

UNDERSTANDING VALUE-ADDED RESELLERS' ASSORTMENTS OF  
MULTICOMPONENT SYSTEMS

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**ABSTRACT**

Inter-connect standards increase choices; e.g., in cardiac pacemakers, the IS-1 standard enables the “pulse generator” from six manufacturers to be combined with the “lead set” from the other five to add up to thirty additional mixed-brand pacemakers. However, observed assortment additions are much smaller, which poses a puzzle since manufacturers in extant models welcome such additions to reduce price competition and increase variety. Instead, conflict with the value-added resellers (VARs) who create, and carry these additions is commonplace. We extend the literature with our analytical model that shows VARs limit the number and composition of additions to gain better upstream terms. This conflict is exacerbated when “keystone” components are relatively more decisive in influencing customer choices, so their exclusion from an addition represents a larger loss. Our empirical study of the multi-billion dollar auto paint refinish market finds assortment additions consistent with our predictions. We conclude with discussing the role of channel support programs to ameliorate these conflicts.

Keywords: Multi-component systems, Value Added Resellers, Compatibility, Interoperability, Mix and Match

## INTRODUCTION

Multi-component products (“systems”) are ubiquitous in contemporary economies. Heavy-duty trucks (engines, cabs, and transmissions), cardiac pacemakers (leads and pulse generators), fighter aircraft (airframes, engines, weapons, and avionics), desktop computers (microprocessors, operating systems) and premium bicycles (frame, derailleur sets, and saddles) all rely on multiple components working well together in an inter-connected fashion for the product to function as intended. Two types of systems are readily distinguished; *pure* systems consisting of interoperable components from a single firm, and *mixed* (mix-and-match) systems consisting of interoperable components from different firms. To illustrate, in the cardiac pacemaker market, Medtronic, Guidant, St. Jude Medical, ELA Medical, Biotronik, and Sorin all produce pulse generators and leads. A pure system would be a Medtronic pulse generator paired with Medtronic leads, whereas a mixed system might be a Medtronic pulse generator paired with Biotronik. Standardized interfaces permit components from different firms to interoperate properly; in this industry, the key is the IS-1 interface standard that permits generators and leads to talk to each other effectively.

Interoperability stems from the American Civil War period, when manufacturing technology finally achieved the precision and repeatability to permit interchangeable parts. As Wilson et al (1990) observe, technological progress fosters modularity, thus more advanced technology settings exhibit greater modularity and standardized interfaces. Not surprisingly, the information technology industry exhibits the greatest degree of interoperable components. Its underlying tools (programming languages) are predominantly “object-oriented” today, which effectively designs-in modularity and interoperability. To illustrate, an online news site can readily combine discrete component sections (politics, sports, food, etc.) from its own and third

party sources into a customizable package for its subscribers. Similar possibilities abound in the audio and video streaming markets enabled by the libraries of objects built up over time.

Notwithstanding interconnect standards, producers retain discretion about mixed systems. To illustrate, a cardiac pacemaker producer might eschew the IS-1 standard interface in favor of its own, proprietary generator-lead interface which effectively prevents the inclusion of its components in any mixed system. What do we know about these incentives? A small, but focused stream of analytical work (Economides, 1989; Wilson et al, 1990, Matutes and Regibeau, 1992) offers a consistent takeaway; *competing producers benefit from mixed systems due to reduced price competition.*

Multi-component systems markets often feature complex value-chains; it is rare that a complete system leaves the producer's factory floor and is sold to the end-user as-is. Particularly with mixed systems, intermediaries actively configure, assemble and install mixed systems. To illustrate, in the cardiac pacemaker market, hospital specialists create preferred configurations of mixed systems that they recommend to physicians. Notice that the downstream intermediary must have access to competing components to influence mixed systems. However, the work described above abstracts away from intermediaries, so we must look elsewhere for insight. As such, we turn to channels models studying multiple producers who employ a common intermediary (e.g., Bernheim and Whinston, 1985, 1986; Choi, 1991) to find a consistent takeaway: *competing producers benefit from a common reseller due to reduced price competition.* However, this literature abstracts away from interoperable components.

Combining the two takeaways suggests a common intermediary who adds mixed systems benefits manufacturers, so the latter should welcome the additions. Anecdotally, however, manufacturers appear to be in conflict with intermediaries over mixed systems. Lawsuits (*cf.* BASF v. Sublime, 2012) and industry accounts of channel conflicts over the composition and

number of mixed systems are readily found, and as we detail later, it is also apparent in our own field work. This is the key gap in our understanding we seek to close in our work.

### ***Goals and Contributions***

We seek to demonstrate that channel conflict over the intermediary's mixed system assortment arises from conflicting motives. Adding mixed systems softens producer price competition, but strategically motivated addition of mixed systems creates winners and losers as well. Intuitively, mixed systems empower the intermediary to extract better upstream terms. Upstream firms lose when their own higher-margin component is purposely excluded from a mixed system.

To make our case, we develop a formal model of manufacturers selling competing systems through a common intermediary. In equilibrium, we find that only a limited number of mixed systems are added. Two factors – (a) differentiation between intermediaries, and (b) the systems' architecture, influence these additions. Intermediaries add mixed systems selectively so as to improve their own upstream terms balanced against softer upstream price competition benefiting producers.

We take these refutable predictions to the multi-billion dollar automobile paint refinish market. To fix the relevance of the model's constructs in this context, we first conducted field work including interviews with producers and intermediaries (value-added resellers-VARs). Following our field work, we collected primary data from VARs to test the refutable hypotheses, and find that the VARs add mixed systems consistent with our predictions.

Our results speak to both theory and practice. Our model extends the insights of two separate streams of literature. In isolation, each one concludes that adding mixed systems is a win-win outcome, but in combination, a very different picture emerges. In counterpoint to prior interoperability models, we show that not all feasible mixed systems with positive consumer

demand will be offered. In counterpoint to prior channels models where producers who engage a common reseller benefit from reduced competition, we show that a common VAR intensifies producer competition through the leverage gained by the latter adding limited mixed systems.

Turning to practice, our empirical work yields advice for producers and channel partners. First, downstream assortments are a strategic issue, and not simply a logistics or operational matter. Inevitably, a limited set of mixed systems are added to existing pure systems assortments. To ameliorate the problem of their own higher-margin components being excluded from these mixed systems, upstream firms can develop marketing programs like joint sales calls, support for buying equipment, etc. that reduce the VAR's own costs. Turning to the VAR, it is important to differentiate itself from other VARs. Not only does this improve its own downstream resale margins, but it also improves its upstream terms of trade because assortments can be strategically used.

The remainder of the paper is structured as follows. Immediately below, we review the extant literature to disclose the relevant constructs and gaps. Next, we develop the analytical model and its refutable predictions. The institutional details of our empirical efforts are detailed next, followed by the research design, data collection, and our results. The paper closes with a discussion of how our work applies more broadly to a variety of B2B and B2C settings.

## **LITERATURE**

There is an enormous literature on compatibility and standards (e.g., see Katz and Shapiro, 1985; Shapiro and Varian, 2013), but this is almost completely concerned with network externalities. The multi-component mixed systems at issue here do not involve externalities, so we must look to elsewhere for insight. There are three strands of relevant literature. Consider each in turn.

### ***Interoperability***

A small, but consistent strand of game-theoretic work on interoperability without network effects (e.g., Matutes and Regibeau, 1988, 1989, 1992; Economides, 1989) offers the following surprising takeaway. Interoperability is the dominant strategy for competing multi-component firms for two inter-related reasons; softer price competition, and greater product variety. To fix the intuition, consider two firms that compete in a two-component systems market. Each firm gains revenue whenever a mixed system is sold because one of their components is included. This positive effect reduces incentives to lower producer prices competitively, all else equal. Furthermore, each additional mixed system increases choices for customers; they can purchase a system configured more closely to their tastes, which increases their willingness to pay.

Notice, however, this literature abstracts away from channels intermediaries. Implicitly, this means that all mix-and-match systems enabled by extant technological interoperability are actually available to end customers. Thus, to the extent a downstream intermediary is involved, they passively pass-through all feasible mixed systems. As we noted earlier, conflict over mixed systems is pervasive, so we must look elsewhere for insights arising from downstream assortment choices.

### ***Downstream Assortments***

The set of systems for sale constitute an assortment, and each added mixed system increases the assortment size, thus we look for insights from the literature on assortments. Generally speaking, a larger assortment better meets consumer demand (e.g., Mahajan and van Ryzin, 2001), but there are limits to assortment expansion. Indeed, studies show that assortments can be profitably pruned by balancing assortment costs versus demand (e.g., Broniarczyk, Hoyer, and McAlister, 1988; Boatwright and Nunes, 2001, 2004; Kurtulus et al. 2014; Misra, 2010). The structure of assortment costs is the key takeaway for our purposes. Each expansion in assortment

size incurs a fixed cost, and these costs must be balanced against the additional demand to shape the final assortment.

### ***Common (multi-brand) Downstream Intermediaries***

Recall that mixed systems were added by a common downstream intermediary who mixes and matches components from competing producers. Understanding the pros and cons of single-brand (exclusive dealing) versus multiple-brand (common intermediary) is a long-standing concern in the marketing literature. As noted previously, the striking takeaway from the game-theoretic work (e.g., Choi, 1991; Moorthy, 2005) is that an intermediary who carries products of competing firms benefits these firms on account of softened upstream price competition. The limitation of this result is that they model only the single product case and abstract away from multiple products and assortments.

There is some work on multiple products (e.g., Coughlan, 1987; Cai, Dai and Zhou, 2012; Dong, Narasimhan and Zhu, 2009) but unfortunately, these studies assume that assortments are exogenously fixed. Endogenizing assortments and prices in the manner reflecting the behavior of intermediaries is a very complex modeling problem, and only one paper (Misra, 2010) has attempted to do it.

