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# Alignment in Cross-Functional and Cross-Firm Supply Chain Planning

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# Alignment in Cross-Functional and Cross-Firm Supply Chain Planning

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In this paper, we seek to use quantitative models to help appreciate the behavioral processes associated with successful cross-functional and cross-firm alignment in supply/demand planning. We model the interaction between a sales and a manufacturing function within a firm, or between an upstream and downstream firm. We claim that misalignment is costly both to the involved functions/firms and to the rest of the organization or supply chain, and focus the paper on studying the circumstances under which alignment will or will not happen. Using game theory, we find that, although misaligned economic incentives can play a role in explaining misalignment of planning behaviors, there is another important issue to consider: in our setting, the key factor that determines whether two functions or firms can align their planning is how much each party knows about the other's beliefs about demand. Thus, in this paper's setting, improved communication can induce alignment even if no economic incentives are changed. While consistent with the predominant view in organizational behavior (OB), this is a fundamental departure from the extant operations management (OM) literature.

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## 1 Introduction

Until now, the existence of misalignment in inventory decisions across different firms within a supply chain has been mostly attributed in the operations management (OM) academic literature to the presence of misaligned economic incentives (Cachon 2001). A similar reasoning has been applied in this literature to the study of decentralized but vertically integrated firms (Lee and Whang 1999). One reason why decentralized but vertically integrated firms can suffer alignment problems similar to the ones observed across firms is that, within many organizations, the administration of its customer-facing and supplier-facing sides are separated in distinct functional groups. Managing such groups so as to minimize mismatches and thus create and capture value is a cross-functional effort requiring integration of the differentiated functions (Lawrence and Lorsch 1986). However, this specialization or differentiation is notorious for generating conflicts in organizations (Shapiro 1977; Fawcett and Magnan 2002; Kahn and Mentzer 1996). As an example of this *intrafirm* focus

in OM, the coordination of manufacturing (production) and marketing (sales) for forecasting and inventory decisions by direct incentive design has been given much prominence (Chen 2005).

However, the changing of incentives either within or between organizations can be difficult and costly to accomplish. Although this fact has not been explicitly considered in most of the extant OM literature, it has been part of the academic debate in economics for some time. For example, Coase (1937), Klein, Crawford and Alchian (1978), Williamson (1978), and others have pointed out that the design and enforcement of contracts and incentives has a cost (which may differ depending on whether the two parties are within or between firms). In addition to this cost, a high potential for unintended consequences makes companies cautious, and sometimes reluctant, to make such incentive changes. Recent case studies and practitioner accounts provide evidence, however, that some organizations manage to achieve an aligned planning and execution of the customer- and supplier- facing sides of the organization without wholesale change in incentives (Lapide 2004a, 2004b, 2005; Oliva and Watson 2007). In fact, gains from supply chain improvement and performance have been posited and empirically shown to be linked to a much broader but more difficult degree of integration which goes beyond incentive alignment (Stank et. al. 1999; Stank et. al. 2001; Shapiro 1998 and Barratt 2004).

Within the quantitative modeling literature, the need for this more elusive, broader-reaching integration has grown out of recognition that both the customer- and supplier-facing sides of the organization or supply chain can be simultaneously influenced and planned resulting in improved performance (Lee 2004). The OM academic literature by and large has reflected practice in studying the demand and supply sides of the organization independently (Federgruen and Heching 1999). Although the trend is reversing given the increased focus on modeling integrated production and pricing decisions (Chen et. al. 2006; Eliashberg and Steinberg 1991; Yano and Gilbert 2004), a clear understanding of the behavioral processes and systems that are associated with successful interdepartmental and inter-firm integration has not been established (Griffin and Hauser 1996; Kahn 1996; Kahn and Mentzer 1998).

We seek, then, to use quantitative models to help appreciate the behavioral processes associated with successful cross-functional and cross-firm integration in supply/demand planning. As in Oliva and Watson (2007), we operationalize this integration as “alignment” which we define as *a congruence in the activities or actions taken in anticipation of demand across functions or firms*. By this we mean, for example, that in an organization the sales function and manufacturing group work towards the same target for the sales of a particular product and respectively create/facilitate the requisite demand and supply so that the target is met. Note that alignment as defined here

is different from what the OM contract theory papers usually call “coordination” or “first-best,” which would be a global maximum or minimum along some objective for the firm/supply chain. We do not necessarily define this alignment or operationalize this integration as achieving first-best performance (Chen; and Porteus and Whang 1991), but rather focus on alignment as an objective *per se*, even if it was “suboptimal”. The distinction here is a subtle but important one. We claim that misalignment can be so costly, that even alignment of plans (and capacities) at a level that is not optimal with respect to the “true” distribution of demand can be better than a misalignment of plans (and capacities) centered around the “true” demand distribution. Since this goes against over 20 years of tradition in research around coordinating systems, we are obligated to make a case for this alternative objective which we attempt as follows.

Let us start by pointing out that the cross-functional/firm context for planning is a complex one implying that optimization as a goal may be behaviorally unrealistic. If this is true, then alignment, even if considered as a “second-best” objective, can still provide powerful benefits to the organization/supply chain. Recall that, as mentioned earlier, most organizations are primarily functional and the customer-facing and supplier-facing sides of the supply chain are usually managed separately by different functions or groups of functions. The complexity of administrating either of these sides, and the specific set of skills required to do so, drives the differentiation into functional groups within the organization, or into different firms within the supply chain. The very same motives that drive this differentiation, however, drive difficulties in the communication and collaboration needed for integrated performance (Lawrence and Lorsch 1986) creating conflicts. These conflicts generally center around differing expectations about both demand and supply, and differing functional/organizational preferences and priorities that can result in mismatches between the capacities invested to meet planned demand and the required planned supply of the organization. Now, true optimization requires the appropriate trade-off of valid priorities of the organization based on appropriate assessment of risks and cost. The extraction and assessment of such valid and appropriate priorities, risks and costs (if they at all can be extracted and assessed) would be similarly compromised by the just described cross-functional/firm context.

We therefore propose alignment as an alternative and argue for its appeal mainly because it can yield two important benefits. First, as action plans become credible and accurate statements of organizational intentions (which is more likely to happen if actions are aligned), the organization’s reputation grows in the eyes of customers, suppliers, employees, and investors, affording powerful leverage through trusted relationships (Kreps 1986). For economist David Kreps (1986), corporate culture is the means to achieve a set of principles upon which reputations can be built,

and reputations are the key to overcoming the problems created either by incomplete contracts (that, for example, do not foresee all possible contingencies) or by transaction costs (that could yield enforcing certain contracts uneconomic). However, for reputations to be effectively built, it is essential that behavior outside the established principles can be identified (and potentially punished by, for example, withdrawing future business). As Kreps points out, observing such breaches of principles is only plausible if the organization (or supply chain) is consistently aligned. This issue can be so important, that Kreps goes as far as stating: “*Consistency and simplicity being virtues, the culture/principle will reign even when it is not first-best*”. Second, if the organization is capable of executing according to stated plans, the door is opened to continuous improvement as stable and predictable processes are the first requirements for reliably interpreting historical data and making inferences for learning and improvement (Spear and Bowen 1999, Oliva and Watson 2007). In addition, there are a number of other strategic, operational and tactical decisions that are influenced and determined by an organization’s lack of a capability for achieving alignment. This fact increases the value of alignment both within and between organizations as, above and beyond reducing waste, the existence of alignment allows decision makers to more clearly observe changes in key variables and take appropriate actions when needed.

To summarize our case for alignment, we have made two claims: (1) that misalignment in actions or activities taken in preparation for future demand can be costly, and (2) that changing contracts and incentives can also be costly (as explained earlier in the introduction). Given this, we model a setting where there is an upstream and a downstream player, each with decision rights over the capacity put in place to meet respectively planned supply and demand. These players can be both independent functions within a decentralized vertically integrated firm or separate firms within a supply chain, and differentiate between (a) players beliefs about demand (which is what some economists call “priors”, see Van den Steen 2001), (b) players beliefs about each other’s beliefs about demand or accuracy, (c) economic incentives in the “traditional” OM sense, and (d) actual actions or activities taken to plan for future demand. The question that we will attempt to answer in this paper is the following: under what circumstances is alignment expected to (spontaneously) happen in actions or activities taken to plan for future demand between a customer-facing and a supplier-facing function (firm) of a firm (supply chain)? Note that, by “spontaneously,” we mean “without changing economic incentives.” Above and beyond its academic contributions, this question can be specially relevant for practice if both the costs in claims (1) and (2) above are high. We find that, even when players have significantly different beliefs about demand and economic incentives, it is possible for actual actions taken by the parties to be aligned. Moreover, our model

indicated that the accuracy of players beliefs about each other is a key ingredient for this alignment to happen. This becomes specially relevant if *the cost of changing incentives is high relative to the cost of improving the players perceptions about each other through improved communications.*

In our model, the capacity put in place to meet planned supply and demand is not only related to demand potential indicated by the perceived probability distribution of demand (and the cost of inventory and opportunity cost of lost demand) but also to the cost of investing in capacity to meet such planned supply and demand. The higher the cost of investing in capacity for such supply and demand, the lower the planned supply and demand capacities (i.e., the organization/supply chain may choose to leave more demand unsatisfied through investing in less capacity). Also, if a certain function in the organization or member of the supply chain plans for a given capacity to meet their perceived demand, the other party would prefer not to invest in any more capacity, since the total company capacity is given by the constraining capacity (e.g., sales will not invest in higher capacity than manufacturing plans to deliver). This set up is similar to Tomlin (2003). Finally, rather than knowing the true demand distribution, functions have perceptions about demand and, sometimes, about the other function's own perceptions (e.g., sales may think demand behaves in a certain way, while manufacturing may think differently; sales may or may not be aware of such difference in perceptions; sales may be commonly accepted to be better than manufacturing at forecasting, etc.). This feature is, as far as we know, unique to this paper.

A relatively recent, related stream of literature within economics/game theory models general situations when two players have different prior beliefs about certain events (Van den Steen 2001, Yildiz 2000). While this literature shares with this paper the fact that parties are allowed to differ in their beliefs even if both parties were exposed to the same information, this paper is different in two ways: (1) this paper models a specific supply chain/firm problem which is common in OM but has not been, to the best of our knowledge, treated in the extant literature, (2) we not only allow for the parties to believe different things about demand, but also about the other party's belief about demand.

