THREE ESSAYS ON STRATEGIC ASPECTS IN OLIGOPOLY WITH VERTICAL STRUCTURE

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I would like to dedicate this dissertation to my family, especially my beloved mother, Ziba (in Persian it means *beautiful*, and she is really beautiful!) for her inspiration and emotional support in every second of my life. I would like also to thank my girlfriend, Haleh, for her patience and encouragement during the period of my research.

Contents

List of Tables

List of Figures

Chapter 1

Chapter 2

Chapter 3

General Introduction

Thus, what is of supreme importance in war is to attack the enemy's strategy.
(Sun Tzu, *The Art of War* (490 B.C.))

Capitalism, regardless of its advantages and disadvantages, relies on a significant pillar that is competitive markets. This economic system provides equal opportunities for all the potential players to enter the market, supply their products and services to the customers who passionate to maximize their utility. There, they may not be alone and should compete with some other rivals that have also found this market attractive. Nowadays it has transformed to a serious war, war of price, quality, quantity, innovation, wage and etc. Hence, firms must equip themselves with effective weapons, and one of the most significant tools is strategic thinking. Doing all the ordinary courses of business considering the analogous action and reaction of the competitors, and try to set its strategy based on this thinking model. Thus, firms' strategy must be strategic. According to Michael Porter, strategy is making choices and trade-offs such as quantity choice, technology choice, capacity investment choice, R&D intensity choice and several other choices. The point is to consider that in the presence of competitors that are also strategic thinkers like us, rules of the competitive market determine the optimal amount of these choices and consequent profits.

This dissertation contains of three independent papers which are approached to capture some strategic aspects in oligopoly with vertical structure. We focus on oligopolistic market structure in which few firms dominate. Firms are completely or partially aware of the actions of their rivals. Decisions of firms in this context affect, and are affected by decisions of other players. Offering *homogeneous* final products to the customers is the main assumption in our models. Cell phone, Film, Gas, Steel and several other examples can be mentioned as actual oligopolistic industries. To model our oligopolistic markets we choose Cournot, *the model which assumes that there are two equally positioned firms; the firms compete on the basis of quantity rather than price and each firm makes an output decision assuming that the other firm's behavior is fixed*. (Kreps, 1990)

To model demand, we employ linear inverse demand function. This demand model represents a consumer choice in which he maximizes a quadratic, strictly concave utility function. In chapter 2 and 3 our market characterized by demand uncertainty, that is occurs in the intercepts of the inverse demand function. In chapter 1, we face with deterministic demand. Game theoretic (static or dynamic – with complete or incomplete information) models are applied to formally plot the sequence of events in each essay. Incentives of players in each model are tried to capture interesting topics of industrial organization, from R&D, knowledge spillover and firm location in chapter 1 to capacity investment decision and technology choice of firms in chapter 2 and finally, information sharing and quantity ordering choice of corporations in chapter 3. All the players are assumed to be risk-neutral and try to maximize their own profit.

The paper "The Effect of Vertical Knowledge Spillovers via the Supply Chain on Location Decision of Firms" which will be discussed in chapter 1 was published in the special issue of *Journal of Business and Policy Research*, April 2012 (*JBPR*, Vol. 7, No. 1). In this research a three-stage game of complete information is employed to model the incentives of two producers and two suppliers of two vertically-structured supply chains considering two different geographical regions, to investigate how the location decision of a producer is influenced by the location patterns of suppliers in the presence of vertical and horizontal knowledge spillovers. Strategic location choice of a producer between geographical *concentration* and *isolation* in equilibrium is the main interest of this essay. Numerical analysis expresses that both scenario (concentration and isolation) is possible depending on the range of model's parameters. Moreover, the impact of different technological level of players on strategic location decisions will be explained.

In chapter 2 the paper “The Effect of Salvage Market on Strategic Technology Choice and Capacity Investment Decision of Firm under Demand Uncertainty” is forthcoming in the *Journal of Business Economics and Management* in 2012. In this essay a multi-stage game with complete information is applied to model three strategic decisions of two competing producers in the presence of a secondary market (we call it salvage market). Technology choice (flexible and inflexible), capacity investment choice (general, specific and unified components) and quantity choice (Cournot competition) are three games which will be sequentially played by producers. Primary market of the model is characterized with demand uncertainty. Indeed this chapter deals with the choice of the flexibility of the production process of an oligopolistic producer facing uncertain demand. The trade-off studied is one between a flexible production process involving the production of generally usable components which are assembled after the size of the demand is known, and a less flexible but less costly production process, where specific products are produced and put on stock. The new feature of the paper compared to the literature is that the strategic effects on competitors in the market of these two choices are taken into account in the analysis.

The paper “Supply Chain Configuration under Information Sharing” in chapter 3 is submitted to the *Journal of Business Economics and Management*. A dynamic multi-stage game with incomplete information (a signaling game) is employed to analytically model the incentives of firm’s to acquire, share and leak demand information, and their impact on order quantities and the configuration of supply chain(s). Private information about market demand is the source of asymmetry between two producers (the incumbent and the entrant), which could be leaked via a common supplier. Trade-off between operation management and information management defines the potential interaction of the players which could result in different supply chain scheme.

Chapter 1

Firm Location and Knowledge Spillovers

In this essay a game theoretic model is employed to analyze the relationship between strategic location decision of firms in the supply chain considering the role of horizontal and vertical knowledge spillovers, and numerical approach is applied to characterize the equilibria of the considered multi-stage game. Geographical concentration or isolation as equilibrium outcome is determined based on our different parameterizations and two scenarios each consists of two separated cases, which we establish according to the location of our agents. In the first scenario both suppliers are supposed to be located in different regions while in the second one they act in a same region. In addition, first case of each scenario considers geographical isolation of two producers whereas second case investigates the geographical concentration. Furthermore, the effect of different technological level of our agents on their final location decision is investigated.

