Effects of Demand Forecast and Resource Sharing on Collaborative New Product Development in Supply Chain

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Abstract- In today's volatile global marketplace co-developing of new products is increasingly important, owing to the uncertainties of developing and launching a new product. The collaborative new product development process however, presents a new challenge for the partner firms due to the sharing of information, resources and technology. Literature has not adequately addressed the issues associated with collaborative decision making that has to be robust in an environment with varying performance, quality and timing uncertainties, despite the growing need to collaborate. In our model, we consider a product development company and a technology development company with different but symbiotic capabilities. We analyze various scenarios, assessing the benefits and downsides of demand forecast information sharing on each company and the supply chain as a whole. The scenarios analyzed vary according to the level of technology, innovation and resources shared between the firms.

Keywords: **New product development process, Collaboration, Stackelberg game, Information sharing.**

1. Introduction

Globalization has boosted the competition within the marketplace. A new product development process in such a scenario has strategic significance as well as repercussions for an organization's performance and competitive position (Langerak, et al., 2005). The pharmaceutical sector would be one such case – where the financial bottom line is directly affected by the speed of product development (Mohan, et al., 2007), (Gupta, et al., 2007). This process is complex and time-consuming (Yan, et al., 2010), with new products taking an average of 12 years and several millions of dollars to launch (California Biomedical Research Association , 2014). This time-critical issue is compounded by other problems like rapid change in technology, global competition, limited budgets and tougher regulations. In response to such competitive environment, firms now have to partner up with other firms for their expertise in specific disciplines or technologies (Quinn, 2000). Rigel and Neurocrine Biosciences, for instance developed a joint relationship to discover novel molecular targets involved in glial cell activation. The president and CEO of Rigel elaborates how this partnership benefitted both the

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firms mutually (Gower, 1998). Rigel has now the access to a larger chemical library, which adds a significant value to its technology. Neurocrine gets new target discovery and validation based on genomics and functional pathway mapping in a target area of strategic interest.

A considerable amount of research literature exists on new product development. Much of it is focused on product development in a single firm, investigated at either the product or project levels. Ozer, for example, studied factors influencing decision making in NPD and provided guidelines to evaluate the new products in a more confident and accurate way (Ozer, 2005). Mu et al. analysed the contribution of individuals within new product development teams to NPD and its performance (Mu, et al., 2011). There exists ample research concentrating on the different aspects of such a process, dealing with improving its performance (Novak & Eppinger, 2001). In this paper, we analyse various possible relationships between a technology and product development company with regard to information, collaboration and innovation sharing. We consider the effect of forecast sharing on prices and profits. We also come across some deviations from expected results.

It has been argued that information sharing is of vital importance in cross-organizational collaboration (Zhijun, 2009) (Zhao, et al., 2002). Many researchers have suggested that making an up-to-date and undistorted data available at every point within the supply chain is important. Yue and Liu (2005) argue that there are two fundamental ways in which sharing information can help the supply chain (Yue & Liu, 2005). Firstly, it enables manufacturers to respond to volatile consumer demand by appropriately scheduling production and replenishing retailer inventory, and secondly, by improving the accuracy of demand forecast. Better forecasting, in turn, can contribute to better price structuring and better inventory management and thus help firms produce high-quality products. While information sharing is important within this context, the significance of its impact on the performance of a supply chain also depends on what information is shared, when, how and with whom it is shared ((Chizzo, 1998), (Holmberg, 2000)).

Even though the benefits of information sharing have been well documented in literature, they have not been studied adequately with reference to the information sharing between firms jointly collaborating to develop a new product. Through this paper, we try to address and analyse this in detail. We analyse various collaborative scenarios between a technology and a product development company involved in innovation, investment and information sharing. We analyse how the firms would handle the demand forecast data based on the type of their collaboration, market demand & customer sensitivities, and subsequently arrive at the equilibrium prices and the level of innovation. We obtain detailed quantitative solutions for these parameters and graphically depict the variation of profit functions of the two firms in these scenarios. In addition to a thorough analysis, this paper tries to address the cases where results are not as expected. For the academia, this paper provides a basis for further research on collaborative NPD. For companies already involved in collaborative NPD we provide a method to optimize their parameters according to their collaboration scenario. And for the companies entering into collaborative NPD a method to compare various scenarios.

The remainder of the paper is organized as follows. In Section 2 we survey related literature on NPD and information sharing. Section 3 builds the model for innovation, demand as well as the profit functions. In Section 4 we provide the detailed analysis for each of these scenarios. Section 5 and 6 finally present the managerial implications and conclusions respectively. Results of all the proofs in the paper are given in the appendix in Section 7.

2. Relevant Literature

As stated previously, an extensive literature exists on the topic of new product development process in single firms, investigated at the product and project levels (Bhaskaran & Krishnan, 2006). The interactions between product and supply chain have emerged as an interesting field ((Rauniar & Rawskib, 2012), (Grahovac & Parker, 2002), (Novak & Eppinger, 2001), (Avag, 2005) and (Schoenherra & Wagnerb, 2016)). Wang & Shu developed a fuzzy model to evaluate the performance of the entire supply chain (Wang & Shu, 2007). Erat and Kavadias (Erat & Kavidas, 2006) studied the development of products in an industrial context, their focus being the inter-temporal discrimination of a technology supplier through partial adoption of technology, while Jayaram (Jayaram, 2007) studied the supplier involvement at length in NPDs and their effects. Another strand of literature views the relationship between financial parameters of a firm and the NPD process ((Chen, et al., 2006), (Koufterosa, et al., 2014)).

There has been substantial research considering R&D alliances ((Ge & Hu, 2008), (Amaldoss, et al., 2000), (Dutta & Weiss, 1997)), knowledge management ((Bradfield & Gao, 2007), (Lee & Ahn, 2007), (Huang & Liang, 2006) and (Honga, et al., 2011)), but these ignore the role of information sharing in the NPD decision making process. More recently, Bhaskaran and Krishnan (Bhaskaran & Krishnan, 2005) consider the concept of collaborative NPD in a supply chain consisting of an upstream supplier and a downstream manufacturer. Their analysis shows that for products with no pre-existing revenues, innovation and investment sharing are important. Also, the benefits depend on the extent to which the revenues are shared between the firms. And then, the above research is extended by Bhaskaran and Krishnan (Bhaskaran & Krishnan, 2006) in which the supply chain they consider consists of two competitive upstream suppliers and a downstream manufacturer.

The information sharing literature consists of studies, particularly pioneered by the works of Clarke (Clarke, 1983), Gal-Or (Gal-Or, 1985), Li (Li, 1985), Novshek and Sonnenschein (Novshek & Sonnenschein, 1982) and Vives (Vives, 1984), that deal with the NPD. This body of research focuses on horizontal information sharing among competitors, i.e., whether or not competing firms have an incentive to share market sensitive information in an oligopoly situation. However, interactions between vertical parties are not considered and hence these could only serve as a benchmark. Samaddar et al. (Samaddar, et al., 2006) investigate the relationships between the design of a supply network and inter-organizational information sharing. Recent studies offer an excellent survey of the literature and points out two areas concerning information sharing in supply chains. Firstly, in case of information asymmetry between the players in the supply chain, members are prompted to engage in screening and signaling. This stream of research evaluates the value of information in improving operational performance (see, (Cachon & Fisher, 2000), (Chiang & Trappey, 2007), (Wang, et al., 2013), (Titah, et al., 2016)) and mostly a channel structure with one supplier and one retailer is considered. The second area considers information sharing in a channel structure of many competing retailers and one supplier ((Li, 2002), (Zhang, 2002), (Li & Zhang, 2008)).

From the NPD and information sharing literature, it is thus clear that adequate research doesn't exist addressing the role and effects of information sharing in a new product development process. In this research, we introduce information sharing into the existing NPD supply chain literature and investigate the effect of information sharing in a collaborative NPD process.

3. The Model

We shall now discuss the background and framework for our model. Let's say one of the firms comes up with the idea for a new product, but doesn't have sufficient infrastructure of its own to carry out the manufacturing. It therefore decides to outsource the manufacturing role to another firm, which happens to be an established player in the market, with sufficient infrastructure base of its own. We refer to the former as the Product Development Company (PDC) and latter as the Technology Development Company (TDC). Through this arrangement, both the firms engage in a collaborative new product development process.

The supply chain, made up of one PDC and one TDC is as shown in Figure 1. In our model we consider the case of a new product which has an improved performance in certain key dimensions and this improved quality has the potential to increase end-customer demand. For this the PDC, as stated earlier, needs input from a specialist firm TDC, which actually engages in the development of the product. In this model, thus, the TDC sets the wholesale price (ω) at which the product is sold to PDC and also decides the innovation level of the product (θ), being the one actually involved in the product development. The PDC in turn sets the retail price (p) at which it finally markets the developed product. The market forecast (denoted by f), we assume is being determined by the PDC since it is the one which finally markets the product. The decision variables are chosen by both the TDC and the PDC so as to maximize the profits.

A key feature in this game is that one of the players i.e. TDC is the firm deciding the level of innovation (θ) for the product. This provides it with a strategic advantage over the partner firm PDC, thereby causing PDC to have to observe TDC's move before arriving at its own decision variables. The modeling of this scenario therefore demands the use of a Stackelberg game. This is because here TDC is aware of the fact that PDC observes its move, before deciding its own. Being a Stackelberg player (leader for TDC) in this case, would result in higher profits than a Nash bargaining game. Hence TDC would tend to make this a Stackelberg game while engaging in the new product development process (Shiau & Michalek, 2009). This is so because the leader (if aware of his position) always benefits by playing a Stackelberg leader rather than playing a naïve Nash player (Choi, et al., 1990), (Wang, et al., 2016).

Thus, in this model, the TDC acts as the Stackelberg leader and the PDC the Stackelberg follower. In such a setting, we now analyze the effects of sharing forecast information (f) between the firms, on individual profits as well as on that of the supply chain as a whole. To derive the optimal decisions, we assume both TDC and PDC know the equilibrium strategies of the other firm and neither of them has anything to gain by changing its own strategy unilaterally. We assume both TDC and PDC to be rational firms.

