Consider a multi-channel supply chain (hereafter SC) system, producing and distributing two substitutable products. Within this framework, we study the SC efficiency by comparing several decentralized SC configurations with a centralized one. Our result show that it is often possible to achieve 93.5% or more of the total profit of a centralized SC in a decentralized configuration, which suggests that choosing SC configuration wisely has the potential to be an alternative to coordination.

I. INTRODUCTION

Distribution channel structure has been a major strategic concern for SC system. Many distribution channels have been observed ranging from traditional retail channel to the direct sales model and the clicks-and-mortar channel (Gap/Gap.com, Staples/Staples.com etc.). The contracting arrangement between a manufacturer and a retailer also varies from channel to channel. Some manufacturers use an exclusive arrangement with a retailer while others use multiple channels. The direct channel is a vertically integrated channel often controlled by a manufacturer (Dell, for example).

The efficiency of a decentralized SC system is defined as the ratio of its total equilibrium profit to the optimal profit of the centralized system. The objective of this paper is to study SC efficiencies under product substitutability and the impact of different SC structures on the total SC profit. To that end, consider two substitutable products, produced either by a single manufacturer or by two manufacturers. The products are sold through utmost two retailers. Within this framework, consider different SC arrangements ranging from a centralized configuration to several decentralized multi-channel ones. The decentralized configurations studied include the single retailer channel (two manufacturers, each producing one product; both sell their products through a single retailer), the single manufacturer channel (one manufacturer, two retailers), and the exclusive channel (two manufacturers and two retailers; each manufacturer sells through only one retailer and each retailer carry only one product). This paper is intended to answer the following questions. Is one SC configuration more desirable than the others? How does product substitutability affect SC efficiency? How efficient are the decentralized channels compared to a centralized one?

Many of the channel arrangements described above are observed in practice. The factory outlets and the direct distribution channels are the typical examples of centralized SC between a manufacturer and a retailer. The
exclusive channel is most often observed in manufacturer-distributor relationships in various industries ranging from chemicals and paper to appliances and Beer. For example, Hercules Inc. is the exclusive distributor for GE Specialty Materials’ water treatment solutions to the paper industry (Challener, 2003); Diego Suarez is the exclusive distributor of Coors brand of beers in Puerto Rico (Allio & Allio, 2002). The Wall Street Journal (October 28, 2003) reports that Estee Lauder has created a new company division, called BeautyBank, to develop cosmetic products exclusively for Kohl’s (Merrick & Beatty, 2003). Different auto makers often sell vehicles through a single dealer in smaller cities, giving rise to a distribution channel similar to the single retailer channel noted above.

This paper compares and contrasts these decentralized SCs with a centralized system, and studies how the configuration offering highest total SC profit changes with the degree of substitutability. The analyses also show that it is often possible to achieve 93.5% or more of the total SC profit of a centralized SC in a decentralized SC with an appropriate configuration. This suggests that SC configuration is likely to be an alternative to SC coordination.

II. LITERATURE REVIEW

SC structure, conflict and coordination have been extensively studied in operations literature. The majority of the works assume a single manufacturer and a single retailer. The typical approach is to study the source of inefficiency (often related to double marginalization), and mechanisms for achieving coordination. Cachon (2001) provides a review of this stream of literature. The channel conflict literature typically considers the scenario where the manufacturer is simultaneously a supplier to and competitor of its retail partner(s). Chiang et al. (2003) consider whether a single manufacturer should sell exclusively through a retailer, direct over the Internet, or through a hybrid channel. Their key finding is that the manufacturer may use a direct channel as a way to combat double marginalization in the retail channel. Ahn et al. (2002) consider the competition between independent retailers and manufacturer-owned stores where parties compete in price. The manufacturer sells an identical product through two spatially separated markets. Tsay and Agarwal (2002) provide a review in modeling channel conflict and coordination. This stream of literature typically considers a single manufacturer selling identical products, whereas this work considers multiple manufacturers selling substitutable products.