The *intra*firm OM literature has either concentrated on approaches for managing the sales force (Chen, Gonik 1978; and Lal and Staelin 1986), or considered schemes for coordinating functions such as manufacturing and marketing so as to achieve the benefits of centralized decision making (Porteus and Whang, Celikbas et. al. 1999, and Li and Atkins 2002). The related *inter*firm OM literature, which considers the interactions between manufacturers and retailers that are not in the same firm, generally concentrates on finding new incentive schemes to achieve the benefits of centralized decision making (Cachon 2001; Cachon and Lariviere 2001; Tomlin 2003), or on

the value of particular supply chain approaches such as information sharing (Fisher and Cachon 2001) and collaborative forecasting (Aviv 2001). The first and fourth set of articles, that is, the intrafirm and interfirm OM literature on value creating approaches, recognize the need for vital information for decision making in the organization or across firms but does not explicitly address cross-functional/firm alignment. The literature on coordinating recognizes the incentive differences between functions or firms but usually assumes the context of the different decision makers to be otherwise congruent (although sometimes acknowledging certain information asymmetries, as in Cachon and Lariviere 2001, or in Cohen Kulp 2002), and goes on to propose incentive schemes to achieve some “global optimum” (i.e., first-best). Thus, these articles assume misalignment to be the result of differences in incentives or knowledge about end-customer demand (and do not explicitly model the perceptions that each party may have about the other party’s perception). Within the collaborative forecasting stream of literature, Miyaoka (2003), Lariviere (2002) and Özer and Wei (2006) argue, among others, that whether the parties reveal truthful information depends on their incentives, and go on to design truth-revealing incentive mechanisms. In Kurtulus and Toktay (2007), the parties must decide whether to invest to improve their forecasting before sharing it. In this paper, we abstract away from the investments that each party may incur to improve their forecast, although we do consider cases when one party’s forecast is perceived to be better than the other’s.

Therefore, given 1) the necessity of alignment of planned activities in order to meet the either strategic, operational or tactical objectives/constraints of an organization within a supply chain (whatever they may be), 2) the difficulty in achieving this alignment, and 3) the fact that the processes and systems for achieving this alignment are not clearly understood in the OM literature (a literature that mostly focuses in changing incentives or information about demand), this paper provides motivation for studying alignment as a key operational objective.

The rest of the paper is organized as follows: Section 2 describes the model, goes into the general profit function for a vertically integrated firm/supply chain and finds the global optimum. The remainder of the paper considers separate objective functions for each function/firm within the supply chain. In Section 3, functions/firms have perfect knowledge about each other’s demand perception and cost parameters. In Section 4, some of this is relaxed. In subsection 4.1, no function/firm knows the demand perceptions of the other function. In subsection 4.2, one function knows the demand perceptions of the other function/firm but not vice versa. In subsection 4.3, both functions/firms know that they have different perceptions about demand, but do not know exactly how these perceptions are different. Section 5 covers cases where one or more functional/firm

perceptions contains information of value for forecasting by the other function/firm. This differs from Section 4 where essentially the assumption is that there is no informational value for forecasting to be deduced from the perception of the other function/firm, thus the perceptions are unaffected when shared. We refer to the perceptions in section 4 as *static* and to the perceptions in Section 5 as *dynamic*. Sections 6 and 7 concludes the paper with a discussion about the insights revealed about the behavioral processes required for generating alignment.

## 2 Model Description

### 2.1 Setting

While the topic of alignment is extremely rich, in this paper we use a simple model to generate some insights and to illustrate how the extant OM literature can be expanded. Consider a decentralized vertically integrated organization or a supply chain which consists of an upstream group or firm (from now on, “manufacturing”) which administers the supply facing side of the organization or supply chain and a downstream group or firm (from now on, “sales”) which administers the demand facing side of the organization. “Manufacturing” supplies “sales” with a product that sales converts into final sales. In order for demand to be met, the organization/supply chain needs both demand and supply to be explicitly planned by both groups/firms by investing in capacity to meet potential end demand.

Let  $K_s$  and  $K_m$  be the capacity invested by these groups/firms in anticipation of future demand. Alignment in planning actions is defined as  $K_s = K_m$ . The unit cost of  $K_s$ , the capacity within sales (i.e., the downstream group) that is needed to satisfy demand, is represented by  $\gamma$ . It can be thought of as the cost of sales-persons, infrastructure or demand creating activities such as promotions, which serve to generate/meet demand. The unit cost of  $K_m$ , the capacity within manufacturing (i.e., the upstream group) that is needed, in addition to inventory, in order to make inventory available to meet existing demand, is  $\alpha$ . Both  $\alpha$  and  $\gamma$  are costs in addition to the costs of acquiring inventory or price that is offered to the customers. We make the assumption of unit capacity costs, because although capacities in aggregate within the upstream and downstream parties are usually added in batches, these capacities usually are allocatable over multiple products in smaller quantities. A complete treatment of such a multi-product setting is avoided here for analytical convenience. Assume also that the manufacturing cost of the product is  $c$ , the retail price is  $p$ , and the transfer price of the product from the upstream to the downstream party is  $w$ . We will assume that  $\alpha$ ,  $\gamma$ ,  $w$ ,  $p$ , and  $c$  are common knowledge across both parties and that true



demand and perceptions of demand can be expressed as probability distributions. The newsvendor-based critical fractiles for sales and manufacturing are recurring elements for our analysis, therefore let  $s^* = \frac{p-w-\gamma}{p-w}$  and  $m^* = \frac{w-c-\alpha}{w-c}$ .

The timing of events is as follows:

1) The upstream and downstream parties make their planning decisions on capacity for inventory and demand, i.e. they choose (and incur the cost of)  $K_s$  and  $K_m$ . In the simultaneous version of the game, both capacity decisions are made simultaneously. In the Stackelberg game, one party announces its capacity plans before the other. In both cases, there is full commitment (i.e. capacity announcements are “binding” agreements, or, in other words, there is no “bluffing”). In this section, the probability distribution of true demand is known, but in the remaining sections there will be different assumptions about demand perceptions.

2) Demand is realized and is satisfied if it has been planned for by both manufacturing and sales.

As a result of our assumptions about demand perceptions, the equilibria for our games described in this paper are slightly non-traditional, in the sense that we are not considering true final payoffs, but, rather, perceived *ex ante* payoffs. This is further compounded by the fact that multiple equilibria exist for most of our games. However, we assume that the players will use the *perceived Pareto dominant equilibrium (PPD)* as a focal point see Kreps. By PPD, we mean the equilibrium that, based on each player’s own perceptions about demand, knowledge of economic parameters, and perception of the other player’s perceptions about demand, is preferred to other equilibria. It is reasonable to predict such equilibria as the unique outcome of the games, as in Wang (2007). However, it is important to note that, in this paper, these equilibria are based on the individual perceptions of decision makers which may not be identical. Therefore, although more profitable alternative actions may exist for a more knowledgeable party (such as the reader), our decision makers are limited by what they know about each other, and what they perceive about demand.

## 2.2 First-best

In this paper, we model a system without explicit costs of changing incentives and costs of misalignment related to learning or reputation effects, but implicitly assume that both are high. As mentioned in Section 1, this implies that first-best performance within this model is not necessarily the global optimum of the supply chain, which is the reason why this paper concentrates on achieving alignment without changing incentives rather on achieving first-best performance according to the model stated here. However, we still find first-best to distinguish it where possible from the

policies under alignment, and because it can also provide a measure of the performance of the decentralized system. Let  $\Phi$  be the true probability distribution for demand  $D$  and let  $\Pi^l(K_s, K_m)$  be the total expected profit for the system. Then:

$$\Pi^l(K_s, K_m) = -\gamma K_s - \alpha K_m + E(p - c) \min[D, K_m, K_s]$$

Note that, in the above expression for  $\Pi^l(K_s, K_m)$ , inventory is only procured for demand when it occurs. Such a setting represents most supply chain setting which are hybrids of make-to-stock (usually as a result of long leadtimes or bottlenecks) and make-to-order systems. This model is, essentially, the initial set up in Tomlin (2003).

**Proposition 2.1** *The optimal plan for the system has planned demand and supply satisfying  $K_s = K_m = \Phi^{-1}\left(\frac{p-c-\alpha-\gamma}{p-c}\right)$ .*

In the integrated system, the optimal plan requires alignment because it saves waste (i.e. by not incurring unnecessarily in  $\alpha$  or  $\gamma$ ). Note that, although not specifically modeled, misalignment may imply other costs discussed in the introduction. In addition, note that the planned capacity of supply and demand is not only related to demand potential indicated by the probability distribution of demand (and the cost of inventory and opportunity cost of lost demand) but also *to the cost of capacities necessary to support supply and demand*. The higher the cost of supply and demand capacity, the lower the planned supply and demand, that is, the organization may choose to leave more demand unsatisfied, that is, suffer more expected lost sales.

### 3 Perfect Information in a Decentralized System

For the remainder of this paper, we either assume that the sales and manufacturing groups are in different firms, or that they are managed in a decentralized way as centers responsible for their own profit and loss, and seek to understand the conditions under which alignment in planning occurs. We consider both simultaneous and Stackelberg games. In the next subsection, we assume that  $\Phi$  (the true distribution of demand) is common knowledge. Propositions of this subsection also hold if  $\Phi$  represents, instead, some firm wide belief about the distribution of demand. In later subsections and sections we will change what each function perceives about demand and what it knows about the other party's perceptions.

#### 3.1 Common Perceptions about Demand

In this subsection, we examine the game results for shared common perception about demand across both sales and manufacturing functions. Let  $\Pi_s(K_s)$  be sales' expected profit as a function of the

planned demand  $K_s$ . Under our assumptions, given planned supply of  $K_m$  from manufacturing, we have

$$\Pi_s(K_s) = -\gamma K_s + E(p - w) \min[D, K_s, K_m].$$

Assuming sales solves

$$\max_{K_s} \Pi_s(K_s),$$

its unique reaction function  $K_s(K_m)$  is given by  $K_s(K_m) = \min[\Phi^{-1}(s^*), K_m]$ . A similar expected profit function  $\Pi_m(K_m)$  can be defined for manufacturing:

$$\Pi_m(K_m) = -\alpha K_m + E(w - c) \min[D, K_s, K_m],$$

where similarly manufacturing's unique reaction function  $K_m(K_s)$  is given by  $K_m(K_s) = \min[\Phi^{-1}(m^*), K_s]$ .

**Proposition 3.1** *There exists a unique PPD Nash Equilibrium to the simultaneous move game given by  $[K_m^{\text{Si}}, K_s^{\text{Si}}]$ , where  $K_m^{\text{Si}} = K_s^{\text{Si}} = \min[\Phi^{-1}(m^*), \Phi^{-1}(s^*)]$ .*

**Proposition 3.2** *The PPD equilibrium is the same in the Stackelberg game irrespective of which group leads as in the simultaneous game.*

The propositions above state that if perceptions about demand are homogeneous across functions, then alignment will happen irrespective of who moves first. Proposition 3.1 is just as the result in Tomlin (2003). Here, however, is where this paper departs from Tomlin (2003), who does not consider Stackelberg games or differences in perceptions, and goes on to look for a contract that would achieve first-best in a perfect information, simultaneous game setting.

The alignment described in Proposition 3.1 and 3.2 surrounds an alignment concerning both the mean inventory and safety stock held in the system (assuming for convenience that it is appropriate to consider our capacities in this conventional inventory perspective). The conditions for alignment in Proposition 3.1 and 3.2 are actually quite strong requirements. Both manufacturing and sales are quite familiar with the decision-making (approach, cost structure, objective, consistency) and information structure available to each other, furthermore these perceptions match with reality. This is clearly not necessarily true across firms, but may also not be true within two groups of the same firm: in fact, in today's conventional functionally oriented organizations this type of familiarity is not easy to find. As a result, the argument can be made that information asymmetries exist within the organization along with incomplete and sometimes inaccurate perceptions of the decision making process of and information available to others. Furthermore, even when the information

structures and decision-making processes are equally known, the information may not be accurate. The question is: When does the alignment shown here break down?