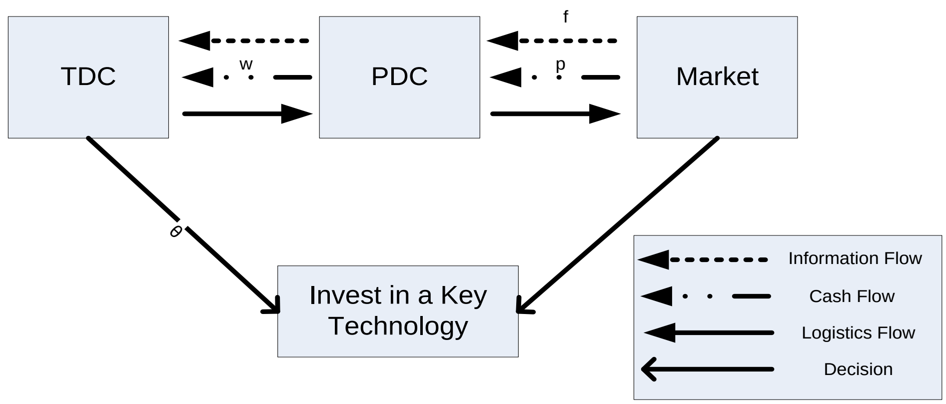

Figure 1: The Model

3.1 Model of Innovation

We model innovation as an attribute that does not increase the firms' marginal cost at the expense of quality. These improvements are referred to as innovation quality dimensions (Abbott, 1953). The required level of innovation (θ) is decided by the firm, and therefore the cost associated with developing the product and the cost for deploying the resources to achieve this innovation is incurred.

There is an upfront investment equal to the fixed cost of investment which is a function of the level of innovation θ. We assume that this cost is $I\theta^n$, where I is the innovation investment parameter and n =2. This value of n is assumed in line with findings from (Bhaskaran & Krishnan, 2005), as the cost of innovation is convex with respect to the level of quality improvement. Another component is the variable development cost which is dependent on the time taken to develop the innovation (Bhaskaran & Krishnan, 2006) and hence is taken to be equal to $c\theta T$. Hence the total cost of development is equal to:

$$\text{Cost of development} = I\theta^2 + c\theta T \qquad (1)$$

3.2 Model of Demand

We model the end-customer demand as a linear demand function, which has been used extensively in the previous literature (refer to (Ray, 2005), (Tsay & Agrawal, 2000) and references therein). The end-customer demand here is a variation of negatively sloped demand function which incorporates the customer's demand for an improved/higher quality i.e. TDC's innovation increases product quality, stimulates demand and shifts it upwards by a factor $d\theta$. So, when *p* is the retail price of the goods, the quantity of the goods made available in the market, Q, is defined as follow,

$$Q = a - bp + d\theta, \;\; \forall \;\; a > 0, b > 0, \; c > 0 \qquad (2)$$

here, a, b and d represent the total market potential and the sensitivity of the customers towards price and innovation levels, respectively.

3.3 Model for Information Structure

We assume the base level of demand 'a' to be a random variable to capture the uncertainties in demand pertaining to the changes in business and economic conditions. For example, the demand for Toprol-XL, a hypertension and heart disease drug, by AstraZeneca was not known with certainty, at the time of introduction and could be affected by a number of factors. Sales figures in the US for Toprol-XL increased by 59% after two of AstraZeneca's competitors have had to withdraw generic products from the market (Financial Times, 2009 (Financial Times, 2009)). We try to incorporate such uncertainties by considering 'a' as a random variable. These factors are monitored by many firms on a regular basis, which helps them keep track of the uncontrollable elements of industry demand.

Thus, more specifically, we assume

$$a = a_0 + e \qquad (3)$$

where, a_0 is the mean base level demand and e is the error term assumed to have a normal distribution with $\mu = 0$ and $\sigma^2 = V$. Thus, $E[(a-a_0)^2] = V$ (Raju & Roy, 2000). The normality assumption associated with equation 3, is widely used in literature due to its simplicity. The demand uncertainty term is used as an unknown additive intercept (Vives, 1984).

The PDC uses its market information gathering techniques as well as the known uncertain market demand (a) to make a forecast. We assume the forecast of the PDC to be:

$$f = a + \varepsilon \qquad (4)$$

where ε is independent of a and has a normal distribution, with $\mu = 0$ and $\sigma^2 = s$. A higher (lower) variance implies a less (more) precise forecast.

The precision parameter is given by $t = V/(V+s)$ and is inversely proportional to the error variances (Yue, et al., 2006). In line with findings of the existing literature (e.g., (Vives, 1984), (Raju & Roy, 2000), (Li, 2002)), all the parameters of the model (except the forecast) are assumed to be of common knowledge to both the firms. If PDC decides to disclose information about demand (*f*) to TDC, we can state that an information sharing agreement has been reached between the two firms. We then rationally assume that TDC will use this information (*f*) to derive the wholesale price (ω).

Case 1: No Information Sharing, No Collaborative NPD, No Innovation Sharing (NNN)

In the NNN strategy, none of the information, investment or innovation is shared between the firms. Equations 5 and 6 give the profit functions for the PDC and the TDC respectively. Note the conditional expectation in case of PDC.

$$E\left(\Pi_{PDC}^{NNN} \middle| f\right) = E\left((p-\omega)(a-bp+d\theta) \middle| f\right) \qquad (5)$$

$$E\left(\Pi_{TDC}^{NNN}\right) = E\left(\omega(a-bp+d\theta) - I\theta^2 - c\theta T_{TDC}\right) \qquad (6)$$

Case 2: No Information Sharing, Collaborative NPD and No innovation Sharing (NCN)

Case 2 is similar in nature to case 1, where no information or innovation is shared between the firms. However in this decentralized channel the PDC agrees to share a fraction of the total investment costs ($\varkappa$) in the technology or service development. If the innovation is successful, the PDC is charged a technology price (ω) for every component procured from the TDC. Profit functions are given by equations 7 and 8.

$$E\left(\Pi_{PDC}^{NCN} \middle| f\right) = E\left(((p-\omega)(a-bp+d\theta) - \chi I\theta^2 - \chi c\theta T_{TDC}) \middle| f\right) \quad (7)$$

$$E\left(\Pi_{TDC}^{NCN}\right) = E\left(\omega(a-bp+d\theta) - (1-\chi)I\theta^2 - (1-\chi)c\theta T_{TDC}\right) \quad (8)$$

Case 3: Information Sharing, No Collaborative NPD and No Innovation Sharing (INN)

In case 3, we assume PDC is willing to share the demand forecast data (*f*) with the TDC and hence note the conditional expectation for TDC. However, there are no investment costs or innovation works undertaken by the PDC. Profit functions are given by equations 9 and 10.

$$E\left(\Pi_{PDC}^{INN} \middle| f\right) = E\left((p-\omega)(a-bp+d\theta) \middle| f\right) \quad (9)$$

$$E\left(\Pi_{TDC}^{INN} \middle| f\right) = E\left((\omega(a-bp+d\theta) - I\theta^2 - c\theta T_{TDC}) \middle| f\right) \quad (10)$$

Case 4: Information Sharing, Collaborative NPD and No Innovation Sharing (ICN)

In case 4, PDC is willing to share the demand forecast data (*f*) with the TDC. The PDC also agrees to share a fraction of the total investment costs ($\varkappa$) in the technology or service development but doesn't take part in innovation work and if the innovation is successful it is charged a technology price (ω) for every component procured from the TDC. Profit functions are given by equations 11 and 12.

$$E\left(\Pi_{PDC}^{ICN} \middle| f\right) = E\left(((p-\omega)(a-bp+d\theta) - \chi I\theta^2 - \chi c\theta T_{TDC}) \middle| f\right) \quad (11)$$

$$E\left(\Pi_{TDC}^{ICN} \middle| f\right) = E\left((\omega(a-bp+d\theta) - (1-\chi)I\theta^2 - (1-\chi)c\theta T_{TDC}) \middle| f\right) \quad (12)$$

Case 5: No Information Sharing, No Collaborative NPD and Innovation Sharing (NNI)

In the NNI strategy, though no information or investment is shared, the PDC shares a part of the innovation work (y) with the TDC and hence is also involved in development work along with TDC. Profit functions are given by equations 13 and 14.

$$E\left(\Pi_{PDC}^{NNI} \middle| f\right) = E\left(((p-\omega)(a-bp+d\theta) - I(y\theta)^2 - c\theta y T_{PDC}) \middle| f\right) \quad (13)$$

$$E\left(\Pi_{TDC}^{NNI}\right) = E\left(\omega(a-bp+d\theta) - I((1-y)\theta)^2 - c(1-y)\theta T_{TDC}\right) \quad (14)$$

Case 6: No Information Sharing, Collaborative NPD and Innovation Sharing (NCI)

In the NCI strategy, though no forecast information is shared, the PDC shares a part of the innovation work with the TDC and also shares a part of investment with PDC. The profit functions are given as in equations 15 and 16.

$$E\left(\Pi_{PDC}^{NCI}\middle| f\right) = E\left(((p-\omega)(a-bp+d\theta) - I(y\theta)^2 - cy\theta T_{PDC} - \chi I((1-y)\theta)^2 - \chi c(1-y)\theta T_{TDC})\middle| f\right) \quad (15)$$

$$E\left(\Pi_{TDC}^{NCI}\right) = E\left(\omega(a-bp+d\theta) - (1-\chi)I((1-y)\theta)^2 - (1-\chi)c(1-y)\theta T_{TDC}\right) \quad (16)$$

Case 7: Information Sharing, No Collaborative NPD and Innovation Sharing (INI)

In the INI strategy, PDC agrees to conduct part of innovation (y) itself and also share the forecast information with TDC. The profit functions would be given by equations 17 and 18.

$$E\left(\Pi_{PDC}^{INI}\middle| f\right) = E\left(((p-\omega)(a-bp+d\theta) - I(y\theta)^2 - c\theta y T_{PDC})\middle| f\right) \quad (17)$$

$$E\left(\Pi_{TDC}^{INI}\middle| f\right) = E\left((\omega(a-bp+d\theta) - I((1-y)\theta)^2 - c(1-y)\theta T_{TDC})\middle| f\right) \quad (18)$$

Case 8: Information Sharing, Collaborative NPD and Innovation Sharing (ICI)

In the ICI strategy, the PDC shares innovation and investment with TDC and also shares the forecast information. The profit functions are as in equations 19 & 20.

$$E\left(\Pi_{PDC}^{ICI}\middle| f\right) = E\left(((p-\omega)(a-bp+d\theta) - I(y\theta)^2 - cy\theta T_{PDC} - \chi I((1-y)\theta)^2 - \chi c(1-y)\theta T_{TDC})\middle| f\right) \quad (19)$$

$$E\left(\Pi_{TDC}^{ICI}\middle| f\right) = E\left((\omega(a-bp+d\theta) - (1-\chi)I((1-y)\theta)^2 - (1-\chi)c(1-y)\theta T_{TDC})\middle| f\right) \quad (20)$$

4. Analysis

As can be inferred from Fig 2, there are basic four different strategies in which two firms involving in a new product development process can collaborate based on which of the investment or innovation is shared.

