makes its quality decision in the second stage of the idealized game, its cost associated with developing the bundle is largely, though not completely, a sunk cost. Therefore, for modeling purposes, we choose not to include the cost of selecting a particular quality level in the entrant's payoff function.

From the customer's viewpoint, the two bundles are perfect substitutes and compatible, but they differ in their aggregate quality. Each consumer n = 1, 2, 3, ⋯, N has a heterogeneous taste for each software component k = 1, 2, 3, ⋯ K. The taste $\Theta_{nk} \in [0,1]$ is distributed independently and identically among the different software components. Consumer n would be willing to pay $\sum_{k=1}^{B} \theta_{nk} s_i$, $i \in \{I, E\}$ for a bundle with size B. Consumers maximize their utility by comparing and purchasing one of the bundles.

The price of the bundle is P_i and we use per-component price $p_i = P_i/B$ for the comparison of consumer surplus in the next section. Extending this reasoning, customer n's average utility per component for a bundle of size B can be expressed as:

$$U_n = \frac{1}{B}\left(\sum_{k=1}^{B}\theta_{nk}s_i - P_i\right) = \bar{\theta}_{nB}s_i - p_i, \qquad (1)$$

where $\bar{B}_{nB} = \frac{1}{B}\sum_{k=1}^{B}\theta_{nk}$ is the average consumer taste for the components in the bundle.

In order to analyze this extensive form game, our analysis starts from the final stage and proceeds backwards later using numerical experimentation.[3] Recall that the customer's utility for a bundle was represented as $\bar{\theta}_{nB}s_I - p_I$ if bought from the incumbent and $\bar{\theta}_{nB}s_E - p_E$ if bought from the entrant. If the incumbent bundle dominates the entrant bundle in terms of quality per dollar, which implies $\frac{s_I}{p_I} > \frac{s_E}{p_E}$, demand for the incumbent bundle in the *dominant* case is

$$Q_I = N\left[1 - F\left(\min(1, \frac{p_I}{s_I})\right)\right] \qquad (2)$$

where $F(\cdot)$ is the cumulative distribution function of $\bar{\theta}_{nB}$. As n increases, the density function $f(\cdot)$ will be approximately normally distributed (bell-shaped curve) as the central limit theorem states. We focus our analysis mainly the case that the bundle size B is big enough to make the density function unimodal. This assumption would not be restrictive for most density functions even with low bundle size B other than some extreme multi-modal density function. If the incumbent bundle does not dominate, we can derive the following demand functions for the incumbent and entrant bundles, as well as for the 'Not Buy' option. Demand in the *non-dominant* case is:

$$\begin{cases} Q_I = N\left[1 - F\left(\min(1, \max(\frac{p_I - p_E}{s_I - s_E}, 0))\right)\right], \\ Q_E = N\left[F\left(\min(1, \max(\frac{p_I - p_E}{s_I - s_E}, 0))\right) - F\left(\min(\frac{p_E}{s_E}, 1)\right)\right], \\ Q_{NB} = N\left[F\left(\min(\frac{p_E}{s_E}, 1)\right)\right] \end{cases} \qquad (3)$$

Payoffs in the third stage are $R_I = p_I Q_I$, $R_E = p_E Q_E$ and they do not include the cost of setting a certain quality level because, as discussed earlier, they are largely sunk costs and do not affect the decision in the third stage. Based on the demand functions in both dominant and non-dominant cases, we can establish three claims regarding price equilibrium in the third stage. Claim 1 establishes the existence of unique optimal prices for both incumbent and entrant in the third stage. Claim 2 proves the existence of Nash equilibrium prices also in the third stage. Both Claims are proved only for the non-dominant case where the incumbent bundle does not dominate the entrant bundle. However, Claim 3 proves that although the incumbent may have an incentive to dominate the market by setting its price low, market outcomes will always be the non-dominant case

3) Game theoretic analysis and the equilibrium concept of subgame perfection are often applied to engineering management such as evaluating the value of information from data mining [22] and configuring platform products and supply chains [11].

because the entrant will react to the price by setting its price to segment the market between incumbent and entrant. Therefore, Claim 3 makes Claim 1 and Claim 2 effective in all the market conditions that actually occur.

Claim 1: Unique optimal prices exist for both incumbent and entrant given any price setting of the opponent in the third stage.

Proof: The first derivatives of the payoff functions are:

$$\frac{\partial}{\partial p_I}R_I = N - NF\left(\frac{p_I-p_E}{s_I-s_E}\right) - \frac{p_I N}{s_I-s_E}f\left(\frac{p_I-p_E}{s_I-s_E}\right) \quad (4)$$

and

$$\frac{\partial}{\partial p_E}R_E = N\left(F\left(\frac{p_I-p_E}{s_I-s_E}\right) - F\left(\frac{p_E}{s_E}\right)\right) - p_E N\left(\frac{1}{s_I-s_E}\right)f\left(\frac{p_I-p_E}{s_I-s_E}\right) + \frac{1}{s_E}f\left(\frac{p_E}{s_E}\right)). \quad (5)$$

For any possible distribution based on B, $F(\frac{p_I-p_E}{s_I-s_E})$ is an increasing function and the probability density function $f(\frac{p_I-p_E}{s_I-s_E})$ is always non-negative with respect to p_I ranging from 0 to 1. Therefore, as p_I increases from 0 to 1, $\frac{\partial}{\partial p_I}R_I$ changes from positive to a negative value and eventually approaches zero. Similarly $\frac{\partial}{\partial p_E}R_E$ transitions from positive to negative values as p_E increases from 0 to a value that satisfies $F(\frac{p_I-p_E}{s_I-s_E}) - F(\frac{p_E}{s_E}) \geq 0$.