### ***Value-Added Resellers***

There are many different types of channels intermediaries. Notice that simply re-selling a pre-configured pure system is much less complicated than the skill and equipment required to combine components from competing firms to create mixed systems. Intermediaries with these skills and roles are denoted value-added-resellers (VARs)<sup>1</sup>, and they are characterized by a significant degree of involvement in configuration and installation tasks (e.g., Ghosh, Dutta and

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<sup>1</sup> In information technology settings, they are also denoted as “systems integrators” which highlights their role in combining components into a workable system.



Stremersch, 2006). They actively select the components to be included, and may price individual components separately versus determining only an overall system price (e.g., Ray, Wood and Messinger, 2012). Finally, VARs often receive subsidies from manufacturers to offset the higher cost of acquiring specialized equipment and training needed relative to channel member who resell pre-configured products.

### ***Summary of Gaps***

There is no work that has incorporated the important elements of our problem; viz. multi-component systems sold through resellers who actively choose to add mixed systems to their assortments. Extrapolating the extant takeaways to our setting, it might seem that producers welcome VARs who add mixed systems. However, this conclusion is at odds with our anecdotal observations of channel conflict over these added systems. We develop a formal model below to sort through these conflicting implications.

## **MODEL**

### ***Customers***

Figure 1(a) describes our customers and products. Each product is comprised of two components (A and B) produced by two manufacturers ( $M_1$  and  $M_2$ ). Denote  $A_1, B_1$  as the components from  $M_1$ ;  $A_2, B_2$  are the competing components from  $M_2$ . The two pure systems are  $A_1B_1$  and  $A_2B_2$ . With technological interoperability, in principle, there are two feasible mixed systems ( $A_1B_2$  and  $A_2B_1$ ) that can be added to the two pure systems.

(----- Figure 1 about here -----)

Following extant models of multi-component systems (e.g., Matutes and Regibeau, 1988), potential customers are located uniformly over a unit square with a common reservation price,  $\rho$ . The x- and y- axes represent the performance or quality levels of the A and B components respectively. The four systems are located at the corners. Since we have ruled out

self-assembly by an end consumer, all sales are made as system sales. As such, a system located at a point  $(x,y)$  away from a consumer yields net utility of  $\rho - (g_A x + g_B y) - p$ , where  $p$  is the price,<sup>2</sup> and  $g_A$  and  $g_B$  are the weights of the attributes, or equivalently, their differentiation.

### ***System Architecture***

Denote the *symmetry* of the system's architecture ( $\gamma$ ) as  $g_A / g_B$ . Without loss of generality, we normalize the more differentiated component, B, to 1; i.e.,  $g_B = 1$ , and  $\gamma = g_A$ . As  $\gamma \rightarrow 1$  the architecture is more symmetric, and vice versa. Intuitively, more asymmetric systems (smaller  $\gamma$ ) have one *keystone* component that is more highly differentiated across manufacturers; thus, that component has a disproportionate impact on consumers' overall preferences and carries higher margins. To illustrate our concept, consider desktop computer systems. The differences between operating systems (e.g., Windows, OSX, etc.) likely contribute the most to the inter-brand differentiation of desktops relative to the contribution from differences between motherboards or keyboards. The operating system is the keystone component, and makes desktop computers a relatively asymmetric system.

### ***Common Intermediary***

A common intermediary carries both manufacturers' products. The channel partner possesses the expertise to specify, assemble, test and install the additional mixed systems. Following extant work on assortments (Misra, 2010), we model their cost structure as follows. Operating costs are  $S = (S' + ns)$  where  $S'$  is the fixed cost of acquiring and maintain the skill to configure and install the pure systems carried,  $s$  is the fixed cost of creating and selling each additional mixed system, and  $n$  is the number of mixed systems added. We assume  $S'$  is low

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<sup>2</sup> Throughout, we assume that  $\rho$  is high enough such all consumers gain positive net utility from making some purchase. This ensures that the complete market is served under any combination of systems offered for sale and removes the market growth rationale for mixing and matching modeled by Wilson et al (1990). This sharpens the focus on interactions between the actors as the motivation for these mix and match decisions.

enough to allow the reseller to sell only the pure systems and still make a profit. Following extant work on VARs, we allow a fraction ( $\alpha$ ) of these costs to be subsidized by the manufacturer.

We assume that the reseller operates at a fixed margin,  $t$ , which simplifies the analysis considerably. A more complex model with explicit reseller pricing and reseller competition yields qualitatively similar results<sup>3</sup>.

The reseller chooses the composition and number of mixed systems to be added to the two pure systems. There are three assortments to consider, a) one pure assortment (P), consisting of the two pure systems  $\{A_1B_1, A_2B_2\}$ , b) two incomplete assortments (N1, N2) each consisting of two pure and one mixed systems,  $\{A_1B_1, A_2B_2, A_1B_2\}$  and  $\{A_1B_1, A_2B_2, A_2B_1\}$  respectively, and c) one complete assortment (C) consisting of two pure and two mixed systems  $\{A_1B_1, A_2B_2, A_1B_2, A_2B_1\}$ .

### ***Producers***

Denote  $c_A$  and  $c_B$  as the production costs of the two components. In order to distinguish strategic channel motivations from producer- or component-specific differences, we consider symmetric components and firms, i.e.,  $c_A = c_B = c$ .<sup>4</sup> Each manufacturer also incurs a fixed cost,  $K$ , and chooses its wholesale prices,  $w_{jA}$  and  $w_{jB}$ , as well as the fraction,  $\alpha_j$ , of the reseller's selling costs ( $S'$ ) that it will subsidize. These subsidies are provided directly and indirectly through support programs, including demonstration units, sales training, co-op advertising, write-downs etc. Notice, however, that the manufacturers do not directly subsidize the VAR's costs of adding mixed systems.

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<sup>3</sup> A single reseller model is used for expositional simplicity while still allowing us to derive our key results. A more complex model with competing resellers is included in the Web Appendix.

<sup>4</sup> Our results only require these costs are close enough to make sales from the more differentiated component more profitable for manufacturer. If the cost of producing the more differentiated component is too high, the value of being included in a mixed system is less valuable to manufacturers.

### *Vertical Game*

Figure 1(b) represents the sequence of moves. In Stage 1, each producer chooses its wholesale (component) prices and subsidy fraction, while taking the other producer's actions as given (Bertrand-Nash). In Stage 2, the VAR makes its assortment decisions after observing the manufacturers' choices (Stackelberg follower). Finally, consumers make their systems purchase decisions after observing the assortments and retail prices.

### *Equilibrium Choices*

We solve backwards from the consumers' purchase decisions to determine the equilibrium assortment of the VAR. For the most part we obtain closed form results; we call out the numerical results as appropriate. To conserve space, we provide the key mathematical outlines of the model in the Appendix and provide more details in the Web Appendix. The insights from the model's propositions are discussed immediately below.

**Proposition 1:** In equilibrium, more asymmetric system architectures induce more mixed systems.

This result arises from strategic motives. The intermediary limits her assortments to get a larger subsidy from upstream producers, who in turn have a greater incentive to do so because a relatively high-margin component might be excluded from the limited assortment of mixed systems. In equilibrium, this results in more mixed systems being added for more asymmetric system architectures.

**Proposition 2:** In equilibrium, a more differentiated intermediary yields more mixed systems.

This result arises from consumer demand for mixed systems. Resellers earning higher margins on account of their differentiation from other resellers are more motivated to satisfy

demand. Such resellers are inclined to carry any mixed system that might conceivably be asked for by a consumer.

### **EMPIRICAL STUDY**

We seek to establish support for our two propositions. We begin with field interviews to pin down the institutional details of a suitable industry context, and to develop and refine the data collection instruments. In the final stage, we conduct a national mail survey of informants from value-added resellers in the selected industry. Our field interviews were conducted in the Summer and Fall of 1998, followed by our survey May- November, 1999.

#### ***Industry Setting***

Auto collision and repair shops that repaint automobiles represent a multi-billion dollar industry. There are two basic painting systems available to repaint an automobile;<sup>5</sup> the basecoat-clearcoat (BCC) painting system and the single stage paint-activator (SPV) painting system. Each of these systems is comprised of two components. The BCC system consists of a basecoat component that provides the foundation layer on the bare metal and a clearcoat component that imparts color and gloss to the finished surface. The SPV system consists of a single-stage-paint component, and an activator component. All these components are stored separately, and loaded into applicators in order to execute a job. A value-added-reseller chooses the brands of components, matches the colors, and applies the paint to the customer's vehicle. Do-it-yourself sales are not a significant factor given the cost, and complexity of the task and the regulatory environment.

*Interoperability.* This industry follows the historical path described by Wilson et al (1990). Improvements in technological standards have greatly modularized hitherto non-standard configurations. The Pantone color standards are probably the most important standard interface;

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<sup>5</sup> <http://www.ibisworld.com/industry/default.aspx?indid=1694> (Dec 25, 2015).

a given Pantone number (e.g., Green 0921 C) will yield the same color regardless of the brand which enables mixing and matching of different brands with consistent results.

There are six major producers of paint. Given extant interoperability, a VAR who initially has six pure BCC systems, could, in principle, add 30 mixed systems. However, during our field visits, we observed that, often, these intermediaries added a smaller, selective subset of mixed systems. To illustrate, one VAR we visited added five mixed BCC systems to the six pure systems; each mixed system consisted of the leading firm's clearcoat component combined with a basecoat from one of the other five firms.<sup>6</sup> From our interviews, these self-limited additions appear driven by several factors, including the VAR's own costs, end consumer perceptions of quality and producer incentives. For instance, a VAR incurs a cost to carry and market each additional mixed system due to the added assets needed for storage, mixing and spraying, similar to the cost of adding a SKU in the reseller assortment literature (e.g. Misra, 2010).

*Asymmetry.* Recall we defined asymmetry with reference to the pattern of end user preferences across different brands of a component. With BCC systems, consumers perceived greater differences, and have stronger preferences across the different clearcoat brands. In contrast, the perceived differentiation across different basecoat brands is much lower, and almost invisible to the consumer. As a consequence, a VAR can more readily switch out a basecoat compared to a clearcoat to create a mixed system, without diminishing its appeal to a customer. Indeed, the leading firm's marketing managers confirmed to us that its basecoat was the component that was most commonly switched out in favor of a less reputed basecoat brand in the added mixed system.