### 3.2 Different but Known Perceptions about Demand

Do the perceptions of demand have to be the same across both functions to ensure alignment? To provide an answer to this question, let  $\bar{\Phi}_m$  ( $\bar{\Phi}_s$ ) be the perception of demand held by manufacturing (sales). Assume, for this subsection, that both sales and manufacturer know each other's perception about demand.

**Proposition 3.3** *For a simultaneous move game, there exists a unique PPD Nash Equilibrium  $[K_m^{\text{Si}}, K_s^{\text{Si}}]$ , where  $K_m^{\text{Si}} = K_s^{\text{Si}} = \min [\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*)]$ .*

**Proposition 3.4** *The PPD equilibrium is the same in the Stackelberg as the simultaneous game irrespective of which function is the leader.*

The main conclusion from the propositions above is that if both parties know each other's perceptions about demand, then alignment will happen even if these perceptions are dissimilar and regardless of who moves first.

### 3.3 One Function is a Known Better Forecaster

Here, just as in the previous section, we assume that both sales and manufacturing know each other's perceptions about demand,  $\Phi_s$  and  $\Phi_m$  respectively. In addition, assume, WLOG that sales is acknowledged by both parties as being a better forecaster. This sense of being a better forecaster can imply any of a number of differences in the forecasting ability of the parties. For example, it can imply a difference in accuracy with accuracy implying proximity of the forecast to the true demand distribution parameters. In situations of similar accuracy, it could imply a greater confidence in the methodology or information used to generate the forecasts. The particular reasons for the mutual acknowledgement of sales being the better forecaster are not crucial to the results in this paper. Note that this notion of "better forecaster" is left intentionally ambiguous. This is because, although mathematically it is possible to be very precise about what one means by this, it may not be realistic to assume that players in a real life situation would. In this section, the question we are trying to address is: what if the parties knew that sales is better at forecasting, but we were not exactly sure in what precise sense it was better?

**Proposition 3.5** *For a simultaneous move game, if sales is a known better forecaster, there exists a unique PPD Nash Equilibrium  $[K_m^{\text{Si}}, K_s^{\text{Si}}]$ , where  $K_m^{\text{Si}} = K_s^{\text{Si}} = \min [\Phi_s^{-1}(m^*), \Phi_s^{-1}(s^*)]$ .*

**Proposition 3.6** *The PPD equilibrium is the same in the Stackelberg game as in the simultaneous game irrespective of which function is the leader.*

Just as in Proposition 3.3, if both parties know each other’s perceptions about demand, then alignment will happen regardless of who moves first. The difference with Proposition 3.3 is that, now, both parties will use the information provided by the better predictor. Essentially, if both parties agree on and are certain about who is the better predictor, and know each other’s perceptions perfectly, then they simply choose to use the best perception of demand. This could be interpreted as a variation of the ideas in section 3.1.

## 4 Imperfect Information: Static Perceptions with Partial Sharing

How does imperfect information about perceptions affect alignment? In this section we assume imperfect information surrounding perceptions of demand across functions (firms). Again, let  $\Phi_m$  ( $\Phi_s$ ) be the perception of demand held by manufacturing (sales). In this section, the other function’s (firm’s) perception of demand is not assumed to have any informational content for forecasting for the current function. We thus assume that each function’s (firm’s) beliefs about demand are unaffected by the sharing of beliefs. We term this case the *static case*. In the next section we will relax this assumption, assuming that, after sharing beliefs about demand, functions (firms) may change their original beliefs.

### 4.1 Difference in Perceptions Unknown

Assume in this subsection that neither sales nor manufacturing knows that their perceptions are not shared. For example, it may be that sales and manufacturing have different information on which to base their predictions, but that they are not aware of this: imagine that sales did not realize that the product features have changed in a subtle way that would impact demand, but that manufacturing did know about such changes and their implications, and thought that sales also knew. In this case, we know from Propositions 3.1 and 3.2 that both manufacturing and sales expect the equilibrium to happen based on their perceptions. For convenience let  $\bar{m}$  denote  $\min [\Phi_m^{-1}(m^*), \Phi_m^{-1}(s^*)]$  and  $\bar{s}$  denote  $\min [\Phi_s^{-1}(m^*), \Phi_s^{-1}(s^*)]$ . Here  $\bar{m}$  ( $\bar{s}$ ) is the limiting capacity based on the perception of manufacturing (sales) of demand and of sales’ (manufacturing’s) capacity decision.

**Proposition 4.1** *The resulting PPD Nash equilibrium for a simultaneous move game is  $[K_m^{\text{Si}}, K_s^{\text{Si}}]$  where  $K_m^{\text{Si}} = \bar{m}$  and  $K_s^{\text{Si}} = \bar{s}$ .*

**Proposition 4.2** *In the Stackelberg game,*

(a) *when manufacturing is the leader, the PPD equilibrium is  $[K_M^{St}, K_s^{St}]$  where  $K_M^{St} = \bar{m}$  and  $K_s^{St} = \min [\bar{m}, \Phi_s^{-1}(s^*)]$ . In this case, the plans are misaligned if and only if  $\Phi_s^{-1}(s^*) < \bar{m}$ .*

(b) *when sales is the leader, the PPD equilibrium is  $[K_m^{St}, K_S^{St}]$  where  $K_m^{St} = \min [\Phi_m^{-1}(m^*), \bar{s}]$  and  $K_S^{St} = \bar{s}$ . In this case, the plans are misaligned if and only if  $\Phi_m^{-1}(m^*) < \bar{s}$ .*

From the Propositions above, it is clear that (1) under the simultaneous move game, misalignment is very likely, (2) a Stackelberg game increases the chances of alignment. However, under the Stackelberg game, because the functions do not know about the other's demand perceptions, it is hard to prescribe *ex ante* who should move first.

## 4.2 Differences in Perceptions Asymmetrically Known

In this subsection, we assume that only one function knows the perceptions of both functions. The other function assumes that their perception is common for both functions. Thus, one function can be considered to be more aware of the functional differences that exist in the organization or between the firms. For example, imagine that manufacturing gave sales its forecast, but that sales did not. Imagine also that manufacturing, rather naively, did not think that sales had any other belief about demand. In this case, if manufacturing's forecast was different than sales', then sales would be aware of this but manufacturing would not. Interestingly such a scenario can be interpreted as a "leader" communicating demand forecasts to a "follower." It is the leader, though, who ends up being the more naive member of the two.

We assume, WLOG, that sales is the function with the greater cross-functional awareness. That is, assume that sales knows both  $\Phi_m$  and  $\Phi_s$  but not vice-versa (i.e. that sales knows both its own and manufacturing's perception about demand, but manufacturing only knows its own perception about demand, and assumes that sales has the same perception). The unique sales reaction function  $K_s(K_m)$  is given by

$$K_s(K_m) = \min [\Phi_s^{-1}(s^*), K_m],$$

while the unique manufacturing function  $K_m(K_s)$  is given by

$$K_m(K_s) = \min [\Phi_m^{-1}(m^*), K_s].$$

However since sales knows manufacturing's perception and knows that manufacturing is unaware of the differences in perception, it knows that manufacturing perceives the sales reaction function to be  $\tilde{K}_s(K_m)$  given by

$$\tilde{K}_s(K_m) = \min [\Phi_m^{-1}(s^*), K_m].$$

This gives the following results concerning alignment.

**Proposition 4.3** *The resulting PPD Nash equilibrium for a simultaneous move game is  $[K_m^{Si}, K_s^{Si}]$ , where  $K_s^{Si} = \min[\bar{m}, \Phi_s^{-1}(s^*)]$ , and  $K_m^{Si} = \bar{m}$ .*

**Proposition 4.4** *The Stackelberg game, when the manufacturing is the leader, gives the same PPD equilibrium as the simultaneous game.*

**Proposition 4.5** *For simultaneous game or Stackelberg game where manufacturing is the leader, the plans are aligned if and only if  $\Phi_s^{-1}(s^*) \geq \bar{m}$ .*

**Proposition 4.6** *In the Stackelberg game, when sales is the leader, the PPD equilibrium is  $[K_m^{St}, K_s^{St}]$  where  $K_m^{St} = K_s^{St} = \min[\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*)]$ .*

The main conclusion from the Propositions above is that sales' better information or greater awareness can be exploited to achieve alignment by making sales move first. Interestingly, in the example cited at the beginning of this section, this would imply that if manufacturing (or our leader) moves first by sharing its forecast with sales (and not vice-versa), then sales (the follower) should move first in terms of capacity investment.

### 4.3 One Function is a Known Better Forecaster

In this section, we assume, that each function knows that the other function has different perceptions about demand, but it does not know what these perceptions are. In addition, WLOG, let sales be the known better forecaster as discussed in section 3.3. Now the question is: is it possible to exploit this extra knowledge?

**Proposition 4.7** *In the simultaneous game, there is no PPD Nash equilibrium.*

**Proposition 4.8** *In the Stackelberg game, if  $s^* \leq m^*$ , sales moves first, and sales is better at forecasting, then the PPD Nash equilibrium is  $[K_m^{St}, K_s^{St}]$  where  $K_m^{St} = K_s^{St} = \Phi_s^{-1}(s^*)$ .*

**Remark 4.9** *In the Stackelberg game, if  $s^* > m^*$ , sales moves first, and sales is better at forecasting, then the PPD Nash equilibrium depends on sales' beliefs about the probability that manufacturing will invest in more capacity. For an example of a possible approach the reader can see Proposition 5.4.*

In Proposition 4.7 we make no assumptions about what players can try to infer about the other player’s perceptions and thus the players are unable to find a suitable focal point as for example, a PPD equilibrium would be. If the players have some defined *a priori* beliefs about the other players perceptions about demand, then the logic of subsection 5.2 would apply.

It can be noted from the propositions above that, under this scenario, alignment will happen if the acknowledged better forecaster has a smaller critical fractile (and is thus, *ceteris paribus*, more likely to be a bottleneck), and makes the first move. It is not clear, however, how to induce alignment without changing incentives if the fractile of the acknowledged better predictor is larger than the other party’s (the situation of Remark 4.9). The reason why it is not clear, is that, in this scenario, the acknowledged better predictor may have an incentive to inflate forecasts to attempt to induce a higher capacity investment by the other party, for example as described by Terwiesch et. al. (2005), a multi-period empirical paper describing forecast sharing between a semiconductor manufacturer and its suppliers. Cachon and Lariviere (2001) focusing on this scenario, add more structure to what they mean by “better” or in their case “accurate” forecasts, and devise an incentive changing scheme based on the ideas of Spence (1973) about signalling that can, under certain conditions, achieve first-best. In any case, one conclusion that can be inferred from the results of this section is that knowing that one party is a better forecaster increases the chances of alignment.

## 5 Imperfect Information: Dynamic Perceptions with Perfect Sharing

In this section we relax the assumption that the perception of the other function has no informational content for forecasting for the current function and allow complete sharing. Now the very act of sharing perceptions adds complexity to the cross-functional setting because perceptions may change as a result of the sharing, thus we refer to them as *dynamic*, but we assume that how they have changed is not explicitly known. Such a setting could in reality be modeled in a number of different ways. We consider two ways here which we feel represent two extremes along a spectrum of responses. In the first subsection, we assume that the perceptions as shared serve as the exclusive options for the function to use for their decision. However, unlike in subsection 3.3, manufacturing (sales) is not exactly sure what sales (manufacturing) thinks about manufacturing’s (sales’) accuracy. In the second subsection, we assume a more general model where after sharing perceptions, functions infer a probability distribution over the other function’s capacity decision.