Based on the preceding observation, it follows that for any price set by the entrant, there exists a unique price for the incumbent at which its own payoff is maximized. Symmetrically, for any price set by the incumbent, there also exists a unique price for the entrant at which the latter's payoff is maximized. Therefore, unique optimal prices exist for both incumbent and entrant. [End of Proof]

Claim 2: Nash Equilibrium prices exist for the incumbent and entrant in the third stage.

Proof: Due to the complexity of the demand function, it was not possible to obtain closed form expressions for the optimal price reaction functions $\{p_I(p_E), p_E(p_I)\}$ from solving $\left\{\frac{\partial}{\partial p_I}R_I = 0,\ \frac{\partial}{\partial p_E}R_E = 0\right\}$ with respect to $\{p_I, p_E\}$ respectively. Each price reaction function is a set of payoff maximizing prices for one player, covering the range of prices that can be charged by the opponent. We can make the following observations regarding the properties of $p_I(p_E)$ that solves $\frac{\partial R_I}{\partial p_I} = N - NF(\frac{p_I-p_E}{s_I-s_E}) - p_I N\frac{1}{s_I-s_E}f(\frac{p_I-p_E}{s_I-s_E}) = 0$:

(i) the intercept is positive. $p_I(0) > 0$ because it should solve $\frac{\partial}{\partial p_I}R_I(p_E=0) = 0$ (from equation (4)), which can be reduced to $1 = F(\frac{p_I}{s_I-s_E}) + p_I\frac{1}{s_I-s_E}f(\frac{p_I}{s_I-s_E})$. Without $p_I(0) > 0$, this equation cannot be satisfied. If $p_I(0) \leq 0$, the equation becomes 1 = 0+0, which is a contradiction.

(ii) The slope of $p_I(p_E)$ is positive. Setting $\frac{\partial}{\partial p_I}R_I = 0$, equation (4) can be reduced to $1-F$

$(\frac{p_I - p_E}{s_I - s_E}) - \frac{p_I}{s_I - s_E} f(\frac{p_I - p_E}{s_I - s_E}) = 0$. This equation will hold only if $p_I(p_E)$ increases as p_E increases. Hence the result follows.
Similar claims can be established for the properties of $p_E(p_I)$.

(iii) the intercept starts from the origin since if $p_I = 0$, p_E must be zero to satisfy the first dlerivative condition: $N(F(\frac{-p_E}{s_I - s_E}) - F(\frac{p_E}{s_E}))$

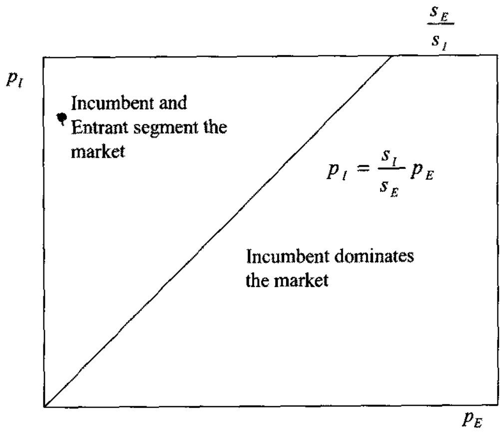
$$-p_E N(\frac{1}{s_I - s_E} f(\frac{-p_E}{s_I - s_E}) + \frac{1}{s_E} f(\frac{p_E}{s_E})) = 0$$

(iv) the entrant's optimal reaction curve must have a steeper positive slope compared to that of the incumbent because $p_E(p_I)$ starts from the origin and must react to any value p_I, implying that Max($p_E(p_I)$) must lie to the left of Max(p_E).

Based on findings (i)~(iv) above that the optimal price reaction curves of the two players always intersect. This establishes the existence of unique Nash equilibrium prices $p_I^* = p_I(s_E, B)$ and $p_E^* = p_E(s_E, B)$ which are themselves functions of the entrant quality s_E and incumbent's bundle size B. [End of Proof]

Claim 3: Nash Equilibrium prices always lead to the case that the incumbent does not dominate but segments the demand with the entrant in the third stage and the reaction curve of the entrant starts from the origin and always in the boundary of the nonominant case.

Proof: For any given price of the incumbent, the entrant has no incentive to cooperate in order that the incumbent can dominate the market and its own revenue becomes zero. We mapped the range of the dominant case $\frac{s_I}{p_I} > \frac{s_E}{p_E}$, i.e. $p_I < \frac{s_I}{s_E} p_E$ in the $p_E - p_I$ plane as shown in <Figure 2>:



<Figure 2> Regions of Dominance and Non-dominance

When incumbent's price takes the maximum value $p_I = 1$, the entrant's price is $p_E = \frac{s_E}{s_I}$.