Substitution has been studied extensively in both Operations and Marketing literature. In Operations, for instance, Boyaci (2003) considers a multi-channel distribution system in presence of both vertical and horizontal competition. He concludes that there is a tendency for both manufacturer and retailer to overstock due to substitution. In Marketing, Raju et al. (1995) consider the introduction and performance of store brands vis-à-vis a national brand. Mahajan and van Ryzin (1999) provide a comprehensive survey of research on demand substitution. However, these studies take the SC structure as given and do not address the issue of SC efficiency. This work differs from these studies by quantifying SC efficiency.

III. MODEL

Consider multi-channel distribution systems for two substitutable products, denoted by 1 and 2. The products reach the end consumer through a two-echelon SC involving manufacturer(s) and retailer(s). Multi-channel systems studied in this paper involve utmost two manufacturers and utmost two retailers. The manufacturers are denoted by $M_1$ and $M_2$ (or by $M$, if there is only one manufacturer), while the retailers will be denoted by $R_1$ and $R_2$ (or by $R$, if there is only one retailer) respectively. Vertical competition is introduced by considering decentralized decision making within the channels; while, the horizontal
competition is introduced by substitutable products. Several different multi-channel distribution systems are considered. Figures 1(a) and 1(b) schematically describe these configurations. The configurations in Figure 1(a) involve either one manufacturer or one retailer, while the configurations in Figure 1(b) involve two manufacturers and two retailers.

The *centralized system* (denoted as C) is a fully integrated system where a single manufacturer produces both products and sells them through an integrated channel. It yields the highest system profit and serves as a benchmark for the decentralized systems. Figure 1(a) describes three decentralized systems. The *decentralized single manufacturer single retailer system* (denoted as DS) involves one manufacturer producing both products and selling them through a single retailer. The retailer makes stocking decisions of the two products independent of the manufacturer. A *single manufacturer system* (denoted as SM) involves one manufacturer and two retailers. The sole manufacturer produces both products and sells each product exclusively through one independent retailer. Under a *single retailer system* (denoted as SR), there are two manufacturers, each producing one product. The manufacturers sell their products through a single retailer who makes the stocking decisions of each product in its own interest.

**FIGURE 1(a): MULTI-CHANNEL DISTRIBUTION SYSTEM CONFIGURATIONS**

**FIGURE 1(b): MULTI-CHANNEL DISTRIBUTION SYSTEM CONFIGURATIONS**
Efficiency of Competing Supply Chains under Price Competition

Wu, Du and Shao

Figure 1(b) describes four decentralized multi-channel distribution systems, each involving two manufacturers and two retailers. Under a partially centralized system (denoted as PC), $M_1$ sells its product exclusively through $R_1$ while $M_2$ sells its products exclusively through $R_2$.

In addition, each of the two competing manufacturer-retailer pair is centralized (or vertically integrated) and the stocking decision within each pair is coordinated. However, there exists horizontal coordination between the two channels. Under a minimally coordinated system (denoted as MC) $M_1$ sells its product exclusively through $R_1$, and $M_2$ sells its products exclusively through $R_2$. In addition, only one of the two vertical channels is coordinated. Assume, without loss of generality, that $M_1$ and $R_1$ are coordinated, while the other manufacturer-retailer pair is not. An exclusive system (denoted as E) is similar to the PC and MC systems except that none of the two manufacturer-retailer pairs is coordinated. Thus, under an exclusive system, $M_1$ sells its product exclusively through $R_1$, $M_2$ sells its products exclusively through $R_2$, and all parties make decisions in self-interest. It is easy to see that the degree of coordination goes down as moving from PC to MC to E.

Without loss of generality, we assume the common marginal production cost for each product is 0. No fixed cost of production is considered and that the production and delivery are assumed to be instantaneous. The manufacturers produce as retailers’ orders under a wholesale price contract. Let $w_1$ and $w_2$ be the wholesale prices of products 1 and 2 respectively. The retailer(s) set the retail prices, denoted by $p_1$ and $p_2$ respectively. Horizontal competition between two channels is modeled by the following demand functions.

$$q_i = 1 - p_i - \theta(p_j - p_i), \quad i, j = 1, 2, i \neq j,$$

where, $q_i$, $i = 1, 2$, is the demand for product $i$, and $\theta$ is a parameter.

In particular, the products are perfectly differentiated when $\theta = 0$. The products are nearly identical as $\theta$ approaches infinity. This type of demand functions is standard in economics and marketing literature modeling product substitutability (Gal-Or, 1991; Raju et al., 1995). Moreover, Lee and Staelin (2000) show that a linear demand function involving substitutable products is indeed consistent with reasonable buyer behavior and market characteristics.

