Chapter 19

SUPPLY CHAIN STRUCTURES ON THE INTERNET

and the role of marketing-operations interaction [1]

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Abstract The widespread adoption of the Internet has resulted in the possibility of separation of information flow and physical goods flow: a company selling a product no longer has to own/deliver it to the customer. As a result, supply chain structures arise in which the retailer is primarily concerned with customer acquisition, and the wholesaler takes inventory risk and performs fulfillment. This form of doing business on the Internet is identical to the practice of drop-shipping that some catalog companies employ. A recent survey indicates that more than 30% of online-only retailers use drop-shipping as the primary way to fulfill orders. Since marketing and operations functions under such arrangement are performed by separate companies, new inefficiencies arise that result in suboptimal system performance.

In this chapter, we analyze the interaction between a wholesaler and a single retailer for drop-shipping supply chains in a multi-period environment. Three distinct drop-shipping models are considered: with a powerful wholesaler, with a powerful retailer and with a wholesaler and a retailer having equal power. Further, we conduct a comparative analysis between the drop-shipping supply chains, a vertically integrated supply chain, and the traditional structure in which the retailer both takes inventory risk and acquires customers. Optimal solutions are obtained for both the traditional and drop-shipping models, and we show that both solutions are system sub-optimal. We demonstrate how decision power in the chain affects decision variables and profits. It is found that both channel members prefer the drop-shipping agreement over the traditional agreement for a wide range of problem parameters. One of our results is that none of the mechanisms described in the literature on channel coordination (except for those that allow side payments) are able to induce an optimal system behavior in the presence of customer acquisition expenses. We therefore propose a new coordination scheme where, in addition to using a compensation plan that is linear in carried-over inventory, the wholesaler subsidizes a part of the retailer's marketing expenses. Extensive comments are provided on the comparative benefits of traditional and drop-shipping supply chains. A link to an interactive web site for numerical experiments is made available at www.nilsrudi.com.

Keywords: Internet, supply chain, competition, Nash, Stackelberg, marketing, advertising

1. Introduction

Spun.com, a small CD/DVD Internet retailer, has about 200,000 CD titles listed on its web site. Surprisingly, the company does not hold/own any inventory of CDs. Instead, the company partnered with the wholesaler Alliance Entertainment Corp. (AEC), which stocks CDs and ships them directly to Spun.com's customers with Spun.com labels on the packages. In this way, the retailer avoided an estimated inventory investment of $8M Forbes (2000), since it only paid the distributor for sold products. AEC calls this distribution system "Consumer Direct Fulfillment." According to the company's web site, "... using AEC as a fulfillment partner gives you more time and resources to focus on attracting more consumers to your store ...". The list of retailers practicing such forms of Internet business includes Zappos.com (Inbound Logistics 2000), Cyberian Outpost (Computer Reseller News 1999) and many others.

Drop-shipping is defined in marketing literature as "a marketing function where physical possession of goods sold bypasses a middleman, while title flows through all those concerned. The function of drop-shipping involves both the middleman who initiates the drop ship order and the stocking entity that provides drop-shipping services by filling the order for the middleman" (Scheel 1990). Clearly, the above example of Spun.com fits this description. Drop-shipping is different from many of the supply chain structures previously described in the literature in which the wholesaler is involved in the retailer's inventory management. It differs from the traditional consignment agreements in which the retailer holds (but does not own) inventory and decides what the stocking policy should be – under drop-shipping the stocking policy is entirely controlled by the wholesaler. Drop-shipping is close to but different from Vendor Managed Inventory (VMI), since the retailer does not deal with inventories and hence does not incur any inventory-related costs. At the same time, the wholesaler does not have direct access to the retailer's store where she could "rent" space and organize it in a way that influences demand according to the wholesaler's preferences (as is often the case under VMI). Drop-shipping also differs from outsourcing of inventory management, since under outsourcing the retailer usually still influences stocking quantities for each product.

Prior to the Internet, the practice of drop-shipping was mainly restricted to two settings. For large transactions of industrial goods, the wholesaler might have the manufacturer make the shipment directly to the retailer (and in some cases directly to the end customer). This is typically beneficial for shipments that in themselves achieve sufficient economies of scale, making the wholesaler act primarily as a market-maker. The second use of drop-shipping, which is more relevant to our setting, occurs when a catalog company has the wholesaler drop-ship the product directly to the end customer. This practice, however, has had very limited success, mainly due to problems in the integration and timeliness of information between the business partners, as well as high transaction costs. As a result, even the catalog companies using drop-shipping only use it for bulky and high cost items (see Catalog Age 1997). Hence, many marketing books see drop-shipping as having limited potential (see literature review in Scheel 1990 page 7). With the Internet, however, real time data-integration is readily available at a low cost. The combination of the physical concept of drop-shipping with the information integration made possible by the Internet resolves the problems that previously limited the adoption of drop-shipping. A survey of Internet retailers (Eretailing World 2000) indicates that 30.6% of Internet-only retailers use drop-shipping as the primary way to fulfill orders, while only 5.1% of multi-channel retailers primarily rely on drop-shipping. In a recent survey of Supply Chain Management in e-commerce applications Johnson and Whang (2002) cite several cases written about companies utilizing drop-shipping (or virtual supply chains).

One of the major differences between selling goods on the Internet and through the conventional brick-and-mortar retailer is the separation of physical goods flow and information flow. In a physical store, a customer selects a product and pays for it at the same time and place that she physically receives the product. On the Internet this is not the case. A customer on the Internet cannot observe from where the product is dispatched. Further, Internet customers (similar to mail-order catalog customers) do not expect an immediate delivery of the product. Together, this allows the retailer and the wholesaler to adopt the drop-shipping agreement efficiently at a low cost. Agreements of this type benefit the retailer by eliminating inventory holding costs and overall up-front capital required to start the company. The wholesaler increases her involvement in the supply chain and hence can potentially demand a higher wholesale price, thus capturing more profits (as evidenced by empirical data in Scheel 1990 page 42). Further, supply chain benefits occur due to risk pooling if the wholesaler performs drop-shipping for multiple retailers. Finally, each party can concentrate its resources: the retailer on customer acquisition and the wholesaler on fulfillment.

Despite several clearly attractive features, drop-shipping introduces new inefficiencies into the supply chain. Under drop-shipping, the wholesaler keeps the decision rights related to stocking policies, while the retailer's main task in the supply chain is customer acquisition. This separation of marketing and operations functions results in inefficiencies, some of which have been the subject of discussion in the literature on marketing-operations coordination. Many questions arise in such a situation: will the supply chain performance under the drop-shipping structure be better than under a traditional structure in which the retailer holds inventory? Further, is it preferable for both the retailer and the wholesaler to engage in this sort of agreement? Can drop-shipping agreements lead to system-optimal performance, and if not, what form of contract can coordinate the supply chain?

To the best of our knowledge, this chapter represents the first formal model of a drop-shipping supply chain, the practice where the retailer acquires customers while the wholesaler is responsible for fulfillment and takes inventory risk. We compare traditional supply chain structures in which the retailer both takes inventory risk and acquires customers with supply chain structures employing drop-shipping agreements. Our focus is on the supply chains in which both the retailer and the wholesaler are present. We concentrate on two cost aspects of the distribution channel: marketing (customer acquisition) and operational (inventory). In the case of Internet retailers, there exists vast evidence that these two cost components constitute a dominant portion of the company's budget. Since e-tailers do not have a physical presence that would attract customers by physical location or strong brand name, customer acquisition becomes a major issue. Online-only retailers spend about twice as much of their budget on customer acquisition as do multi-channel retailers Computer World (2000). At the early stages of Internet development, the typical marketing budget of an Internet-only retailer was 40.5% of sales, while the marketing budget for a multi-channel retailer was 21.4% Eretailing World (2000). A survey of online retailers conducted in 2000 shows that the catalog-based companies spend on average $11 to acquire a customer, compared to the $32 spent by a physical store and $82 by an e-tailer Computer World (2000). Although after the Internet bubble advertising spendings have gone down, Internet retailers still spend much more on advertising than traditional retailers (see Latcovich and Smith (2001). Furthermore, empirical studies have shown that advertising is used by the Internet retailers to signal quality and since Internet shoppers respond much more to advertising than to low prices (Latcovich and Smith 2001). These findings support our use of advertising as a key aspect of the Internet retailing. On the other hand, to be able to compete with traditional retailers, Internet companies typically offer extensive product variety and a high service level that in turn requires a large inventory investment. In addition, at the present time Internet retailing is in its early stages of development, and the demand for products is highly uncertain; hence, large inventories must be carried to maintain high service levels.

To better understand the wholesaler-retailer interaction and inventory risk allocation in drop-shipping supply chains, we focus on a simple model with a wholesaler and a single retailer. Note that for cases where the retailer buys directly from the manufacturer the wholesaler in our model is simply replaced by the manufacturer without any effect on other results. Three main models are analyzed and compared in this chapter: a traditional vertically integrated channel (Model I for "Integrated"), a traditional vertically disintegrated channel (Model T for "Traditional") and a drop-shipping channel (Model D for "Drop-shipping"). The solution for the drop-shipping channel further depends on the channel power (where power is modeled as being the first mover in a Stackelberg game). Hence, within the drop-shipping model we further consider three submodels, in which either the wholesaler or the retailer is a Stackelberg leader or where each party has an equal decision power (i.e. moves simultaneously) and the solution is a Nash equilibrium. First, we demonstrate that a unique competitive equilibrium exists in each model, and we find optimal inventory and customer acquisition spending for each channel in analytical form. We find that, for the drop-shipping channel, marketing-operations misalignment results from the fact that these functions are managed by two different firms. In addition, double marginalization is present in both the traditional and drop-shipping structures. Under identical problem parameters, we analytically compare the models in terms of decision variables and profits and show that the drop-shipping models, as well as the traditional model, always lead to underspending on customer acquisition in addition to understocking. We characterize the situations where drop-shipping supply chains outperform traditional supply chains and our analysis indicates the importance of the effects of channel power on supply chain performance. We then show that a price-only contract, a revenue sharing contract, or a returns/purchase commitment contract cannot coordinate the supply chain when customer acquisition costs are present. For the traditional and drop-shipping supply chains we propose a contract that combines a compensation plan that is linear in carried over inventory with subsidized advertising, and show that this contract induces coordination.