What we try to do here finding the values of $p_E(p_I = 0)$ and $p_E(p_I = 1)$ to understand the basic shape of $p_E(p_I)$. We focus our attention on the value of $p_E(p_I = 1)$. Equation (5) in the paper is the implicit function of $p_E(p_I)$ such that

$$\frac{\partial}{\partial p_E} R_E = N(F(\frac{p_I - p_E}{s_I - s_E}) - F(\frac{p_E}{s_E}))$$
$$-p_E N(\frac{1}{s_I - s_E} f(\frac{p_I - p_E}{s_I - s_E}) + \frac{1}{s_E} f(\frac{p_E}{s_E})) = 0$$

Then, $p_E(p_I=1)$ is

$$N(F(\frac{1-p_E}{s_I-s_E})-F(\frac{p_E}{s_E}))$$
$$-p_E N(\frac{1}{s_I-s_E}f(\frac{1-p_E}{s_I-s_E})+\frac{1}{s_E}f(\frac{p_E}{s_E}))=0.$$

(i) If $p_E \geq \frac{s_E}{s_I}$ when $p_I=1$, then we can substitute $p_E=\frac{s_E+\epsilon}{s_I}$ where $0 \leq \epsilon \leq s_I-s_E$. Then equation (5) can be rewritten as

$$N(F(\frac{s_I-s_E-\epsilon}{s_I(s_I-s_E)})-F(\frac{s_E+\epsilon}{s_I s_E}))$$
$$-\frac{s_E+\epsilon}{s_I}N(\frac{1}{s_I-s_E}f(\frac{s_I-s_E-\epsilon}{s_I(s_I-s_E)})$$
$$+\frac{1}{s_E}f(\frac{s_E+\epsilon}{s_I s_E}))=0.$$

However, $F(\frac{s_E+\epsilon}{s_I s_E})=1$ makes the above equation a contradiction because the left term is negative such that $N(F(\frac{s_I-s_E-\epsilon}{s_I(s_I-s_E)})-1)$ $-\frac{s_E+\epsilon}{s_I}N\frac{1}{s_I-s_E}f(\frac{s_I-s_E-\epsilon}{s_I(s_I-s_E)}))<0$.
Therefore, when we fix $p_I=1$, the entrant's price is not equal to or greater than $\frac{s_E}{s_I}$

(ii) If $p_E=\frac{s_E}{s_I}$, then $p_E=\frac{s_E-\epsilon}{s_I}$ where $0 \leq \epsilon \leq s_E$. Then equation (5) becomes

$$N(F(\frac{s_I-s_E+\epsilon}{s_I(s_I-s_E)})-F(\frac{s_E-\epsilon}{s_I s_E}))-\frac{s_E-\epsilon}{s_I}N$$
$$\times\frac{1}{s_I-s_E}f(\frac{s_I-s_E+\epsilon}{s_I(s_I-s_E)})+\frac{1}{s_E}f(\frac{s_E-\epsilon}{s_I s_E}))=0.$$

Since $F(\frac{s_I-s_E+\epsilon}{s_I(s_I-s_E)})=1$, the equation is equivalent to $N(1-F(\frac{s_E-\epsilon}{s_I s_E}))-\frac{s_E-\epsilon}{s_I}N$ $(\frac{1}{s_E}f(\frac{s_E-\epsilon}{s_I s_E}))=0$, which does result in a contradiction.

Therefore we have established that $p_E(p_I=1)$ $<\frac{s_E}{s_I}$. This fact allows us to conclude that $p_E(p_I)$ starts and ends in the boundary where incumbent and entrant segment the market in <Figure 2>.

To summarize, the reaction curve of entrant $p_E(p_I)$ always exists only in the non-dominant region and the reaction curves start from the origin due to the fact that entrant will adjust its price to result in non-dominant case with respect to any price incumbent may select. Therefore the market outcome will be the non-dominant case in most cases in our game setting.
[End of Proof]

Although closed form expressions for this equilibrium cannot be derived analytically for a general distribution of the taste function, we can work backward to the second and first stages to establish the impacts of equilibrium bundle size and entrant quality upon pricing and profitability using numerical analysis. The preceding model of competition between non centric bundles, and the establishment of the existence of a Nash equilibrium, provides a basis for numerical experiments from which one may deduce the nature of equilibrium solutions and their managerial and policy implications.

4. Experimentation and Results

The distribution of the customer taste function $F(\bar{\theta}_{nB})$ does not, in general, have a closed form solution and numerical integration needs to be used instead. Two special cases of $F(\bar{\theta}_{nB})$ are a uniform distribution when B = 1 and a normal distribution when the bundle size is large. However as noted earlier, competing bundles have a small number of components. For small bundle size, the functional form of $F(\bar{\theta}_{nB})$ cannot be determined analytically in general. Moreover, as seen in the previous section, closed form expressions could not be obtained for the equilibrium solution of the three stage game. For these reasons, we used a numerical experimentation approach to examine the behavior of the incumbent and entrant in our model. The objective is to examine the impact of bundle size B and entrant quality s_E upon firm payoffs, consumer surplus and total surplus.

In the experiments, bundle size was varied from 1 to 100 while entrant bundle quality varied from 0.00 to 0.99. A procedure was written in Visual Basic 6.0 to strictly follow the sequence of decisions in the 3-stage game de-