1. No collaboration (No investment/innovation sharing)
2. Pure Investment sharing (No innovation sharing)
3. Pure Innovation sharing (No investment sharing)
4. Combined Investment & Innovation sharing

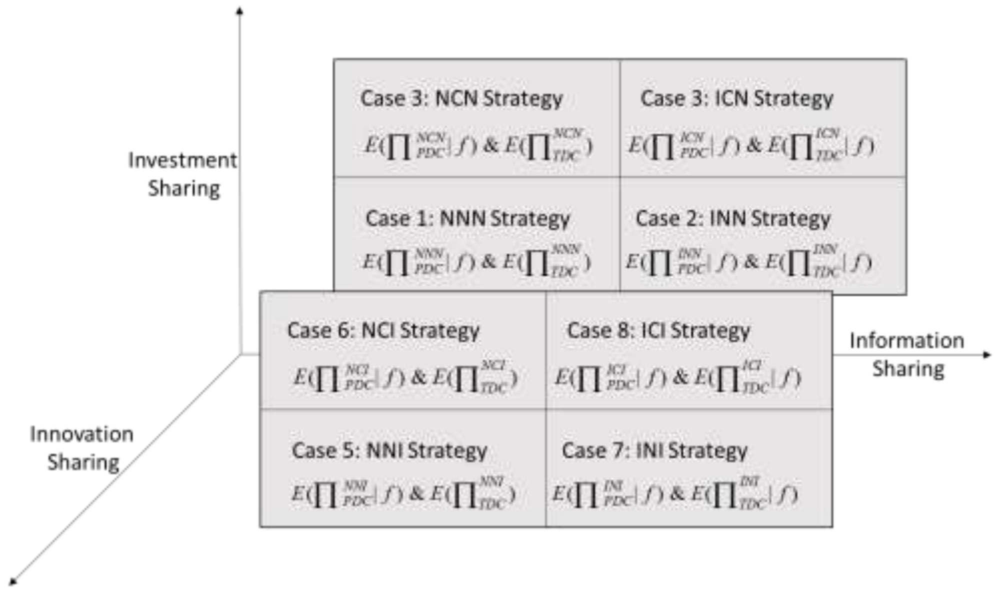

Figure 2: Profit Functions

Now, depending on whether or not the forecast information is shared in these 4 cases, we arrive at the eight possible strategies enlisted in the previous section. We will now analyze the effect of sharing forecast information in each of the above four strategies.

4.1 No Collaboration Scenario

Scenario 1 represents cases 1 and 3. The sequence of actions for this scenario is represented in Figure 3. We derive the optimal retail price (p), wholesale price (ω), innovation level (θ) and profits in the two situations:

(1) when information is not shared by the firms; (2) when information is shared by the firms.

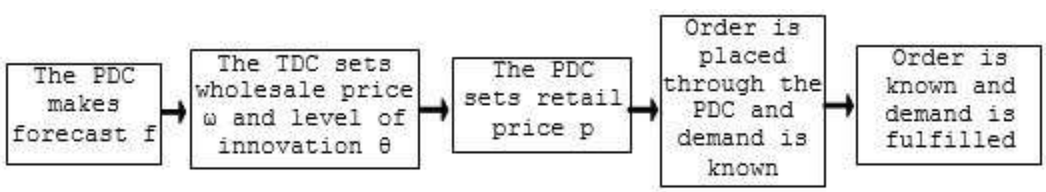

Figure 3: Sequence of actions in a no collaboration scenario

4.1.1. No Information Sharing

Both the PDC and TDC maximize their profits as shown in equations 5 and 6. Since TDC is the leader and PDC is the follower in this Stackelberg game, we derive the optimal solution by first deriving the optimal θ and ω followed by the optimal p. We obtain the following result.

Result 1: The optimal wholesale price and the optimal level of innovation for the TDC are not related to the forecast of the PDC, for the Stackelberg model with no information sharing and no collaborative NPD at the equilibrium. Table 1 shows the optimal values of retail price and wholesale price, level of innovation and expected profits for PDC and TDC in a no collaboration and no information sharing scenario.

Table 1: Optimal values for no information sharing and no collaborative NPD strategy

Variable	Value
p^{NNN}	$\frac{\left(8bI-d^2\right)\left(\left(1-t\right)a_0+tf\right)+a_0\left(d^2+4bI\right)-6dbcT_{TDC}}{2b\left(8bI-d^2\right)}$
ω^{NNN}	$\frac{4Ia_0-2dcT_{TDC}}{8bI-d^2}$
θ^{NNN}	$\frac{da_0-4bcT_{TDC}}{8bI-d^2}$
$E\Pi_{PDC}^{NNN}$	$\frac{16b^2I^2a_0^2+Vt\left(8bI-d^2\right)^2-16a_0Ib^2dcT_{TDC}+4b^2d^2c^2T_{TDC}^2}{4b\left(8bI-d^2\right)^2}$
$E\Pi_{TDC}^{NNN}$	$\frac{Ia_0^2-a_0dcT_{TDC}+2bc^2T_{TDC}^2}{8bI-d^2}$

Proof: Given the following values: sharing level ϰ, wholesale price ω and innovation level θ, the PDC determines the retail price (p) that maximizes its anticipated profit (equation 5). Taking the first order condition (FOC), we get

$$\frac{\partial E\left(\Pi_{PDC}^{NNN}\middle|f\right)}{\partial p}=E\left(a\right)-2bp+d\theta+b\omega=0 \qquad (21)$$

As can be seen the second order condition (SOC) is negative, which implies that the profit function of the PDC is concave in p. We can obtain the value of p from equation 21 as:

$$p\left(\theta,\omega\right)=\frac{a_0+d\theta+b\omega}{2b} \qquad (22)$$

The TDC forecasts the retail price of PDC as $E(p) = (a_0+d\theta+b\omega)/(2b)$ (from (22)), in the absence of the forecast data. When this is substituted into the profit function of the TDC, we can obtain the optimal innovation level and wholesale price from the TDC's profit function through the two FOCs ($\partial E(\Pi_{TDC})/\partial\omega=0$ and $\partial E(\Pi_{TDC})/\partial\theta=0$), and are given by

$$\omega^{NNN}=\frac{4a_0I-2dcT_{TDC}}{8bI-d^2} \quad ;\theta^{NNN}=\frac{a_0d+4bcT_{TDC}}{8bI-d^2} \qquad (23)$$

As can be noted from (23), the two parameters for the TDC at equilibrium are not related to the forecast of the PDC. This is because the PDC does not share its forecast information with the TDC, and the TDC has to make its decisions by using only the available market information.

On the other hand, it is evident from Table 1 that the optimal price of the PDC is dependent on market information and forecast and also an increasing function of the PDC forecast data. This implies that if the PDC is optimistic about the market potential it would set a higher retail price and vice versa. We also notice that the quality of forecast directly affects the profitability of the PDC as would be expected.

Result 2: The expected equilibrium profit of the TDC in this situation is independent of the market forecast level as well as forecast accuracy while that of PDC increases with forecast accuracy. (Fig 4).

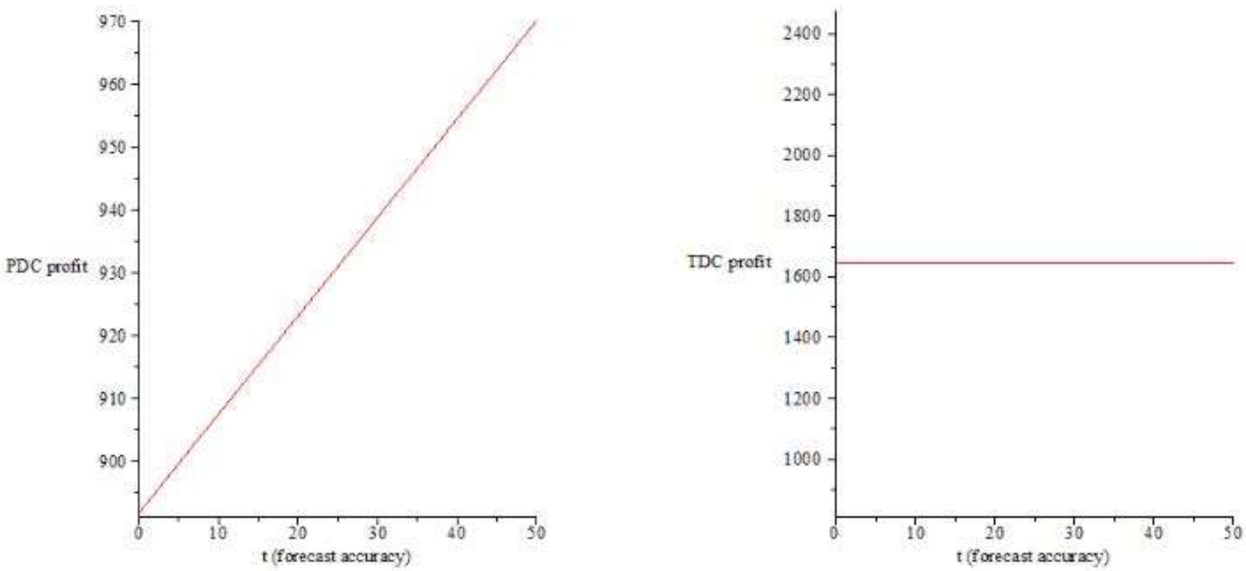

Figure 4: Variation of profits with forecast accuracy
(No information sharing in a no collaboration scenario)

We now contrast the optimal values (from table 1) with the case where PDC shares forecast information with TDC.

4.1.2Information Sharing

In this scenario, the PDC shares the market forecast data with the TDC before making any decisions. The PDC and the TDC maximize their profit functions as given in equations 9 and 10 and the following result holds at the Stackelberg equilibrium.

Result 3: The optimal wholesale price and the optimal level of innovation for the TDC are related to both the forecast level and forecast accuracy of the PDC. Table 2 shows the optimal values of parameters for both the TDC and the PDC in an information sharing and no collaborative NPD environment at the equilibrium.

Table 2: Optimal values for information sharing and no collaborative NPD strategy

Variable	Value
p^{INN}	$\frac{6I\left(\left(1-t\right)a_0+tf\right)-3dcT_{TDC}}{8bI-d^2}$
ω^{INN}	$\frac{4I\left(\left(1-t\right)a_0+tf\right)-2dcT_{TDC}}{8bI-d^2}$
θ^{INN}	$\frac{d\left(\left(1-t\right)a_0+tf\right)-4bcT_{TDC}}{8bI-d^2}$
$E\Pi_{PDC}^{INN}$	$\frac{4I^2b\left(a_0^2+tV\right)+bd^2c^2T_{TDC}^2-4bdcT_{TDC}Ia_0}{\left(8bI-d^2\right)^2}$
$E\Pi_{TDC}^{INN}$	$\frac{I\left(a_0^2+tV\right)+2c^2T_{TDC}^2b-a_0T_{TDC}cd}{(8bI-d^2)^2}$

As is evident from table 2, the structure of the optimal values for the information sharing situation is similar to the no information sharing situation in table 1. The major difference observed is that the optimal wholesale price and the optimal level of innovation are now both related to the forecast of the PDC.