## 5.1 Anchoring on Shared Perceptions

Again, let  $\Phi_m$  ( $\Phi_s$ ) be the perception of demand held by manufacturing (sales). Assume that both sales and manufacturing know each other's perceptions about demand. Now, suppose that, either through past interactions, knowledge of economic parameters or other signals, both sales and manufacturing have an opinion about how likely it is that the other party's forecast is a better forecast than theirs for predicting demand, again analogous to our discussion in section 3.3. This opinion need not be right. Let  $pa_m$  ( $pa_s$ ) be what sales (manufacturing) thinks is the probability that manufacturing (sales) will be the better forecaster<sup>1</sup>. Each party does not know the other's exact opinion about them, but know if the corresponding probability is  $\leq 0.5$ . Will these opinions get in the way of alignment?

Given our assumption that functions/firms anchor on one of the shared perceptions there are 16 possible equilibrium outcomes of the form  $[a, b]$  based on the combinations of four possible capacity decisions,  $\Phi_m^{-1}(s^*)$ ;  $\Phi_m^{-1}(m^*)$ ;  $\Phi_s^{-1}(s^*)$ ; and  $\Phi_s^{-1}(m^*)$ , for both manufacturing and sales. In this scenario, the Nash Equilibrium depends on (1)  $pa_m$ ,  $pa_s$ , (2) the perceived profits achievable for manufacturing and sales at each point, and (3) the relative magnitude of  $\Phi_m^{-1}(s^*)$ ,  $\Phi_m^{-1}(m^*)$ ,  $\Phi_s^{-1}(s^*)$ , and  $\Phi_s^{-1}(m^*)$ .

Depending on who is perceived by each party to be more likely the better forecaster, there are four main possible belief combinations about forecast quality of the other party, which we will call Case I to IV:

1.  $pa_m > 0.5$  and  $pa_s < 0.5$ , i.e., sales and manufacturing both believe that manufacturing's forecast is more likely to be better,
2.  $pa_m < 0.5$  and  $pa_s < 0.5$ , i.e., both functions believe that their forecast is more likely to be better,
3.  $pa_m < 0.5$  and  $pa_s > 0.5$ , i.e., sales and manufacturing both believe that sales' forecast is more likely to be better,
4.  $pa_m > 0.5$  and  $pa_s > 0.5$ , i.e., both functions believe that the other function's forecast is more likely to be better.

Within each Case, as it will be explained below, and for each player, three different possible preference sets among our four (4) capacity decisions are viable, see Table 1. For example, will

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<sup>1</sup>At the extreme, the reader can think of this probability as the probability that the function's forecast matches exactly that of the true demand distribution.

sales prefer a capacity that uses what it thinks to be the more likely worse forecast but that maximizes profits over sales' cost parameters to a capacity that uses what it thinks to be the more likely better forecast although it optimizes profits over manufacturing's cost parameters? Given that each player can respond to such questions in different ways depending on what they believe to be the shape of their expected profit function, and on  $pa_i, i \in \{m, s\}$ , there are nine possible preference set combinations. The total number of feasible combinations of beliefs about forecast quality (i.e. cases) and preference sets (i.e. beliefs about the shape of the expected profit function) is thus  $4 \cdot 9 = 36$ . Now, for each of the 36 combinations of beliefs and preferences, there are 12 possible ordering for the four capacity decisions, from the smallest to the largest (e.g.,  $\Phi_m^{-1}(s^*) < \Phi_s^{-1}(s^*) < \Phi_m^{-1}(m^*) < \Phi_s^{-1}(m^*)$ , etc.)<sup>2</sup>. The order is relevant because it determines whether a given capacity can be “undercut” by the other player. Thus, there are a total of  $12 \cdot 36 = 432$  possible games. We will show that, in a simultaneous game, for all possible games we can find a unique Nash equilibrium while in Stackelberg games we find unique PPD equilibria depending on who plays first.

More formally, define  $\succ$  as a preference relation where  $\succeq$  means “is at least as preferable as.”

We define the following preference relations for sales:

S1)  $\Phi_m^{-1}(s^*) \succeq \Phi_m^{-1}(m^*)$  because  $s^*$  optimizes sales's profits under  $\Phi_m$ .

S2)  $\Phi_s^{-1}(s^*) \succeq \Phi_s^{-1}(m^*)$  because  $s^*$  optimizes sales's profits under  $\Phi_s$ .

and for manufacturing:

M1)  $\Phi_m^{-1}(m^*) \succeq \Phi_m^{-1}(s^*)$  because  $m^*$  optimizes manufacturing's profits under  $\Phi_m$ .

M2)  $\Phi_s^{-1}(m^*) \succeq \Phi_s^{-1}(s^*)$  because  $m^*$  optimizes manufacturing's profits under  $\Phi_s$ .

Under different Cases for the perceived probabilities of accuracy  $pa_i, i \in \{m, s\}$ , other preference relationships can be defined. Consider Case I: where  $pa_m > 0.5$  and  $pa_s < 0.5$ , i.e., both sales and manufacturing think that it is likely that manufacturing's forecast is better.

For sales, unless restricted by the other party's capacity choices, we know that:

S3)  $\Phi_m^{-1}(s^*) \succeq \Phi_s^{-1}(s^*)$  because sales thinks  $\Phi_m$  is more likely to be a better forecast than  $\Phi_s$ .

S4)  $\Phi_m^{-1}(s^*) \succeq \Phi_s^{-1}(m^*)$  transitivity with S2) and S3)

For manufacturing, unless restricted by the other party's capacity choices, we know that:

M3)  $\Phi_m^{-1}(m^*) \succeq \Phi_s^{-1}(m^*)$  because manufacturing thinks  $\Phi_m$  is more likely to be a better forecast than  $\Phi_s$ .

M4)  $\Phi_m^{-1}(m^*) \succeq \Phi_s^{-1}(s^*)$  transitivity with M2) and M3).

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<sup>2</sup>Of the 24 ( $4 \cdot 3 \cdot 2$ ) potential orderings exactly half are eliminated since ordering implied by  $s^* < (>)m^*$  must be consistent for both perceptions  $\Phi_m$  and  $\Phi_s$ .

Without violating any of the rules above, Table 1 shows the two preference sets which are possible for sales and for manufacturing individually:

Sales	Manufacturing
$\Phi_m^{-1}(s^*) \succeq \Phi_s^{-1}(s^*) \succeq \Phi_m^{-1}(m^*) \succeq \Phi_s^{-1}(m^*)$	$\Phi_m^{-1}(m^*) \succeq \Phi_s^{-1}(m^*) \succeq \Phi_m^{-1}(s^*) \succeq \Phi_s^{-1}(s^*)$
$\Phi_m^{-1}(s^*) \succeq \Phi_s^{-1}(s^*) \succeq \Phi_s^{-1}(m^*) \succeq \Phi_m^{-1}(m^*)$	$\Phi_m^{-1}(m^*) \succeq \Phi_s^{-1}(m^*) \succeq \Phi_s^{-1}(s^*) \succeq \Phi_m^{-1}(s^*)$
$\Phi_m^{-1}(s^*) \succeq \Phi_m^{-1}(m^*) \succeq \Phi_s^{-1}(s^*) \succeq \Phi_s^{-1}(m^*)$	$\Phi_m^{-1}(m^*) \succeq \Phi_m^{-1}(s^*) \succeq \Phi_s^{-1}(m^*) \succeq \Phi_s^{-1}(s^*)$

Table 1: Preference Sets for Sales and for Manufacturing

Although in all cases sales would prefer optimizing their profit function using the better forecast over its own economic parameters (for example, in this case, sales would strictly prefer  $\Phi_m^{-1}(s^*)$  to anything else), the remaining preferences, and thus which set truly represents sales's total preferences, will depend on the particular situation. For example, note that in the second set, sales thinks that optimizing manufacturing's profit function using the more likely better forecast is preferable than optimizing their profit function using the more likely worse forecast (i.e.  $\Phi_m^{-1}(m^*) \succeq \Phi_s^{-1}(s^*)$ ), while for the first and second set, the opposite is true (i.e.  $\Phi_s^{-1}(s^*) \succeq \Phi_m^{-1}(m^*)$ ). Note that, although sales (manufacturing) will know exactly which set represents its own preferences, manufacturing (sales) will not be able to tell. The only thing that manufacturing (sales) can be sure of is that, as long as  $pa_m > 0.5$ , ( $pa_s < 0.5$ ) sales' most preferred option is  $\Phi_m^{-1}(s^*)$  ( $\Phi_m^{-1}(m^*)$ ). Note in Table 1 the similarities of manufacturing's preferences to that of sales.

As mentioned previously, the viable preference sets for sales and manufacturing in this case can be combined in nine different ways. There are also 12 possible ordering for the four plays, from the smallest to the largest (e.g.,  $\Phi_m^{-1}(s^*) < \Phi_s^{-1}(s^*) < \Phi_m^{-1}(m^*) < \Phi_s^{-1}(m^*)$ , etc.). Thus, there are  $9 \times 12 = 108$  possible games where both sales and manufacturing think that it is likely that manufacturing's forecast is better. Each game may yield a different PPD Nash Equilibrium. The possible preference sets for the remaining cases can be similarly enumerated as is done in the proof.

**Proposition 5.1** *In the simultaneous game, for all feasible combinations of the preference sets for sales and manufacturing, there exists a unique Nash Equilibrium  $[K_m^{\text{Si}}, K_s^{\text{Si}}]$  where  $K_m^{\text{Si}} = K_s^{\text{Si}} = \min[\bar{m}, \bar{s}]$ .*

From Proposition 5.1 we see that in all cases a unique equilibrium with alignment is always possible but only on the constraining capacity across both perceptions and function. Note that in Case I and III, depending on the constraining capacity across both perceptions and function, that this equilibrium can be at a capacity decision which for both parties, is based on the forecast that both think is more likely to be the worse of the two forecasts. Similarly, in Case II and IV, as highlighted by the results for the Stackelberg game below, unperceived Pareto dominant solutions are ignored.

For the results on the Stackelberg games below, we define the following:

-  $s \max_{\succeq}(a, b) = a$  if  $a \succeq b$  given the preference set for sales, otherwise  $b$ .

-  $s \max_{\succeq}(a, b, c) = s \max_{\succeq}(s \max_{\succeq}(a, b), s \max_{\succeq}(a, c))$

-  $m \max_{\succeq}(a, b) = a$  if  $a \succcurlyeq b$  given the preference set for manufacturing, otherwise  $b$ .

-  $m \max_{\succeq}(a, b, c) = m \max_{\succeq}(m \max_{\succeq}(a, b), m \max_{\succeq}(a, c))$

Here  $s \max_{\succeq}(\cdot, \cdot)$  and  $m \max_{\succeq}(\cdot, \cdot)$  define “maximum” functions based on the preference set of sales and manufacturing respectively.