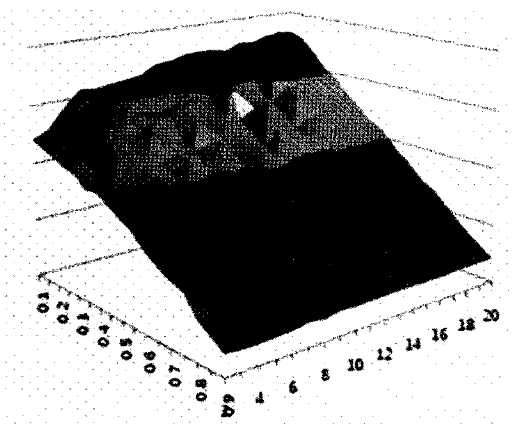
<Table 3> Algorithm for Numerical Experiments (See Appendix for a Simulation Screenshot)

```
FOR bundle size B = 1 to 100, Step by 1 DO;
    FOR entrant quality q = 0 to 0.99, Step by 0.01 DO;
        FOR consumer n = 1 to 200, Step by 1 DO;
          (a) Generate the average of B random numbers to calculate the taste parameter
          (b) FOR entrant price p_E = 0 to 1.000, Step by 0.005 DO;
                FOR incumbent price p_I = 0 to 1.000, Step by 0.005 DO;
                    Each consumer makes purchase decision
                    Generate Incumbent_Demand(p_E, p_I) and Entrant_Demand(p_E, p_I)
                Next incumbent price
             Next entrant price
      Next consumer
        (c) Incumbent's best_response_price p*_I = 0
            and entrant's best_response price p*_E = 0
            For 20 iterations DO;
                For incumbent price p_I = 0 to 1.000 Step by 0.005 DO;
                        Find the best_response_price p_I
                        that maximizes p_I (Incumbent_Demand (p*_E, p_I))
                Next incumbent price
                Update p*_I
                For entant price p_E = 0 to 1.000 Step by 0.005 DO;
                        Find the best_repsonse_price p_E
                        that maximizes p_E (Entrant_Demand (p_E, p*_I)
                Next entrant price
                Update p*_E
             Next Iteration
    Next quality
Next Bundle Size
```

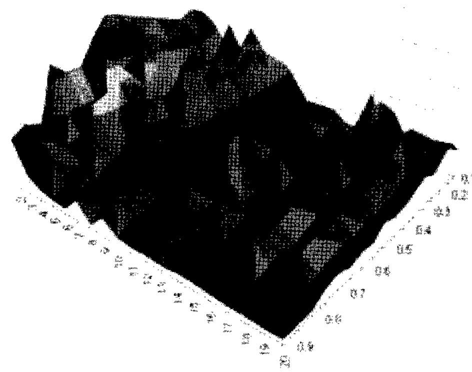
scribed earlier. The major steps in the experiment are shown in <Table 3>. Notice that the simulation algorithm does not make the simplifying assumptions made earlier in deriving the analytical results. In particular it allows for general distributions for the quality tastes of individual customers, customers are allowed to have different taste parameters etc.

For each iteration in section (c), each firm takes turns in setting price to maximize its own payoff. In each iteration, best response prices are updated by examining 200 price points each, for the incumbent and entrant, respectively. We found that the best response prices converged to an equilibrium within 5 iterations in most cases.

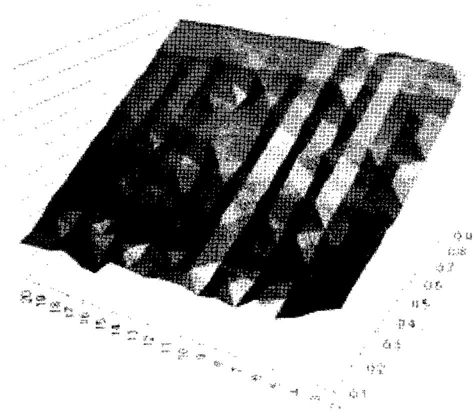
<Figure 3>~<Figure 6> show the impact of varying bundle size (2~20) and entrant quality (0.05~0.95) on the incumbent and entrant's payoffs, and on consumer and total surplus.



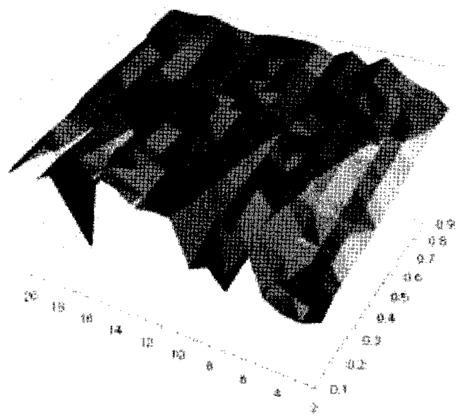
<Figure 3> Impact of Bundle Size and Entrant Quality on Incumbent's Payoff



<Figure 4> Impact of Bundle Size and Entrant Quality on Entrant's Payoff



<Figure 5> Impact of Bundle Size and Entrant Quality on Consumer Surplus



<Figure 6> Impact of Bundle Size and Entrant Quality on Total Surplus

We discuss each in turn.

<Figure 3> and <Figure 4>, taken together, show that for any fixed entrant quality level, as bundle size increases the incumbent's payoff increases gradually while the entrant's payoff decreases rapidly. This suggests that *an incumbent may use bundling as an effective way of competing against an entrant.* The entrant's payoff is relatively small compared to the incumbent for most quality levels. When its quality level is low, the entrant attracts few customers. When the entrant's quality is high, it attracts more customers, but more fierce price competition due to less quality gap limits the increase in its payoffs. So the same amount of net payoff change as the entrant's quality increases can be proportionally large to the entrant but small to the incumbent ($\left|\frac{\Delta R_E}{R_E}\right| > \left|\frac{\Delta R_I}{R_I}\right|$ as s_E increases). In the same context, the impact of marginal payoff as the bundle size increases is proportionally large to the entrant but small to the incumbent ($\left|\frac{\Delta R_E}{R_E}\right| > \left|\frac{\Delta R_I}{R_I}\right|$ as B increases). <Figure 5> and <Figure 6> show that for any given entrant quality, as bundle size increases, consumer surplus decreases gradually while total surplus increases. That means the increase in incumbent's payoff is greater than the decrease in entrant payoff and consumer surplus combined. This outcome occurs because, as bundle size increases, customers in the 'Do not purchase' category gradually see higher utility in the larger bundles and become buyers. <Figure 5> and <Figure 6> taken together show that *bundling is more effective in transferring consumer surplus and entrant's payoff to the incumbent's payoff when the entrant's quality is low than when the entrant's quality is high.*