4.1.3 Value of Information Sharing

We use the profit expressions from tables 1 and 2 to observe the impact information sharing has on each firm's performance in case of a non-collaborative NPD. The value of information sharing to the PDC and TDC in both the collaborative NPD situation can be interpreted from the following:

$$V_{PDC}^{N}=E\Pi_{PDC}^{INN}-E\Pi_{PDC}^{NNN}=-\frac{tV\left(12bI-d^2\right)\left(4bI-d^2\right)}{4b\left(8bI-d^2\right)^2} \quad (24)$$

$$V_{TDC}^{N}=E\Pi_{TDC}^{INN}-E\Pi_{TDC}^{NNN}=\frac{ItV}{(8bI-d^2)^2}>0 \quad (25)$$

Result 4: The value of information sharing to the TDC is always positive as can be seen from the above equation (25). On the other hand, the value of information sharing to the PDC is positive iff.

$$\frac{d^2}{12b} < I < \frac{d^2}{4b} \qquad (26)$$

Result 4 presents some interesting and important observations. The value of information sharing being positive for the NPD is intuitive, because in this situation, the TDC sets the wholesale price and makes all innovation decisions after knowing the PDC's market forecast data. However, as shown in our model, this has implications for the PDC, who might see a decrease in profit (when. $I \notin \left(d^2/(12b), d^2/(4b)\right)$). This is because the TDC maximizes its own profit at the expense of the PDC by using the market forecast information strategically. Equation 26 implies that the investment parameter should be moderate, i.e. $I \in \left(d^2/(12b), d^2/(4b)\right)$. Under this condition, the PDC has an incentive to share forecast information with the TDC and would lead to mutual benefits for the two.

Another set of findings and their interpretation, drawn for the two situations of sharing and not sharing information, are as follows:

Result 5: If $f \geq a_0$, then, $p^{INN} \geq p^{NNN}$, $\omega^{INN} \geq \omega^{NNN}$ and $\theta^{INN} \geq \theta^{NNN}$; and if $f < a_0$, then, $p^{INN} < p^{NNN}$, $\omega^{INN} < \omega^{NNN}$ and $\theta^{INN} < \theta^{NNN}$.

If PDC is optimistic about the market potential demand (e.g., $f \geq a_0$) the PDC will set a high retail price (p) in an information sharing situation. The TDC on the other hand will set higher wholesale price (ω) which will affect the PDC's profitability. Furthermore, the TDC will make a higher level of innovation (θ) in an information sharing case, which indicates that there is an incentive for the TDC, when the PDC is optimistic about the market potential demand.

We also try to graphically observe the relative values of the profits of the two firms in both cases. The values for the coefficients have been taken so as to mirror the real world scenario. The parameters are mostly product/drug specific and need to be calculated separately for each drug. The percentage increase in the demand of a drug over its predecessor is an indicator of its level of innovation and hence has been taken as the proxy for the drug's θ. The cost of development of a drug along with the actual time for its development is used to calculate constants of equation 1. Similarly, the price of the drug and its sales (customer base) are used to calculate the sensitivity constants in equation 2. Fig 5 represents the plots using parameters corresponding to those of a drug Brintellix. We can note from Fig 5 that the value of information sharing to the supply chain is slightly positive in the no-collaboration scenario. Using the parameter values corresponding to different drugs, gives similar relative positions for the graphs of PDC profit and TDC profit for the two cases. As can be seen, the value of information sharing is positive to the PDC in the middle range, but decreases at extreme values of b on either side.

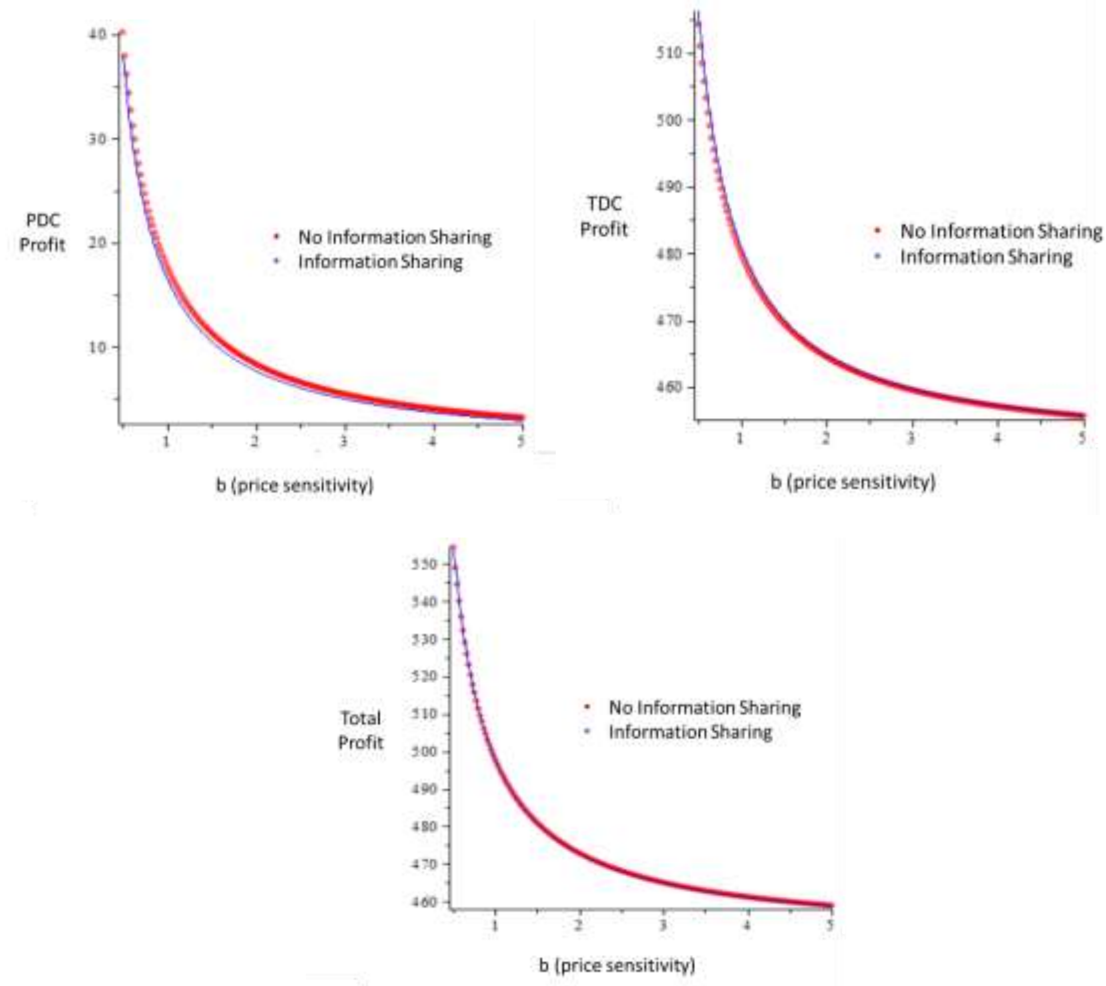

Figure 5: Comparison of profits with/without information sharing in no collaboration scenario

4.2 Pure Investment Sharing Scenario

The sequence of actions for this scenario, which represents cases 2 and 4, is represented in Figure 6.

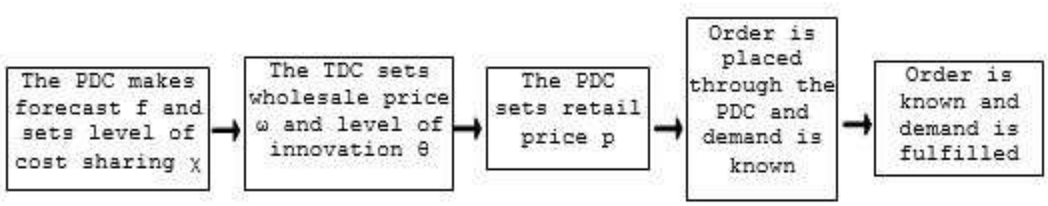

Figure 6: Sequence of actions in a pure investment sharing scenario

We derive the level of investment sharing (χ), wholesale price (ω), optimal retail price (p), innovation level (θ) and profits in two situations:

(1) when information is not shared by the firms; (2) when information is shared by the firms.

4.2.1 No Information Sharing

In this scenario, the PDC and the TDC maximize profit as per equations 7 and 8. We prove the following result.

Result 6: The forecast information (f) or the forecast accuracy (t) does not influence PDC's equilibrium contribution $\varkappa$ in the investment sharing, in the no information sharing case in pure investment sharing scenario.

Proof: Given the following values: sharing level $\varkappa$, wholesale price ω and innovation level θ, the PDC determines the retail price (p) that maximizes its anticipated profit (equation 7). Taking the first order condition (FOC), we get

$$\frac{dE\left(\Pi_{PDC}^{NCN}\middle| f\right)}{dp} = E\left(a\middle| f\right) - 2bp + d\theta + b\omega = 0$$

As can be seen the second order condition (SOC) is negative, which implies that the profit function of the PDC is concave in p. We can obtain value of p as

$$p\left(\theta,\omega\right) = \frac{E\left(a\middle| f\right) + d\theta + b\omega}{2b}$$

The TDC forecasts the retail price of PDC as $E(p) = (a_0 + d\theta + b\omega)/(2b)$, in the absence of the forecast data. If this value is substituted into the profit function of the TDC, we can obtain the optimal innovation level and wholesale price from the PDC's profit function which are given by

$$\omega^{NCN}\left(\chi\right) = \frac{2(2a_0 I - dcT_{TDC})\left(1-\chi\right)}{8bI\left(1-\chi\right) - d^2} \; ; \; \theta^{NCN}\left(\chi\right) = \frac{a_0 d - 4bcT_{TDC}\left(1-\chi\right)}{8bI\left(1-\chi\right) - d^2} \qquad (27)$$

Substituting values from equation (27) into the profit function of the PDC in equation (7), we get

$$E\left(\Pi_{PDC}^{NCN}\middle| f\right) = E\left(\left(p\left(\theta,\omega\right) - \omega\left(\chi\right)\right)\left(a - bp\left(\theta,\omega\right) + d\theta\left(\chi\right)\right) - \chi I\theta^2\left(\chi\right) - \chi c\theta T_{PDC}\middle| f\right)$$