**Proposition 5.2** *i) In the Stackelberg game, regardless of who moves first, there exists a unique Nash Equilibrium  $[K_m^{St}, K_s^{St}]$  with  $K_m^{St} = K_s^{St}$  under the following conditions:*

Case	Condition	Equilibrium
I	$\Phi_m^{-1}(s^*) = \min[\bar{m}, \bar{s}]$	$K_m^{St} = K_s^{St} = \Phi_m^{-1}(s^*)$
I	$\Phi_m^{-1}(m^*) = \min[\bar{m}, \bar{s}]$	$K_m^{St} = K_s^{St} = \Phi_m^{-1}(m^*)$
II	$\Phi_s^{-1}(s^*) = \min[\bar{m}, \bar{s}]$	$K_m^{St} = K_s^{St} = \Phi_s^{-1}(s^*)$
II	$\Phi_m^{-1}(m^*) = \min[\bar{m}, \bar{s}]$	$K_m^{St} = K_s^{St} = \Phi_m^{-1}(m^*)$
III	$\Phi_s^{-1}(s^*) = \min[\bar{m}, \bar{s}]$	$K_m^{St} = K_s^{St} = \Phi_s^{-1}(s^*)$
III	$\Phi_s^{-1}(m^*) = \min[\bar{m}, \bar{s}]$	$K_m^{St} = K_s^{St} = \Phi_s^{-1}(m^*)$
IV	$\Phi_s^{-1}(m^*) = \min[\bar{m}, \bar{s}]$	$K_m^{St} = K_s^{St} = \Phi_s^{-1}(m^*)$
IV	$\Phi_m^{-1}(s^*) = \min[\bar{m}, \bar{s}]$	$K_m^{St} = K_s^{St} = \Phi_m^{-1}(s^*)$

*ii) Otherwise, in the Stackelberg game, depending on who moves first, there exists a unique PPD*

*Nash Equilibrium  $[K_m^{St}, K_s^{St}]$  such that  $K_m^{St} = K_s^{St}$  under the following conditions:*

Case	Condition	First-Mover	Equilibrium
I	$\Phi_s^{-1}(s^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\succeq}(\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\succeq}(\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*))$
	$\Phi_s^{-1}(m^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\succeq}(\Phi_m^{-1}(s^*), \Phi_s^{-1}(m^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\succeq}(\Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*))$
II	$\Phi_m^{-1}(s^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\succeq}(\Phi_s^{-1}(s^*), \Phi_m^{-1}(s^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\succeq}(\Phi_m^{-1}(m^*), \Phi_m^{-1}(s^*))$
	$\Phi_s^{-1}(m^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\succeq}(\Phi_s^{-1}(s^*), \Phi_s^{-1}(m^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\succeq}(\Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*))$
III	$\Phi_m^{-1}(s^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\succeq}(\Phi_s^{-1}(s^*), \Phi_m^{-1}(s^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\succeq}(\Phi_s^{-1}(m^*), \Phi_m^{-1}(s^*))$
	$\Phi_m^{-1}(m^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\succeq}(\Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\succeq}(\Phi_s^{-1}(m^*), \Phi_m^{-1}(m^*))$
IV	$\Phi_s^{-1}(s^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\succeq}(\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\succeq}(\Phi_s^{-1}(m^*), \Phi_s^{-1}(s^*))$
	$\Phi_m^{-1}(m^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\succeq}(\Phi_m^{-1}(s^*), \Phi_m^{-1}(m^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\succeq}(\Phi_s^{-1}(m^*), \Phi_m^{-1}(m^*))$

Proposition 5.2, as expected, provides greater opportunity for alignment at economically more opportunistic capacity decisions (especially in Cases I and III) than in the simultaneous game where alignment is always at the minimum capacity over perceptions and functions. In (i) when

this minimum capacity is the most preferred capacity decision for one of the functions, it forms the equilibrium irrespective of who plays first. Otherwise, as shown in (ii), the Stackelberg game allows the leader to partially reveal their preference set and lead to a perceived Pareto dominant solution versus the minimum capacity when it can exist. Note that this perceived Pareto dominant solution can be described as a compromise since when it differs from the minimum capacity, it optimizes the profit function of the “follower” in Cases I and III and also uses the forecasts that the “follower” believes is more likely to be better in Cases II and IV.

In summary, the Propositions above indicate that, with partial knowledge of the other party’s beliefs about demand, and an anchoring on the capacities implied by shared perceptions alignment is guaranteed. However, the Stackelberg game provides the opportunity for perceived Pareto dominant solutions as equilibrium.

## 5.2 Inferring Capacity Decisions

In this section, we assume that after sharing initial perceptions of demand, both sales and manufacturing only know that the other function has a different perception about demand, but that neither function knows how these perceptions have changed as a result of sharing. However, based on the perceptions, and either through past interactions, knowledge of economic parameters or other signals, both sales and manufacturing have an opinion about how the other party is likely to now perceive demand. This opinion need not be right. Each party does not know the other’s opinion about them. Let  $p_m(K_s)$  ( $p_s(K_m)$ ) be what sales (manufacturing) thinks is the probability that manufacturing (sales) will choose a capacity above sales’s (manufacturing’s) own chosen capacity,  $K_s(K_m)$  (note that these probabilities would be similar to what some economists call “priors”, as in Van den Steen 2001). Assume that  $\frac{dp_m}{dK_s} \leq 0$  ( $\frac{dp_s}{dK_m} \leq 0$ ) and  $\frac{d^2p_m}{d^2K_s} \leq 0$  ( $\frac{d^2p_s}{d^2K_m} \leq 0$ ), i.e., assume that sales (manufacturing) believes that the larger its capacity, the less likely it is that the other party will choose a larger capacity, and that the change in this probability decreases with capacity.

Sales’s expected profit function given planned supply of  $K_m$  from manufacturing is:

$$\begin{aligned} E[\Pi_s(K_s)] &= p_m(K_s) \cdot (-\gamma K_s + E(p - w) \min[D, K_s]) \\ &\quad + (1 - p_m(K_s)) \cdot (-\gamma K_s + E(p - w) \min[D, K_m]). \end{aligned}$$

The above functions' first order condition is:

$$\begin{aligned}
\frac{dE[\Pi_s(K_s)]}{dK_s} &= -\gamma + \left( \int_{K_s}^{\tau} (p-w)\phi_s(D) dD \right) p_m(K_s) + \\
&\left( \int_0^{K_s} D(p-w)\phi_s(D) dD + \int_{K_s}^{\tau} K_s(p-w)\phi_s(D) dD \dots \right. \\
&\left. \dots - \int_0^{K_m} D(p-w)\phi_s(D) dD - \int_{K_m}^{\tau} K_m(p-w)\phi_s(D) dD \right) p'_m(K_s) \\
&= 0,
\end{aligned}$$

where  $\tau$  is the supremum of the support of the demand distribution  $\Phi_s$ . The above condition means that, to choose the optimal  $K_s$ , sales has to consider

- (1) the impact of the cost of  $K_s$ ,
- (2) the potential extra sales revenue generated by  $K_s$  if  $K_s < K_m$ ,
- (3) the fact that, via  $p'_m[K_s]$ , a change in  $K_s$  also affects the probability that  $K_s > K_m$ .

This does not necessarily represent a mathematically complex problem, since,

$$\begin{aligned}
\frac{d^2E[\Pi_s(K_s)]}{d^2K_s} &= -(p-w)\phi_s(K_s) p_m(K_s) + 2 \left( \int_{K_s}^{\tau} (p-w)\phi_s(D) dD \right) p'_m(K_s) + \\
&\left( \int_0^{K_s} D(p-w)\phi_s(D) dD + \int_{K_s}^{\tau} K_s(p-w)\phi_s(D) dD \dots \right. \\
&\left. \dots - \int_0^{K_m} D(p-w)\phi_s(D) dD - \int_{K_m}^{\tau} K_m(p-w)\phi_s(D) dD \right) p''_m(K_s) \\
&< 0.
\end{aligned}$$

Notes:

(1) If  $\frac{dp_m}{dK_s} = 0$ , i.e. if sales assumes that manufacturing is absolutely unresponsive to  $K_s$ , then  $\Pi_s(K_s)$  is minimized at  $K_s^* = \Phi_s^{-1}\left(\frac{(p-w)p_m - \gamma}{(p-w)p_m}\right)$ , which can significantly reduce its investment in capacity (w.r.t.  $s^*$ ). A similar conclusion can be claimed for manufacturing's beliefs about sales.

(2) If sales' and manufacturing's beliefs about each other are correct, i.e., if each others' estimates of the probability of the other party being over for each capacity chosen is correct, then the results of Proposition 3.3 hold, and thus there will be alignment.

**Proposition 5.3** *The resulting PPD outcome of a simultaneous move game is  $[K_m^{\text{Si}}, K_s^{\text{Si}}]$  where*

$$\begin{aligned}
K_m^{\text{Si}} &= \underset{K_m}{\text{ArgMax}} [p_s(K_m) \cdot (-\alpha K_m + E(w-c) \min[D, K_m]) + \dots \\
&\dots (1 - p_s(K_m)) \cdot (-\alpha K_m + E(w-c) \min[D, K_s])] \\
K_s^{\text{Si}} &= \underset{K_s}{\text{ArgMax}} [p_m(K_s) \cdot (-\gamma K_s + E(p-w) \min[D, K_s]) + \dots \\
&\dots (1 - p_m(K_s)) \cdot (-\gamma K_s + E(p-w) \min[D, K_m])].
\end{aligned}$$

**Proposition 5.4** *In the Stackelberg game,*

(a) *if sales moves first, the PPD Nash equilibrium is  $[K_m^{St}, K_s^{St}]$  where  $K_m^{St} = \min [K_s^{Si}, \Phi_m^{-1}(m^*)]$ , and  $K_s^{St} = K_s^{Si}$ . In this case, plans are misaligned if and only if  $K_s^{Si} > \Phi_m^{-1}(m^*)$ .*

(b) *if manufacturing moves first, the PPD Nash equilibrium is  $[K_M^{St}, K_s^{St}]$  where  $K_M^{St} = K_m^{Si}$ , and  $K_s^{St} = \min [\Phi_s^{-1}(s^*), K_m^{Si}]$ . In this case, plans are misaligned if and only if  $K_m^{Si} > \Phi_s^{-1}(s^*)$ .*

Proposition 5.3 helps shed light on the benefits of sharing perceptions. Namely, it points out that sharing perceptions may not always lead to alignment, in fact, it shows that perception could exacerbate misalignment. Recall that the sharing of perceptions creates opinions  $p_m(\cdot)$  ( $p_s(\cdot)$ ) about the planning choices of the other player which need not be correct. Sharing perceptions could exacerbate misalignment if the sharing of perception causes a decrease in the accuracy of the opinions held by functions in such a way that the capacity mismatch is more severe. An example of such a scenario is sales sharing (and receiving) perceptions but over-estimating the influence of their perceptions on manufacturing, an over-estimate which may not have happened if sales hadn't shared their perception and only received that of manufacturing.

It should be noted from the above propositions that the condition for alignment in the Stackelberg game cannot be known *a priori* by the functions (since, in this scenario, final demand perceptions about the other function are unknown to each other by definition). Thus, although the Stackelberg game does result in a higher chance of alignment, it is not easy to prescribe who should move first without knowing about each function's perceptions about demand. However, as each other's perceptions of the other's potential moves becomes more accurate, the chance of alignment will increase, since each party does incorporate part of the cost of misalignment in its objective function.