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<sup>6</sup> Parenthetically, we note that a manufacturer can prevent mixed systems with an exclusive dealing contract. However, such exclusivity is rare in this market.

In contrast to BCC systems, SPV systems are much less asymmetric. The two SPV components (the single-stage paint and the activator) are fairly equally differentiated across the six brands. This is because both SPV components play a role in imparting the visible gloss and finish.

These architectural differences carry over into margins as well; keystone components carry relatively higher margins. For BCC systems, a clearcoat yields a higher margin than does its corresponding basecoat. Thus, when a firm's clearcoat is substituted out, leaving only their lower-margin basecoat in a mixed system, the loss of revenues creates channel conflict. In the SPV systems, such conflicts over exclusion from a mixed system are more muted because the margins for the single-stage component and activator are relatively more equal. In our interviews, our cooperating manufacturer said its revenue loss from its components being switched out from mixed systems by VARs was around 5–15% of its multi-billion dollar sales.

### ***Appropriateness of Industry Setting***

An appropriate research context for the question at hand must satisfy the following conditions: (i) intermediaries (VARs) sell multi-component systems with insignificant self-assembly by end-users, (ii) technological interoperability between components from different firms permit mixed systems, (iii) VARs carry multiple manufacturers' brands (no exclusive dealing). Consider these elements in our selected setting.

With respect to (i), realistically, end users cannot buy separate paint components and paint repaired automobiles themselves. The skills and tools needed are simply out of reach, not to mention the costs of environmental compliance. The capital equipment needed and the environmental hazards associated with painting require the expertise and investments of VARs. They buy the applicators, mixing units, etc., and these costs grow as more systems are added to their assortment. Criterion (ii) is satisfied because there are no serious technological

impediments or contractual restrictions on mixing and matching components from different producers. The economics of combining components from different manufacturers do not foreclose VARs from including mixed systems, if they are so inclined. Indeed, mixed systems are pervasive at these businesses. Criterion (iii) is satisfied as we found very little exclusive dealing contracts in this channel; almost all VARs carry competing lines.

### ***Preliminary Industry Evidence***

The VAR's behavior regarding mixed systems is our core concern. We undertake two efforts: (a) establishing the existence, extent and variation in mixed system emphasis across VARs and across the BCC and SPV systems; and (b) establishing the salient influences on the VARs' assortment decisions in this empirical setting.

In addition to the field study described above that we conducted with industry participants, a leading paint manufacturer provided us with extracts from two reports commissioned the year prior to our own survey; a) a utilization rate study performed by this firm, and b) a channel survey performed by this firm. These studies were prompted by management concern about their components being switched out and replaced with cheaper components in mixed systems. For our purposes, these studies are valuable because the data concretize our theoretical constructs, and the manner in which they manifest themselves in this setting. We caution that we did not have access to the entire studies themselves, or their methods; only extracts from the reports and data were made available. Further details are in the Web Appendix.

*OEM's Utilization Rate Study.* This study sought to establish the significance of lost sales because of their components being excluded from mix-and-match configurations sold by their VARs. Although the firm has detailed records about the volume of each its own components shipped to each intermediary location, one cannot invert their sales data to infer lost sales



because they do not know the mix of pure and mixed sales at that VAR. The VARs will not provide such data to the producer.

Instead, the report relied on the firm's engineering, and sales staff as well as internal business records to develop a "normalized" or benchmark utilization volume for each of their components (basecoats, clearcoats, single stage paints and activators) at each of 47 reseller locations, which represents the volumes that would have been sold if all their components were sold as pure systems. Denote this as the 100% utilization rate for each component.

The actual volumes of each component shipped are then divided into the benchmark volumes; these ratios are denoted as the utilization rates. These ratios range from 35% to 140%. A utilization rate less than 100% means that component was excluded from some mixed system sales; e.g., 35% implies that 65% of the would-be sales of that component were substituted away in favor of a competing firm's component through mixed systems sales. Conversely, 140% means that another firm's component was substituted out in favor of our component in mixed system sales.

The principal insight comes from the relative rates across components. In this regard, this firm under-achieved more so with its higher-margin components. For instance, its high-end line of activator component achieved a 35% utilization rate, while its two lower-end lines of activator components achieved better results (75% and 94%). Their VARs appear to switch away more of the firm's higher-margin components.

This pattern is consistent with our model's insight that the reseller chooses mixed systems strategically to gain leverage against the firm. Channel conflict over this issue is understandable. These estimated utilization rates are also markedly different across the 47 locations studied— smaller VARs display a greater tendency towards mixed systems. This gives

us confidence that variation across VAR locations points to meaningful variation in our constructs of interest.

*OEM's Channel VAR Survey.* This survey was also undertaken prior to our own study, and had different objectives from the utilization rate study. We see that our constructs of interest arise within this study as well. For example, resellers located at locations with greater customer heterogeneity report greater mixed systems sales. This echoes our model insight that mixed systems are beneficial in catering to diverse customers. Second, resellers report that manufacturers exercise efforts to shape and influence their decisions about mixed systems. This also comports with our model that mixed systems decisions arise out of the vertical strategic interactions between the manufacturer and its reseller.

Collectively, these data offer evidence about the relevance of the model's constructs in this setting, and confirm the appropriateness of the setting to conduct a systematic test of our predictions.

### ***Survey Research Design***

The primary challenge for observational surveys is omitted variable bias. While our model highlights the effects of system architecture and VAR differentiation on mixed systems assortment, plainly, many other variables (both nuisance factors and theoretically relevant factors) are also likely to influence the outcome variable. Our research design controls for the unobserved variable problem in two ways.

*Controlling for Unobserved Effects.* Repeated measurements on the same observational unit afford control for unobserved effects even with observational data, so panels have become the preferred design for observational studies. Our design created such an observational structure. Recall that each VAR sells both BCC and SPV systems. Thus, any unobserved VAR-specific effect should be constant across the two (repeated) observations at the same VAR. These

dual observations create a nested structure (painting system within VAR), which controls for VAR-specific unobserved effects.

*Control Variables.* In addition to the focal independent variables, (asymmetry and differentiation), we measured other factors (e.g., customer heterogeneity) implicated in the related literature as well as the firm's own reports.

### ***Data Collection***

Panel data from administrative records of prices and quantities of each component sold and the composition of the components comprising each transaction at a sample of VARs might be the ideal dependent measure of mixed systems. However, neither the upstream firms nor even the VARs themselves possess such data. Recall the OEM's own utilization rate study relied on indirect estimates given the absence of such data. We concluded a survey-based data collection effort was the most feasible approach.

*Sampling Plan.* We sampled from a frame consisting of a national list of 2,819 auto-paint refinish resellers, purchased from Dunn and Bradstreet.<sup>7</sup> After screening the list for incomplete records, and obviously inappropriate addresses or names, we retained 1092 names. Our key informants were managers responsible for the selection, evaluation and marketing of the assortment of systems marketed by that VAR. They were identified in four stages. First, an introductory letter was mailed requesting their participation. Second, they were contacted by phone to qualify the firm and informant, and to ensure willingness to participate. We verified that their firms were indeed independent channel members, and that they carried products from a minimum of two manufacturers.

Our efforts yielded 308 qualified contacts who agreed to participate in the study. They were mailed a survey packet including a postage-paid return envelope. Prior to the full mail-out,

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<sup>7</sup> We specified NAICS 423120 (Motor Vehicle Supplies and New Parts Merchant Wholesalers).

we conducted an extensive pre-test.<sup>8</sup> We made reminder calls two weeks after the mailing, and a new survey was mailed as needed. Thirty-four respondents declined to participate. We received 110 surveys, and we discarded six surveys because of excessive missing data. Using the 104 usable responses, the response rate was calculated at about 30.1%. (In our analysis later, the effective sample size is 97 because of list-wise deletion of missing data.)

### ***Dependent Variable Measures***

Proposition 1 speaks to the VAR's limited mixed systems assortment. The model equilibrium abstracts this to three systems – two pure and one mixed system versus the four systems in the complete assortment. Proposition 2 concerns incentives to expand the assortment of mixed systems, abstracted in the model to four systems – two pure and two mixed systems versus the three-system assortment.

At first glance, the obvious candidate dependent measure seems to be the number of mixed systems sold by the VAR. As detailed previously, such data are unavailable from accounting records. We attack the problem as follows. Observationally, the difference between selling three and four systems in the abstracted model is the self-imposed restriction on the number of mixed systems sold. Selling three systems represent a restriction on selling mixed systems versus the full four system assortment. Notice that the pure systems at hand constitute part of that VAR's assortment in both conditions. This allows us to place a VAR's behavior on a continuum as follows. At one end, the VAR sells its pure systems and proactively sells certain

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<sup>8</sup> In the pre-test of the survey we first personally contacted a total of 15 channel firms' managers in and around a large mid-western metropolis. They were briefed on the general purpose of the research and were given a survey packet with a postage paid return envelope. A total of 6 agreed to help and all gave us their written comments on the survey in general, and for specific questions they felt was unclear. A personal debriefing session was conducted subsequently to clarify each question and comment. The feedback was incorporated in the final instrument. Finally, before mailing any survey we tested the survey with one manufacturer's marketing staff and a sample of the qualified key informants. This pre-test was conducted between March and May, 1999.

mixed systems. At the other end, the VAR sells the same pure systems but is willing to meet customer requests for any feasible mixed system.