From the FOC, we obtain the optimal sharing level as:

$$\chi = \frac{-1}{48}\frac{(-12^{1/3}K^{2/3} - 8d^3 12^{2/3} cT_{TDC} a_0 I + 2d^4 12^{2/3} c^2 T_{TDC}^2 + 8d^2 12^{2/3} I^2 a_0^2 + 6K^{1/3} cT_{TDC} d^2 - 48K^{1/3} cT_{TDC} a_0 b)}{K^{1/3} cT_{TDC} a_0 b}$$

where,

$$K = d^2(-144c^3T_{TDC}^3 Ibd^2 - 108cT_{TDC}d^2I^2a_0^2 - 576cT_{TDC}I^3a_0^2b - 108c^2T_{TDC}^2a_0d^3I + 576c^2T_{TDC}^2a_o dI^2b + 27c^3T_{TDC}^3d^4 + 108cT_{TDC}d^2I^2tV - 576cT_{TDC}I^3tVb$$
$$+\sqrt{3}\sqrt{((T_{TDC}dc - 2a_0I)^4(275d^4c^2T_{TDC}^2 - 2592Ibc^2T_{TDC}^2d^2 + 6912b^2c^2T_{TDC}^2I^2 - 128cT_{TDC}a_0d^3I + 128d^2I^2a_0^2)})$$

We observe that the equilibrium value of χ is independent of demand forecast (f) or the forecast accuracy (t). This demonstrates that PDC's share in the investment at the equilibrium remains unaffected by the variations of the demand forecast and also the accuracy in determining this forecast data. This may be attributed to the lack of information sharing which leads to ω and θ being independent of f and t at the equilibrium, resulting in equilibrium ϰ being independent.

4.2.2 Information Sharing

In this scenario, the PDC shares the market forecast data with the TDC before making any decisions. The PDC and the TDC maximize their profit functions as given in equations 11 and 12.

Result 7: Table 3 shows the optimal Stackelberg parameters for both the TDC and the PDC with information sharing in pure investment sharing scenario in the decentralized supply chain at the equilibrium. Sharing level ϰ, wholesale price ω and innovation level θ are dependent on the forecast level and accuracy.

Table 3: Optimal values for information sharing case in a pure investment sharing NPD strategy

Variable	Value
p^{ICN}	$\frac{3(-\chi+1)(dcT_{TDC}-2I\left((1-t)a_0+tf\right)}{\left(d^2-8Ib(-\chi+1)\right)}$
ω^{ICN}	$\frac{2(-\chi+1)(dcT_{TDC}-2I\left((1-t)a_0+tf\right)}{\left(d^2-8Ib(-\chi+1)\right)}$
θ^{ICN}	$\frac{4(-\chi+1)bcT_{TDC}-\left((1-t)a_0+tf\right)d}{\left(d^2-8Ib(-\chi+1)\right)}$
$E\Pi_{PDC}^{ICN}$	$\frac{(1+\chi^2)(-4bdcT_{TDC}Ia_0+4bI^2tV+4bI^2a_0^2+16\chi Ib^2c^2T_{TDC}^2)+\chi(8bI+d^2)(cT_{TDC}da_0-ItV)}{(d^2-8Ib+8\chi Ib)^2}+\frac{-8bI^2\chi a_0^2-\chi Id^2a_0^2+bd^2c^2T_{TDC}^2-6bd^2c^2\chi T_{TDC}^2+5bd^2c^2T_{TDC}^2\chi^2-32\chi^2Ib^2c^2T_{TDC}^2}{(d^2-8Ib+8\chi Ib)^2}$
$E\Pi_{TDC}^{ICN}$	$\frac{-1+\chi(-2b\chi c^2T_{TDC}^2+2bc^2T_{TDC}^2+Ia_0^2+ItV-dcT_{TDC}a_0)}{(d^2-8Ib+8\chi Ib)^2}$

where,

$$\chi=\frac{-1}{48}\frac{(-12^{1/3}K^{2/3}+8d^2 12^{2/3}I^2a_0^2-8d^3 12^{2/3}cT_{TDC}a_0I+2d^4 12^{2/3}c^2T_{TDC}^2+8d^2 12^{2/3}I^2tV+6K^{1/3}cT_{TDC}d^2-48K^{1/3}cT_{TDC}a_0b)}{K^{1/3}cT_{TDC}a_0b}$$

and

$$K=d^2(-144c^3T_{TDC}^3Ibd^2-108cT_{TDC}d^2I^2a_0^2-576cT_{TDC}I^3a_0^2b-108c^2T_{TDC}^2a_0d^3I+576c^2T_{TDC}^2a_odI^2b+27c^3T_{TDC}^3d^4+108cT_{TDC}d^2I^2tV-576cT_{TDC}I^3tVb)+(4I^2a_0^2-4dcT_{TDC}Ia_0+d^2c^2T_{TDC}^2+4I^2tV)\sqrt{3})\times$$

$$(\sqrt{128d^2I^2tV+128d^2I^2a_0^2+6912b^2c^2T_{TDC}^2I^2-2592Ibc^2d^2T_{TDC}^2-128d^3cT_{TDC}Ia_0+275d^4c^2T_{TDC}^2}$$

4.2.3 Value of information sharing

To compare the effect of information sharing on the profits of individual firms in this case, we use plots of the profit functions obtained for the firms in the two cases, as well as the total chain profits. The profit functions are plotted against customer sensitivity towards price (b). As before, the relative positions of the profit curves for a firm are indifferent to the drug considered. Following results are thus observed from the plots.

Result 8: For a pure investment sharing scenario, the total chain profit is greater when information is shared between the firms. (Fig 7)

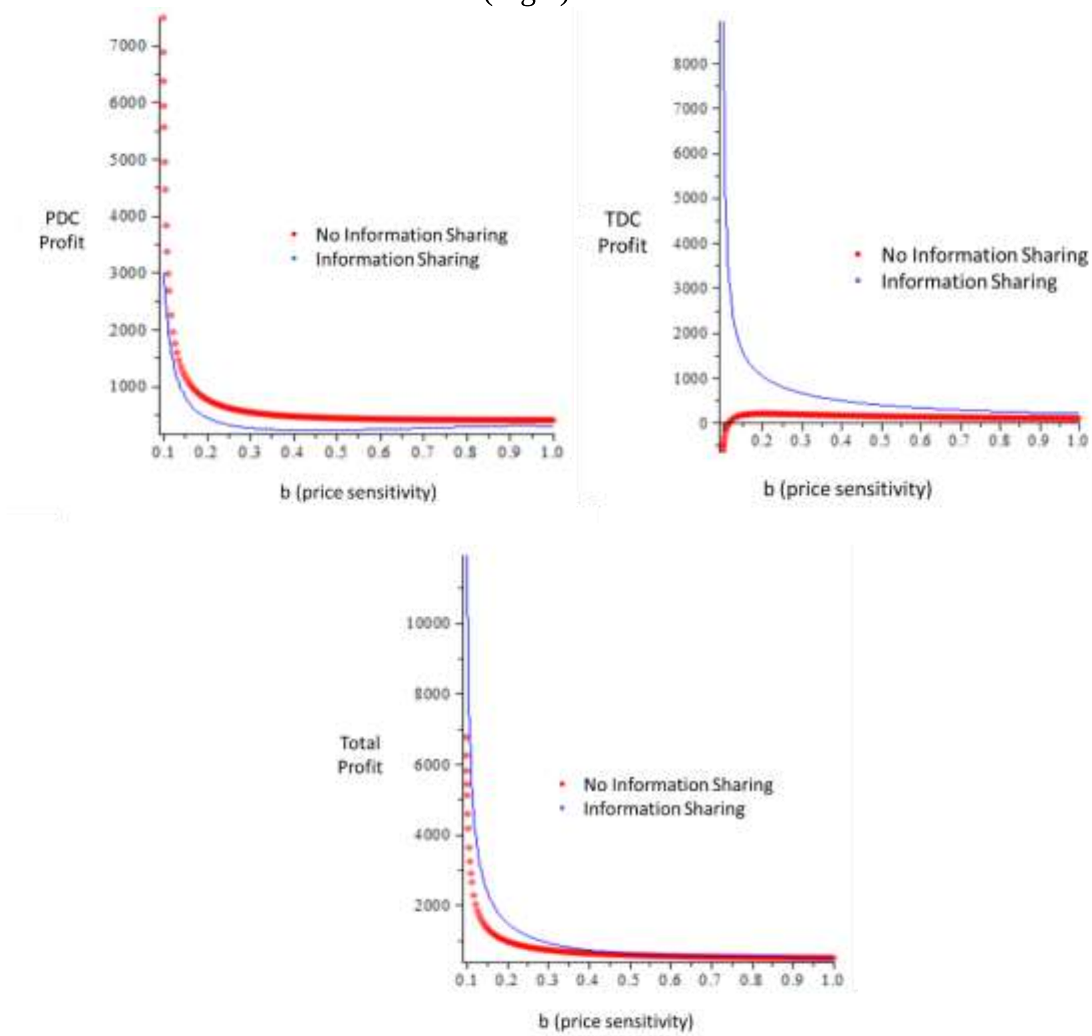

Figure 7: Comparison of profits with/without information sharing in pure investment sharing scenario (Brintellix)

As is evident from Fig 7, the profits for the PDC remain higher in the no-information sharing case while the opposite holds true for TDC. The decrease in the profits for PDC is however more than compensated by the increase in the profits for TDC in the information sharing case leading to overall higher profits for the supply chain when information is shared between the two firms. The analysis of this model hence suggests that the information sharing in the pure investment sharing scenario would lead to higher profits in the collaboration.

4.3 Pure Innovation Sharing Scenario

This scenario constitutes cases 5 and 7. The sequence of actions for this scenario is represented in Figure 8.

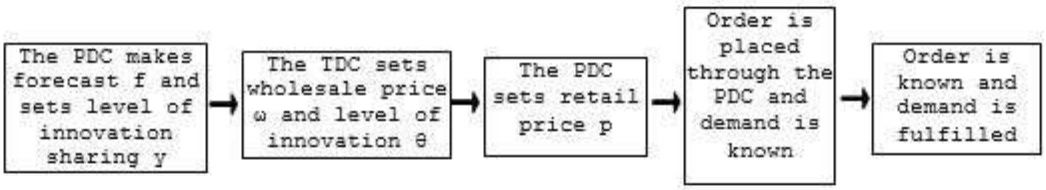

Figure 8: Sequence of actions in a pure innovation sharing scenario

We again try to derive the optimal retail price (p), wholesale price (ω), innovation level (θ) and profits in the two situations:
(1) when information is not shared by the firms; (2) when information is shared by the firms.