Our main interest in this chapter is to get a better understanding of inventory risk allocation issues in drop-shipping supply chains as well as the impact of power distribution between the channel entities. To keep focus and to not diffuse economic insights, we do not explicitly reflect other issues encountered in e-commerce fulfillment, since many are hard to include in a formal model. Among these issues are: possible differences in transportation costs and responsiveness, coordination issues arising when multiple wholesalers are needed to fulfill a single order, and the rationing of inventory when a wholesaler serves multiple retailers. These and other issues are treated qualitatively in Randall et al. (2002).

The rest of the chapter is organized as follows. In the next section, we provide a survey of the relevant literature. Section 3 outlines the notation and modeling assumptions. In Section 4, all three models are presented and in Section 5, we show that none of the channel coordination mechanisms described in the literature can achieve a first-best solution. Optimal coordinating contracts are also proposed in this section. Section 6 contains numerical experiments, and in Section 7 we wrapup the chapter with a discussion of managerial insights and conclusions.

2. Literature survey

The practice of drop-shipping has been described qualitatively in the marketing literature (see Scheel 1990 and references therein, page 7), but, to the best of our knowledge, its distinct features, i.e., the wholesaler taking inventory risk while the retailer, a separate firm, acquiring customers, have never been formally modeled and analyzed previously [2]. In a majority of marketing textbooks, the qualitative analysis of drop-shipping is limited to one paragraph. Further, the literature on drop-shipping does not raise the issue of marketing-operations misalignment and power in the supply chain. With the exception of Scheel (1990), all the sources we cite either ignore inventory or assume that inventory is held by the retailer.

Operations management has a wealth of literature that deals with the inventory aspects of the supply chain, but ignores marketing expenses like customer acquisition costs (see, for example, Tayur et al. 1998). At the same time, the marketing literature tends to deal with customer acquisition costs in the form of advertising and sales support (see, for example, Lilien et al. 1992), but ignores operational issues. For example, Chu and Desai (1995) model a supply chain with a retailer and a wholesaler, both investing into improvement of customer satisfaction which stimulates demand. However, they do not explicitly consider inventory risk.

This work belongs to the recent stream of research dealing with the alignment of marketing and operations incentives (see Shapiro 1977 and Montgomery and Hausman 1986 for discussions of some of the problems that arise from marketing-operations misalignment). Our model differs from the previous literature in several ways. First, in our drop-shipping model operations and marketing functions are performed by two independently owned and operated companies that make their decisions competitively. Since marketing and operational functions are performed by separate companies and we do not consider information asymmetry, the problem we consider is different from sales agent compensation. Second, inventory risk in the drop-shipping model is with the wholesaler, resulting in channel dynamics that differ from the existing literature. Finally, the marketing function is customer acquisition that affects demand for the product, while the sales price is exogenous. The majority of papers in this area assume that the marketing function is to set the sales price or promotion level and manufacturing makes production decisions within one company (see, for example, Sagomonian and Tang 1993 and references therein). De Groote (1989) considers product line choice as a marketing function. Eliashberg and Steinberg (1987) give an excellent summary of a number of papers modeling operations/marketing interfaces, but none of the papers they cite model uncertain demand.

Porteus and Wang (1991) model a company where the principal specifies compensation plans for one manufacturing and multiple marketing managers within the same company. Each product is exclusively assigned to a marketing manager, who stimulates the product's demand by effort. The manufacturing manager can affect capacity available to produce all these products. Although this paper is somewhat similar to our chapter in terms of structure of the problem and the issues considered, the principal-agent framework used by Porteus and Wang makes differences in motivation, structure and modeling. Porteus and Wang (1991) also cite a number of relevant papers, but none of these papers model customer acquisition spending or advertising as a marketing decision variable. Balcer (1980) models coordination of advertising and inventory decisions within one company and focuses on a dynamic nonstationary model in which demand is influenced by the level of goodwill.

Balcer (1983) further extends this model by assuming that the advertising effect lasts for more than one period. Gerchak and Parlar (1987) look at a single-period model in which demand is a specific function of the marketing effort. None of the latter three papers consider supply chain issues, i.e., the interaction between several firms.

For traditional supply chains only, some papers model situations that in certain aspects are related to ours. Cachon and Lariviere (2000), among others, model a situation where the retailer both takes inventory risk and influences demand by exerting effort. They assume that the effort cannot be contracted upon, and hence they do not find a contract that coordinates the supply chain. While this assumption is reasonable in the problem setting they use, on the Internet it is possible to contract upon at least some forms of customer acquisition spending. For example, if the retailer pays for advertising based on the volume of click-through and purchase by the customers, then this type of customer acquisition can easily be independently verified and contracted upon. In the last section, we will comment more specifically on the viability of this type of contract and on practical ways to implement such contracts. Narayanan and Raman (1998) look at a problem that in some ways is the opposite of drop-shipping, i.e., where the retailer cannot affect demand distribution but the manufacturer can. In their paper, the manufacturer's effort is incorporated analogously to the way we use customer acquisition spending by the retailer. Most of their analysis, however, is done with some quite restrictive assumptions about the functional forms of the problem parameters and decision power in the channel. They demonstrate that vertical disintegration of the channel leads to suboptimal performance but do not derive an optimal coordination contract that would mitigate this problem without side-payments. Cachon (2003) studies a model that is closely related to ours: either the retailer, the wholesaler, or both may own inventory. He focuses on Pareto-improving wholesale price contracts while we take wholesale prices as exogenous. For the majority of the analysis, advertising effort is not considered and channel power is not an issue in his work.

Relevant work on supply chain coordination in traditional supply chains includes penalty contracts (Lariviere 1999) and returns contracts (Pasternak 1985 and Kandel 1996). See also Cachon (2002) for a survey of contracting literature in Supply Chain Management. Jeuland and Shugan (1983) model marketing effort for the problem of distribution channel coordination under deterministic demand, but ignore inventory issues. The marketing literature has widely addressed a phenomena of subsidized advertising in the context of franchising agreements (see Michael 1999 and references therein). The only work we are aware of that addresses subsidized customer acquisition or advertising between two firms that are not bound by a franchising agreement is Berger (1983), Berger (1972) and Berger and Magliozzi (1992), with inventory issues ignored. Corbett and DeCroix (2000) consider a shared savings contract, a problem that is different from ours but is similar in mathematical structure: in our problem, customer acquisition expenses affect the demand; in their problem, use-reduction effort affects the consumption of indirect materials. In their problem, however, there is no inventory involved, and both the upstream supplier and the downstream buyer exert effort of the same nature. Hence, issues related to marketing-operations interaction do not arise.

There is a wealth of marketing and economics literature addressing Internet-related issues, though, to the best of our knowledge, the practice of drop-shipping has never been mentioned. The most relevant work is Hoffman and Novak (2000), who describe customer acquisition models on the Internet. Finally, the only relevant operations management paper addressing supply chain structures on the Internet of which we are aware is Van Mieghem and Chopra (2000), in which the authors qualitatively address the choice of e-business for a given supply chain (without considering drop-shipping).

3. Notation and modeling assumptions

We model a supply chain with two echelons: wholesaler and retailer. Only a single product and a single firm in each echelon is considered. Demand for the product in each time period is uncertain and mean demand depends on the amount of customer acquisition spending by the retailer in this period (by customer acquisition we imply the total cost a company spends on advertising and marketing promotions). This is an extension of the standard marketing models that usually assume deterministic demand. Since our focus is the wholesaler-retailer interaction, we assume that the unit price is exogenously given, which is a departure from the traditional literature on the marketing-operations interface in which the price is a primary marketing decision variable. This assumption might be reasonable for Internet retail since advertising seem to influence Internet shoppers more than low prices (see Latcovich and Smith 2001 for discussion and many examples). Further, all the problem parameters are identical for the retailer and the wholesaler and known to everyone (there is no information asymmetry). We use a multi-period framework with lost sale representing a penalty for understocking through lost margin. Left-over inventory is carried over to the next period incurring holding cost. The following notation is used throughout the chapter (superscript t indicates relevant time period, vectors are underlined):

x^t beginning inventory before placing the order in period t,

Q^t order-up-to quantity in period t, $Q^t \geq x^t$,

r unit revenue,

w unit wholesale price,

c unit cost,

β discounting factor, $\beta \in [0, 1)$,

h unit holding cost per period,

A^t customer acquisition spending (includes all types of related marketing activities),

$D^t(A^t)$ demand (random variable), parameterized by the customer acquisition spending,

$f_D(\cdot)$ probability density function of the demand,

Π_r, Π_w, Π discounted infinite-horizon expected profit function of retailer, wholesaler, and total supply chain, correspondingly.

Superscripts I, T and D will denote vertically integrated, vertically disintegrated (traditional), and drop-shipping supply chains, correspondingly. Further, we will consider three drop-shipping models. In Model DW the wholesaler has channel power, in Model DR the retailer has channel power, and in Model DN the players have equal power. We also assume the following quite general form of the demand distribution:

Assumption 1. Demand distribution has the following form: $D^t(A^t) = \theta(A^t) + \varepsilon^t$, where $\theta(A^t)$ is a real-valued function and ε^t are i.i.d. random variables such that $D^t(0) \geq 0$.