Now, observe that any VAR who carries  $n$  pure systems is, literally speaking, carrying  $n \times (n - 1)$  mixed systems as well because each component is stored and applied separately. Thus, one VAR we observed in our field study who carried six BCC brands literally “carried” 30 mixed systems as well because of the 12 components at hand. While the VAR’s goals and actions for its six pure systems are negotiated with the six manufacturers, mixed systems sales are their own initiative. In fact, this particular VAR proactively marketed only certain favored mixed systems, while specifically forgoing others. However, this VAR could have elected to be agnostic about mixed systems, and be neutrally disposed to providing *any* mixed systems requested by a customer. This would be tantamount to allowing customers to freely mix and match thereby de-emphasizing specific mixed systems sales. Thus, in developing a dependent measure of mixed systems sales, the list of component SKUs at a VAR does not suffice, because this does not tell us if all feasible mixed systems are actually being sold. Transaction level data on the components of each sale might appear to contain the necessary information, but this is infeasible given the channel members’ wariness about sharing information about this channel conflict issue. Mixing and matching is a sensitive topic because of the gains and losses to the different channel actors.

As such, our dependent measure is the VAR’s self-reported focus on proactively selling mixed systems. At the top end of this continuum, the VAR’s sales effort focuses proactively on mixed systems, whereas at the bottom end, the VAR does not put any particular effort into pushing sales of mixed systems; instead, they reactively allow free mixing and matching as demanded by the consumer.

*VAR Focus on Mixed Systems.* A 3 item scale was constructed for each of the two systems (BCC and SPV) using their responses to the following questions. Denote the measure as *Mix\_bcc* for BCC, and *Mix\_spv* for SPV. Larger numbers represent a greater VAR focus on mixed systems.

For the BCC (SPV) systems you sell, please assess the nature of your sales efforts for mixed systems vis-à-vis that of pure systems. (reversed 7-point scale from “ALWAYS mixed/NEVER pure systems” to “ALWAYS pure/NEVER mixed systems”)

1. Our sales of BCC (SPV) systems are:
2. Our sales pitch for BCC (SPV) systems emphasizes:
3. Our pricing for BCC (SPV) systems emphasizes:

The observable pattern of data that corresponds from propositions 1 and 2 are as follows:

**H1:** VAR focus on mixed systems is positively associated with system asymmetry.

**H2:** VAR focus on mixed systems is negatively associated with VAR differentiation.

### ***Independent Variables***

*System Asymmetry.* Recall that  $\gamma$  denoted the ratio of the importance attached by consumers to the two components after normalizing the more differentiated component, “B”, to 1 (i.e.,  $g_B=1$ ); thus  $\gamma=g_A/g_B$  reduces to  $g_A$ . We construct our *asymmetry* measure as follows. First, we identify the more differentiated component, B, for each painting system as follows:

For the BCC (SPV) systems that you carry, please circle the more important component with respect to the four issues below. (response format is Basecoat/Clearcoat; SingleStage/Activator)

1. Impact on system performance:
2. Delivering customer value:
3. Impact on system quality:
4. Impact on technical requirements:

(----- Table 1 about here -----)

Table 1 shows that virtually all (93%) informants identified the clearcoat as the more important component for BCC systems. A similar percentage identified the Single Stage Paint as

the more important component for SPV systems. Thus, we identify clearcoat and single-stage paint as the “B” components for BCC and SPV systems respectively.

Next, we capitalize on the fact that the manufacturer’s margins vary directly with the differentiation of a component. As such, we asked the informant to assign points to the components as follows:

For the BCC (SPV) systems carried, please assign 100 points in proportion to the contribution of the components to the bottom line of a typical full-line manufacturer.

Basecoat —%, Clearcoat —% (SingleStage —%, Activator —%)

Our *asymmetry* measures,  $Asym\_bcc$  and  $Asym\_spv$  for the BCC and SPV systems respectively, are constructed from the question as follows. The difference in points assigned to B versus A component for each system represents asymmetry with bigger numbers representing more asymmetry.

*VAR Differentiation.* In our model,  $t$  is the extent to which a VAR is differentiated from other VARs in its market. We measure this construct with three questions that assess the ease with which a VAR’s customers can migrate to another VAR. The measure is denoted  $VARdiff$  with larger numbers representing more differentiation. Notice this varies at the level of the VAR, not the painting system.

Please circle your response to each question below (7-point format – Strongly Disagree to Strongly Agree)

1. There are needs of the customer that cannot be easily addressed by other firms. (SW2).
2. There are not many other vendors that can meet the customer’s needs as well as we can. (SW3).
3. It will take a lot of time and effort for the customer to find another vendor to substitute our firm. (SW4).

*Customer Heterogeneity.* Extant work on multi-component systems (e.g., Wilson et al, 1990) shows that heterogeneous customer preferences are more closely satisfied by mixed and matched systems. Thus, the VAR’s emphasis on mixed systems might well be expected to track greater heterogeneity in their customers’ preferences. Our scale measure, *Heter*, consists of the

following three items. Notice this varies at the level of the VAR, not the individual painting system.

For the systems carried, please circle your response to each question below (7-point format (reversed) – Strongly Disagree to Strongly Agree)

1. Our systems customers have very similar pricing needs (HET1).
2. Our systems customers have very similar needs for quality (HET2).
3. Our systems customers have very similar technical needs (HET3)

*Demand Expansion.* In the extant literature (e.g., Wilson et al, 1990) mixed systems expand market demand. Briefly, the increased variety offered by adding mixed systems attracts new customers whose needs are now better served with the added systems. Thus, the VAR's emphasis on mixed systems might well be expected to track a greater potential for market expansion in their market. Our scale measures of market demand for each painting system, denoted *Dmd\_bcc* and *Dmd\_spv* for the BCC and SPV painting systems respectively consist of the following three items.

For the BCC (SPV) mixed systems carried, please circle your response to each question below (7-point format – Strongly Disagree to Strongly Agree)

1. BCC (SPV) mixed systems tap unmet needs in the market. (DMB1, DMS1).
2. BCC (SPV) mixed systems cater to new customers. (DMB2, DMS2).
3. BCC (SPV) mixed systems keep customers one would otherwise lose. (DMB3, DMS3)

### ***Data Quality***

*Non-response.* We ascertained non-response bias in our final sample of 104 VARs in two ways. First, we compared the sample average annual sales against data from a national sample of resellers obtained from a leading paint manufacturer. Second, we divided the respondents themselves into early and late categories and compared their average monthly sales and the number of their direct competitors. No statistically significant differences were found in either case. We conclude that the data are sufficiently free of non-response bias to warrant further analysis.



*Multi-item Scale Quality.* Each multi-item scale (*Mix\_bcc*, *Mix\_spv*, *VARdiff*, *Dmd\_bcc*, *Dmd\_spv*, *Heter*) was subjected to the following analyses to ascertain their psychometric reliability and validity.

(----- Table 2 about here -----)

Following Gerbing and Anderson (1988), we estimated a confirmatory factor model, where each item loads only on its own underlying construct variable. We allowed for correlated errors for the items of the following construct pairs: *Mix\_bcc* – *Mix\_spv*, and *Dmd\_bcc* – *Dmd\_spv* to account for unobserved VAR-specific errors. The fit statistic ( $\chi^2(138) = 126.22$ ,  $p=0.75$ ) indicates a good fit. We present the covariance matrix in Table 2. The own-trait loadings as well as the composite scale reliability calculated from these estimates are shown in Table 3. See the Web Appendix for more details.

(----- Table 3 about here -----)

To assess discriminant validity, we estimated a series of confirmatory models, each of which constrained a particular inter-construct correlation at 1.0. The difference in fit between the baseline unrestricted model above and each of these restricted models tests the discriminant validity of the pair of constructs whose correlation was constrained. All these differences were significant at  $p < 0.001$ , which indicates that the constructs comprising each pair are discriminated from each other. Consider the fit differences for the most similar pairs. The *Mix\_bcc* – *Mix\_spv* pair is  $\chi^2(1) = 88.76$  ( $p < 0.001$ ) and that for the *Dmd\_bcc* – *Dmd\_spv* pair is  $\chi^2(1) = 114.91$  ( $p < 0.001$ ). In sum, our multi-item scales display sufficient internal consistency reliability (Cronbach's  $\alpha$  greater than 0.80) and are discriminated well from each other.

## RESULTS

### *Sample Characteristics*

The median VAR is an independently owned and operated business with \$960,000 in annual sales, and has long run, albeit non-contractual, supplier ties (15 years median), and their primary supplier accounts for 30% of its business. On average, they face three direct competitors at their location.

Approximately 80% of VARs combined their primary supplier's BCC clearcoat with some other supplier's BCC basecoat. Likewise, 76% combined their primary supplier's SPV single-stage component with another supplier's SPV activator component. The inter-quartile range of mixed systems sales is 5–57% for BCC and 5–67% for SPV, so mixed systems are pervasive, and this varies considerably in our sample. Furthermore, as Table 4 shows, the fraction of mixed systems sales grows with overall sales. Mixed systems comprise 10% of sales for the bottom quartile of VARs, but over 50% for the top quartile.

(----- Table 4 about here -----)

However, the median VAR added only 33% of the feasible number of mixed BCC systems, and 12% of the number of feasible mixed SPV systems. In sum, mixed systems are commonplace, but they constitute a) a limited subset of the feasible set, and b) the BCC mixed system assortments are larger than the corresponding SPV assortments. These are directionally supportive of the model's predictions that mixed systems assortments are pervasive, but limited, in scope and that the more asymmetric system (BCC) induces greater mixed systems assortments.

### ***Tests of Hypotheses***

Recall that our hypotheses posited that system asymmetry and VAR differentiation influenced VAR behavior for BCC, SPV systems. In addition, we controlled for demand expansion and customer heterogeneity and unobserved effects. As such, we estimate the following equation system.

$$Mix\_BCC = \gamma_{11}Asym\_BCC + \gamma_{12}VARdiff + \gamma_{13}Dmd\_BCC + \gamma_{14}Heter + \zeta_1$$

$$Mix\_SPV = \gamma_{21}Asym\_SPV + \gamma_{22}VARdiff + \gamma_{23}Dmd\_SPV + \gamma_{24}Heter + \zeta_2$$

Each construct that is measured with a multiple item scale has an associated measurement model that is included in the estimation, but these are suppressed here for clarity. (Please see the Web Appendix for more details). Importantly, the covariance of the equation errors,  $\sigma(\zeta_1, \zeta_2)$ , accounts for unobserved VAR-specific effects. A test of the joint significance of the *Asym\_BCC* and *Asym\_SPV* coefficients establishes support for the asymmetry effect (H1), while the joint significance of the *VARdiff* coefficients establishes support for the VAR differentiation effect (H2). The *Dmd\_BCC* and *Dmd\_SPV* coefficients represent demand expansion effects, and *Heter* coefficients represent customer heterogeneity effects.