## 6 Discussion

### 6.1 Managing Communication of Perceptions

**Summary 6.1** *Figure 1 summarizes the main results from the previous sections:*

Sections 3 and 4 make a strong case for the mutual sharing of the perceptions of demand across functions in order to have alignment assuming static perceptions. This case is strengthened when we recognize that under this static perceptions assumptions there is no disincentive to sharing perceptions as functions only benefit from sharing as it reduces their own wasted capacity and state this as a theorem.

Main Section	Subsection	Recommendation	Alignment guaranteed?
Section 3. Perfect Information in a Decentralized System	3.1 Common preceptions about demand	Indifferent	Yes
	3.2 Different but known perceptions about demand	Indifferent	Yes
	3.3 One Function is a Known Better Forecaster	Indifferent	Yes
Section 4. Imperfect Information: Static Perceptions with Partial Sharing	4.1 Difference in perceptions unknown	Stackelberg, unclear who moves first	No
	4.2 Differences in Perceptions Asymmetrically known	Stackelberg, knowledgeable party moves first.	Yes
	4.3 Difference in Perceptions Partially known	Stackelberg, better forecaster moves first.	No
Section 5. Imperfect Information: Dynamic Perceptions with Perfect Sharing	5.1 Anchoring on Shared Perceptions	Stackelberg, indifferent who moves first.	Yes
	5.2 Inferring Capacity Decisions	Stackelberg, unclear who moves first	No.

Figure 1:



**Theorem 6.2** *Under static perceptions, there is no disincentive to sharing one’s perception with another function with mutual sharing of perceptions resulting in functional alignment in capacity planning.*

However under dynamic perceptions (Section 5), mutual sharing of perceptions may not always create alignment. Furthermore, though not explicitly examined in Section 5, incentives can exist for manipulation by sharing false perceptions, for example, if it affects perceived probabilities of accuracy (as in Section 5.1) or one’s own opinion of the planning choices likely to be made by the other player (as in Section 5.2). It is even possible that, as argued in Section 5.2, such sharing, if left unattended, could even exacerbate misalignment.

Observations for managing alignment in such a setting can still be generated from our results. For example, when the “right” party takes the initiative (as modeled by Stackelberg games) the chances of alignment are increased. Alignment is also encouraged by either natural or artificial limiting of the capacity decisions although leadership may still be required to encourage more Pareto dominating outcomes. Theorem 6.2 and the observation that it is the lack of knowledge of how perceptions are affected by sharing which affects alignment provides some guidance for any communication structure between the players which supports alignment. Such communication should try to mimic the end-conditions of perception sharing under static perceptions, that is, that players have a greater sense of the final perceptions of the other player as a result of sharing. Note that, to achieve alignment, this communication need not align perceptions, but make the final perceptions better known by one or both parties. Based on Theorem 6.2, it would not be erroneous to expect that mutual sharing of true perceptions of demand would at least not be discouraged under such a structure.

## 6.2 Managing Alignment in Practice

Three dimensions for supporting alignment (integration) have been identified in the academic literature on coordination within planning contexts: roles/responsibilities, structures and processes with the literature primarily concentrating on the first two dimensions. These dimensions have been characterized more explicitly for cross-functional integration (Oliva and Watson 2007), but coordination efforts across firms can be categorized similarly. By responsibilities, we mean the participants and the distribution of decision rights among them in the collaborative effort, and by structures we mean the accompanying formal systematic arrangements, relationships and infrastructure.

The literature on responsibilities for cross-functional coordination primarily draws on the organizational behavior literature. Lawrence and Lorsch (1986) recommend explicitly the role of

integrators for coordinating unity of effort. These integrators act as translators, mediators and integrative goal setters facilitating the differing cognitive and emotional perspectives of the various functions and directing collective efforts. Across firms, the role of intermediaries such as Li & Fung in the apparel supply chain and distributors like Arrow Electronics in the electronic component supply chain share some similarities with integrators. The allocation of decision rights or focus has also been argued to be important for coordination across firms (Anand and Mendelson 1997; Kraiselburd, Narayanan and Raman, 2004; Watson and Zheng 2005). Within firms, structural recommendations for improving integration have come from analysis of the informational and organizational infrastructure impeding integration. Such infrastructure includes the level of information sharing among functional decision makers (Dougherty 1992; Shapiro 1977; Van Dierdonck and Miller 1980) including that facilitated by enterprise information systems (Al-Mashari et. al. 2003); evaluation and incentive systems whether for individual functions (Chen 2005; Gonik 1978; Kouvelis and Lariviere 2000; Porteus and Whang 1991) or collective incentives (Mallik and Harker 2004); support for complex decision making whether from quantitative models (Yano and Gilbert 2004), decision support systems (Crittenden et. al. 1993), outsourcing planning decision-making to competent third parties (Troyer et. al. 2005); and formal arrangements systematizing the desired integrative norms (Stonebraker and Afifi 2004) such as standardization of policies, compatible communications formats, and formal hierarchies and departmentalization. An emphasis on incentives as discussed in the introduction, characterizes the literature on cross-firm coordination.

In terms of general process features for integration, the OB literature posits that interdepartmental integration is fostered by two types of activities (Barratt 2004): (1) interaction/communication activities (Dougherty 1992; Griffin and Hauser 1992; Ruekert and Walker 1987), and (2) collaboration-related activities (Lawrence and Lorsch 1986; Pinto et. al. 1993). Both types of activities are facilitated by norms and specific responsibilities and goals. Interaction/communication activities, however, relate to the activities that enable the existing types, quantity, quality, and frequency of information flows (structure) between functions. Collaboration activities, on the other hand, relate to the roles (responsibilities) spread across functions that in combination –and usually in the short term– have shared goals. Whereas integration and communication activities are necessary for collaboration, collaborative activities are generally believed to be a precondition for full integration (Barratt 2004). One type of internal planning processes examined in the practitioner literature (Bower 2005; Lapide 2004a; 2004b; 2005a; 2005b) is referred to as a Sales and Operations planning (S&OP) process. A basic S&OP process facilitates the transfer of information needed from demand planning to master planning; however both practitioners and academics argue that

the S&OP process can move beyond this superficial synchronizing of master planning with demand planning and begin to approach coordinated joint planning with a certain degree of sophistication surrounding the quality of plans generated (Lapide 2005a; Van Landeghem and Vanmaele 2002). Planning processes across firms tend to be less explicitly defined and range from simple call-and-response processes, (sending of production requests with sometimes an unverifiable commitment in response,) to more sophisticated interactions, for example, with embedded liaisons in either customer or supplier operations, or collaborative planning processes like collaborative planning forecasting and replenishment (CPFR). Interestingly these interfirm processes can be compromised by lack of intrafirm alignment, Flidner (2003).

Our analysis suggests an understanding of how the three dimensions of responsibilities, structure and process can effect alignment as we model it here. Integrators or intermediaries and the supporting structure can serve as conduits for the sharing of perceptions, helping with elucidation of perceptions and then their translation, so that other functions can assimilate the information. Our perceptions of demand, modeled here as probability distributions, greatly simplifies differences that can exist between how different functions, (firms) think about and represent uncertainty in demand. Intermediaries familiar with such differences can help in translating and, if necessary, embellishing or reducing information so as to aid understanding. This translation-related activity arguably enhances the additional structural recommendations for coordination such as enterprise resource information systems within firms and EDI protocols across firms by basically ensuring that the message being sent is the message being received. Finally, if our recommendation for managing dynamic perceptions has merit, then processes would prove instrumental in allowing or helping functions to generate or revise “final” (static) perceptions after initial perception sharing or subsequent updates. Forecasting methods involving the combination of forecasts provide one such mechanism for generating perceptions, but even the need for these methods imply that, in general, combining perceptions of demand is not a trivial task. Such an approach is even further complicated by the observation that black box analytical approaches have diminished persuasive value in many of the subjective planning approaches which characterize planning in and across firms.

For one perspective on achieving alignment in practice, we related the findings from a case study which examined the implementation of an S&OP process in an effort to understand the systems and behavioral process associated with cross functional integration (Oliva and Watson 2007). Central to this instance of the S&OP processes was the use of consensus forecasting among the participating groups in the process. Here, the intention was for participant groups to come to an agreement

concerning the forecast that would be used for planning purposes. This agreement also carried over to the plan that was eventually developed based on the forecasts after being validated for both financial and external supply chain viability. The authors argue that the quality of demand and supply planning can be roughly related to the quality of information used, the quality of the inferences made from available data (e.g., forecasts and plans), and the organization's conformance to the plans that are generated, that is, the organizational alignment. A significant fraction of the reported benefits, however, was not exclusively the result of a logical and efficient information-processing. It was argued that improvements in forecast accuracy and other operating metrics were less the result of a better forecasting process than of an aligned organization working with unity of purpose to realize those forecasts and plans.

## 7 Conclusions

We used game theory to explore the conditions required for intrafirm and between firm supply chain coordination. One of our main conclusions, which is consistent with the OB literature, is that although incentive misalignment in the sense studied in the OM literature may be a factor in determining alignment, it is not necessarily a central one. For example, in Sections 3 and 4.2, alignment can be guaranteed even if there are misaligned incentives in the traditional sense. What we learnt from our models is that it is often the communication structure which ends up determining whether alignment will happen or not. This would support the emphasis placed in the OB literature on better communication, rather than incentive alignment, for improved coordination. In our setup, the key to alignment is not so much how each function is rewarded (i.e. the transfer prices, etc.), it is more what each function knows about the other function's beliefs. According to this, any effort to increase knowledge of each other's (final) perspective will improve the chances of alignment, even if no change in incentives is made. This is a fundamental departure from most papers in OM, where the claim is often that both parties do not align because of each party's differing economic incentives, or knowledge about end demand. In many of these papers, misalignment happens even if both parties knew each other perfectly. While we do not disagree that the right incentives can induce alignment in actions, we claim, instead, that incentive alignment is not a necessary condition for alignment in actions, and that the key to alignment in actions lies in the degree of knowledge about each other's beliefs. Although this claim is predominant in the OB literature, we are unaware of any other paper that explicitly models coordination issues and yet reaches similar conclusions. The use of mathematical modeling and game theory to reach such conclusion matters because we are able to show that this seemingly behavioral, psychological effects (i.e. alignment

happening despite “misaligned” incentives in the traditional sense, etc.) may still happen if both parties are rational profit maximizers (vs. boundedly rational profit satisfiers, etc.). Although we do not negate the importance of such behavioral effects on decision making, our contribution pushes the frontier of what the “rational, profit maximizing agent” assumption can find within the set of problems covered by the OM literature .

## 8 Appendix: Proofs

Throughout the proofs, we will follow the convention of making the upstream party (i.e. manufacturing) female, and the downstream party (i.e. sales), male.

**Proof.** Proposition 2.1

By inspection, it can be noted that the optimum involves setting  $K_m = K_s$ , since any differences in the capacities would incur the cost of  $\lambda$ , and either  $\gamma$  or  $\alpha$  without increasing revenues.

If we set  $K_m = K_s = K$ , the problem becomes the standard newsvendor problem, whose solution is as stated. ■

**Proof.** Proposition 3.1

Assume, WLOG, that  $\min[\Phi^{-1}(m^*), \Phi^{-1}(s^*)] = \Phi^{-1}(m^*)$  (i.e. manufacturing would prefer to be the bottleneck).