Assumption 2. Expected demand is increasing in customer acquisition spending and it is always profitable to spend a non-zero amount on customer acquisition:

$$\frac{dED^t(A^t)}{dA^t} \geq 0, \ \lim_{A^t \to 0} \frac{dED^t(A^t)}{dA^t} = \infty.$$

Assumption 3. Expected demand is diminishingly concave (i.e., it is "flattening out" as A approaches infinity) in customer acquisition spending:

$$\frac{d^2 ED^t(A^t)}{d\left(A^t\right)^2} \leq 0, \frac{d^3 ED^t(A^t)}{d\left(A^t\right)^3} \leq 0.$$

The form of the demand function specified in Assumption 1 is used extensively in the operations and economics literature (see Petruzzi and Dada 1999 and references therein). Under this assumption, only the mean demand depends on A^t, and the uncertainty is captured by an error term ε^t. The first part of Assumption 2 is standard in marketing models (see page 265 in Lilien et al. 1992). We add the conditions that guarantee the existence of the non-degenerate (interior) solution, which is needed for the comparisons of the models. Assumption 3 is supported by empirical evidence from the marketing literature (see, for example, Simon and Arndt 1980 and Aaker and Carman 1982).

4. Supply chain models without coordination

In this section we will assume that the retailer and the wholesaler are employing a contractual agreement with a fixed transfer price. This might be a result of outside competition or other arrangements existing in the industry. The objective is to maximize infinite-horizon discounted expected profit. If a product is out of stock, the sale is lost. Unsold inventory is carried over to the next period incurring holding cost. The lost sale assumption leads to the following inventory balance equation in all models:

$$x^{t+1} = \left(Q^t - D^t\left(A^t\right)\right)^+.$$

4.1 Model I - vertically integrated supply chain

The wholesaler and the retailer are vertically integrated. At the beginning of each period, the product is purchased at a fixed unit cost c and sold to the customers at a fixed unit price r. The integrated retailer-wholesaler is the sole decision maker who chooses both the stocking quantity and the customer acquisition spending. Using a standard setup (see Heyman and Sobel 1984), the integrated firm will seek to maximize the following objective function:

$$\Pi^I\left(\underline{A}, \underline{Q}, x^1\right) = \sum_{t=1}^{\infty} \beta^{t-1} E\left[r \min\left(D^t(A^t), Q^t\right) - h\left(Q^t - D^t\left(A^t\right)\right)^+ - c\left(Q^t - x^t\right) - A^t\right].$$

The profit contribution in each period consists of the following four terms: revenue generated by the units sold (limited by demand and supply), holding cost for the units carried over (positive difference of supply and demand), purchasing cost of inventory (difference between order-up-to level and starting inventory), and customer acquisition spending. By standard manipulation, we can re-write the optimization problem as follows:

$$\max_{Q^t \geq x^t, A^t \,\forall t} \Pi^I \left(\underline{A}, \underline{Q}, x^1\right) = \max_{Q^t \geq x^t, A^t \,\forall t} \left[c x^1 + \sum_{t=1}^{\infty} \beta^{t-1} \pi^{I,t} \left(Q^t, A^t, x^t\right) \right],$$

where $\pi^{I,t}$ is the expectation of the single-period objective function defined as follows:

$$\pi^{I,t}\left(Q^t, A^t, x^t\right) = E\left[(r + h - c\beta) \min\left(D^t(A^t), Q^t\right) - (h + c\,(1-\beta))\, Q^t - A^t\right].$$

Proposition 1. *There exists a unique pair* $\left(Q^I, A^I\right)$ *optimizing the single-period objective function without starting inventory (i.e., unconstrained)* $\pi^I = \pi^{I,t}(Q^t, A^t, 0)$, *characterized by the following system of equations:*

$$\Pr\left(D\left(A^I\right) < Q^I\right) = \frac{r-c}{r+h-\beta c}, \tag{19.1}$$

$$\left.\frac{dED(A)}{dA}\right|_{A^I} = \frac{1}{r-c}. \tag{19.2}$$

Then, for any $x^1 \leq Q^I$, *the solution* $\left(Q^I, A^I\right)$ *is a unique stationary solution to the infinite-horizon problem.*

Proof: Consider the single-period unconstrained objective function π^I. To demonstrate uniqueness of the solution we will show concavity of the objective function, or equivalently we will verify that the diagonal elements of the Hessian matrix of the objective function are negative and that the determinant of the Hessian is positive. The first derivatives are

$$\frac{\partial \pi^I}{\partial Q} = (r+h-\beta c) \Pr(D(A) > Q) - (h + c\,(1-\beta)), \tag{19.3}$$

$$\frac{\partial \pi^I}{\partial A} = (r+h-\beta c) \Pr(D(A) < Q) \frac{dED(A)}{dA} - 1. \tag{19.4}$$

The second derivatives are

$$\frac{\partial^2 \pi^I}{\partial Q^2} = -\,(r+h-\beta c)\, f_{D(A)}(Q) < 0,$$

$$\frac{\partial^2 \pi^I}{\partial A^2} = -\,(r+h-\beta c)\, f_{D(A)}(Q) \left(\frac{dED(A)}{dA}\right)^2$$

$$+ (r+h-\beta c)\Pr(D(A)<Q)\frac{d^2ED(A)}{dA^2} < 0,$$

$$\frac{\partial^2 \pi^I}{\partial Q \partial A} = (r+h-\beta c)\, f_{D(A)}(Q)\frac{dED(A)}{dA} > 0.$$

The diagonal elements are clearly negative by Assumptions 2 and 3. Positivity of the determinant is equivalent to the following condition:

$$\frac{\partial^2 \pi^I}{\partial Q^2}\frac{\partial^2 \pi^I}{\partial A^2} > \frac{\partial^2 \pi^I}{\partial Q \partial A}\frac{\partial^2 \pi^I}{\partial A \partial Q}.$$

This can be expanded as follows:

$$-f_{D(A)}(Q)\times\left[-f_{D(A)}(Q)\left(\frac{dED(A)}{dA}\right)^2 + \Pr(D(A)<Q)\frac{d^2ED(A)}{dA^2}\right] > \left[f_{D(A)}(Q)\frac{dED(A)}{dA}\right]^2.$$

After collecting similar terms we obtain

$$-f_{D(A)}(Q)\Pr(D(A)<Q)\frac{d^2ED(A)}{dA^2} > 0.$$

This is true by Assumption 3, which completes the proof of uniqueness. To obtain the system of optimality conditions, it is convenient to substitute the first optimality condition into the second. Finally, following Section 3.1 in Heyman and Sobel (1982), the solution to the problem is myopic in nature. Furthermore, if initial inventory is sufficiently low for our problem, i.e. $x^1 \le Q^I$, the solution is stationary (i.e. the unconstrained solution is feasible). This completes the proof.

4.2 Model T - traditional supply chain

The wholesaler buys the product at a fixed unit cost c and sells it to the retailer at a fixed unit wholesale price w. The retailer holds inventory and sells it to the customers at a fixed unit price r. The retailer here is the sole decision maker who decides on both the stocking quantity and the customer acquisition spending. Similar to model I,

$$\max_{Q^t \ge x^t, A^t\,\forall t} \Pi_r^T\left(\underline{A}, \underline{Q}, x^1\right) = \max_{Q^t \ge x^t, A^t\,\forall t}\left[wx^1 + \sum_{t=1}^{\infty}\beta^{t-1}\pi_r^{T,t}\left(Q^t, A^t, x^t\right)\right],$$

where $\pi_r^{T,t}$ is the expectation of the retailer's single-period objective function defined as follows:

$$\pi_r^{T,t}\left(Q^t, A^t, x^t\right) = E\left[(r+h-w\beta)\min\left(D^t(A^t), Q^t\right) - (h + w(1-\beta))\,Q^t - A^t\right]. \tag{19.5}$$

The wholesaler's expected profit is

$$\Pi_w^T\left(\underline{A},\underline{Q},x^1\right)=-\left(w-c\right)x^1+\sum_{t=1}^{\infty}\beta^{t-1}\pi_w^T\left(Q^t,A^t,x^t\right),$$

where $\pi_w^{T,t}$ is the expectation of the wholesaler's single-period expected profit:

$$\pi_w^{T,t}\left(Q^t,A^t,x^t\right)=\left(w-c\right)E\left[\left(1-\beta\right)Q^t+\beta\min\left(D^t\left(A^t\right),Q^t\right)\right]. \tag{19.6}$$

PROPOSITION 2. *There exists a unique pair* $\left(Q^T,A^T\right)$ *optimizing the retailer's single-period objective function without starting inventory (i.e., unconstrained)* $\pi_r^T=\pi_r^{T,t}\left(Q^t,A^t,0\right)$*, characterized by the following system of equations:*

$$\Pr\left(D\left(A^T\right)<Q^T\right) = \frac{r-w}{r+h-w\beta}, \tag{19.7}$$

$$\left.\frac{dED(A)}{dA}\right|_{A^T} = \frac{1}{r-w}. \tag{19.8}$$

Then, for any $x^1\leq Q^T$*, the solution* $\left(Q^T,A^T\right)$ *is a unique stationary solution to the infinite-horizon problem (i.e. the unconstrained solution is feasible).*

PROOF: Similar to Proposition 1.

Note that although in this model the retailer is the sole decision maker and therefore seems to possess some power in the chain, he also bears all the inventory-related risk. In addition, customer acquisition spending incurred by the retailer not only benefits him but also benefits the wholesaler. As we will demonstrate later, this leads to the suboptimal performance of the channel.

4.3 Model D – drop-shipping

The wholesaler buys the product at unit cost c, holds inventory, and ships the product directly to the customer upon the retailer's request. The retailer acquires customers and makes sales. He pays unit wholesale price w per closed sale to the wholesaler, receives fixed unit revenue r from the customer, and does not hold inventory. Note at this point that under drop-shipping, contracts between the wholesaler and the retailer are not limited to the transfer pricing agreements. Since the product is never physically transferred to the retailer, it is often natural to consider a contract where the revenue is split between the retailer and the wholesaler in proportions λ and $1-\lambda$, and there is no need to establish a wholesale price. For example, Scheel (1990), page 17, indicates that in the drop-shipping business the dominant practice is for the wholesaler to give the retailer a discount over the suggested retail price. We do not consider such agreements since the analysis is identical to the transfer price contracts with $w = (1-\lambda)r$.