Collectively, these results suggest that the incumbent's bundling strategy not only transfers the entrant's payoff and consumer surplus to its own, but also leads to a higher total surplus. This finding shows that Dewan and Freimer's [2003] result that "*The total surplus of all consumers increases with bundling if bundling increases the base software producer's payoff*", which was established in a centric bundling environment, also holds in our market setting of non centric bundle competition. The implication of these results for policy makers is that allowing bundling of non-centric software may hurt competition and consumers by moving surplus to the incumbent, but may lead to greater social welfare by attracting more consumers who would not buy in the absence of bundling. However, this effect of transferring surplus to the incumbent will diminish as the entrant's quality increases.

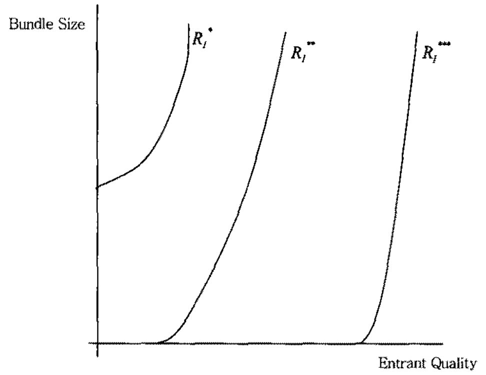
We now discuss the impact of varying entrant quality. <Figure 3> and <Figure 4> show that for a given bundle size, as entrant quality increases, the incumbent's payoff decreases monotonically while the entrant's payoff increases at first and then decreases. Note that as the quality difference between incumbent and entrant decreases, price competition increases. The incumbent's payoff decreases monotonically because it needs to lower price while also losing demand to the entrant. As a result of increased quality, the entrant keeps gaining more demand which contributes to increased payoff. However, as price competition becomes fiercer, the entrant needs to reduce prices to match moves by the incumbent and this reduces its payoff. The net result is that the entrant's payoff first increases and then decreases. <Figure 5> and <Figure 6> also show that as the entrant's quality increases, consumer surplus and total surplus both increase. Thus vendors and consumers, collectively, are better off as the qualities of the two software suites become comparable. Since higher price competition reduces prices and attracts more consumers, reducing the quality gap transfers the incumbent's payoff to consumer surplus while increasing total surplus at the same time. Thus, policy makers can increase consumer surplus and total surplus at the same time if they can encourage quality enhancement of the entrant relative to the incumbent. This may be achieved either by imposing legal restrictions solely upon the incumbent or by subsidizing the new entrant's quality improvement. Examples of such action include (excerpts from [Hahn, 2002]): (1) Singapore government agency (EDB) offering temporary tax reductions and financial grants to fund Linux-related projects (2001), (2) the Bundestag in Germany mandating a new IT environment: Linux on Servers, Windows on desktops, and (3) in Brazil, a legislation mandating open source software be given preference in municipal governments.

Interestingly, <Figure 4> shows that as the incumbent increases its bundle size, the entrant's payoff-maximizing quality choice decreases. This result implies that the entrant will set its quality to optimally segment the market with the incumbent instead of trying to take the incumbent head on with superior quality. The entrant achieves its highest payoff by becoming a price leader with lower-end quality.

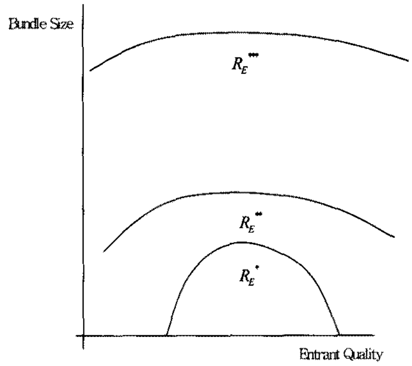
To summarize the implications for competitive strategy and public policy purposes, we next present and discuss our experimental results using iso-contour lines of payoffs, consumer surplus, and total surplus. These contour lines provide a set of bundle size and entrant's quality combination that generate the same level of payoffs and surpluses.

In <Figure 7>, R_I^{*}, R_I^{**}, and R_I^{***} depict iso-payoff curves of the incumbent where $R_I^{***} < R_I^{**} < R_I^{*}$. It shows that incumbent's payoff increases as the entrant's quality decreases or the bundle size increases. Similarly <Figure 11> shows iso-payoff curves of the entrant where $R_E^{***} < R_E^{**} < R_E^{*}$. The entrant's payoff decreases as bundle size increases. Also, as entrant's quality increases, its payoff increases initially but decreases subsequently. Note that the entrant's quality choice has less effect on its payoff when the bundle size is relatively high. Consumer surplus contours ($CS^{***} < CS^{**} < CS^{*}$) in <Figure 9> increase as the entrant's quality increases and bundle size decreases. However, the impact of bundle size on consumer surplus is less when the entrant's quality is relatively high. Total surplus ($TS^{***} < TS^{**} < TS^{*}$) increases as both bundle size and entrant's quality increase, as shown in <Figure 10>.