Then, manufacturing will want to play  $K_m^{\text{Si}} = \Phi^{-1}(m^*)$ , because it is her optimum value, and she knows that sales will not go lower than this because if he sets a capacity lower than this, he will make less profits. For manufacturing, setting a capacity higher than this will be a waste, since manufacturing is the bottleneck. Therefore, sales will align with manufacturing.

Similar logic applies if  $\min[\Phi^{-1}(m^*), \Phi^{-1}(s^*)] = \Phi^{-1}(s^*)$ . ■

**Proof.** Proposition 3.2

Assume, WLOG, that  $\min[\Phi^{-1}(m^*), \Phi^{-1}(s^*)] = \Phi^{-1}(m^*)$ .

If manufacturing moves first, she will play  $\Phi^{-1}(m^*)$ , knowing, as in the proof of Proposition 3.1, that sales will not go lower than this. Sales will align, because going lower means less profits for him, and going higher is a waste of capacity.

If sales moves first, although he would prefer the equilibrium to be  $\Phi^{-1}(s^*)$ , he is forced to play  $\Phi^{-1}(m^*)$  because he knows that if he plays anything higher than this, manufacturing will undercut him by playing  $\Phi^{-1}(m^*)$ , making any capacity above this a waste.

Similar logic applies if  $\min[\Phi^{-1}(m^*), \Phi^{-1}(s^*)] = \Phi^{-1}(s^*)$ . ■

**Proof.** Proposition 3.3

The same logic as in the proof of Proposition 3.1. holds if we just replace, at the appropriate places,  $\Phi^{-1}$  with  $\Phi_i^{-1}$   $i \in \{m, s\}$ . ■

**Proof.** Proposition 3.4

Again, the same logic as in the proof of Proposition 3.2. holds if we just replace, at the appropriate places,  $\Phi^{-1}$  with  $\Phi_i^{-1}$   $i \in \{m, s\}$ . ■

**Proof.** Proposition 3.5

Sales would prefer  $\Phi_s^{-1}(s^*)$  to  $\Phi_m^{-1}(s^*)$  because  $\Phi_s$  is more accurate than  $\Phi_m$ . Similarly, manufacturing would prefer  $\Phi_s^{-1}(m^*)$  to  $\Phi_m^{-1}(m^*)$ . So the possible plays are  $\Phi_s^{-1}(s^*)$  and  $\Phi_s^{-1}(m^*)$ .

Assume  $\min[\Phi_s^{-1}(m^*), \Phi_s^{-1}(s^*)] = \Phi_s^{-1}(s^*)$ . Sales will play  $\Phi_s^{-1}(s^*)$ . Although manufacturing would prefer otherwise, she will match sales because playing her preferred capacity would result in a waste.

Now, assume  $\min[\Phi_s^{-1}(m^*), \Phi_s^{-1}(s^*)] = \Phi_s^{-1}(m^*)$ . Although sales would prefer to play the higher capacity, he will play  $\Phi_s^{-1}(m^*)$  because he knows that manufacturing will play this anyway, and any capacity above it will be wasted. ■

**Proof.** Proposition 3.6

The logic of the proof to Proposition 3.5 still holds if one of the players moves first. ■

**Proof.** Proposition 4.1

Since players are unaware of each other's differences, they will each play as in Proposition 3.3.

■

**Proof.** Proposition 4.2

(a) Since manufacturing is unaware of sales having a different perception about demand, she assume she is in the situation of Proposition 3.4 and plays  $K_M^{St} = \bar{m}$ .

Sales will simply chose either his optimal value  $\Phi_s^{-1}(s^*)$ , or, if this is lower than what manufacturing played, simply match manufacturing.

(b) Symmetric to proof of Proposition 4.2 (a) ■

**Proof.** Proposition 4.3

Since manufacturing is unaware of sales having a different perception about demand, she will assume she is in the situation of Proposition 3.4 and play  $K_M^{St} = \bar{m}$ .

Knowing what manufacturing will play (because he knows manufacturing's perception), sales will simply chose either his optimal value  $\Phi_s^{-1}(s^*)$ , or, if this is lower than what manufacturing played, simply match manufacturing. ■

**Proof.** Proposition 4.4

The logic is almost exactly as in the proof of Proposition 4.3, because manufacturing's move will not change. ■

**Proof.** Proposition 4.5

This is a direct consequence of Proposition 4.3 and 4.4 ■

**Proof.** Proposition 4.6

Assume  $\min [\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*)] = \Phi_s^{-1}(s^*)$ . Then, since sales knows that manufacturing will not prefer going lower, he will play  $\Phi_s^{-1}(s^*)$ . Despite preferring a larger capacity, manufacturing will match sales' move because playing any larger capacity would be a waste for her.

Now, assume  $\min [\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*)] = \Phi_m^{-1}(m^*)$ . Despite preferring a larger capacity, sales will play  $\Phi_m^{-1}(m^*)$  because he knows that if he plays any larger capacity, he will be undercut by manufacturing. Since this is manufacturing's preferred capacity, she will match it. ■

**Proof.** Proposition 4.7

Without additional structure on the knowledge of payoffs, for example as in Proposition 5.3, if the players do not know anything about the other players perceptions, they are unable to select among different perceived equilibria. ■

**Proof.** Proposition 4.8

Sales simply plays  $\Phi_s^{-1}(s^*)$  because it is its global optimum. Since  $s^* \leq m^*$ , and sales is supposed to be the best forecaster, manufacturing reasons as follows: "If I knew sale's perception of demand (which is better than mine), I would not want to undercut sales, because his fractile is smaller than mine". Thus, manufacturing will not undercut sales. ■

**Proof.** Proposition 5.1

Case I

Recall Table 1 the possible set of preferences of sales and manufacturing.

(a) Let  $\Phi_m^{-1}(s^*) = \min[\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*)]$ .

Throughout the proof, an underlined play means that this is what sales (manufacturing) would strictly play if manufacturing (sales) played the capacity stated in the row (column).

(Sales, Manufacturing)

$(\underline{\Phi_m^{-1}(s^*)}, \underline{\Phi_m^{-1}(s^*)})$	$(\Phi_s^{-1}(s^*), \Phi_m^{-1}(s^*))$	$(\Phi_m^{-1}(m^*), \Phi_m^{-1}(s^*))$	$(\Phi_s^{-1}(m^*), \Phi_m^{-1}(s^*))$
$(\Phi_m^{-1}(s^*), \underline{\Phi_s^{-1}(s^*)})$	$(\Phi_s^{-1}(s^*), \Phi_s^{-1}(s^*))$	$(\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*))$	$(\Phi_s^{-1}(m^*), \Phi_s^{-1}(s^*))$
$(\Phi_m^{-1}(s^*), \Phi_m^{-1}(m^*))$	$(\Phi_s^{-1}(s^*), \underline{\Phi_m^{-1}(m^*)})$	$(\Phi_m^{-1}(m^*), \underline{\Phi_m^{-1}(m^*)})$	$(\Phi_s^{-1}(m^*), \underline{\Phi_m^{-1}(m^*)})$
$(\underline{\Phi_m^{-1}(s^*)}, \Phi_s^{-1}(m^*))$	$(\Phi_s^{-1}(s^*), \Phi_s^{-1}(m^*))$	$(\Phi_m^{-1}(m^*), \underline{\Phi_s^{-1}(m^*)})$	$(\Phi_s^{-1}(m^*), \Phi_s^{-1}(m^*))$

Based on our examination of possible outcomes above, the NE is  $(\underline{\Phi_m^{-1}(s^*)}, \underline{\Phi_m^{-1}(s^*)})$  for all  $9 \times 3 = 27$  combinations (of preferences and capacities).

The NE can be explained the following way: since sales's most preferred option is also a minimum, he will play it because it cannot be undercut by manufacturing. Manufacturing knows this, and, thus, matches sales's play. A similar logic can be applied throughout.

(b) Let  $\Phi_m^{-1}(m^*) = \min[\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*)]$

(Sales, Manufacturing)

$(\Phi_m^{-1}(s^*), \Phi_m^{-1}(s^*))$	$(\Phi_s^{-1}(s^*), \Phi_m^{-1}(s^*))$	$(\Phi_m^{-1}(m^*), \Phi_m^{-1}(s^*))$	$(\Phi_s^{-1}(m^*), \Phi_m^{-1}(s^*))$
$(\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*))$	$(\Phi_s^{-1}(s^*), \Phi_s^{-1}(s^*))$	$(\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*))$	$(\Phi_s^{-1}(m^*), \Phi_s^{-1}(s^*))$
$(\Phi_m^{-1}(s^*), \Phi_m^{-1}(m^*))$	$(\Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*))$	$(\Phi_m^{-1}(m^*), \Phi_m^{-1}(m^*))$	$(\Phi_s^{-1}(m^*), \Phi_m^{-1}(m^*))$
$(\Phi_m^{-1}(s^*), \Phi_s^{-1}(m^*))$	$(\Phi_s^{-1}(s^*), \Phi_s^{-1}(m^*))$	$(\Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*))$	$(\Phi_s^{-1}(m^*), \Phi_s^{-1}(m^*))$

Again based on our examination of possible outcomes above, the NE is  $(\Phi_m^{-1}(m^*), \Phi_m^{-1}(m^*))$

for all  $9 \times 3 = 27$  combinations (of preferences, and capacities).

(c) Let  $\Phi_s^{-1}(s^*) = \min[\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*)]$ . Now since  $\Phi_s^{-1}(s^*) \leq \Phi_s^{-1}(m^*)$  this implies that  $\Phi_m^{-1}(s^*) \leq \Phi_m^{-1}(m^*)$ . This is sufficient to imply the following results for equilibrium for all  $9 \times 3 = 27$  combinations (of preferences, and capacities).

(Sales, Manufacturing)

$(\Phi_m^{-1}(s^*), \Phi_m^{-1}(s^*))$	$(\Phi_s^{-1}(s^*), \Phi_m^{-1}(s^*))$	$(\Phi_m^{-1}(m^*), \Phi_m^{-1}(s^*))$	$(\Phi_s^{-1}(m^*), \Phi_m^{-1}(s^*))$
$(\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*))$	$(\Phi_s^{-1}(s^*), \Phi_s^{-1}(s^*))$	$(\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*))$	$(\Phi_s^{-1}(m^*), \Phi_s^{-1}(s^*))$
$(\Phi_m^{-1}(s^*), \Phi_m^{-1}(m^*))$	$(\Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*))$	$(\Phi_m^{-1}(m^*), \Phi_m^{-1}(m^*))$	$(\Phi_s^{-1}(m^*), \Phi_m^{-1}(m^*))$
$(\Phi_m^{-1}(s^*), \Phi_s^{-1}(m^*))$	$(\Phi_s^{-1}(s^*), \Phi_s^{-1}(m^*))$	$(\Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*))$	$(\Phi_s^{-1}(m^*), \Phi_s^{-1}(m^*))$

Here the equilibrium as far as manufacturing is concerned optimizes the profit function of sales using the worse forecast of the two. An alternative equilibrium is not allowed because of the exact preference of each function is unknown.

(d) Let  $\Phi_s^{-1}(m^*) = \min[\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*)]$ . Now since  $\Phi_s^{-1}(m^*) \leq \Phi_s^{-1}(s^*)$  this implies that  $\Phi_m^{-1}(m^*) \leq \Phi_m^{-1}(s^*)$ . This is sufficient to imply the following results for equilibrium for all  $9 \times 3 = 27$  combinations (of preferences, and capacities).