$\pi$, with subscripts and superscripts, is used to denote profit. A subscript of “M” or “R” is used to refer to a manufacturer or a retailer respectively. Superscripts are used to denote a specific SC configuration. Thus, $\pi_{E_i}$ denotes the profit of retailer $i$ under an exclusive system. The notation $j$ denotes an index on the SC configurations under consideration. Clearly, $j = C, DS, SM, SR, PC, MC, E$. The total SC profit (i.e. the sum of the profits of retailer(s) and manufacturer(s)) under configuration $j$ will be denoted as $\pi^j$ (no subscripts).

The centralized system yields the highest profit and serves as a benchmark for the decentralized systems noted earlier. The profit maximization problem of a centralized system is:

$$\max_{p_1, p_2} \pi^C = p_1 [1 - p_1 + \theta(p_2 - p_1)] + p_2 [1 - p_2 + \theta(p_1 - p_2)].$$

(2)

The solution of the above optimization problem yields the following results.

$$p_1^* = p_2^* = p^{C*} = \frac{1}{2}; \quad q_1^* = q_2^* = q^{C*} = \frac{1}{2};$$

and $\pi^{C*} = \frac{1}{2}$. (3)

For the reasons of brevity, among the decentralized SC configurations only the single retailer (SR) system is described here. The rest will have similar formulations. Under a single retailer system, both manufacturers sell their products through a single retailer. The profit maximization problem of the retailer is:

$$\max_{q_1, d_2} \pi^{SR}_{R_i} = (p_1 - w_1) [1 - p_1 + \theta(p_2 - p_1)] + (p_2 - w_2) [1 - p_2 + \theta(p_1 - p_2)].$$

(4)

The 1st-order conditions (it is easy to verify that the second order conditions are satisfied) yield:
The two manufacturers select their wholesale prices by solving the following problems.

\[ p_{i}^{sr^*}(w_{1}, w_{2}) = \frac{(1 + 2\theta) + (1 + \theta)^2 w_{i} + \theta(1 + \theta)w_{j}}{2(1 + 2\theta)}, \]

\[ q_{i}^{sr^*}(w_{1}, w_{2}) = \frac{1 - (1 + \theta)w_{i}}{2} \quad (5) \]

The two manufacturers select their wholesale prices by solving the following problems.

\[ \bar{w}_{i} \max \pi_{i}^{sr} = w_{i}q_{i}^{sr^*}(w_{1}, w_{2}), \quad i = 1,2. \quad (6) \]

The equilibrium wholesale price \( w_{1}^* \) and \( w_{2}^* \) can be found by solving the 1st-order conditions given by (6). Once \( w_{1}^* \) and \( w_{2}^* \) are known, the equilibrium prices, quantities, and profits as well as the total profit can be calculated accordingly. Similarly, I can solve for the equilibrium prices, quantities, and profits for the other decentralized SC configurations. Tables 1(a) and 1(b) describe the equilibrium results for the SC configurations described in Figures 1(a) and 1(b) respectively. Note that wholesale prices, retailer’s profit, and manufacturers’ profit do not exist for the coordinated systems (C and PC). Note also that the retail prices and the order quantities are symmetric with respect to the two products. This is because of the assumption of symmetric cost structure for the two products. This assumption is not critical to our model. Rather, it allows us to compare and contrast different SC configurations rather elegantly.