We estimate these equations via maximum likelihood procedures. Table 5 reveal a good fit of the model to the data ( $\chi^2(142) = 134.97$ ,  $p = 0.65$ ). As noted previously, the measurement coefficients are suppressed for clarity. Several constrained models were estimated to test the hypotheses.

(----- Table 5 about here -----)

A constrained model where *Asym\_BCC* ( $\gamma_{11}$ ) and *Asym\_SPV* ( $\gamma_{21}$ ) coefficients are set to zero shows a significant drop in fit ( $\chi^2(144) = 149$ ;  $\Delta\chi^2(2) = 14$ ,  $p < 0.01$ ). The positive  $\gamma_{11}$  and  $\gamma_{21}$  coefficients are in the direction posited in H1. Greater asymmetry induces a greater emphasis on mixed systems.

A constrained model where the *VARdiff* coefficients are set to zero shows a significant drop in model fit ( $\chi^2(144) = 144$ ;  $\Delta\chi^2(2) = 9$ ,  $p < 0.01$ ). The negative  $\gamma_{12}$  and  $\gamma_{22}$  coefficients are in the direction posited in H2. More differentiated VARs focus less on mixed systems sales.

A constrained model where the *Dmd\_BCC* and *Dmd\_SPV* coefficients are set to zero reveals a significant positive effect. VARs facing the possibility of greater demand expansion have a greater focus on mixed systems focus.

Finally, a constrained model with the *Heter* coefficients set to zero reveals a significant positive effect. VARs facing a more heterogeneous mix of customers have a greater focus on mixed systems. (Please see the Web Appendix for additional details of our analyses.)

## DISCUSSION

In many industries, technological interoperability enables mixing and matching components from different producers to create mixed systems. The expanded assortment increases consumer choice, but manufacturers lose revenues when their own higher-margin component is switched out. An added complication is that the expertise needed to configure, assemble, install and test these systems is often beyond the capabilities of end customers, so value-added channel intermediaries perform these tasks. However, they have their own motives and incentives, which may conflict with the upstream manufacturers. We assess these competing effects with a game theoretic analytic model of this channel, and subsequent empirical tests.

In equilibrium, our model predicts that VARs add mixed systems, but they strategically limit the number and composition of the added systems. There are two sharp takeaways. First, VARs add more mixed systems when asymmetries are greater; i.e., customer preferences are dominated by keystone components. Second, VARs add fewer mixed systems when they are more differentiated from competing VARs.

We collaborated with the leading manufacturer in the automobile paint refinish business, who provided us with extracts from two separate studies that sought to pin down the scale, scope and consequences of mixed systems added by VARs. Not only do these efforts indicate the economic importance of this issue, but they provide evidence that our constructs are salient in

this industry setting, and that these patterns vary meaningfully at the level of individual VARs and systems.

Next, we mounted our own empirical study of this industry. After controlling for unobserved VAR-specific effects with our twinned survey observations per VAR, we find statistical support for two key model predictions; the more asymmetric architecture of BCC systems evoke a greater focus on mixed systems, while more differentiated VARs focused less on mixed systems.

### ***Theory Implications***

Our work offers a counterpoint to the takeaway from two complementary strands of the analytic modeling literature. First, when producers employ a common reseller, channels models (e.g., Choi, 1991) show that producer competition is reduced. Second, when firms compete to sell multi-component systems, (e.g., Matutes and Regibeau, 1988) interoperability reduces producer competition. In contrast, our VARs intensify competition between producers by their selective addition of mixed systems. We also contribute to the long-standing interest in vertical strategic interactions in channels. While the extant theoretical work focuses almost exclusively on pricing, we include assortments as an additional strategic decision, which extends the prior takeaways. In spirit this is similar to the extant work in the transaction cost literature that has studied dependence balancing (e.g., Heide and John, 1988) where a channel member balances its dependence on its powerful upstream partner by developing stronger customer bonds downstream, which provides leverage against opportunistically inclined upstream partners.

### ***Managerial Implications***

To a manufacturer, every added mixed system appears to be a revenue loss because his own component is switched out for a component from another firm. An instinctive move is to impose contractual obligations on the VAR, such as disallowing warranties for their own

components when included in a mixed system, or enforcing fixed-proportions quotas on them (i.e., sell  $n$  units of component A, and  $m$  units of component B) or offering support contingent on resellers disavowing mixed systems. These are blunt instruments, and even large, prominent firms find themselves involved in costly litigation over such requirements.

For example, BASF provided paint mixing equipment to a reseller, Sublime, on the condition that only BASF-produced paint could be used in the equipment, which effectively disallowed mixed system. Sublime allegedly violated these stipulations (BASF v. Sublime, 2012). Similarly, PPG provided investment and support to its reseller, J.A. McFall Inc. on the condition that only PPG-produced paint was sold with its support (PPG v. J.A. McFall, 2011). Notice that this is also an effort to exclude mixed systems. Here too, this resulted in litigation over the reseller's alleged violation of the requirement. Akzo Nobel's reseller, Auto Paint and Supply, was subject to an exclusive dealing requirement which APS allegedly violated by negotiating to carry DuPont's painting systems (AKZO v. Auto Paint and Supply, 2011).

Our view is that contractual efforts to disallow mixed systems within an interoperable components market is foolhardy even for large, powerful firms. As our model and data show, there are powerful economic and technological forces that work to add mixed systems. A more balanced approach would first appraise the potential for adding mixed systems, and then fashion remedies in a targeted fashion. To begin with, we know that asymmetric systems with keystone components which disproportionately influence customer preferences are more at risk.

Our advice is to fashion unilateral support programs for resellers commensurate with the risk to shoulder their costs and to support their margins. Indeed, our own data can be marshalled to provide support for such a response.

### *Devising Support Programs*

Recall our theory that mixed systems leverages the VAR's position against its suppliers, so greater support from the manufacturer reduces the VAR focus on mixed systems. What forms of manufacturer support might be useful? During our fieldwork, we identified several programs and arrangements. Some of these programs reduce out of pocket expenses for the VAR (e.g., subsidized equipment, coop advertising, etc.) while other protect their margins (e.g., exclusive territory, inventory buy-backs, etc.). In our survey, we asked informants whether they engage their primary supplier on the following arrangements:

- (a) Co-operative advertising;
- (b) Joint Sales Calls;
- (c) Subsidized Equipment/Services for their (VAR's) Customers
- (d) Exclusive Territory Agreement
- (e) Just-in-Time Delivery
- (f) Excess Inventory Buy-Backs
- (g) Warranty coverage for Mixed Systems.

(----- Table 6 about here -----)

Table 6 shows that these support programs are pervasive, with participation ranging from 85% for subsidized equipment to 13% for warranties. Is greater participation associated with less mixed system focus?

We created a formative scale measure comprised of the number of program elements the VAR participates for BCC (*part\_BCC*; mean=3.682; median=4) and SPV (*part\_SPV*; mean=3.422; median=3) systems. Correlating these participation measures with our mixed system focus measures, we find a significant negative correlation for BCC ( $-0.277$ ,  $p=0.004$ ) and a negative, albeit insignificant correlation for SPV. ( $-0.135$ ,  $p=0.215$ ).

A median split analysis of these data yields the same conclusions. The VAR's focus on mixed BCC is lower in the above-median BCC participation group, (mean *Mix\_BCC* = 2.624 for high group versus 3.374 for low,  $p = 0.004$ ). The corresponding difference is not significant for SPV systems (mean *Mix\_SPV* = 2.691 for high group versus 2.8214 for low,  $p = 0.734$ ).

Together, we see support for the theoretical expectation in BCC, and directional (but insignificant) support in SPV.

Overall, these analyses of manufacturer support programs support our theory-derived suggestions for practice. Greater VAR participation in these programs limits their mixed systems focus. These programs can be targeted at the most at-risk resellers; viz. the resellers facing the greatest economic pressure, and those with more heterogeneous customers.

Notice that our suggestions are at variance with the "all or none" approach that seems to drive the disputes in the litigated cases. Of course, these managerial recommendations rest on further research and stronger empirical evidence to support them, so they are best viewed as exploratory steps at this point. Hopefully, future work will establish their utility.

### ***Concluding Comments on Generalizability***

We have leaned heavily on the institutional details of the automobile paint refinish marketplace to develop our empirical tests. How generalizable are our results? Generalizability rests on the applicability of the primitives of the theory to other contexts combined with strong internal validity of the available empirical results.

Our model's primitives are as follows: a) systems comprised of interoperable components, b) the architecture of the system, and c) value-chain participants that assemble systems from competing firms. Consider them in turn.

Our first primitive, interoperability, is discernible in virtually every aspect of the economy. Recall that as technology progressed, modular designs emerge, and more comprehensive interconnect standards appear. Indeed, Chesbrough (2003) makes a compelling argument that these forces have transformed contemporary business models more broadly, particularly in innovative, and technologically sophisticated industries. Historically, innovation consisted of a firm-centric "closed" process, but these modularity trends have transformed



innovation into an inter-firm, “open” process. Thus, our model applies broadly beyond the specific industries and examples provided in the paper.

Our second primitive, system architecture, is also discernible to varying degrees across many settings. Keystone components that carry a disproportionate burden of differentiation, and which carry higher producer margins are identifiable in many instances. Recall that operating systems are the keystone components for desktops versus keyboards that have become a lowest common denominator component that is minimally differentiated across producers. In fact, it is hard to imagine a contemporary multi-component system where the magnitude of differences between each set of interoperable components are identical across the sets of components.