(Sales, Manufacturing)

$(\Phi_m^{-1}(s^*), \Phi_m^{-1}(s^*))$	$(\Phi_s^{-1}(s^*), \Phi_m^{-1}(s^*))$	$(\Phi_m^{-1}(m^*), \Phi_m^{-1}(s^*))$	$(\Phi_s^{-1}(m^*), \Phi_m^{-1}(s^*))$
$(\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*))$	$(\Phi_s^{-1}(s^*), \Phi_s^{-1}(s^*))$	$(\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*))$	$(\Phi_s^{-1}(m^*), \Phi_s^{-1}(s^*))$
$(\Phi_m^{-1}(s^*), \Phi_m^{-1}(m^*))$	$(\Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*))$	$(\Phi_m^{-1}(m^*), \Phi_m^{-1}(m^*))$	$(\Phi_s^{-1}(m^*), \Phi_m^{-1}(m^*))$
$(\Phi_m^{-1}(s^*), \Phi_s^{-1}(m^*))$	$(\Phi_s^{-1}(s^*), \Phi_s^{-1}(m^*))$	$(\Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*))$	$(\Phi_s^{-1}(m^*), \Phi_s^{-1}(m^*))$

Similar to (c) here the equilibrium as far as sales is concerned optimizes the profit function of manufacturing using the worse forecast of the two. Again an alternative equilibrium is not allowed because the exact preference of each function is unknown.

A similar enumeration provides the results for Case III.

We now consider Case II.

Table 2 provides the possible preferences for sales and manufacturing.



Sales	Manufacturing
$\Phi_s^{-1}(s^*) \succeq \Phi_m^{-1}(s^*) \succeq \Phi_s^{-1}(m^*) \succeq \Phi_m^{-1}(m^*)$	$\Phi_m^{-1}(m^*) \succeq \Phi_s^{-1}(m^*) \succeq \Phi_m^{-1}(s^*) \succeq \Phi_s^{-1}(s^*)$
$\Phi_s^{-1}(s^*) \succeq \Phi_m^{-1}(s^*) \succeq \Phi_m^{-1}(m^*) \succeq \Phi_s^{-1}(m^*)$	$\Phi_m^{-1}(m^*) \succeq \Phi_s^{-1}(m^*) \succeq \Phi_s^{-1}(s^*) \succeq \Phi_m^{-1}(s^*)$
$\Phi_s^{-1}(s^*) \succeq \Phi_s^{-1}(m^*) \succeq \Phi_m^{-1}(s^*) \succeq \Phi_m^{-1}(m^*)$	$\Phi_m^{-1}(m^*) \succeq \Phi_m^{-1}(s^*) \succeq \Phi_s^{-1}(m^*) \succeq \Phi_s^{-1}(s^*)$

Table 2: Preference Sets for Sales and for Manufacturing

Let  $b = \min[\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*)]$ . A similar analysis as in Case I a) and b) implies that, the NE is  $[b, b]$  for all  $9 \times 12 = 108$  combinations (of preferences, and capacities). This result can be seen from observing in Table 2 that the first and third preference sets are completely reversed for the two functions and although this is not true for the second preference set, recall that the exact preference of each function is unknown to the other party. Therefore, an alternative equilibrium is not allowed because without knowing exact preferences, if one party has preference to choose higher than the constrained capacity, the other party will be assumed to not share this preference. A similar logic provides the results for Case IV. ■

**Proof.** Proposition 5.2

i) In all cases and conditions, the minimum capacity decision over all perceptions and functions is the most preferred capacity decision for one of the functions. Thus this function will play this capacity decision whether it is a leader or follower because it is always available. Thus the results.

ii) Begin with Case I and the claims of the proposition:

Case	Condition	First-Mover	Equilibrium
I	$\Phi_s^{-1}(s^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\succeq} (\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\succeq} (\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*))$
	$\Phi_s^{-1}(m^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\succeq} (\Phi_m^{-1}(s^*), \Phi_s^{-1}(m^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\succeq} (\Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*))$

a) Let  $\Phi_s^{-1}(s^*) = \min[\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*)]$ . Now since  $\Phi_s^{-1}(s^*) \leq \Phi_s^{-1}(m^*)$  this implies that  $\Phi_m^{-1}(s^*) \leq \Phi_m^{-1}(m^*)$ . The following, based on Table 1, shows the manufacturing and sales response in columns 2 and 3 respectively to the capacity play by the opposing function (sales and manufacturing respectively) as leader in column 1:

Leader	Manufacturing	Sales
$\Phi_m^{-1}(s^*)$	$m \max_{\succeq} (\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \min[\Phi_s^{-1}(m^*), \Phi_m^{-1}(s^*)])$	$\Phi_m^{-1}(s^*)$
$\Phi_s^{-1}(s^*)$	$\Phi_s^{-1}(s^*)$	$\Phi_s^{-1}(s^*)$
$\Phi_m^{-1}(m^*)$	$\Phi_m^{-1}(m^*)$	$\Phi_m^{-1}(s^*)$
$\Phi_s^{-1}(m^*)$	$m \max_{\succeq} (\Phi_s^{-1}(m^*), \min[\Phi_m^{-1}(s^*), \Phi_s^{-1}(m^*)], \min[\Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*)])$	$\Phi_s^{-1}(s^*)$

Consider sales as leader and that she plays  $\Phi_m^{-1}(s^*)$ . Manufacturing will play the most preferred decision that is less than or equal to that played by  $\Phi_m^{-1}(s^*)$ . This gives the result  $m \max_{\succeq} (\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \min[\Phi_s^{-1}(m^*), \Phi_m^{-1}(s^*)])$ . Note that  $\Phi_m^{-1}(m^*)$  is not considered since  $\Phi_m^{-1}(s^*) \leq \Phi_m^{-1}(m^*)$ . A similar analysis follows for all other plays for sales and manufacturing. When sales is the leader and does not know manufacturing's preference, the responses from manu-

facturing in the above table which are thus unresolved are not viable as perceived equilibria. The other responses provide then the basis for the PPD equilibrium for sales as leader. When manufacturing is the leader, since sales response is also limited to two capacity decision, this provides the basis for the PPD equilibrium for manufacturing as leader. A similar logic is applied in the rest of the examples below.

b) Let  $\Phi_s^{-1}(m^*) = \min[\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*)]$ . Now since  $\Phi_s^{-1}(m^*) \leq \Phi_s^{-1}(s^*)$  this implies that  $\Phi_m^{-1}(m^*) \leq \Phi_m^{-1}(s^*)$ . The following, based on Table 1, shows the manufacturing and sales response to the capacity play by the opposing function (sales and manufacturing respectively) as leader:

Leader	Manu.	Sales
$\Phi_m^{-1}(s^*)$	$\Phi_m^{-1}(m^*)$	$\Phi_m^{-1}(s^*)$
$\Phi_s^{-1}(s^*)$	$\Phi_s^{-1}(m^*)$	$s \max_{\geq} (\Phi_s^{-1}(s^*), \min[\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*)], \min[\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*)])$
$\Phi_m^{-1}(m^*)$	$\Phi_m^{-1}(m^*)$	$s \max_{\geq} (\Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*), \min[\Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*)])$
$\Phi_s^{-1}(m^*)$	$\Phi_s^{-1}(m^*)$	$\Phi_s^{-1}(m^*)$

These results prove the claims above.

The claims for case III are similarly proved by enumeration.

Consider Case II: The claims for the case are proved below:

Case	Condition	First-Mover	Equilibrium
II	$\Phi_m^{-1}(s^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\geq} (\Phi_s^{-1}(s^*), \Phi_m^{-1}(s^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\geq} (\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*))$
	$\Phi_s^{-1}(m^*) = \min[\bar{m}, \bar{s}]$	Manufacturing	$K_m^{St} = K_s^{St} = m \max_{\geq} (\Phi_s^{-1}(s^*), \Phi_s^{-1}(m^*))$
		Sales	$K_m^{St} = K_s^{St} = s \max_{\geq} (\Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*))$

a) Let  $\Phi_m^{-1}(s^*) = \min[\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*)]$ . Now since  $\Phi_m^{-1}(s^*) \leq \Phi_m^{-1}(m^*)$  this implies that  $\Phi_s^{-1}(s^*) \leq \Phi_s^{-1}(m^*)$ . The following, based on Table 2, shows the manufacturing and sales response to the capacity play by the opposing function (sales and manufacturing respectively) as leader:

Leader	Manufacturing	Sales
$\Phi_m^{-1}(s^*)$	$\Phi_m^{-1}(s^*)$	$\Phi_m^{-1}(s^*)$
$\Phi_s^{-1}(s^*)$	$m \max_{\geq} (\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \min[\Phi_m^{-1}(m^*), \Phi_s^{-1}(s^*)])$	$\Phi_s^{-1}(s^*)$
$\Phi_m^{-1}(m^*)$	$\Phi_m^{-1}(m^*)$	$\Phi_m^{-1}(s^*)$
$\Phi_s^{-1}(m^*)$	$m \max_{\geq} (\Phi_m^{-1}(s^*), \min[\Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*)])$	$\Phi_s^{-1}(s^*)$

These results prove the claims above.

b) Let  $\Phi_s^{-1}(m^*) = \min[\Phi_m^{-1}(s^*), \Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*), \Phi_s^{-1}(m^*)]$ . Now since  $\Phi_s^{-1}(m^*) \leq \Phi_s^{-1}(s^*)$  this implies that  $\Phi_m^{-1}(m^*) \leq \Phi_m^{-1}(s^*)$ . The following, based on Table 2, shows the manufacturing and sales response to the capacity play by the opposing function (sales and manufacturing respectively) as leader:

Leader	Manufacturing	Sales
$\Phi_m^{-1}(s^*)$	$\Phi_m^{-1}(m^*)$	$s \max_{\geq} (\Phi_m^{-1}(s^*), \Phi_s^{-1}(m^*), \min[\Phi_s^{-1}(s^*), \Phi_m^{-1}(s^*)])$
$\Phi_s^{-1}(s^*)$	$\Phi_s^{-1}(m^*)$	$\Phi_s^{-1}(s^*)$
$\Phi_m^{-1}(m^*)$	$\Phi_m^{-1}(m^*)$	$s \max_{\geq} (\Phi_s^{-1}(m^*), \min[\Phi_s^{-1}(s^*), \Phi_m^{-1}(m^*)])$
$\Phi_s^{-1}(m^*)$	$\Phi_s^{-1}(m^*)$	$\Phi_s^{-1}(m^*)$

These results prove the claims above.

The claims for case IV are similarly proved by enumeration. ■

**Proof.** Proposition 5.3

Each party will just play the capacity that maximizes his or her expected profits taking into consideration what they believe about the other party's behavior. ■

**Proof.** Proposition 5.4

(a) Sales, being the first mover, will just play  $K_s^{St} = K_s^{Si}$  as in Proposition 5.3, which maximizes his profits given what he knows and believes. Manufacturing will either lower this (if her ideal capacity,  $\Phi_m^{-1}(m^*)$ , is smaller than what sales played), or match it (her ideal capacity is larger than what sales played).

(b) Symmetric to Proposition 5.4, (a). ■

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