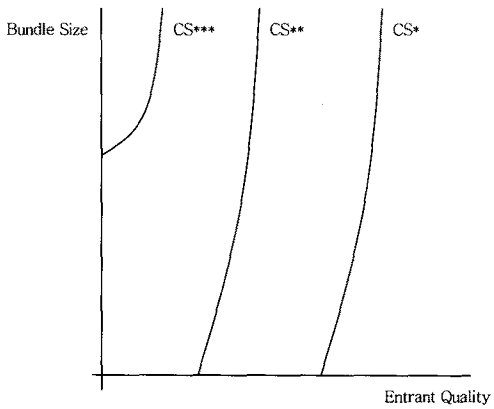
<Figure 11> provides an integrated view of the impact on vendor payoffs and participant (vendor or consumer) surplus as a function of actions taken by the two competitors. Using a baseline combination of bundle size and entrant quality for reference, represented by the point BL in <Figure 11>, one can summarize how wealth allocations among the different participants will change as one moves away from this baseline combination through competitive or regulatory policy actions:



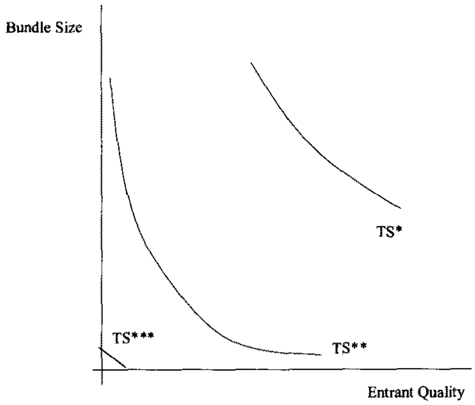
<Figure 7> Isocontour lines of Incumbent Payoff



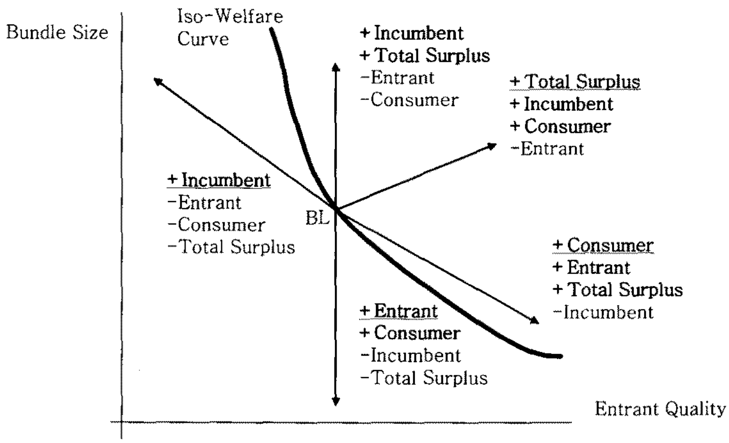
<Figure 8> Isocontour Lines of Entrant Payoff



<Figure 9> Isocontour Lines of Consumer Surplus



<Figure 10> Isocontour Lines of Total Surplus



<Figure 11> Strategic and Policy Options (Major Beneficiary is Underlined)

(1) If a policy maker *shifts up* the combination by legally allowing a greater bundle size, it will *only favor incumbents* at the cost of the consumer and the entrant. However the total surplus in this case would increase. So one could say that society is better off, although the distribution of the increased wealth is concentrated in one participant-the incumbent.

(2) If a policy maker shifts the combination downwards by putting legal constraints on bundle size, it will most benefit the entrant and then the consumer, at the cost of the incumbent and eventually sacrifice total surplus. So this policy move may not be desirable in the long run as it makes society worse off, but it may still make sense in the short run if there are other reasons to encourage fledgling entrants in a particular software market.

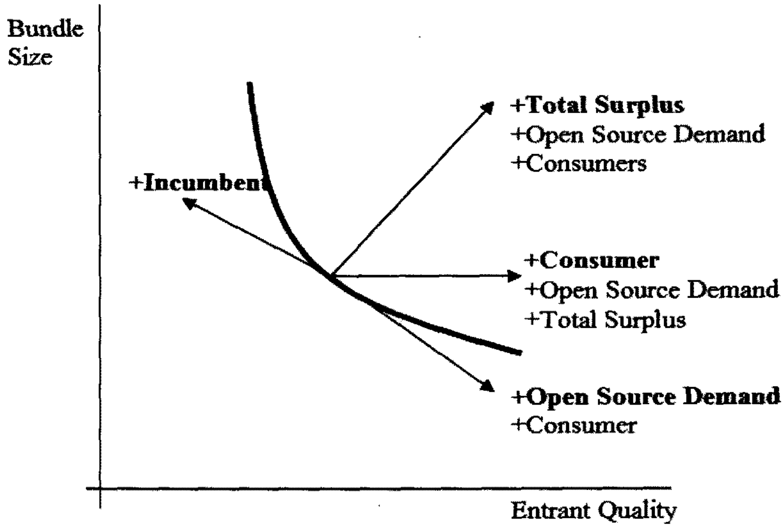
(3) If a policy action causes the combination to shift up and to the left, the result will only favor the incumbent at the cost of the entrant, consumers and total surplus. It is difficult to envision a practical scenario where this kind of policy action might be desirable, but we mention this alternative it for completeness.

(4) If policy actions cause the combination to shift up and to the right, the impact would be an increase in total surplus, with the additional benefits going to the consumer and incumbent, not to the entrant. This situation can arise when there are no regulatory constraints on bundling, while at the same time there is pressure to enhance software quality. This may explain the periodic complaints from new entrants about the bundling practices of incumbents and associated pleas for regulatory relief.