Under a drop-shipping arrangement, the channel members will make their decisions strategically and hence a game-theoretic situation arises. Similar to Cachon and Zipkin (1990), we consider games where each player chooses a stationary policy: the retailer's strategy is A and the wholesaler's strategy is order-up-to quantity Q. Three situations arise: either the wholesaler or the retailer might have negotiation power in the supply chain and act as Stackelberg leaders, or it is possible that the players have equal power and therefore the solution is in the form of a Nash equilibrium. We will consider all three situations.

Denote the best response function of the retailer by $R_r(Q)$ and the best response function of the wholesaler by $R_w(A)$, both defined for zero initial inventory. At this point we have not demonstrated uniqueness or even existence of the equilibrium. It helps, however, to visualize the problem first. We begin by presenting the game graphically (see Figure 19.1, parameters are taken from the example in Section 6 with $r = 8$). The point (A^{DN}, Q^{DN}) is a Nash equilibrium that is located on

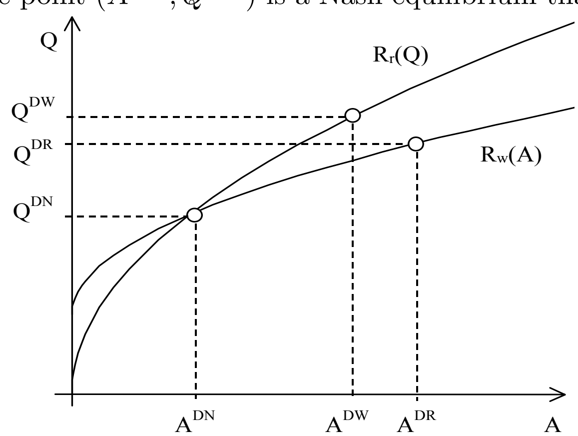

Figure 19.1. Stackelberg and Nash equilibria.

the intersection of the best-response curves. A Stackelberg equilibrium with the wholesaler as a leader (A^{DW}, Q^{DW}) is located on the retailer's best-response curve, and a Stackelberg equilibrium with the retailer as a leader (A^{DR}, Q^{DR}) is located on the wholesaler's response curve. We begin by characterizing the best response curves analytically. For a given Q, the retailer's optimization problem is

$$\max_A \Pi_r^D (A,Q) = \max_A \left[\sum_{t=1}^{\infty} \beta^{t-1} \pi_r^D (Q,A) \right],$$

where π_r^D is the expectation of the retailer's single-period objective function defined as follows:

$$\pi_r^D (A,Q) = E\left[(r-w) \min (D(A),Q) - A \right]. \tag{19.9}$$

Note that the objective function is concave, and hence the retailer's first-order condition characterizes the unique best response. For stationary policies, it is sufficient to consider the best response functions in the single-period game. The slope of the retailer's best-response function is found by implicit differentiation as follows:

$$\frac{dR_r(Q)}{dQ} = -\frac{\frac{\partial^2 \pi_r^D}{\partial A \partial Q}}{\frac{\partial^2 \pi_r^D}{\partial A^2}} = \frac{f_D(Q)\frac{dED(A)}{dA}}{f_D(Q)\left(\frac{dED(A)}{dA}\right)^2 - \Pr(D(A)<Q)\frac{d^2ED(A)}{dA^2}} > 0, \tag{19.10}$$

where the second term of the denominator is positive by Assumption 3. Positivity of the slope means that the retailer's customer acquisition spending is increasing in the quantity that the wholesaler stocks. However, due to the complexity of the expression for the slope, we are unable to verify either concavity or convexity of the best response function. Fortunately, this is not essential for any of the later results. Note that Figure 19.1 shows the retailer's best-response as a convex function, which is the case for the specific problem parameters used. We will now characterize the wholesaler's best response. For a given A, the wholesaler's optimization problem is,

$$\max_{Q \geq x^1} \Pi_w^D \left(\underline{A}, \underline{Q}, x^1 \right) = \max_{Q \geq x^1} \left[cx^1 + \sum_{t=1}^{\infty} \beta^{t-1} \pi_w^D (Q,A) \right],$$

where π_w^D is the expectation of the retailer's single-period objective function defined as follows:

$$\pi_w^D (A,Q) = E\left[(w+h-c\beta) \min (D(A),Q) - (h + c(1-\beta))\, Q \right]. \tag{19.11}$$

Again the objective function is concave, and the wholesaler's first-order condition characterizes the unique best response. The slope of the wholesaler's best response function is found by implicit differentiation as follows:

$$\frac{dR_w(A)}{dA} = -\frac{\frac{\partial^2 \pi_w^D}{\partial Q \partial A}}{\frac{\partial^2 \pi_w^D}{\partial Q^2}} = \frac{dE(D)}{dA} > 0. \tag{19.12}$$

We see that the stocking quantity of the wholesaler is increasing in the customer acquisition spending by the retailer. This time we can also establish the sign of the second derivative

$$\frac{d^2 R_w(A)}{dA^2} = \frac{d^2 E(D)}{dA^2} < 0,$$

and it follows that the wholesaler's best response function is concave. We are then ready to demonstrate that, when the retailer and the wholesaler have equal power in the channel, there will be a unique Nash equilibrium.

PROPOSITION 3. *There exists a unique Nash equilibrium pair* (Q^{DN}, A^{DN}) *in the single-period drop-shipping game without starting inventory that is characterized by the following system of equations:*

$$\Pr\left(D\left(A^{DN}\right) < Q^{DN}\right) = \frac{w-c}{w+h-\beta c}, \tag{19.13}$$

$$\left.\frac{dED(A)}{dA}\right|_{A^{DN}} = \frac{1}{r-w}\frac{w+h-\beta c}{w-c}. \tag{19.14}$$

Then, for any $x^1 \leq Q^{DN}$, *the solution* (Q^{DN}, A^{DN}) *is a unique Nash equilibrium of the multi-period game.*

PROOF: Existence of the equilibrium follows from the concavity of the retailer's and the wholesaler's objective functions (see Moulin 1986 page 114). To show uniqueness it is sufficient to notice that the optimality conditions can be solved sequentially, i.e., condition (19.14) can be solved uniquely for A^{DN} and then condition (19.13) can be solved uniquely for Q^{DN}.

We now consider the problem in which the wholesaler acts as a Stackelberg leader and offers the retailer a "take-it-or-leave-it" contract that specifies a quantity of merchandise that the wholesaler is willing to stock.

PROPOSITION 4. *Define:*

$$\xi(A^{DW}, Q^{DW}) = \min\left[\frac{w+h-\beta c}{w-c}, 1 - \frac{dED(A)}{dA} \times \left.\frac{\partial R_r(Q)}{\partial Q}\right|_{A^{DW}, Q^{DW}}\right].$$

For ε *having an Increasing Failure Rate (IFR) distribution, there exists a unique Stackelberg equilibrium solution pair* (Q^{DW}, A^{DW}) *in the single-*

period game with a powerful wholesaler and without starting inventory that is characterized by the following system of equations:

$$\Pr(D(A^{DW}) < Q^{DW}) = \frac{w-c}{\xi\left(A^{DW}, Q^{DW}\right)(w+h-\beta c)}, \quad (19.15)$$

$$\left.\frac{dED(A)}{dA}\right|_{A^{DW}} = \frac{1}{r-w}\frac{\xi\left(A^{DW}, Q^{DW}\right)(w+h-\beta c)}{w-c} \quad (19.16)$$

Then, for any $x^1 \leq Q^{DW}$*, the solution* (Q^{DW}, A^{DW}) *is the unique Stackelberg equilibrium of the multi-period game.*

PROOF: The retailer acts second by solving (19.9). The wholesaler takes the retailer's best response function into account and solves the following problem:

$$\max_Q \pi_w^D(Q) = \max_Q E\left[(w+h-\beta c)\min(D(R_r(Q)), Q) - (h + c(1-\beta))Q\right].$$

Since the retailer's best response function is single-valued, the Stackelberg equilibrium exists. Further, we will show that the second derivative of the wholesaler's objective function is negative (i.e., the objective function is concave), and so the Stackelberg equilibrium is unique. The first derivative of the wholesaler's objective function is

$$\begin{aligned}
\frac{d\pi_w^D}{dQ} &= \frac{\partial \pi_w^D}{\partial Q} + \frac{\partial \pi_w^D}{\partial A}\frac{dR_r(Q)}{dQ} \\
&= (w+h-\beta c)\Pr(D(R_r(Q)) > Q) \\
&\quad + (w+h-\beta c)\Pr(D(R_r(Q)) < Q)\frac{dED(A)}{dA}\frac{dR_r(Q)}{dQ} \\
&\quad - (h + c(1-\beta)) \\
&= (w-c) - (w+h-\beta c)\Pr(D(R_r(Q)) < Q)\left(1 - \frac{dED(A)}{dA}\frac{dR_r(Q)}{dQ}\right).
\end{aligned}$$

The second derivative is:

$$\begin{aligned}
\frac{d^2\pi_w^D}{dQ^2} &= -(w+h-\beta c)\frac{d\Pr(D(R_r(Q)) < Q)}{dQ}\left(1 - \frac{dED(A)}{dA}\frac{dR_r(Q)}{dQ}\right) \\
&\quad + (w+h-\beta c)\Pr(D(R_r(Q)) < Q)\frac{d\left(\frac{dED(A)}{dA}\frac{dR_r(Q)}{dQ}\right)}{dQ}.
\end{aligned}$$

Note first that

$$1 - \frac{dED(A)}{dA}\frac{dR_r(Q)}{dQ} = 1 - \frac{f_D(Q)\left(\frac{dED(A)}{dA}\right)^2}{f_D(Q)\left(\frac{dED(A)}{dA}\right)^2 - \Pr(D(A) < Q)\frac{d^2ED(A)}{dA^2}} > 0.$$

From the second derivative, consider the term:

$$\frac{d\,\Pr(D(R_r(Q)) < Q)}{dQ} = f_D(Q)\left(1 - \frac{dED}{dA}\frac{dR_r(Q)}{dQ}\right) > 0.$$