Our last primitive, assembly of components from multiple, competing firms by a downstream participant in the industry value chain is also commonly observed across many industries. In our specific setting, a value-added-reseller accomplishes this assembly task, but other parties take up the task elsewhere. For instance, in the heavy truck market, the task of matching components from suppliers, and assembling them into a final product is undertaken by OEMs like Peterbilt, Mack etc. using engines from Cummins, Caterpillar, etc. axles from Dana, Eaton, etc. and other components, but our model’s insights still apply. Notice that these OEMs are not vendor-neutral; they mix and match components selectively and strategically like our VARs.

In sum, the theoretical underpinnings of our work apply very broadly to current B2B and B2C settings. Is this potential generalizability compromised by our single-industry empirical research setting? We believe otherwise for three reasons. First, the multi-billion dollar automobile paint refresh market is economically significant in its own right. Second, this large single-industry setting strengthens the internal validity of the empirical results by minimizing extraneous variation, while resting our external validity claims on the broad applicability of the

primitives. Third, the vertical channel tensions that we highlight in our work continue to be significant factors in the current industry. We see this not only in the litigation between manufacturers and their resellers, but also in the technological changes over the last decade -- in particular, the emergence of nanotechnology amplifies the VAR role, by introducing additional compatible components that can be added to the existing systems to modify properties such as scratch, wear and corrosion resistance of the paint job. Nevertheless, the industry continues to be characterized by a few major players and the two-component systems we study, are still a big focus in today's marketplace. So, while our specific ratios and numbers may not represent the current market, the direction and importance of the incentives we study are likely to be just as relevant. That said, confirmation of our results in other settings would obviously strengthen them, so further work in other settings is warranted.

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## MODEL APPENDIX

### ***Consumer Demand***

The consumer at  $(x,y)$  derives net utility  $U_{(x,y)}(i,j) = \{\rho - p^{ij} - \gamma d_x - d_y\}$  from system  $A_i B_j$ , where  $d_x$  and  $d_y$  are the distances of the system's location from  $(x,y)$ . The consumer maximization problem is  $U_{(x,y)}^* = \underset{i,j}{Max}[U_{(x,y)}(i,j)]$ . We derive demand expressions shown in Table 1(a) for the four assortments (P, N1, N2, and C). Details on the derivations of these demand expressions are presented in the Web Appendix.

(----- Table A1 about here -----)

### ***Assortments***

The downstream intermediary chooses the assortment  $\sigma$  (i.e., P, N1, N2 and C assortments) to maximize its profits. The objective function is:

$$Max_{\sigma} \Pi = t \cdot q_{\sigma} - S_{\sigma} + F_1(\sigma) + F_2(\sigma)$$

where  $q_{\sigma}$  is the demand vector from Table 1,  $S_{\sigma}$  is the intermediary's fixed costs with  $S_P = S'$ ,  $S_{N1} = S_{N2} = S' + s$ ,  $S_C = S' + 2s$  for the four assortments respectively, and  $F_1(\cdot)$  and  $F_2(\cdot)$  are the subsidies from Manufacturers 1 and 2 respectively.

### ***Manufacturer Decisions***

Each manufacturer chooses its wholesale prices,  $w$ , and subsidy payments,  $F$ , in a Bertrand-Nash fashion with the other manufacturer, while acting as a Stackelberg leader who incorporates the downstream assortment reactions and mark-ups into its decision. We assume that the upstream manufacturers know both  $S'$  and  $s$ . We solve this problem by folding the downstream payoffs into the manufacturer's maximization problem. Consider the price and subsidy in turn.

*Wholesale Prices.* For assortment  $\sigma$ , manufacturer  $i$ 's objective function is:

$Max_{w,F} \Pi_i = w^j \cdot q_\sigma^i - c_\sigma^i \cdot q_\sigma^i - F_{i\sigma} - K$  where,  $\tilde{w}^i$ , is the wholesale price vector,  $c_\sigma^i$  and  $q_\sigma^i$  are the component cost and system demand vectors relevant to  $\sigma$ ,  $F_{i\sigma}$  is the subsidy and  $K$  is the fixed cost of the manufacturer. We solve for the wholesale prices under each possible VAR assortment.

*Subsidies.* Each manufacturer chooses  $\alpha_j$ , the fraction of the intermediary's cost,  $S$  to be subsidized. Denote the resulting transfer,  $F_j$  as  $\alpha_j S$ . To solve for  $F_j$ , we first express the manufacturers' profits for each of the assortment cases by folding in the solutions above for the demand and wholesale prices. Given our assumptions on mark-ups and completely served market, the equilibrium demands are expressed wholly in terms of the wholesale prices as shown in Table A1(b). Writing down the manufacturers' problems we solve for the subsidies for each assortment.

### ***Equilibrium Assortment***

The intermediary's objective function is  $Max_\sigma \Pi = t \cdot q_\sigma - S_\sigma + F_1(\sigma) + F_2(\sigma)$ .

Substituting for previously solved demand and subsidy expressions, the payoffs for different assortments and costs are presented in Table A2(a). For each row (costs), we can identify the equilibrium assortment.

(----- Table A2 about here -----)

Notice the choices available depend on the costs. In the first row where  $s$  is so high as to make both the complete (C) and incomplete (N) assortments unprofitable, the only option is pure (P) ( $s \geq s_H$ , where  $s_H = t - S' + \Delta \Pi_N^*$ ). For the second row, the intermediate magnitude of  $s$  makes the pure (P) and incomplete (N1) assortments the only profitable options ( $s_L < s < s_H$ ). For the third row,  $s$  is low enough to make all assortment options profitable ( $s \leq s_L$ , where  $s_L = (t - S')/2$ ).

For each row, we identify the intermediary's best option as follows. In the first row (high  $s$ ), P is his only option. In the second row, the choice between the two feasible options (P, N1) depends on the relative magnitudes of  $s$  and  $\Delta\Pi_N^*$ . From above, we know that  $\partial \Delta\Pi_N^* / \partial \gamma < 0$ , so the incentive to shift to N is decreasing in  $\gamma$ . At  $\gamma = 1$ , the choice is P. As  $\gamma$  gets smaller, the choice moves towards N. In the third row (low  $s$ ), C is dominated by P, so the relevant choice is same as the previous row. Collecting these results, we can state the following:

**Proposition 1:** *As the asymmetry of the system's architecture increases, in equilibrium, a more mixed systems are added to the assortment.*

### ***Market Growth Considerations***

Thus far, we have considered a completely served market to isolate the vertical strategic incentives. However, market growth is cited as a rationale for mixing and matching interoperable components (e.g., Wilson et al., 1990). Is our proposition robust to allowing growth? To this end, we extend the model to allow customers to be able to leave the focal VAR and purchase a more preferred system elsewhere.

We introduce a parameter,  $T$ , as the migration cost to move away from this intermediary to purchase a more preferred system. Such customer switching costs are proportional to the degree to which the VAR is differentiated and are a source of margins for VARs. To simplify the exposition, therefore, we set  $T = t$  from our previous model and assume that prices at the other sources are similar to that of the focal VAR. All other assumptions remain identical.

### ***Equilibrium Assortments***

The intermediary's objective function now includes the potential lost customers ( $Q_\sigma^*$ ). Hence, it becomes  $Max_\sigma \Pi = t \cdot q_\sigma - S_\sigma + F_1(\sigma) + F_2(\sigma) - tQ_\sigma^*$  where  $q_\sigma$  is the demand vector,  $S_\sigma$ , the VAR's fixed costs with  $S_P = S'$ ,  $S_{N1} = S_{N2} = S' + s$ ,  $S_C = S' + 2s$  and  $F_1(\cdot)$  and  $F_2(\cdot)$  are the



subsidies from Manufacturers 1 and 2 respectively;  $Q_\sigma^*$  are as before with

$$Q_P^* = Q^*, Q_N^* = Q^*, Q_C^* = 0.$$

We keep the manufacturer's decisions the same as in the original model, so we have the same wholesale prices and subsidies solved for previously. Substituting for these previously solved expressions, the downstream payoffs for different assortments and costs are presented in Table A2(b). For each row (costs), we can identify the equilibrium assortment.

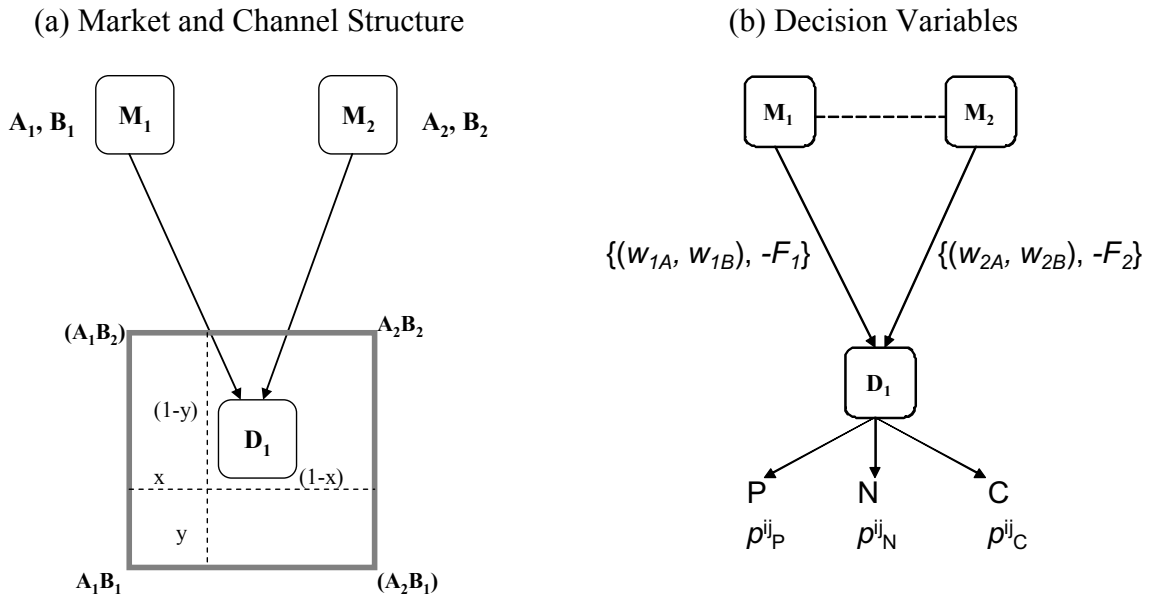
The VAR who limits his assortment of mixed systems loses incremental sales because some customers may consider those missing mixed systems to be a better fit for their needs. The magnitude of this loss is framed by  $t$ , the markup earned by the VAR. Crucially, more differentiated VARs earn higher margins per se, thus are more loath to lose these incremental sales. Instead, they are more inclined to reactively assemble and deliver any demanded system. The following proposition follows:

**Proposition 2:** *In equilibrium a more differentiated VAR adds more mixed systems to its incomplete assortment.*

From this, one can get a sense of the role of downstream costs and margins on mixed systems. If the focal VAR does not have high margins (low  $t$ ), the key to its profitability lies more in its ability to leverage asymmetry (lower  $\gamma$ ) than in preventing migration, leading to the incomplete assortment decisions. If on the other hand, the focal VAR has high margins (higher  $t$ ); it is much less willing to tolerate any migration due to limited assortments, especially if it cannot leverage sufficient asymmetry (high  $\gamma$ ), thereby leading to the complete assortment equilibrium. Figure A plots the parameter space that defines these outcomes.

(----- Figure A about here -----)

Figure 1: Model



M – Manufacturer; D – Downstream Intermediary;  
 A, B – Components;  $(x,y)$  – End Customer Location  
 W – Wholesale Price; F – Subsidy; P, N, C – Assortments;  
 $p^{ij}_A$  – Downstream price of product  $ij$  given assortment A

Figure A: Assortment Equilibria

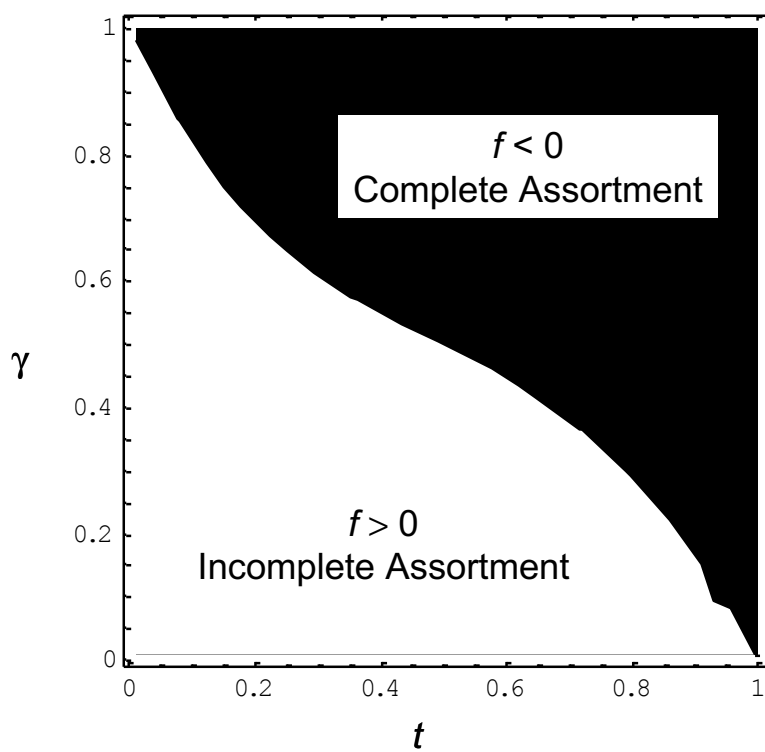


Table 1: Component Importance (in %)

(BC=Basecoat, CC=Clearcoat, AV=Activator, SS=Single Stage Paint)

| Items                            | BCC   |       |       |       | SPV  |       |       |       |
|----------------------------------|-------|-------|-------|-------|------|-------|-------|-------|
|                                  | BC    | CC    | Equal | Total | AV   | SS    | Equal | Total |
| optimum system performance       | 1.15  | 20.69 | 78.16 | 100   | 6.90 | 19.54 | 73.56 | 100   |
| (customer) expectations of value | 8.05  | 27.59 | 64.37 | 100   | 9.20 | 25.29 | 65.52 | 100   |
| (...) expectations of quality    | 6.90  | 32.18 | 60.92 | 100   | 5.75 | 24.14 | 70.11 | 100   |
| (...) technical needs            | 11.49 | 16.09 | 72.41 | 100   | 5.75 | 19.54 | 74.71 | 100   |
| Mean                             | 6.90  | 24.14 | 68.97 | 100   | 6.90 | 22.13 | 70.98 | 100   |

Table 2: Covariance Matrix

| Items | YNB1  | YNB3  | YNB4  | YNS1  | YNS3  | YNS4  | DMB1  | DMB2  | DMB3  | DMS1  | DMS2  | DMS3  | SW2   | SW3   | SW4   | HET1  | HET2  | HET3  | GB2     | GS2    |  |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---------|--------|--|
| YNB1  | 2.74  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |         |        |  |
| YNB3  | 2.17  | 2.41  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |         |        |  |
| YNB4  | 1.93  | 1.82  | 2.53  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |         |        |  |
| YNS1  | 1.93  | 1.57  | 1.39  | 2.74  |       |       |       |       |       |       |       |       |       |       |       |       |       |       |         |        |  |
| YNS3  | 1.79  | 1.66  | 1.40  | 2.27  | 2.62  |       |       |       |       |       |       |       |       |       |       |       |       |       |         |        |  |
| YNS4  | 1.81  | 1.47  | 1.93  | 2.12  | 2.11  | 3.09  |       |       |       |       |       |       |       |       |       |       |       |       |         |        |  |
| DMB1  | 0.81  | 0.55  | 0.46  | 0.75  | 0.73  | 0.66  | 3.15  |       |       |       |       |       |       |       |       |       |       |       |         |        |  |
| DMB2  | 1.08  | 0.75  | 0.93  | 1.18  | 0.92  | 0.99  | 2.42  | 3.54  |       |       |       |       |       |       |       |       |       |       |         |        |  |
| DMB3  | 0.80  | 0.52  | 0.82  | 0.90  | 0.60  | 1.08  | 1.95  | 2.35  | 3.46  |       |       |       |       |       |       |       |       |       |         |        |  |
| DMS1  | 0.94  | 0.74  | 0.69  | 1.28  | 0.95  | 1.14  | 1.87  | 1.60  | 1.01  | 3.25  |       |       |       |       |       |       |       |       |         |        |  |
| DMS2  | 1.08  | 0.91  | 0.89  | 1.52  | 1.16  | 1.34  | 1.39  | 2.10  | 1.25  | 2.52  | 3.36  |       |       |       |       |       |       |       |         |        |  |
| DMS3  | 0.79  | 0.59  | 0.93  | 1.43  | 1.03  | 1.47  | 1.24  | 1.55  | 1.95  | 2.40  | 2.61  | 3.77  |       |       |       |       |       |       |         |        |  |
| SW2   | -0.98 | -0.93 | -0.80 | -0.62 | -0.49 | -0.50 | -0.69 | -0.70 | -0.59 | -0.66 | -0.61 | -0.65 | 2.56  |       |       |       |       |       |         |        |  |
| SW3   | -1.10 | -0.96 | -0.89 | -0.90 | -0.65 | -0.84 | -0.61 | -0.79 | -0.45 | -0.83 | -0.86 | -0.82 | 2.00  | 2.90  |       |       |       |       |         |        |  |
| SW4   | -0.97 | -0.95 | -0.85 | -0.41 | -0.43 | -0.58 | -0.54 | -0.65 | -0.58 | -0.38 | -0.48 | -0.67 | 1.70  | 1.82  | 3.58  |       |       |       |         |        |  |
| HET1  | 0.59  | 0.64  | 0.58  | 0.19  | 0.43  | 0.22  | 0.00  | 0.15  | 0.05  | -0.10 | 0.00  | -0.22 | -0.69 | -0.52 | -0.27 | 1.81  |       |       |         |        |  |
| HET2  | 0.63  | 0.63  | 0.50  | 0.25  | 0.35  | 0.27  | 0.10  | 0.28  | 0.12  | -0.17 | 0.29  | -0.10 | -0.78 | -0.45 | -0.34 | 1.29  | 2.18  |       |         |        |  |
| HET3  | 0.52  | 0.52  | 0.32  | 0.15  | 0.18  | -0.02 | 0.09  | 0.33  | 0.19  | -0.12 | 0.29  | -0.11 | -0.76 | -0.22 | -0.37 | 1.11  | 1.68  | 2.03  |         |        |  |
| GB2   | -0.80 | 0.40  | -4.13 | -6.67 | -4.49 | -2.57 | 0.80  | -2.80 | -0.20 | 6.17  | 2.78  | -1.23 | 0.38  | 2.51  | 2.10  | -5.89 | -7.98 | -6.62 | 780.42  |        |  |
| GS2   | 12.00 | 11.61 | 8.22  | 19.01 | 18.70 | 15.55 | 5.45  | 3.42  | -0.53 | 10.43 | 11.39 | 11.40 | -4.27 | -9.65 | -0.60 | 4.74  | 4.22  | 1.12  | -424.28 | 975.19 |  |
| Mean  | 2.89  | 2.27  | 2.79  | 2.75  | 2.27  | 2.74  | 4.11  | 4.38  | 4.79  | 3.62  | 3.77  | 4.04  | 4.63  | 5.04  | 4.09  | 2.83  | 2.80  | 2.96  | 4.96    | 10.31  |  |