(5) If policy actions cause the combination to shift down and to the right, this will also result in an increase in total surplus. However the additional benefits now accrue to the entrant and the consumer, not to the incumbent. This situation can arise if bundle sizes are restricted through laws and if incentives are offered to entrants to encourage quality enhancement.

5. Competition with Free Bundles

As mentioned earlier in the paper, the Open Source movement has resulted in a variety of free software becoming available on the market. Obviously the entrant's payoff is not relevant here but the demand it generates may have an impact on consumer surplus, incumbent payoff as well as total surplus. In order to examine the impact of an entrant offering a free bundle (e.g. Open Office), we conducted the same experiment while holding the price of the entrant bundle at zero. The experiments show the following effects. As bundle size increases, both the incumbent's payoff and total surplus increase. Consumer surplus is not affected if the bundle size is small (1-5) but eventually decreases when the bundle size becomes relatively large (21-100). As the entrant's quality increases, the incumbent's payoff decreases and both consumer surplus and total surplus increase. In other words, the impact of bundling and quality setting by the entrant, upon incumbent payoff, consumer surplus, and total surplus are similar to those in the



<Figure 12> Strategic and Policy Options for Free Bundle Competition

base model. Thus, offering free software does not change the general nature of the impact of bundle size and entrant quality upon participants as shown graphically in <Figure 12>.

6. Conclusion

Since many software products are sold as bundles of components, bundling may be used by software vendors as an additional dimension of product design and competitive strategy. In this paper we investigate if a bundling strategy is still effective when there is a competitor who reacts to an incumbent by controlling the quality level of its competing bundle. Competitive outcomes in the following areas are studied: payoff for the incumbent and the entrant, consumer surplus and total surplus. Our findings have managerial implications for both the incumbent and entrant. They also have public policy implications that can help guide action aimed at achieving desirable allocations of the total economic welfare among different market participants.

The first managerial implication of our results is that bundling can still be an effective competitive strategy for an incumbent even when there is a new entrant who imitates the incumbent's bundling strategy. In particular, by increasing its bundle size, an incumbent can increase its payoff while decreasing the entrant's payoff. This result is consistent with Nalebuff's [2004] finding in a monopolist setting, that bundling can be considered as an entry barrier rather than just a price discrimination tool. Our model suggests that bundling by an incumbent remains an effective strategy to compete with a new entrant even in an oligopoly market.

From the entrant's viewpoint, the managerial implication of our results is that it can maximize its own payoffs by judiciously setting the quality level of its bundle. For any given bundle size chosen by the incumbent, the best strategy for the entrant is to deliberately set its quality, and the associated price, lower than that of the incumbent in order to counteract the bundling effect to some degree. Our results show that this quality setting strategy is more effective when bundle size is relatively small (less than 5). As bundle size gets larger, the incumbent's payoff increases at the expense of the entrant and it becomes harder for the entrant to compete against the incumbent.

Our results also show the welfare implications of bundling for the different market participants and hence have implications for public policy. Earlier results in the literature [Bakos and Brynsolfsson, 1999] showed that in a monopoly market, a monopolist can use bundling to increase its own payoffs at the cost of consumer surplus, but the total social welfare remains constant. Our results extend that understanding by showing that in an oligopoly market, an incumbent can increase its own payoff at the expense of an entrant's payoffs but total social welfare is increased. In other words, a society may be collectively better off if bundling strategies are permitted when there is competition. We also find that, in a competitive market, quality enhancements by the entrant increases total social welfare. This result may be relevant for policy makers who face the issue of maintaining desirable allocations of social welfare among the different market participants. Consumer interests must not be compromised, but at the same time the incumbent and entrant must have reasonable prospects of obtaining payoffs from their ventures as well. Bundling has come under scrutiny in recent times because of claims that it stifles competition, but our results indicate that it may not be undesirable from a social welfare standpoint. Similar results are found in the extended model where the incumbent competes against an entrant who introduces free-software bundles. Our model helps software vendors and policy makers understand the impact of bundling and quality setting by offering an integrated view of strategic actions and welfare considerations in a competitive market environment. Multiple factors affect the effectiveness of a bundling strategy. Our findings suggest that the type of market-e.g. monopoly, oligopoly, or free software offering-as well as strategic variables-e.g. quality level-should be considered when assessing the effectiveness of bundling as a competitive strategy.

As with any model, ours has limitations. One of the assumptions made in the paper is that the entrant's quality is lower than that of the incumbent, the latter being normalized to one. The rationale was that quality perceptions take time to build up in customers' minds and the entrant is at a disadvantage relative to the incumbent in this regard. However, there could be situations, albeit infrequent, where the entrant has the higher quality and which is recognized by customers. In the context of our stylized game, the first and second stages, where incumbent sets bundle size and entrant responds with a quality setting, would remain the same. However, the roles of incumbent and entrant would need to be reversed in the third stage where the competitors set price. The three claims made earlier would continue to hold, viz. existence of unique optimal prices for the two competing players in stage three of the game, existence of a Nash equilibrium price for the two players in the third stage and

Nash equilibrium prices always leading to the nondominant case. However, due to the reversal of roles, the welfare distribution outcomes would be different from those outlined earlier and the managerial implications mentioned in the previous section would change. For instance, if we reverse roles in <Figure 7> and <Figure 8>, the incumbent may be better off by reducing the bundle size and the entrant may be better off by choosing the highest possible quality. Consumer surplus and total surplus implications are not influenced by the reverse role setting. Therefore the implications of bundle size and entrant quality would remain same even though we reverse roles in <Figure 9> and <Figure 10>.