Next, consider the term:

$$\frac{d\left(\frac{dED(A)}{dA}\frac{\partial R_r(Q)}{\partial Q}\right)}{dQ} = \frac{d\left(\frac{1}{1-\frac{\Pr(D(A)<Q)}{f_D(Q)}\times\frac{d^2ED(A)}{dA^2}\Big/\left(\frac{dED(A)}{dA}\right)^2}\right)}{dQ}$$

$$= \frac{\frac{d}{dQ}\left(\frac{\Pr(D(A)<Q)}{f_D(Q)}\right)\frac{d^2ED(A)}{dA^2}\Big/\left(\frac{dED(A)}{dA}\right)^2 + \frac{\Pr(D(A)<Q)}{f_D(Q)}\frac{d}{dQ}\left(\frac{d^2ED(A)}{dA^2}\Big/\left(\frac{dED(A)}{dA}\right)^2\right)}{\left(1-\frac{\Pr(D(A)<Q)}{f_D(Q)}\times\frac{d^2ED(A)}{dA^2}\Big/\left(\frac{dED(A)}{dA}\right)^2\right)^2},$$

where

$$\frac{d}{dQ}\frac{\Pr(D(A) < Q)}{f_D(Q)} = \frac{d}{dQ}\frac{\Pr(\varepsilon < Q - \theta(A))}{f_\varepsilon(Q - \theta(A))} > 0,$$

since ε has an IFR distribution, and finally

$$\frac{d}{dQ}\left(\frac{d^2ED(A)}{dA^2}\Big/\left(\frac{dED(A)}{dA}\right)^2\right) = \frac{\frac{d^3ED(A)}{dA^3}\left(\frac{dED(A)}{dA}\right)^2 - 2\left(\frac{d^2ED(A)}{dA^2}\right)^2\frac{dED(A)}{dA}}{\left(\frac{dED(A)}{dA}\right)^4}\frac{dR_r(Q)}{dQ} < 0,$$

by Assumptions 2 and 3 so that $d\left(\frac{dED(A)}{dA}\frac{\partial R_r(Q)}{\partial Q}\right)\Big/dQ < 0$ and the result follows.

We would like to point out that the IFR assumption on ε is very non-restrictive since the IFR family includes just about any commonly used demand distribution.

Suppose now that the retailer acts as a Stackelberg leader and offers the wholesaler a "take-it-or-leave-it" contract that specifies an amount of money the retailer is willing to spend on customer acquisition.

PROPOSITION 5. *There is a unique Stackelberg equilibrium solution pair* (Q^{DR}, A^{DR}) *in the single-period game with a powerful retailer and without starting inventory that is characterized by the following system of equations:*

$$\Pr(D(A^{DR}) < Q^{DR}) = \frac{w - c}{w + h - \beta c}, \tag{19.17}$$

$$\left.\frac{dED(A)}{dA}\right|_{A^{DR}} = \frac{1}{r - w}. \tag{19.18}$$

Then, for any $x^1 \leq Q^{DR}$, the solution (Q^{DR}, A^{DR}) is a unique Stackelberg equilibrium of the multi-period game.

PROOF: The wholesaler acts second by solving (19.11). The retailer takes into account the wholesaler's best response function and solves the following problem:

$$\max_A \pi_r^D(A) = \max_A E\left[(r-w)\min(D(A), R_w(A)) - A\right].$$

Since the wholesaler's best response function is single-valued, the Stackelberg equilibrium exists. The first derivative is

$$\begin{aligned}
\frac{d\pi_r^D}{dA} &= \frac{\partial \pi_r^D}{\partial A} + \frac{\partial \pi_r^D}{\partial Q}\frac{dR_r(A)}{dA} \\
&= (r-w)\Pr(D<Q)\frac{dE(D)}{dA} \\
&\quad +(r-w)\Pr(D>Q)\frac{dR_w(A)}{dA} - 1 = (r-w)\frac{dE(D)}{dA} - 1,
\end{aligned}$$

and the second derivative is

$$\frac{\partial^2 \pi_r^D}{\partial A^2} = (r-w)\frac{d^2E(D)}{dA^2} < 0.$$

The retailer's objective function is clearly concave, and the uniqueness of the Stackelberg equilibrium follows. Finally, the optimality conditions are found by equating the first derivatives to zero.

Note that in Model D, as opposed to Model T, the wholesaler bears all the inventory-related risk. The retailer still incurs all the customer acquisition costs that will benefit not only him, but also the wholesaler. Hence, none of the players has an incentive to behave system-optimally, as we will show later.

4.4 Comparative analysis of the stationary policies

The interpretation of the first optimality condition (for Q) in each model is a standard one for the newsvendor-type models: equating the marginal cost of stocking an extra unit of the product with the marginal benefit. The second optimality condition (for A) has a similar interpretation in the marketing literature.

OBSERVATION 1. *Denote by $\eta(A)$ the elasticity of expected demand w.r.t customer acquisition spending. Formally:*

$$\eta(A) = \frac{dED(A)}{dA} \bigg/ \frac{ED(A)}{A}.$$

Then the optimality condition that defines customer acquisition for all Models can be re-written as follows:

$$
\begin{aligned}
\eta(A^I)\frac{r-c}{r} &= \frac{A^I}{rED(A^I)}, \\
\eta(A^T)\frac{r-w}{r} &= \frac{A^T}{rED(A^T)}, \\
\eta(A^{DW})\frac{w-c}{\xi\left(w+h-\beta c\right)}\frac{r-w}{r} &= \frac{A^{DW}}{rED(A^{DW})}, \\
\eta(A^{DR})\frac{r-w}{r} &= \frac{A^{DR}}{rED(A^{DR})}, \\
\eta(A^{DN})\frac{w-c}{w+h-\beta c}\frac{r-w}{r} &= \frac{A^{DN}}{rED(A^{DN})}.
\end{aligned}
$$

Each optimality condition is interpreted as follows: the ratio of the total customer acquisition spending to the total expected revenue (right-hand side) is equal to the demand elasticity times the retailer's relative marginal profit (left-hand side which is revenue minus marginal cost divided by the revenue).

The result of Observation 1 parallels a result frequently encountered in the marketing literature (see, for example, page 571 in Lilien et al. 1992).

OBSERVATION 2. *In all models, customer acquisition spending and stocking quantity are strategic complements.*

PROOF: A sufficient condition for strategic complementarity is positivity of the cross-partial derivative (see Moorthy 1993) of the objective function, which can be easily verified.

For identical parameters and no initial inventory we can perform analytical comparisons of the models. Since all the solutions are stationary, it is sufficient to compare single-period profits. The following table summarizes the optimality conditions of the five models:

Model I		$\Pr\left(D\left(A^I\right) < Q^I\right) = \frac{r-c}{r+h-\beta c}$	$\frac{dED(A)}{dA} = \frac{1}{r-c}$
Model T		$\Pr\left(D\left(A^T\right) < Q^T\right) = \frac{r-w}{r+h-\beta w}$	$\frac{dED(A)}{dA} = \frac{1}{r-w}$
	Powerful wholesaler	$\Pr\left(D\left(A^{DW}\right) < Q^{DW}\right) = \frac{w-c}{\xi(w+h-\beta c)}$	$\frac{dED(A)}{dA} = \frac{1}{r-w}\frac{\xi(w+h-\beta c)}{w-c}$
Model D	Powerful retailer	$\Pr\left(D\left(A^{DR}\right) < Q^{DR}\right) = \frac{w-c}{w+h-\beta c}$	$\frac{dED(A)}{dA} = \frac{1}{r-w}$
	Nash equilibrium	$\Pr\left(D\left(A^{DN}\right) < Q^{DN}\right) = \frac{w-c}{w+h-\beta c}$	$\frac{dED(A)}{dA} = \frac{1}{r-w}\frac{w+h-\beta c}{w-c}$

The next Proposition summarizes the comparative behavior of the models under the same wholesale price.

PROPOSITION 6. *Suppose that in all five models the retail price, the wholesale price, the unit product cost, and the demand distribution are identical. Then the following characterizations hold:*

a) **Customer acquisition:** $A^I \geq A^T = A^{DR} \geq A^{DW} \geq A^{DN}$, *the customer acquisition spendings are highest in Model I and lowest in Model D.*

b) **Stocking quantities:** $Q^I \geq Q^T$ *and* $Q^I \geq Q^{DR} \geq Q^{DN}$. *If* $(w+h-\beta c) \leq \sqrt{(h+c(1-\beta))(r+h-\beta c)}$ *then* $Q^T \geq Q^{DR} > Q^{DN}$, *otherwise* $Q^{DR} > Q^T$ *and* $Q^{DR} > Q^{DN}$. *Further, among the three drop-shipping models, Model DN always has the lowest stocking quantity,* $Q^{DW} \geq Q^{DN}$ *and* $Q^{DR} \geq Q^{DN}$.

c) **Retailer's profits:** $\pi_r^{DR} \geq \pi_r^{DN}, \pi_r^{DW} \geq \pi_r^{DN}$, *the retailer makes the lowest profits under the Nash equilibrium.*

d) **Wholesaler's profits:** $\pi_w^{DR} \geq \pi_w^{DW} \geq \pi_w^{DN}$.

e) **System profits:** *For* $(w+h-\beta c) \leq \sqrt{(h+c(1-\beta))(r+h-\beta c)}$, $\pi^I \geq \pi^T \geq \pi^{DR}$, *otherwise* $\pi^I \geq \pi^{DR} \geq \pi^T$. *Further, it is always true that* $\pi^{DW} \geq \pi^{DN}$ *and* $\pi^{DR} \geq \pi^{DN}$.