4.3.1 No Information Sharing

Here, both firms (PDC and TDC) maximize their profits as per equations 13 and 14. We can derive the optimal Stackelberg solution by deriving optimal p and using it to get optimal ω and θ. The following result holds.

Result 9: The forecast information (f) or the forecast accuracy (t) does not influence PDC's equilibrium contribution y in the investment sharing, in the no information sharing case in pure innovation sharing scenario.

Proof: Given the following values: sharing level y, wholesale price ω and innovation level θ, PDC determines the retail price (p) that maximizes its anticipated profit (equation 13). Using first order condition, we get

$$\frac{dE\left(\Pi_{PDC}^{NNI}\middle| f\right)}{dp} = E\left(a\middle| f\right) - 2bp + d\theta + b\omega = 0$$

As can be therefore seen the second order condition is negative, which implies that the profit function of the PDC is concave in p. We can obtain value of p as

$$p(\theta,\omega) = \frac{E\left(a\middle| f\right) + d\theta + b\omega}{2b}$$

The TDC forecasts the retail price of PDC as $E(p) = (a_0 + d\theta + b\omega)/(2b)$, in the absence of the forecast data. If this is substituted into the profit function of the TDC, we can obtain the optimal innovation level and wholesale price from the PDC's profit function which are given by

$$\omega^{NNI}(y) = \frac{2(2Ia_0 - dcT_{TDC} + dcT_{TDC}y - 4Iya_0 + 2y^2Ia_0)}{8bI - d^2 - 16Iyb + 8y^2Ib} \; ; \theta^{NNI}(y) = \frac{da_0 - 4bcT_{TDC} + 4bcT_{TDC}y}{8bI - d^2 - 16Iyb + 8y^2Ib} \quad (28)$$

Substituting these values from equation (28), we get the profit function of the PDC and TDC as given in Table 4.

Table 4: Optimal values for no information sharing case in a pure innovation sharing NPD strategy

Variable	Value
p^{NNI}	$\frac{\left(8bI-d^2-16Iyb+8y^2Ib\right)\left((1-t)a_0+tf\right)+a_0\left(d^2+4bI-8Iyb+4y^2Ib\right)-6dbcT_{TDC}+6bdcT_{TDC}y}{2b\left(8bI-d^2-16Iby+8y^2Ib\right)}$
ω^{NNI}	$\frac{2(2Ia_0-dcT_{TDC}+dcT_{TDC}y-4Iya_0+2y^2Ia_0)}{8bI-d^2-16Iyb+8y^2Ib}$
θ^{NNI}	$\frac{da_0-4bcT_{TDC}+4bcT_{TDC}y}{8bI-d^2-16Iyb+8y^2Ib}$
$E\Pi_{PDC}^{NNI}$	$\frac{(1-y)(-384y^2c^2b^3T_{PDC}T_{TDC}I-16yc^2T_{PDC}b^2T_{TDC}d^2)+(1+y^2)(-32ycT_{PDC}b^2a_0dI-16b^2dcT_{TDC}a_0I}{4(-d^2+8Ib-16Iyb+8y^2Ib)^2b}$ $\frac{-64y^2Ib^3c^2T_{TDC}^2+4b^2d^2c^2T_{TDC}^2-64a_0^2I^2b^2y-256b^2I^2ytV-16d^2ItVb)+(1-y^3)(128yc^2T_{PDC}b^3T_{TDC}I)}{4(-d^2+8Ib-16Iyb+8y^2Ib)^2b}$ $\frac{+(1+y^4)(64b^2I^2tV+16a_0^2I^2b^2)+4ycT_{PDC}ba_0d^3+48b^2dcT_{TDC}a_0I-16b^2dcT_{TDC}y^3a_0I}{4(-d^2+8Ib-16Iyb+8y^2Ib)^2b}$ $\frac{+64y^2cT_{PDC}b^2a_0dI+d^4tV+32d^2IytVb+384b^2I^2y^2tV-4a_0^2d^2y^2Ib-8b^2d^2c^2T_{TDC}^2y}{4(-d^2+8Ib-16Iyb+8y^2Ib)^2b}$ $\frac{+128y^3Ib^3c^2T_{TDC}^2+96a_0^2I^2b^2y^2}{4(-d^2+8Ib-16Iyb+8y^2Ib)^2b}$
$E\Pi_{TDC}^{NNI}$	$\frac{(1-y)(-2c^2T_{TDC}^2by-Iya_0^2+Ia_0^2+2c^2T_{TDC}^2b-dcT_{TDC}a_0)}{(-d^2+8Ib-16Iyb+8y^2Ib)}$

The value of *y* is provided in Appendix along with proof of these results.

This result thus shows that the PDC's equilibrium decision regarding its share in the innovation efforts remains unaffected by the variations of the demand forecast and also the accuracy in predicting the data. This can again be attributed to lack of information sharing with TDC leading to the equilibrium ω and θ being independent of f and t, causing equilibrium y to behave similarly.

4.3.2 Information Sharing

In this scenario, the PDC shares the market forecast data with the TDC before making any decisions. The PDC and the TDC maximize their profit functions as given in equations 17 and 18. We show that the following result holds.

Result 10: Table 5 enlists the Bayesian Stackelberg optimal parameters and the expected profits for both the firms with information sharing in pure innovation sharing scenario at the equilibrium. Equilibrium constant in investment sharing y, wholesale price ω and innovation level θ are dependent on the forecast level and accuracy

Table 5: Optimal values for information sharing case in a pure innovation sharing NPD strategy

Variable	Value
p^{INI}	$\frac{3(1-y)\ (2I\left((1-t)a_0+tf\right)-dcT_{TDC}-2Iy\left((1-t)a_0+tf\right))}{\left(8bI-d^2-16Iby+8y^2Ib\right)}$
ω^{INI}	$\frac{2(2Ia_0-dcT_{TDC}+dcT_{TDC}y-4Iy\left((1-t)a_0+tf\right)+2y^2I\left((1-t)a_0+tf\right))}{8bI-d^2-16Iyb+8y^2Ib}$
θ^{INI}	$\frac{d\left((1-t)a_0+tf\right)-4bcT_{TDC}+4bcT_{TDC}y}{8bI-d^2-16Iyb+8y^2Ib}$
$E\Pi_{PDC}^{INI}$	$\frac{(1-y)(-4yc^2bT_{PDC}T_{TDC}d^2-96y^2c^2T_{PDC}b^2T_{TDC}I)+(1+y^2)(-16bI^2ytV-4bdcT_{TDC}a_0I}{(-d^2+8Ib-16Iyb+8y^2Ib)^2}$ $\frac{-16y^2Ib^2c^2T_{TDC}^2-8ycT_{PDC}dIba_0-16bI^2ya_0^2+bd^2c^2T_{TDC}^2)+(1-y^3)(32yc^2T_{PDC}T_{TDC}b^2I)}{4(-d^2+8Ib-16Iyb+8y^2Ib)^2b}$ $\frac{+(1+y^4)(4bI^2tV+4bI^2a_0^2)+(tV+z^2)(24bI^2y^2-y^2Id^2)+ycT_{PDC}d^3a_0+12bdcT_{TDC}Iya_0}{(-d^2+8Ib-16Iyb+8y^2Ib)^2}$ $\frac{-2bd^2c^2T_{TDC}^2y+32y^3Ib^2c^2T_{TDC}^2-4bdcT_{TDC}y^3Ia_0+16y^2cT_{PDC}dIba_0}{4(-d^2+8Ib-16Iyb+8y^2Ib)^2b}$
$E\Pi_{TDC}^{INI}$	$\frac{(1-y)(-2c^2T_{TDC}^2by-Iy\left((1-t)a_0+tf\right)^2+I\left((1-t)a_0+tf\right)\ +2c^2T_{TDC}^2b-dcT_{TDC}\left((1-t)a_0+tf\right))}{(-d^2+8Ib-16Iyb+8y^2Ib)}$

The value of *y* is provided in Appendix along with proof of these results.

4.3.3 Value of information sharing

To compare the effect of information sharing on the profits of individual firms, the plots of the profit functions obtained for the firms in the two cases, as well as the total chain profits are studied. Fig 9 below represents the profit function plots against customer sensitivity towards price (b) for the drug Brintellix. Parameters corresponding to the different drugs cause no change in the relative position of profits in the two cases.

Result 11: For a pure innovation sharing scenario, the total chain profit is greater when information is shared between the firms. (Fig 9)

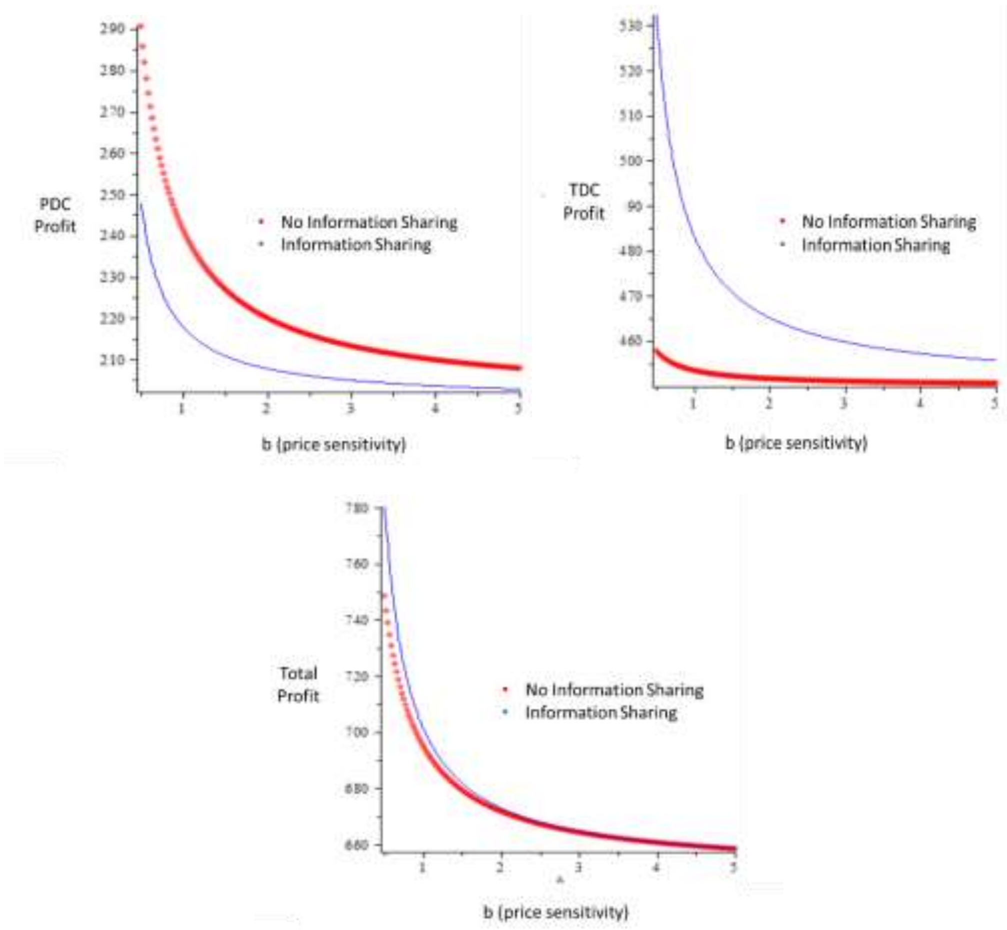

Figure 9: Comparison of profits with/without information sharing in pure innovation sharing scenario

As evident from Fig 9, the profit for PDC is greater in the no information sharing case while for the TDC it's greater for the information sharing scenario. The total chain profit is however greater when information is shared between PDC and TDC.