Earlier in the paper, we have assumed that the cost of quality, while not zero, is a sunk cost and is therefore not considered in the third stage analysis which looks at revenue streams. In this stage, firms compete in setting prices for their bundles, the size and bundle qualities having been set in earlier stages. In order to be fully realistic in considering the costs of enhancing quality or increasing bundle size, we need to apply the equilibrium concept of subgame perfection and backward induction to the previous stages of quality setting and bundle size decision. However, it is mathematically intractable, unless we fix the bundle size 2 or infinite, to extend our analysis to the second stage of entrant quality setting and even to the first stage of incumbent setting bundle size. Based on the shape of revenue in the third stage, we can conjecture that the optimal level of quality that maximizes entrant's payoff in the second stage should be lower than that of quality that maximizes revenue in the third stage. By the same logic, we conjecture that the incumbent payoff in the first stage will not be monotone increasing in bundle size in the third stage. If the cost of increasing the bundle size for the incumbent is high enough, there will be an optimal level of incumbent's bundle size where the marginal cost equals the marginal revenue from increasing the bundle size. While incorporating costs of increasing quality and bundle size to our analysis may add to the accuracy of our model, its contributions to our understanding may be limited because the major findings with respect to the pattern of impacts of incumbent's bundle size and entrant's quality setting upon firm profits and surpluses would be still valid.

Our model can be extended in different ways. The current analysis is limited to *"pure bundling"*, i.e. consumers purchase either the entire bundle or nothing. One extension would be to explore the option of *mixed bundling* where consumers may choose from a menu including bundles, individual software components or nothing. Another is to explore different functional forms for the customer's value function. It has been assumed to be linear in our current analysis, but one can make an argument for examining a convex value function. This is because an integrated bundle may facilitate exchange of information between components or the integration of their content, making it more valuable than the value of components taken individually. Other extensions consist of relaxing some of the limitations mentioned in the previous paragraph. One alternative is to allow the incumbent and entrant's bundle size to be unequal, while another would be to allow components within each bundle to have different quality levels. Most, if not all, of these extensions would need to be studied through simulation experiments as the proliferation of model parameters and decision variables would quickly render the analytical models intractable.

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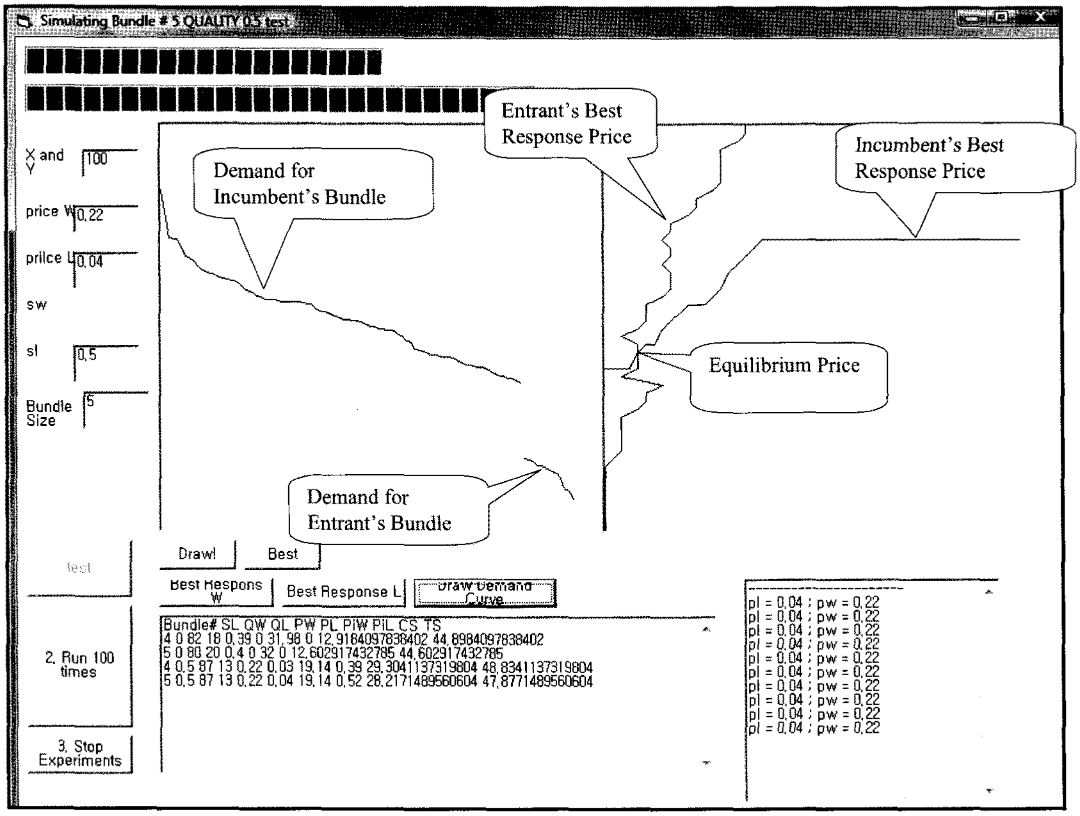
〈Appendix〉 Numerical Experimentation Screenshot



The demand curve (left) and best response functions (right) are captured during the simulation.

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