PROOF: Results *a*), *b*), and *c*) are obtained by a pair-wise comparison of the first-order conditions and employing the fact that $dED(A)/dA$ is decreasing in A. Results $\pi_r^{DR} \geq \pi_r^{DN}$ and $\pi_w^{DW} \geq \pi_w^{DN}$, i.e. the Stackelberg leader makes more profits than in a Nash equilibrium, are standard for Stackelberg games (see Simaan and Cruz 1976). The other results in *c*) and *d*) are obtained as follows:

$$\pi_r^{DN} = \pi_r^D(A^{DN}, Q^{DN}) \leq \pi_r^D(A^{DN}, Q^{DW}) \leq \pi_r^D(A^{DW}, Q^{DW}) = \pi_r^{DW},$$

where the first inequality follows from the observation that in Model D the retailer's profit is increasing in Q for a fixed A, and the second inequality holds since A^{DW} is an optimal response to Q^{DW}. Similarly

$$\pi_w^{DN} = \pi_w^D(A^{DN}, Q^{DN}) \leq \pi_w^D(A^{DW}, Q^{DN}) \leq \pi_w^D(A^{DW}, Q^{DW}) = \pi_w^{DW},$$

and also

$$\pi_w^{DW} = \pi_w^D(A^{DW}, Q^{DW}) \leq \pi_w^D(A^{DR}, Q^{DW}) \leq \pi_w^D(A^{DR}, Q^{DR}) = \pi_w^{DR}.$$

Finally, *e*) follows from the fact that the system profit is jointly concave in A and Q, combined with the results in *c*) and *d*).

From part *a*) of Proposition 6, we see that vertical disintegration leads to underspending on customer acquisition by the retailer, and in drop-shipping models the retailer underspends more than in the traditional model due to the misalignment of marketing and operations functions. It is interesting to note that the drop-shipping model performs the worst when players have equal power. The customer acquisition spending is closest to the system optimum when the retailer has channel power. The first part of this finding, $A^I \geq A^T$, that vertical disintegration leads to underspending on marketing effort, is similar to the result obtained by Jeuland and Shugan (1983). They, however, ignore inventory issues and consider deterministic price-dependent demand.

The intuition behind part *b*) of the proposition is that not only does vertical disintegration lead to putting too little effort into customer acquisition in Models T and D, but also it leads to understocking. This is an effect caused by the double marginalization that was described in the economics, marketing, and operations literatures. We also see that, for moderate to high wholesale price, the drop-shipping model with a powerful retailer always leads to ordering more than in the traditional model. The model with powerful wholesaler is not particularly transparent to the analysis, due to the presence of ξ, which depends on problem parameters in a non-trivial way. Note, however, that by studying Figure 19.1 we can see that Q^{DW} can be above or below Q^{DR}, depending on the curvature of the best response functions. The Nash equilibrium again results in the lowest (i.e. the worst) stocking quantity.

Parts *c*) and *d*) state that in Model DN both players are worse off than in the other two drop-shipping models. The intuition behind this result is as follows: note that both best response functions are monotonically increasing, and that the integrated solution consequently has higher optimal decision values than in the Nash equilibrium. It is well known that a Stackelberg leader is better off than under the Nash equilibrium. Hence, the Stackelberg solution will be within the rectangular area formed by the Nash equilibrium and the integrated solution (see Figure 1). Finally, since the follower's profit is increasing in the leader's decision variable, the result follows. Also, the wholesaler prefers the model with a powerful retailer over the other two. This makes Model DR a potential candidate for the best of the three drop-shipping arrangements.

Finally, part *e*) summarizes the most important comparative findings. We see that for a relatively small w there is no hope that either Model DR or DN will outperform the traditional model. However, for moderate to high wholesale prices, Model DR always outperforms the traditional model. Moreover, there is hope that even Model DN outperforms the traditional model for high wholesale prices. Note also that in the condition $(w + h - \beta c) > \sqrt{(h + c(1 - \beta))(r + h - \beta c)}$, the threshold value $\sqrt{(h + c(1 - \beta))(r + h - \beta c)}$ is closer to $h + c(1 - \beta)$ than to $r + h - \beta c$, and hence this condition accounts for more than 50% of the possible values of $w + h - \beta c$.

5. Supply chain coordination

In the previous section, we demonstrated that the solutions of Models T and D are generally different from the system-optimal solution. In addition to the double marginalization effect, drop-shipping is also plagued by marketing-operations misalignment. Can we come up with a mechanism that will induce coordination? As the next observation shows, a price-only contract is not sufficient.

Observation 3. *In Model T, the sole price-only contract that induces coordination has $w^T = c$ in which the retailer captures all profits, and in Model D there is no such contract.*

Not only are the price-only contracts inefficient, but also none of the other currently known contracts can coordinate the supply chain when customer acquisition expenses are considered.

Observation 4. *None of the following contracts – returns, quantity-flexibility, penalty (all as described by Lariviere 1999), revenue sharing (as described by Cachon and Lariviere 2000), or quantity discount (as described by Jeuland and Shugan 1983) – can coordinate the supply chains in Models T or D.*

To our knowledge, the only known contracts that work here are quantity forcing and franchising (Lariviere 1999). These contracts, however, might be difficult to implement in practice, as was noted in the literature. Clearly, in order to coordinate the supply chains considered here, we need a new form of contract. In Model T, we need a mechanism that will allocate a part of inventory risk to the wholesaler and also make the wholesaler bear some part of the marketing expenses. Pasternak (1985) and Kandel (1996) show that a returns contract in which the wholesaler offers partial credit for returned merchandise achieves supply chain coordination in the absence of marketing aspects. In our model this mechanism corresponds to the wholesaler offering the retailer a compensation proportional to the inventory carried over in each period (somewhat similar to holding cost subsidy in Cachon and Zipkin 1999). To achieve coordination, we add the notion of subsidized advertising similar to Chu and Desai (1995) who use the term "customer satisfaction assistance".

PROPOSITION 7. *The following contract achieves supply chain coordination in Model T: the wholesaler sponsors a portion of the retailer's customer acquisition expenses* $a = (w - c)/(r - c)$*, and at the same time offers the retailer a compensation* $b = a\,(r\,(1-\beta) + h)$ *for each unit of inventory carried over in each period. Under this contract, the retailer and the wholesaler split the total profit in proportions* $1 - a$ *and* a*, respectively.*

PROOF: Under the coordinating contract, the wholesaler's objective function is

$$\pi_w^T = E\left[(1-\beta)\,(w-c)\,Q + \beta\,(w-c)\min\left(D,Q\right) - b(Q-D)^+ - aA\right].$$

By substituting the proposed coordinating parameters and using the fact that $(Q-D)^+ = Q - \min(Q,D)$, we get

$$\begin{aligned}\pi_w^T &= aE\left[(1-\beta)\,(r-c)\,Q + \beta\,(r-c)\min\left(D,Q\right) - (r\,(1-\beta)+h)\,(Q - \min(Q,D)) - A\right] \\ &= aE\left[(r+h-\beta c)\min\left(D,Q\right) - (h + c\,(1-\beta))\,Q - A\right].\end{aligned}$$

Clearly, the objective function in the brackets is the integrated supply chain's profit. Similarly, the retailer's objective function is

$$\pi_r^T = E\left[(r+h-w\beta)\min\left(D(A),Q\right) - (h + w\,(1-\beta))\,Q - A\right].$$

Using the same technique we get

$$\pi_r^T = (1-a)\,E\left[(r+h-c\beta)\min\left(D(A),Q\right) - (h + c\,(1-\beta))\,Q - A\right].$$

Hence, the retailer will choose the system optimal decisions. This completes the proof.

Interestingly, the proportion of profit captured by the wholesaler is equal to the proportion of the customer acquisition costs she sponsors. If the wholesaler can influence the wholesale price w, she should choose it in combination with a according to the coordinating contract, so that a is as high as possible. This finding has an interesting implication for business practices on the Internet. Currently, many e-tailers are plagued by huge marketing expenditures, while our finding demonstrates that wholesalers should consider subsidizing a significant proportion of these expenditures to their own benefit. Of course, the higher the subsidized advertising, the higher the wholesale price. In practice this would mean that a retailer without sufficient funds for customer acquisition should seek a contract with a wholesaler who would be willing to subsidize a large portion of advertising in exchange for a higher wholesale price.

A different but somewhat similar contract works for Model D. We need a contract that would allocate some inventory-related risk to the retailer, while at the same time allocating some marketing expenses to the wholesaler. One such contract would be for the retailer to compensate the wholesaler for each unit of the inventory carried over while the wholesaler subsidizes a portion of customer acquisition expenses.

Proposition 8. *The following contract achieves supply chain coordination in Model D: the wholesaler sponsors a proportion of the retailer's customer acquisition expenses* $a = (w - c)/(r - c)$*, and at the same time the retailer partially compensates the wholesaler for all unsold merchandise in the amount* $p = (h + c\,(1 - \beta))\,(1 - a)$ *per unit. Under this contract, the retailer and the wholesaler split total profit in proportions* $1 - a$ *and* a*, respectively.*
Proof: Similar to Proposition 7.

The insights here are similar: the wholesaler gets a proportion of profits that is equal to the proportion of the customer acquisition expenses she sponsors. It follows that the wholesaler should strive to sponsor a relatively large portion of the retailer's customer acquisition expenses in combination with charging a higher wholesale price and receiving lower inventory compensation according to the coordinating contract. Note that both optimal contracts do not depend on the demand distribution, as was noted by Pasternak (1985) for pure returns contracts. This leads us to another observation:

Observation 5. *Propositions 7 and 8 hold for any demand distributions, including the ones that do not satisfy Assumptions 1-3.*

The last observation shows that the contracts we propose are robust, as has been repeatedly shown for returns contracts. We can do some comparison of the optimal contracts for Models T and D. First, note that in both cases the wholesaler sponsors the same proportion of the retailer's marketing costs (provided that the wholesale price is the same). This is a convenient property since, in this way, if the wholesaler works with both the traditional and the drop-shipping retailers, she does not need to discriminate among them. Discrimination in terms of subsidized customer acquisition costs might invoke some undesirable consequences due to legal limitations, since such discrimination might be considered as preferential treatment for some retailers. It is, however, possible that the wholesale prices in Models T and D will be different. Since the wholesaler in Model D has more involvement in channel functions and takes inventory risk, she is likely to demand a higher wholesale price. Scheel (1990), page 42, provides empirical data that indicates 10-20% higher wholesale prices for drop-shipping vs. conventional distribution established by the wholesalers to cover their extra costs.