**IV. RESULTS AND ANALYSES**

**TABLE 1(a): EQUILIBRIUM PRICES, QUANTITIES, AND PROFITS**

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>DS</th>
<th>SM</th>
<th>SR</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w_{i} )</td>
<td>N/A</td>
<td>1/2</td>
<td>1/2</td>
<td>( 1/(\theta + 2) )</td>
</tr>
<tr>
<td>( p_{i} )</td>
<td>( p^{cs} = 1/2 )</td>
<td>3/4</td>
<td>( (\theta + 3)/[2(\theta + 2)] )</td>
<td>( (\theta + 3)/[2(\theta + 2)] )</td>
</tr>
<tr>
<td>( q_{i} )</td>
<td>( q^{cs} = 1/2 )</td>
<td>1/4</td>
<td>( (\theta + 1)/[2(\theta + 2)] )</td>
<td>( (\theta + 1)/[2(\theta + 2)] )</td>
</tr>
<tr>
<td>( \pi_{Ri} )</td>
<td>N/A</td>
<td>1/8</td>
<td>( (\theta + 1)/[4(\theta + 2)^2] )</td>
<td>( (\theta + 1)^2 /[2(\theta + 2)^2] )</td>
</tr>
<tr>
<td>( \pi_{Mi} )</td>
<td>N/A</td>
<td>1/4</td>
<td>( (\theta + 1)/[2(\theta + 2)] )</td>
<td>( (\theta + 1) /[2(\theta + 2)^2] )</td>
</tr>
<tr>
<td>( \pi )</td>
<td>( \pi^{cs} = 1/2 )</td>
<td>3/8</td>
<td>( (\theta + 3)(\theta + 1)/[2(\theta + 2)^2] )</td>
<td>( (\theta + 1) (\theta + 3)/[2(\theta + 2)^2] )</td>
</tr>
</tbody>
</table>

In this section, we analyze different SC structures and their efficiencies under vertical (double marginalization) and horizontal (substitutability) competition. The magnitude of the parameter \( q \) determines the degree of substitutability between the two products.

**Theorem 1:** At equilibrium, the following relationships hold.

(a) \( \pi_{1}^{MC^*} \geq \pi_{R2}^{MC^*} + \pi_{R1}^{MC^*} \),

(b) \( \pi_{1}^{MC^*} \geq \pi^{EC^*}/2 \),

and (c) \( \pi_{1}^{MC^*} \geq \pi^{PC^*}/2 \).

Theorem 1 has important implications. Under a minimally coordinated system, \( M_{1} \) and \( R_{1} \) are coordinated while \( M_{2} \) and \( R_{2} \) are not. Part (a) of the theorem states that a vertically integrated channel yields a higher profit than a non-integrated channel, given the coexistence of the two different channels selling two substitutable products. Thus, if the competing channel is not integrated, the best choice for a firm contemplating entry in a market is to establish an integrated channel. Part (b) of the theorem states that the integrated channel in the MC system earns more profit than either of the two non-integrated channels of the exclusive SC. Part (c) of the theorem states a similar result for the partially centralized SC.
TABLE 1(b): EQUILIBRIUM PRICES, QUANTITIES, AND PROFITS

<table>
<thead>
<tr>
<th>PC</th>
<th>MC</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w_i )</td>
<td>N/A</td>
<td>( w_1 = 0 )</td>
</tr>
<tr>
<td>( p_i )</td>
<td>( \frac{1}{\theta + 2} )</td>
<td>( p_1^{MC} = \frac{(\theta + 1)(3\theta^2 + 9\theta + 4)}{2(\theta + 2)(\theta^2 + 4\theta + 2)} )</td>
</tr>
<tr>
<td>( q_i )</td>
<td>( \frac{\theta + 1}{\theta + 2} )</td>
<td>( q_1^{MC} = \frac{(\theta + 1)(3\theta^2 + 9\theta + 4)}{2(\theta + 2)(\theta^2 + 4\theta + 2)} )</td>
</tr>
<tr>
<td>( \pi_{Ri} )</td>
<td>N/A</td>
<td>( \pi_{R2}^{MC} = (\theta + 1)[4(\theta + 2)^2] )</td>
</tr>
<tr>
<td>( \pi_{Mi} )</td>
<td>N/A</td>
<td>( \pi_{M2}^{MC} = \frac{(\theta + 1)(3\theta + 2)}{4(\theta + 2)(\theta^2 + 4\theta + 2)} )</td>
</tr>
<tr>
<td>( \pi )</td>
<td>( \frac{2(\theta + 1)}{(\theta + 2)^2} )</td>
<td>( \pi_1^{MC} = \frac{(\theta + 1)(3\theta^2 + 9\theta + 4)^2}{4(\theta + 2)^2(\theta^2 + 4\theta + 2)^2} )</td>
</tr>
</tbody>
</table>

Recall that because of symmetric cost structure, the terms \( \pi^{E^C}/2 \) and \( \pi^{PC}/2 \) represent the optimal profit of either channel in the exclusive and partially centralized SCs respectively. It implies that a firm will get the highest benefit of centralization when its competing channel is not centralized.