Table 3: Measure Validity

| Factors                          | Items | Reliability<br>$\alpha$ | Confirmatory Factor Analysis |         |
|----------------------------------|-------|-------------------------|------------------------------|---------|
|                                  |       |                         | Std. Loadings.               | t-value |
| <i>Mix_bcc</i>                   | YNB1  | 0.92                    | 0.93                         | 11.70   |
|                                  | YNB2  |                         | 0.91                         | 11.44   |
|                                  | YNB3  |                         | 0.79                         | 9.41    |
| <i>Mix_spv</i>                   | YNS1  | 0.91                    | 0.92                         | 11.60   |
|                                  | YNS2  |                         | 0.91                         | 11.46   |
|                                  | YNS3  |                         | 0.80                         | 9.67    |
| <i>Dmd_bcc</i>                   | DMB1  | 0.86                    | 0.80                         | 9.43    |
|                                  | DMB2  |                         | 0.90                         | 10.88   |
|                                  | DMB3  |                         | 0.76                         | 8.93    |
| <i>Dmd_spv</i>                   | DMS1  | 0.89                    | 0.85                         | 10.56   |
|                                  | DMS2  |                         | 0.89                         | 10.94   |
|                                  | DMS3  |                         | 0.83                         | 10.29   |
| <i>VARdiff</i>                   | SW1   | 0.83                    | 0.88                         | 9.92    |
|                                  | SW2   |                         | 0.84                         | 9.28    |
|                                  | SW3   |                         | 0.65                         | 6.78    |
| <i>Heter</i>                     | HET1  | 0.84                    | 0.70                         | 7.50    |
|                                  | HET2  |                         | 0.93                         | 11.18   |
|                                  | HET3  |                         | 0.85                         | 9.80    |
| <i>Asym_bcc</i>                  | GB2   | N.A.                    | 1.00                         | 13.86   |
| <i>Asym_spv</i>                  | GS2   | N.A.                    | 1.00                         | 13.86   |
| $\chi^2(138) = 126.22, p = 0.75$ |       |                         |                              |         |

Table 4: Mixed System Sales

|            | %BCC mixed_systems | %SPV mixed systems |
|------------|--------------------|--------------------|
| N of Cases | 102                | 97                 |
| 25%-ile    | 5.00               | 5.00               |
| 50%-ile    | 25.00              | 20.00              |
| 75%-ile    | 56.25              | 67.50              |

Table 5: Tests of Estimated Coefficients

| Independent Variable | Dependent Variable          |                            | Expectations                   |
|----------------------|-----------------------------|----------------------------|--------------------------------|
|                      | <i>Mix_BCC</i>              | <i>Mix_SPV</i>             |                                |
| <i>Asym_BCC</i>      | $\gamma_{11}$ 0.06 (0.79)   | –                          | $\gamma_{11}, \gamma_{21} > 0$ |
| <i>Asym_SPV</i>      | –                           | $\gamma_{21}$ 0.17 (2.23)  |                                |
| <i>VARdiff</i>       | $\gamma_{12}$ -0.40 (-3.52) | $\gamma_{22}$ -0.18 (1.58) | $\gamma_{12}, \gamma_{22} < 0$ |
| <i>Dmd_BCC</i>       | $\gamma_{13}$ 0.12 (1.49)   |                            |                                |
| <i>Dmd_SPV</i>       | –                           | $\gamma_{23}$ 0.34 (3.79)  |                                |
| <i>Heter</i>         | $\gamma_{14}$ 0.18 (1.77)   | $\gamma_{24}$ 0.06 (0.67)  |                                |

t-values in parentheses

Baseline Model:  $\chi^2(142)=135$ ,  $p > 0.10$

Model with  $\gamma_{11}, \gamma_{21}=0$ ;  $\chi^2(144)=149$ ;  $\Delta\chi^2(2)=14$ ,  $p < 0.01$

Model with  $\gamma_{11}, \gamma_{21}=0$ ;  $\chi^2(144)=144$ ;  $\Delta\chi^2(2)=9$ ,  $p < 0.01$

The estimates of the measurement sub-models are not shown to reduce clutter.



Table 6: Manufacturer Participation and VAR Subsidy

|                           |                            | Yes | No | Missing | total | % Yes |
|---------------------------|----------------------------|-----|----|---------|-------|-------|
| <b>BASECOAT</b>           |                            |     |    |         |       |       |
| a)                        | Co-op Advertisements       | 49  | 54 | 7       | 110   | 47.57 |
| b)                        | Joint Sales Calls          | 86  | 18 | 6       | 110   | 82.69 |
| c)                        | Subsidized Equipments      | 88  | 16 | 6       | 110   | 84.62 |
| d)                        | Exclusive Territory        | 46  | 56 | 8       | 110   | 45.10 |
| e)                        | JIT Delivery Agreement     | 37  | 65 | 8       | 110   | 36.27 |
| f)                        | Excess Buy Back Agreement  | 64  | 39 | 7       | 110   | 62.14 |
| g)                        | Warranty for Mixed systems | 13  | 91 | 6       | 110   | 12.50 |
| <b>SINGLE STAGE PAINT</b> |                            |     |    |         |       |       |
| a)                        | Co-op Advertisements       | 39  | 50 | 21      | 110   | 43.82 |
| b)                        | Joint Sales Calls          | 72  | 18 | 20      | 110   | 80.00 |
| c)                        | Subsidized Equipments      | 66  | 23 | 21      | 110   | 74.16 |
| d)                        | Exclusive Territory        | 35  | 54 | 21      | 110   | 39.33 |
| e)                        | JIT Delivery Agreement     | 30  | 59 | 21      | 110   | 33.71 |
| f)                        | Excess Buy Back Agreement  | 52  | 37 | 21      | 110   | 58.43 |
| g)                        | Warranty for Mixed systems | 14  | 76 | 20      | 110   | 15.56 |

Table A1

| (a): Preliminary Demand Expressions                          |  |  |   |
|--|--|--|---|
| P  | N1   | N2   | C   |
| $Q^{11} = \{1 - (w_{1A} + w_{1B}) + (w_{2A} + w_{2B})\} / 2$ | $Q^{11} = (1 - w_{1B} + w_{2B}) (3\gamma - w_{1A} + w_{2A}) / 8\gamma$ | $Q^{11} = (\gamma - w_{1A} + w_{2A}) (3 - w_{1B} + w_{2B}) / 8\gamma$  | $Q^{11} = (\gamma - w_{1A} + w_{2A}) (1 - w_{1B} + w_{2B}) / 4\gamma$ |
| $Q^{22} = \{1 - (w_{2A} + w_{2B}) + (w_{1A} + w_{1B})\} / 2$ | $Q^{22} = (\gamma + w_{1A} - w_{2A}) (3 + w_{1B} - w_{2B}) / 8\gamma$  | $Q^{22} = (1 + w_{1B} - w_{2B}) (3\gamma + w_{1A} - w_{2A}) / 8\gamma$ | $Q^{22} = (\gamma + w_{1A} - w_{2A}) (1 + w_{1B} - w_{2B}) / 4\gamma$ |
| $Q^{12} = 0$   | $Q^{12} = (\gamma - w_{1A} + w_{2A}) (1 + w_{1B} - w_{2B}) / 4\gamma$  | $Q^{12} = 0$   | $Q^{12} = (\gamma - w_{1A} + w_{2A}) (1 + w_{1B} - w_{2B}) / 4\gamma$ |
| $Q^{21} = 0$   | $Q^{21} = 0$   | $Q^{21} = (\gamma + w_{1A} - w_{2A}) (1 - w_{1B} + w_{2B}) / 4\gamma$  | $Q^{21} = (\gamma + w_{1A} - w_{2A}) (1 - w_{1B} + w_{2B}) / 4\gamma$ |
| (b) Equilibrium Demand                                       |  |  |   |
| $Q^{11} = 1/2$   | $Q^{11} = (1 - w_{1B} + w_{2B}) (3\gamma - w_{1A} + w_{2A}) / 8\gamma$ | $Q^{11} = (\gamma - w_{1A} + w_{2A}) (3 - w_{1B} + w_{2B}) / 8\gamma$  | $Q^{11} = 1/4$  |
| $Q^{22} = 1/2$   | $Q^{22} = (\gamma + w_{1A} - w_{2A}) (3 + w_{1B} - w_{2B}) / 8\gamma$  | $Q^{22} = (1 + w_{1B} - w_{2B}) (3\gamma + w_{1A} - w_{2A}) / 8\gamma$ | $Q^{22} = 1/4$  |
| $Q^{12} = 0$   | $Q^{12} = (\gamma - w_{1A} + w_{2A}) (1 + w_{1B} - w_{2B}) / 4\gamma$  | $Q^{12} = 0$   | $Q^{12} = 1/4$  |
| $Q^{21} = 0$   | $Q^{21} = 0$   | $Q^{21} = (\gamma + w_{1A} - w_{2A}) (1 - w_{1B} + w_{2B}) / 4\gamma$  | $Q^{21} = 1/4$  |

P=Pure Assortment; N1=Incomplete ( $A_1B_2$ ); N2=Incomplete ( $A_2B_1$ ); C=Complete.

Table A2

| (a): Equilibrium VAR Payoffs                        |                 |                                      |               |
|---|-----------------|--------------------------------------|---------------|
| VAR Type  | P               | N1 / N2                              | C             |
| $s \geq s_H$  | $t - S'$        | Negative                             | Negative      |
| $s_L < s \leq s_L$                                  | $t - S'$        | $t - S' - s + \Delta \Pi_N^*$        | Negative      |
| $s < s_L$   | $t - S'$        | $t - S' - s + \Delta \Pi_N^*$        | $t - S' - 2s$ |
| (b) Equilibrium VAR Payoffs with Customer Migration |                 |                                      |               |
| $s \geq s_H$  | $t - S' - tQ^*$ | Negative                             | Negative      |
| $s_L < s \leq s_L$                                  | $t - S' - tQ^*$ | $t - S' - s + \Delta \Pi_N^* - tQ^*$ | Negative      |
| $s < s_L$   | $t - S' - tQ^*$ | $t - S' - s + \Delta \Pi_N^* - tQ^*$ | $t - S' - 2s$ |