It is thus implied that in the pure innovation sharing scenario, information would be shared between the two firms so that the total profit for the supply chain be maximized.

4.4 Combined Investment & Innovation sharing scenario

This represents cases 6 and 8. The sequence of actions for this scenario is represented in Fig10.

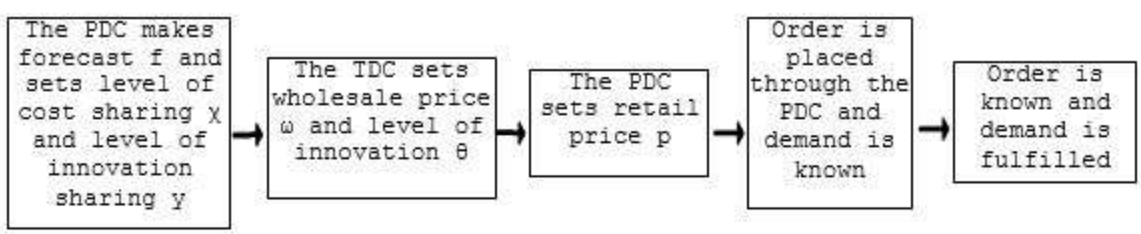

Figure 10: Sequence of actions in a combined investment-innovation sharing scenario

We derive the optimal retail price (p), innovation level (θ), wholesale price (ω) and profits in two situations: (1) when information is not shared by the firms; (2) when information is shared by the firms.

4.4.1 No Information Sharing

Here, both firms maximize their profits as per equations 15 and 16. Optimal solution by deriving optimal p followed by optimal ω and θ. (Proof provided in the Appendix)

Result 12: Table 6 provides the equilibrium Stackelberg retail price, innovation level and wholesale price with no information sharing in a combined investment and innovation sharing NPD scenario in a decentralized supply chain. As expected wholesale price ω and innovation level θ are independent of the forecast level and accuracy.

Table 6: Optimal values for no information sharing with combined investment-innovation sharing

Variable	Value
p^{NCI}	$\dfrac{(1-\chi)(-4Ib\,(1-2y)(2((1-t)a_0+tf)+z)-6dcT_{TDC}(1-y))-4by^2I(2((1-t)a_0+tf)+a_0)+d^2(((1-t)a_0+tf)-a_0)}{2b\left(d^2-8bI+8xIb+16Iby-8y^2Ib+8y^2\chi Ib\right)}$
ω^{NCI}	$\dfrac{2\,(1-y)\,(1-\chi)\,(2Iya_0+dcT_{TDC}-2Ia_0)}{d^2-8bI+8\chi Ib+16Iyb-16I\chi yb-8y^2Ib+8Ib\chi y^2}$
θ^{NCI}	$\dfrac{4bcT_{TDC}-a_0d-4bcT_{TDC}\chi-4bcT_{TDC}y+4bcT_{TDC}\chi y}{d^2-8bI+8\chi Ib+16Iyb-16I\chi yb-8y^2Ib+8Ib\chi y^2}$

4.4.2 Information Sharing

In this scenario, the PDC shares the market forecast data with the TDC before making any decisions. The PDC and the TDC maximize their profit functions as given in equations 19 and 20.

Result 13: Table 7 gives the Stackelberg retail price, innovation level and wholesale price with information sharing in a combined investment and innovation sharing NPD scenario in a decentralized supply chain at the equilibrium. Wholesale price ω and innovation level θ are dependent on the forecast level and accuracy.

Table 7: Optimal values for information sharing case with combined investment-innovation sharing

Variable	Value

p^{ICI}	$\dfrac{3(1-\chi)(1-y)(2\left((1-t)a_0+tf\right)Iy+dcT_{TDC}-2\left((1-t)a_0+tf\right)I)}{\left(d^2-8bI+8xIb+16Iby-8y^2Ib+8y^2\chi Ib\right)}$
ω^{ICI}	$\dfrac{2\ (1-y)\ (1-\chi)\ (2Iy\left((1-t)a_0+tf\right)+dcT_{TDC}-2I\left((1-t)a_0+tf\right))}{d^2-8bI+8\chi Ib+16Iyb-16I\chi yb-8y^2Ib+8Ib\chi y^2}$
θ^{ICI}	$\dfrac{4bcT_{TDC}-\left((1-t)a_0+tf\right)d-4bcT_{TDC}\chi-4bcT_{TDC}y+4bcT_{TDC}\chi y}{d^2-8bI+8\chi Ib+16Iyb-16I\chi yb-8y^2Ib+8Ib\chi y^2}$

4.3.3 Value of information sharing

To compare the effect of information sharing on the profits of individual firms, we consider the profit functions for the firms obtained for the two cases, as well as the total chain profit. The profit functions in this case, however give plots whose relative positions differ highly with parameters corresponding to different drugs. It may be thus inferred from above, that the value of information sharing in case of a collaborative investment and innovation sharing is prominently dependent on the drug under consideration and seems to vary across different cases rendering it inappropriate to conclude in general of the value of information sharing.

Result 14: For a collaborative investment and innovation sharing scenario, the total chain profits vary depending on the parameter values according to which the total chain profit in the information sharing case may either be greater or lesser relative to when information is not shared between the firms.

The collaborative investment and innovation sharing scenario thus would require some additional analysis and cautious consideration as the effect of information sharing varies greatly with the particular product being considered.

5. Managerial Implications

Through analyzing the model of a collaborative NPD so developed, we notice that in the non-collaborative case with no information sharing (scenario 1), the expected equilibrium profit of the TDC (as well as ω and θ) is independent of the accuracy of the market demand forecast, while that of the PDC increases proportionately (result 2). This would cause the managers at PDC to essentially invest to improve their forecast accuracy, as it leads to a definite increase in the profits for the PDC with no corresponding increase in the wholesale price ω by TDC. However, the expected equilibrium profits for both the PDC and the TDC (along with ω and θ) are increasing functions of the accuracy of the market forecast in the information sharing situation.

We further derive that in the no collaboration scenario (result 5), the level of innovation input by the TDC is greater in the information sharing case, when PDC is optimistic about the market demand. However, opposite is true when the PDC demand forecast is lower than the base demand a_0. This would cause the managers at the PDC to be willing to share the forecast information with their counterparts at TDC when they are optimistic about it, but will prefer not sharing it otherwise, so as to achieve higher levels of innovation in the product.

Also, we find that for the pure investment sharing scenario (scenario 2), sharing forecast information with the TDC decreases the individual profits of PDC but increases the profit of the supply chain as a whole (result 8). The managers at the PDC in such situation would still choose to share the information with TDC, as the increased profits of supply chain (TDC in particular) could be reinvested to further improve the level of innovation and would be beneficial for the collaboration in the long run. The pure innovation sharing scenario (scenario 3) provides similar results where managers at the PDC would be motivated to share the market forecast information with the TDC.

For the combined investment-innovation scenario (scenario 4), sharing market forecast information with the TDC provided varying results depending on the drug under consideration. Hence such a scenario doesn't yield generalized results with respect to the value of information sharing and would require further deliberation on part of the managers.

6. Conclusion

Literature on new product development has focused on the level of NPD for a single firm or collaborative NPD between two firms, but ignores the role and the impact of information sharing in the collaborative new product development process. In this paper, we analytically study the effects of sharing demand forecast information on a NPD supply chain in the pharmaceutical industry, consisting of two firms- Technology Development Company and Product Development Company, based on a Stackelberg game model developed.

The paper broadly enlists all the possible ways in which the two firms can collaborate to participate in a new product development process. For each relationship, we analyze in depth how the PDC and TDC would handle demand forecast data based on the type of their collaboration, market demand & customer sensitivities, and subsequently arrive at the equilibrium prices and the level of innovation. Further, we arrive at the detailed quantitative solutions for each of the above parameters in the eight possible scenarios and also try to graphically depict the variation of profit functions of the two firms in these scenarios.

The research from this paper can readily be extended to other industries with suitable modifications to the demand and pricing functions. Another stream of research could deal with the sharing of information besides that of demand forecast and their subsequent effects on the collaboration and the price levels and innovation level. The research in the paper attempts to analyze quantitatively (through Stackelberg game model) and qualitatively (through its managerial implications) the effect of forecast information sharing in a joint new product development process in the pharmaceutical industry; and could ably serve as the framework for further research in collaborative new product development.

7. Appendix

Proof for Result 1:

We can find the optimal decisions of PDC and TDC by backward induction. Firstly, given wholesale price ω and innovation level θ, the PDC determines retail price p that maximizes equation (4). The first order condition (FOC) is

$$\frac{dE\left(\Pi_{PDC}^{NNN}\middle| f\right)}{dp} = E\left(a\middle| f\right) - 2bp + d\theta + b\omega = 0 \qquad \text{(A1)}$$

where $E\left(a\middle| f\right) = (1-t)a_0 + tf$. Note that $(1-t)a_0 + tf$ captures a consensus prediction of the total market potential using PDC's information and the prior information (a_0). The second-order condition is negative and hence the profit function of the PDC is concave in p. We can obtain

$$p(\theta,\omega) = \frac{E\left(a\middle| f\right) + d\theta + b\omega}{2b} \qquad \text{(A2)}$$

The TDC forecasts the retail price of the PDC as $E(p) = (a_0 + d\theta + b\omega)/(2b)$ when the PDC doesn't share its forecast with the TDC. Substituting this into the profit function of the TDC, we can solve for the optimal innovation level and wholesale price from PDC's profit function which are respectively

$$\omega^{NNN} = \frac{4Ia_0 - 2dcT_{TDC}}{8bI - d^2}\, ; \theta^{NNN} = \frac{da_0 - 4bcT_{TDC}}{8bI - d^2} \qquad \text{(A3)}$$

We need $8bI - d^2 > 0$ in order that the profit function in decentralized supply is jointly concave in ω and θ. Substituting these back into equation (A1), we get the optimal retail price is

$$p^{NNN} = \frac{\left(8bI - d^2\right)\left((1-t)a_0 + tf\right) + a_0\left(d^2 + 4bI\right) - 6dbcT_{TDC}}{2b\left(8bI - d^2\right)} \qquad \text{(A4)}$$

Substituting equations (A3) and (A4) into the profit functions of the PDC, the TDC and supply chain, we get the optimal expected profits of the PDC, the TDC and supply chain are given in table 1.