**Theorem 2:** At equilibrium, the following relationships hold.

(a) \( \pi^{PC} \geq \pi^{MC} \geq \pi^{E}, \) for \( 0 \leq \theta < 0.6635 \),
(b) \( \pi^{MC} \geq \pi^{PC}, \) and \( \pi^{MC} \geq \pi^{E}, \)
(c) \( \pi^{E} \geq \pi^{MC} \geq \pi^{PC}, \) for \( 0.8518 < \theta \).

The above theorem captures the effects of vertical and horizon competition simultaneously in the three systems with two manufacturers and two retailers. However, the degree of vertical integration is different among them. The exclusive system is completely decentralized, while the degree of vertical coordination increases from the exclusive system to the partially centralized system, and to the partially centralized system. However, increasing the degree of vertical integration does not necessarily improve the efficiency. It is interesting to note that as the substitutability increases, the less coordinated configurations become more efficient.

**Theorem 3:**

(a) \( \pi^{E} \geq \pi^{SM} \geq \pi^{DS}, \)
(b) \( \pi^{E} \geq \pi^{SR} \geq \pi^{DS}, \) for all \( \theta \).

This theorem says that the increase in the degree of horizontal integration does not necessarily lead to the increase in the SC efficiency. Indeed, the SC structure in which horizontal integration is realized on both manufacture and the retailer’s levels yields the worst SC efficiency. Next, the
efficiency of each SC configuration will be calculated and compared to identify the most efficient decentralized SC configurations. Recall that the efficiency of decentralized SC $j$ is defined as the ratio of equilibrium total SC profit under configuration $j$ to that of the centralized SC; i.e., $R^j = \pi^j / \pi^C, \forall j$. Given that the centralized system yields the highest system profit, $0 \leq R^j \leq 1, \forall j$. Table 2 summarizes the efficiency for each SC configuration.

The following Theorem identifies the most efficient SC configurations for any given $q$.

**Theorem 4:** When the substitutability is relatively small ($0 < \theta \leq 0.6635$), the PC system offers the highest efficiency. For $0.6635 < \theta \leq 0.8518$, the MC system offers the highest efficiency; For $0.8518 < \theta \leq 3.88$, the exclusive system offers the highest efficiency; For $\theta > 3.88$, the SR system offers the highest efficiency.

### TABLE 2: EFFICIENCIES OF DIFFERENT SC CONFIGURATIONS

<table>
<thead>
<tr>
<th>Configuration ($j$)</th>
<th>Efficiency ($R^j$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralized (C)</td>
<td>1.0</td>
</tr>
<tr>
<td>Decentralized Single (DS)</td>
<td>0.75</td>
</tr>
<tr>
<td>Single Manufacturer (SM)</td>
<td>$(\theta + 3)(\theta + 1)/((\theta + 2)^2)$</td>
</tr>
<tr>
<td>Single Retailer (SR)</td>
<td>$(\theta + 3)(\theta + 1)/((\theta + 2)^2)$</td>
</tr>
<tr>
<td>Partially Centralized (PC)</td>
<td>$4(\theta + 1)/((\theta + 2)^2)$</td>
</tr>
<tr>
<td>Minimally Coordinated (MC)</td>
<td>$(\theta + 1)(13\theta^4 + 82\theta^3 + 167\theta^2 + 120\theta + 28) / 2(\theta + 2)^2(\theta^2 + 4\theta + 2)^2$</td>
</tr>
<tr>
<td>Exclusive (E)</td>
<td>$8(\theta + 1)(\theta^2 + 4\theta + 2)(2\theta^2 + 6\theta + 3)/[(\theta + 2)^2(\theta^2 + 7\theta + 4)^2]$</td>
</tr>
</tbody>
</table>

### FIGURE 2: EFFICIENCIES OF DIFFERENT SC CONFIGURATIONS
Let $\lambda = 1 - e^{-\theta}$. Hence $\lambda \in [0,1]$ and $\theta = -\ln(1 - \lambda)$. Now product substitutability is rescaled from $[0, \infty)$ to $[0, 1]$ and captured by $\lambda$.