OBSERVATION 6. *Suppose $w^T < w^D$. Then in coordinated supply chains, $a^T < a^D$ and $\pi_w^T < \pi_w^D$, the wholesaler sponsors more of the customer acquisition costs and has higher expected profit in the drop-shipping model.*

Drop-shipping requires a certain investment from the wholesaler, since she should be able to handle small shipments directly to the customer. In addition, there are costs associated with taking inventory risk. This would lead the wholesaler to demand an increase in the wholesale price, resulting in, as the last observation shows, capturing more profits, which is beneficial in the long run.

6. Numerical experiments

To illustrate the models and gain additional insights into the differences among the alternative supply chain structures, we will now consider a specific form of the demand distribution and a specific form of its dependence on customer acquisition expenses[3]. Let the random term of the demand follow a uniform distribution, $U[0, \Delta]$. Further, let $\theta(A) = \sqrt{A}$. For numerical experiments, we will assume that $c = 5$, $h = 1$, $\beta = 0.95$, and $\Delta = 1$. The variable of interest is, of course, the wholesale price. This also allows insight into cases where the wholesale price of the drop-shipping supply chains is different from the wholesale price of the traditional supply chain. In what follows, we assume that the price-only contract is used. We analyze two scenarios: $r = 8$ and 12, to illustrate the situations with low and high margins. Note that the optimal profits and decision variables can be obtained and compared in closed-form. First, we look at the optimal customer acquisition expense (Figure 19.2) and stocking quantity (Figure 19.3).

Note the strange form of A^{DW} that is a result of highly non-linear term $\xi\left(A^{DW}, Q^{DW}\right)$ in the optimality condition. As we can see from both

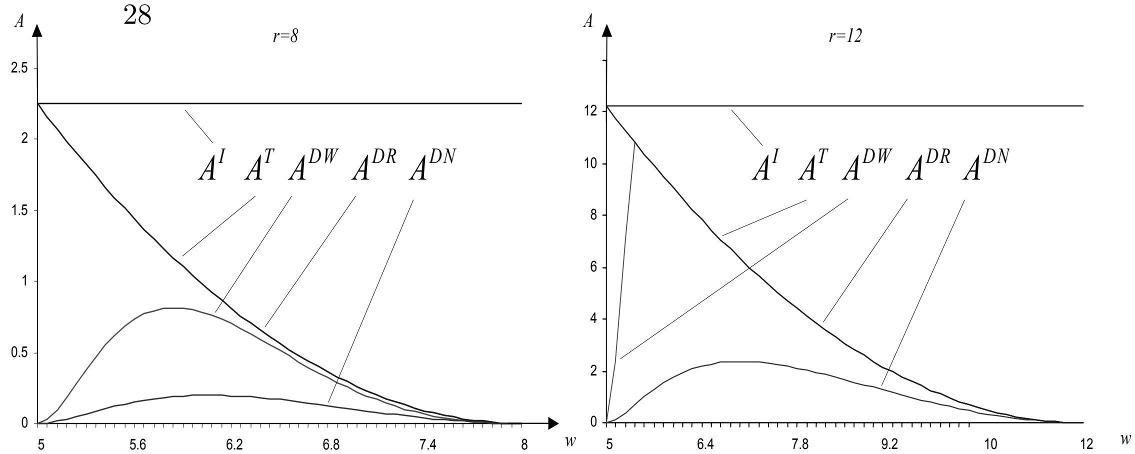

Figure 19.2. Optimal customer acquisition spending.

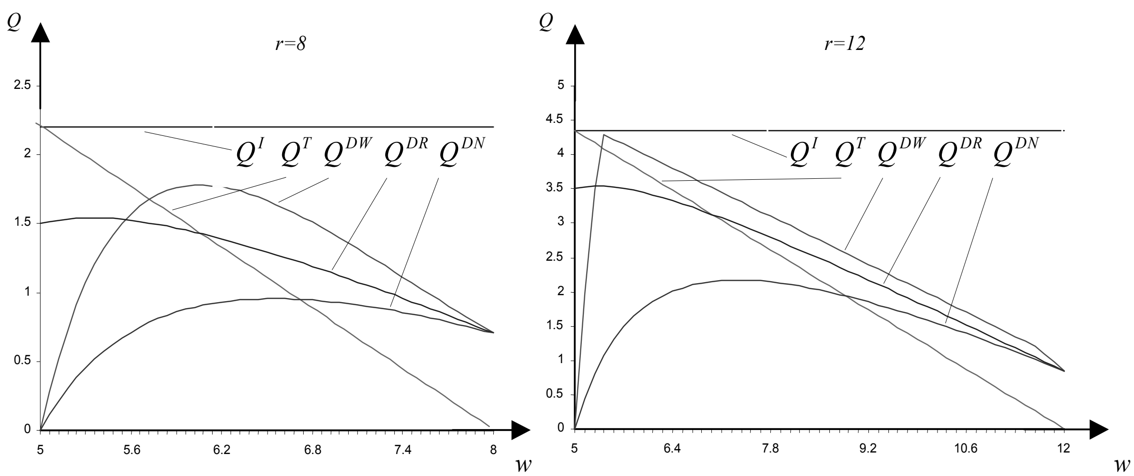

Figure 19.3. Optimal stocking quantity.

figures, in Model DN the retailer severely underspends on the customer acquisition and understocks. When margins are high, drop-shipping models with a Stackelberg leader closely resemble the traditional model. We will see this phenomenon again later. Finally, Model DW with the powerful wholesaler appears to perform somewhere in between the other two drop-shipping models, approaching Model DN for low margins and Model DR for high margins. We will now consider the retailer's profits

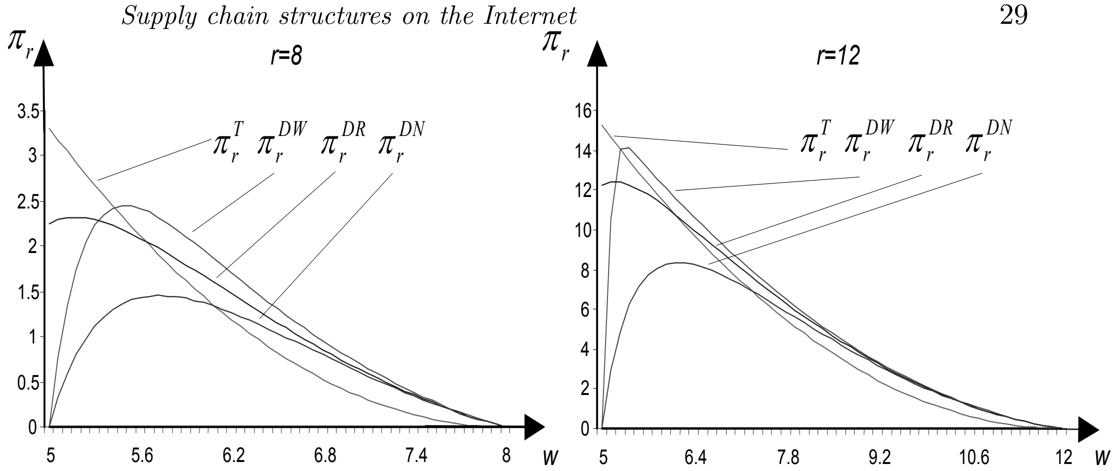

Figure 19.4. Retailer's profit.

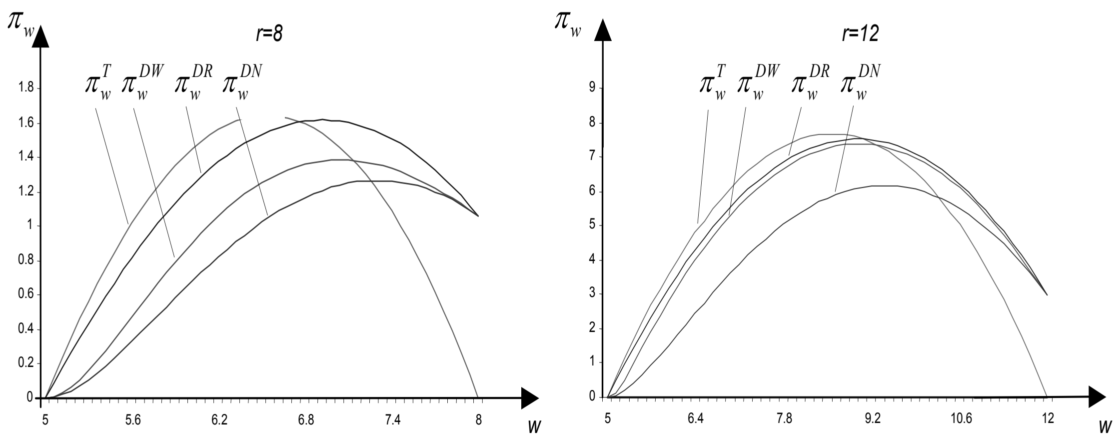

Figure 19.5. Wholesaler's profit.

(Figure 19.4).

In terms of the retailer's profit, the drop-shipping models outperform the traditional vertically disintegrated model for a wide range of parameters. The retailer (not surprisingly) is generally better off in Model DR where he has negotiation power. But even when the negotiation power is with the wholesaler (Model DW), the retailer's profit is higher than when the solution is a Nash equilibrium (Model DN), as we have demonstrated analytically. Any drop-shipping model dominates the traditional model for moderate to high wholesale prices. We consider the wholesaler's profit next (Figure 19.5).

Negotiation power does not do the wholesaler much good: she is generally better off when the retailer acts as a leader. The wholesaler's expected profit is virtually the same in the traditional channel structure T as in the drop-shipping structure with powerful retailer DR. When the wholesale price is relatively high, then both players prefer Model DR over Model T – this gives indications for when (i.e. in terms of wholesale price) this model is preferable. The Nash equilibrium is again the least attractive to anyone. Model DW performs somewhere in between Models DR and DN. We then look at the system profits (Figure 19.6).