Proof for Result 2:

Differentiating $E\Pi_{PDC}^{NNN}$ and $E\Pi_{TDC}^{NNN}$ with respect to t, we get $\partial E\Pi_{PDC}^{NNN} / \partial t > 0$ and $\partial E\Pi_{TDC}^{NNN} / \partial t = 0$.

Proof for Result 3:

We can find the optimal decisions of the PDC and the TDC similarly by backward induction. The optimal response function is given by equation (A2). The TDC forecasts the retail price of the PDC is $E\left(p\middle| f\right) = \left(E\left(a\middle| f\right) + d\theta + b\omega\right)/(2b)$, where $E\left(a\middle| f\right) = (1-t)a_0 + tf$, when the PDC shares his forecast with the TDC. Substituting this into the profit function of the TDC, we can solve for the optimal innovation level and wholesale price from the PDC's profit function are given in table 2.

Proof for Result 4

This can be inferred directly from equations 24 and 25.

Proof for Result 5

This can be inferred directly from the values of p, ω and θ provided in tables 1 and 2.

Proof for Result 7

The optimal decisions for the information sharing case can be found similarly as in Result 6. TDC in this case forecasts the retail price as $E(p|f)=\left(E(a|f)+d\theta+b\omega\right)/(2b)$ where $E(a|f)=(1-t)a_0+tf$. On substituting into TDC's profit function, we can solve for the optimal innovation level and wholesale price. We use these to subsequently arrive at profit function values as given in table 3.

Proof for Result 8

This is found using the profit functions derived for the PDC and the TDC for the no information sharing and information sharing case and plotted using the values a_0=30, d=1, I=2, T_{TDC}=3, V=10, c=20, t=0.7, T_{PDC}=2.

Proof for Result 9

y is a root of the equation :

$$
\begin{aligned}
&((32b^2dcT_{TDC}a_0I^2+64cT_{PDC}b^2a_0dI^2+256c^2T_{PDC}b^3T_{TDC}I^2+256I^2b^3c^2T_{TDC}^2)y^4+(48b^2d^2c^2T_{TDC}^2I\\
&-128cT_{PDC}b^2a_0dI^2-768I^2b^3c^2T_{TDC}^2+128b^2dcT_{TDC}a_0I^2+64c^2T_{PDC}b^2T_{TDC}d^2I-1024c^2T_{PDC}b^3T_{TDC}I^2)y^3+(12bd^3cT_{TDC}a_0I\\
&-48b^2d^2c^2T_{TDC}^2I+1536c^2T_{PDC}b^3T_{TDC}I^2-192c^2T_{PDC}b^2T_{TDC}d^2I+48a_0^2I^2bd^2+768I^2b^3c^2T_{TDC}^2-384b^2dcT_{TDC}a_0I^2)y^2\\
&+((-8c^2T_{PDC}bT_{TDC}d^4+128cT_{PDC}b^2a_0dI^2+8bd^3cT_{TDC}a_0I-64a_0^2I^2bd^2+256b^2dcT_{TDC}a_0I^2-256I^2b^3c^2T_{TDC}^2\\
&-1024c^2T_{PDC}b^3T_{TDC}I^2+2a_0^2d^4I-16cT_{PDC}ba_0d^3I-2bd^4c^2T_{TDC}^2-16b^2d^2c^2T_{TDC}^2I+192c^2T_{PDC}b^2T_{TDC}d^2I)y+16\,b^2d^2c^2T_{TDC}^2I\\
&+16cT_{PDC}ba_0d^3I-12bd^3cT_{TDC}a_0I-32b^2dcT_{TDC}a_0I^2-64c^2T_{PDC}b^2T_{TDC}d^2I+2bd^4c^2T_{TDC}^2+4c^2T_{PDC}bT_{TDC}d^4\\
&+256c^2T_{PDC}b^3T_{TDC}I^2-cT_{PDC}a_0d^5-64cT_{PDC}b^2a_0dk^2+16a_0^2I^2bd^2)=0
\end{aligned}
$$

This is found using the profit functions derived for the PDC and the TDC for the no information sharing and information sharing case and plotted using the values a_0=30, d=1, I=2, T_{TDC}=3, V=10, c=20, t=0.7, T_{PDC}=2.

Proof for Result 10

y is a root of the equation:

$$
\begin{aligned}
&((256I^2b^3c^2T_{TDC}^2+256c^2T_{PDC}b^3T_{TDC}I^2+64cT_{PDC}dI^2b^2a_0+32I^2b^2dcT_{TDC}a_0)y^4+(48b^2d^2c^2T_{TDC}^2I\\
&-768I^2b^3c^2T_{TDC}^2+64c^2T_{PDC}b^2T_{TDC}d^2I+128b^2dcT_{TDC}a_0I^2-128cT_{PDC}dI^2b^2a_0-1024c^2T_{PDC}b^3T_{TDC}I^2)y^3\\
&+(48bI^2tVd^2-384b^2dcT_{TDC}a_0I^2+768I^2b^3c^2T_{TDC}^2-192c^2T_{PDC}b^2T_{TDC}d^2I-48Ib^2d^2c^2T_{TDC}^2+\\
&48ba_0^2I^2d^2+1536c^2T_{PDC}b^3T_{TDC}I^2+12bd^3cT_{TDC}a_0I)y^2+((128cT_{PDC}dI^2b^2a_0+2Ia_0^2d^4\\
&+8bd^3cT_{TDC}a_0I-16cT_{PDC}bd^3a_0I-64bI^2a_0^2d^2-256I^2b^3c^2T_{TDC}^2-2bd^4c^2T_{TDC}^2-8c^2T_{PDC}bT_{TDC}d^4\\
&+2Id^4tV+192c^2T_{PDC}b^2T_{TDC}d^2I-1024c^2T_{PDC}b^3T_{TDC}I^2+256b^2dcT_{TDC}a_0I^2-16b^2d^2c^2T_{TDC}^2I-64bI^2t^2Vd^2)y\\
&+2bd^4c^2T_{TDC}^2+16Ib^2d^2c^2T_{TDC}^2-cT_{PDC}a_0d^5+16bI^2a_0^2d^2-32I^2b^2dcT_{TDC}a_0+16cT_{PDC}d^3ba_0I+16bI^2tVd^2\\
&+256c^2T_{PDC}b^3T_{TDC}I^2-12bd^3cT_{TDC}a_0I-64cT_{PDC}b^2a_0dk^2-64c^2T_{PDC}b^2T_{TDC}d^2I+4c^2T_{PDC}bT_{TDC}d^4)=0
\end{aligned}
$$

The optimal decisions for the information sharing case can be found similarly as in Result 9. TDC in this case forecasts the retail price as $E(p|f)=\left(E(a|f)+d\theta+b\omega\right)/(2b)$ where $E(a|f)=(1-t)a_0+tf$. Substituting this into the profit function for TDC, we solve for the optimal innovation level and wholesale price, which yields values of profit functions as given in table 5.

Proof for Result 11

This is found using the profit functions derived for the PDC and the TDC for the no information sharing and information sharing case and plotted using the values a_0=30, d=1, I=2, T_{TDC}=3, V=10, c=20, t=0.7, T_{PDC}=2.

Proof for Result 12

Given the innovation sharing level y and investment sharing level x, wholesale price ω and innovation level θ, the PDC determines the retail price (p) that maximizes its anticipated profit (equation 15) which yields

$$p(\theta,\omega)=\frac{E(a|f)+d\theta+b\omega}{2b}$$

The TDC forecasts the retail price of PDC as $E(p) = (a_0+d\theta+b\omega)/(2b)$, in the absence of the forecast data. When this value is substituted into the profit function of the TDC, we obtain the optimal innovation level and wholesale price from the PDC's profit function.

Substituting these into the profit function of the PDC in equation (15), we get

$$E\left(\Pi_{PDC}^{NCI}\middle| f\right)=E(((p-\omega)(a-bp+d\theta)-I(y\theta)^2-cy\theta T_{PDC}-\chi I((1-y)\theta)^2-\chi c(1-y)\theta T_{TDC})\,|\,f)\quad \text{(A5)}$$

From the FOC, we obtain the value of optimal sharing level y and ϰ.

Proof for Result 13

The optimal decisions for the information sharing case can be found similarly as in Result 12. The only difference that the TDC in this case forecasts the retail price as $E(p|f)=\left(E(a|f)+d\theta+b\omega\right)/(2b)$. Substituting this into the profit function for TDC, we can solve for the optimal innovation level and wholesale price from the PDC's profit function A5, and are given in table 7.

Proof for Result 14

Given the innovation sharing level y and investment sharing level x, wholesale price ω and innovation level θ, the PDC determines the retail price (p) that maximizes its anticipated profit (equation 15) which yields

$$p(\theta,\omega)=\frac{E(a|f)+d\theta+b\omega}{2b}$$

The TDC forecasts the retail price of PDC as E(p) = (a_0+dθ+bω)/(2b), in the absence of the forecast data. When this value is substituted into the profit function of the TDC, we obtain the optimal innovation level and wholesale price from the PDC's profit function.

Substituting these into the profit function of the PDC in equation (15), we get

$$E\left(\Pi_{PDC}^{NCI}\middle| f\right)=E\left(((p-\omega)(a-bp+d\theta)-I(y\theta)^2-cy\theta T_{PDC}-\chi I((1-y)\theta)^2-\chi c(1-y)\theta T_{TDC})\middle| f\right)$$

From the FOC, we obtain the value of optimal sharing level y and x

Proof for Result 15

The optimal decisions for the information sharing case can be found similarly as in Result 14. The TDC in this case forecasts the retail price as $E(p|f)=\left(E(a|f)+d\theta+b\omega\right)/(2b)$. Substituting this into the profit function for TDC, we can solve for the optimal innovation level and wholesale price from the PDC's profit function are given in table 7.

Proof for Result 16

This is found using the profit functions derived for the PDC and the TDC for the no information sharing and information sharing case and plotted using the values a_0=30, d=1, I=2, T_{TDC}=3, V=10, c=20, t=0.7, T_{PDC}=2.

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