Figure 2 plots the efficiencies with respect to $\lambda$ of the four possible most efficient SC configurations: PC, MC, E and SR.

It is easy to see from Figure 2 and Theorem 4 that when the substitutability is relatively low, the PC system yields the highest efficiency. However, as the substitutability goes up, the MC system, and subsequently, the E and SR systems become more efficient. The result is quite intuitive. When $\theta = 0$, the two products are completely different. Thus, the partially centralized system behaves like two centralized SCs, one for each product, and yields highest possible efficiency. Note from Table 2 and Figure 2 that for $\theta = 0$, $R_{PC} = 1$. However, as the horizontal competition intensifies ($\theta$ increases), the efficiency of PC drops. For moderate level of substitutability ($0.6635 \leq \theta < 0.8518$), MC yields the highest efficiency and when $0.8518 < \theta \leq 3.88$, E yields the highest efficiency. Finally, when the products are highly substitutable ($\theta > 3.88$), E yields the highest efficiency.

Particularly, when the products are completely differentiated ($\theta = 0$), the efficiency of the PC system equals that of the centralized system (100%). The intuitive reason for this is the following. Under PC system, when the products are completely differentiated, the two channels in the system work like two independent centralized systems. Note figure 2 suggests that we can combine PC, MC, E and SR for different product substitutability to approximate centralized system and obtain an efficiency of at least 93.5% (when $\theta = 0.8518$, the best approximation reaches the least efficiency which is 93.5%).

V. SUMMARY AND CONCLUSIONS

Multi-channel distribution systems with differing channel configurations are widely observed in practice. This paper studied the efficiency of different SC configurations under product substitutability. Six decentralized SC configurations with different degree of horizontal and vertical integration were discussed. We compare and contrast the equilibrium SC profits of different SC structures.

The most important contribution of this paper is to have identified the most efficient decentralized SC configurations. When the substitutability is low, the PC system yields the highest total SC profit. At moderate levels of substitutability, the MC and E structures offer the highest system profit, while the SR yields the highest system profit at high level of substitutability.

Another important finding is that the decentralized SCs do not necessarily suffer a huge loss in efficiency compared with centralized system. A decentralized SC system is often able to achieve 93.5% or better of the total profit of the centralized system. Thus, choosing the most efficient SC configuration is likely to be an alternative to SC coordination/integration. Additionally, it is also shown that partial (horizontal and/or vertical) integration does not always improve the efficiency of a decentralized SC system.

This work has the following implications for the practitioners. As described earlier, manufacturers often change the contracting arrangements from exclusive to competitive or the vice-versa. The model in general and Figure 2 in particular, can offer valuable qualitative insights about which configurations of SC to choose in presence of substitutable products. The analyses also suggest that in absence of complete centralization, an increase in the degree of centralization does not necessarily result in an increase in total SC profit in a decentralized multi-channel SC system. It is shown that the total SC profit of an exclusive system can exceed that of the partially centralized system even though the later is more centralized than the former.
Like any other analytical work, this paper is not free of assumptions, which leave much room for future research. One key underlying assumption is that all the SC configurations are exogenously given. Neither manufacturer nor retailer can choose its SC structure interactively. Also, although many SC configurations are considered, they are still a very small portion of all possible multi-channel-multi-echelon SC systems. It will be interesting, although difficult, to investigate more complex SC configurations, such as SC systems with more than two echelons or with more than two manufacturers/retailers. If SC systems of three or more echelons are considered, the tractability of the resulting analytic models significantly decreases. We intend to investigate the scenarios with multiple manufacturers and multiple retailers. Indeed, we are studying some of these scenarios in which a retailer carries products of two or more manufacturers. A consequence of doing so is that the Bertrand Paradox may arise. To circumvent such a difficulty, we employ quantity competition in our investigation rather than price competition. But the limitations of quantity competition are rather obvious.

Another extension we consider pursuing is to relax the assumption made in this paper that the demand functions of two retailers are symmetric. It will be very intriguing to see how sensitive the results in this article are to the changes in the demand function structures.

VI. REFERENCES


Davis, J., “Manufacturers are Testing the Web for Direct Sales; Some are Finding Success,” InfoWorld, 23(5), 2001, 102-103.