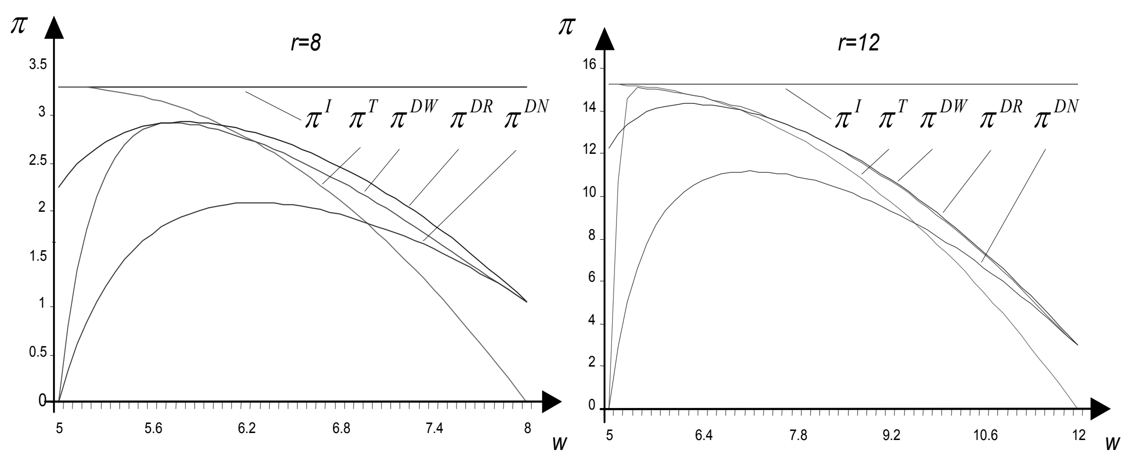

Figure 19.6. System profit.

The drop-shipping model with the powerful retailer proves to be superior under moderate to high wholesale prices, as we demonstrated earlier. Under a very high wholesale price, any drop-shipping model outperforms the traditional model. Among the three drop-shipping models, Model DN is consistently the worst, and Model DR is consistently the best.

Finally, we will illustrate the coordinating contracts. Assume that $c = 5$, $r = 8$, and $\Delta = 1$. We denote profits for the retailer and the wholesaler resulting from the coordinating contract by π_r^C and π_w^C, correspondingly. As we noted before, a returns contract for the traditional supply chain and a penalty contract for the drop-shipping models splits profits in the same proportions. Figure 19.7 presents retailer's and wholesaler's profits with and without coordination for all models.

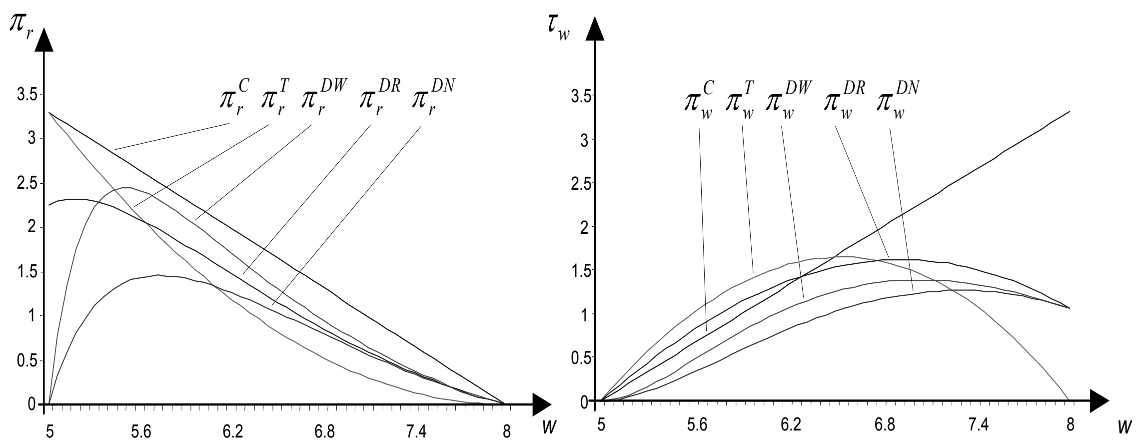

Figure 19.7. Retailer's and wholesaler's profits with and without coordination.

Observe that, in our example, under the coordinating contract, the retailer always makes more profit than without the coordinating contract. This is not true in general: under the low unit-revenue and high variability the retailer may be better off without the contract for high wholesale prices. The wholesaler, however, might be better off without coordination for low wholesale prices. Thus, Pareto optimality of the coordinating contract depends on the problem parameters.

7. Conclusions and discussion

Drop-shipping is a novel way of doing business on the Internet that has been inherited from catalog businesses and has already gained tremendous popularity. Since under drop-shipping the wholesaler takes inventory risk and performs fulfillment, the retailers can focus on customer acquisition. Currently, large retailers are able to capture a major part of the supply chain profit. Adopting drop-shipping will give wholesalers an opportunity to change this unbalance by increasing their involvement into the supply chain operations. Simultaneously, small retailers will benefit since barriers to entry in the form of large up-front inventory investment will diminish.

We find that drop-shipping introduces a conflict between marketing and operations functions that results in inefficiencies in the form of simultaneous understocking and spending too little on customer acquisition. As a result, both the retailer and the wholesaler should choose drop-shipping over the traditional contract only when the wholesale price is moderate to high. For example, if supply chain members decide to move from a traditional way of doing business to drop-shipping, one should consider a simultaneous wholesale price increase. This finding is consistent with the fact that under drop-shipping the wholesaler carries inventory-related risk and therefore should be able to increase the wholesale price; it is also consistent with the existing practice in catalog drop-shipping. Drop-shipping is more attractive when the retailer has the channel's power and can exercise it over the wholesaler. When channel power is equal, the retailer and the wholesaler arrive at a unique competitive equilibrium solution that significantly degrades system performance and usually does not benefit anyone.

We find simple contracts that achieve coordination in both the traditional supply chain and the supply chain with drop-shipping. According to these contracts, in the traditional channel the wholesaler subsidizes a portion of customer acquisition expenses as well as compensates the retailer for inventory carried over. In the case of drop-shipping inventory compensation goes from the retailer to the wholesaler. If the wholesaler can choose the wholesale price, the proportion of the customer acquisition expenses to subsidize, and the inventory compensation, an arbitrary split of profits can be achieved. In any case, the proportion of profits that the wholesaler captures coincides with the proportion of customer acquisition costs she subsidizes. Therefore, the higher the subsidy, the higher the wholesale price and the higher the wholesaler's profits.

One may wonder if a contract that specifies a proportion of subsidized customer acquisition expenses is enforceable. We have observed that some forms of subsidized marketing expenses are already in use by wholesalers. Alliance Entertainment Corp., a wholesaler that has implemented drop-shipping agreements, is one example. AEC publishes electronically an "All Media Guide" that is available to retailers working with AEC. According to AEC, the purpose of this database is to "... guide the consumer to make an intelligent purchasing decision and learn more about music and video." In order to publish this catalog, AEC employs about 600 professional and free-lance writers who create the content. Why would the wholesaler get involved into this completely different form of business? The "All Media Guide" is a form of subsidized customer acquisition expense. Spun.com, a retailer working with AEC according to the drop-shipping agreement, pays a basic weekly price of

$1500 for access to the database, whereas it would cost Spun.com about $20M to create its own contents Forbes (2000).

Other methods of sponsoring customer acquisition costs are possible. Many companies now provide tools that register how many visitors saw the advertisement, how many interacted with it, and how many clicked through and made the purchase. Companies providing this kind of service include AdKnowledge, DoubleClick, MatchLogic, and others. By using these tools, both the retailer and the wholesaler can observe the impact of customer acquisition expenditures and contract upon it. As Scheel (1990), page 89, describes, in the practice of catalog drop-shipping it is conventional for the wholesaler to provide "... free photos, graphics, catalog sheets, color separations or other advertising aids or allowances." This practice seem to indicate that some sort of subsidized customer acquisition exists in drop-shipping.

Our model is an effort to introduce and understand the supply chain issues that arise under a drop-shipping supply chain structure with emphasis on the inventory risk allocation, supply chain interaction, and issues of channel power. Many extensions to our model are possible. The risk pooling effect when one wholesaler supplies several retailers will make drop-shipping even more appealing than with a single retailer as described in this chapter (see Netessine and Rudi 2002 for the analysis of this issue). It is, however, very encouraging to see that even without the risk pooling effect, drop-shipping in many cases outperforms the traditional supply chain structure. With multiple retailers, it is even possible that the system profit under drop-shipping can exceed the profit of a vertically integrated supply chain since the integrated channel does not enjoy the benefits of pooling. Finally, as Scheel (1990) suggests, retailers can carry the most popular products in inventory and drop-ship the rest directly from the wholesaler. This dual-sourcing problem raises many interesting questions for further research: which products should be stocked vs drop-shipped etc.

Notes

1. This is an invited chapter for the book "Supply Chain Analysis in the eBusiness Era" edited by David Simchi-Levi, S. David Wu and Zuo-Jun (Max) Shen, to be published by Kluwer. http://www.ise.ufl.edu/shen/handbook/. The authors are grateful to Gerard Cachon, Preyas Desai, Paul Kleindorfer and Martin Lariviere for helpful suggestions that significantly improved the chapter. The chapter also benefited from seminar discussions at the following universities: University of Rochester, Dartmouth College, Emory University, INSEAD, Georgia Institute of Technology, Cornell University, Northwestern University, University of Chicago, New York University, Columbia University, Carnegie Mellon University, Washington University at St. Louis, Duke University, University of Pennsylvania and University of Utah.

2. The exceptions are follow-up papers by Netessine and Rudi 2002 where multiple retailers are modeled and by Randall et al. 2003 that focuses on the empirical analysis of Internet companies. These papers build upon the analysis in this chapter and do not analyze marketing aspects

3. A link to an interactive web site for numerical experiments is provided at www.nilsrudi.com.

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