1. Introduction

"*Everything is related to everything else, but near things are more related than distant things*." (Waldo Tobler) The importance of location decision of firms and its consequent effect on knowledge spillovers and innovation intensity of even whole industry has been emphasized in recent studies. "*Innovation has become the defining challenge of global competitiveness; to manage it well, companies must harness the power of location in creating and commercializing new ideas"*. (Porter and Stern, 2001, pp. 28) Clusters as geographical concentration of interconnected companies and institutions in a particular filed (See Porter 1998), is an interesting concept appears in economic geography and innovation literature. "*What happens inside companies is important, but clusters reveal that the immediate business environment outside companies plays a vital role as well. This role of location has been long overlooked, despite striking evidence that innovation and competitive success in so many fields are geographically concentrated – whether it's entertainment in Hollywood, finance on Wall Street or consumer electronics in Japan"*. (Porter, 1998, pp. 78)

Furthermore recent empirical evidence shows that cost considerations have obtained significant attention relative to market entry and are concerned recently in many cases the main factor affecting firms' location decisions. (See Kinkel and Lay, 2004) Beside factor costs and entry into new markets, some other relevant arguments including availability of skilled labor, the local institutional environment, the size or economic importance of a region in relation to the expected intensity of competition or the possibility to improve production due to technological spillovers from other firms or research institute in the local proximity can affect the location decision of firms.

In this chapter a different viewpoint to location decision of firms in the presence of knowledge spillovers is applied. Actually strategic location decision of producers with respect to technological activities of their respected suppliers in a framework of supply chain is examined, which has been studied rarely in literatures. (See Ishii, 2004) Indeed the role of vertical knowledge spillovers between producer and supplier via supply chain is highlighted and distinguished from horizontal knowledge spillovers which occur between two firms from same stream of a market. Here we are eager to respond the question that under which circumstances vertical knowledge spillovers via supply chain lead to geographical concentration.

In this research we try to bind economic geography concepts like isolation or concentration of firms with knowledge spillover context which has origin in R&D literatures which has not done independently and numerically in previous literature. For this purpose a three-stage game theoretic model is established as in the first stage, our economic agents including two suppliers and their respected producers locate in two geographically different regions based on the framework of our model, then in the second stage they invest on R&D activities in the form of marginal cost reduction and finally in the third stage they compete on the amount of output they will produce strategically via Cournot market structure.

2. Literature Review

Several studies have been done so far in the appreciation of geographical concentration e.g. Krugman (1991) has mentioned three reasons for localization: first, the concentration of several firms in a single location offers a pooled market for workers with industry-specific skills, ensuring both a lower probability of unemployment and a lower probability of labor shortage; Second, localized industries can support the production of no tradable specialized inputs and third informational spillovers can give clustered firms a better production function than isolated producers.

Almazan, De Motta and Titman (2007) introduced a model which exhibits that the choice of locating within rather than away from industry clusters is influenced by the extent to which training costs are borne by firm versus employees. Moreover, the uncertainty about future productivity shocks and the ability of firms to modify the scale of their operations also influence location choice.

Moreover, several economists have investigated different aspects of investment on R&D activities e.g. Poyago-Theotoky (1991) established her static game theoretic model based on empirical evidence that the number of cooperative agreements in R&D has increased since 1980s. In her viewpoint R&D cooperation not only leads firm to engage in more R&D and thus produce more R&D output (in the form of cost reduction) but, in addition, has also the beneficial effect of making firms fully disclose their information. This kind of R&D cooperation is seen to improve own firm profitability and social welfare as it involves lower prices and higher total output relative to non-cooperation. She considered knowledge spillovers endogenously in her model.

Gersbach and Schmutzler (2003) endogenized technological spillovers with a new approach via static game theoretic model in which firms compete for knowledge by making wage offers to each other's R&D employees. They showed that incentives to acquire spillovers and incentives to prevent spillovers are stronger under quantity competition than under price competition.

D'Aspremont and Jacquemin (1988) investigated the effect of cooperation level of firms on social welfare considering duopoly market in the presence of knowledge spillovers. They considered two types of agreements in which in the first one companies share basic information and efforts in the R&D stage but remain rival in the marketplace while in the second case, extended collusion between partners, creating common policies at the product level.

Dawid and Wersching (2007) showed that because of competition effects, technological spillovers as a technological coordination device negatively affect the profits of cluster firms. Moreover Dawid, Greiner and Zou (2010) established a dynamic model of a firm which is deciding whether to outsource parts of its production to a less developed economy where wages and the level of technology are lower. Outsourcing reduces production costs but is associated with spillovers to foreign potential competitors which increase productivity of those firms over time and make them stronger competitor on the common market.

Considering all above mentioned outstanding studies in this filed, this paper focuses on the effects of vertical knowledge spillover between a supplier and its respected producer -which may appear in the form of some R&D cooperation agreements in order to eliminate duplication of R&D efforts- plus horizontal knowledge spillover between two firms of the same stream of the market -which compete with each other in the same marketplace- on the location decision of these agents which may result geographical concentration or isolation. It is often pointed out in the literature that the close relationships between final-good producer and its respected supplier are important for successful innovation efforts. (See von Hippel 1988; Riggs and von Hippel, 1994)

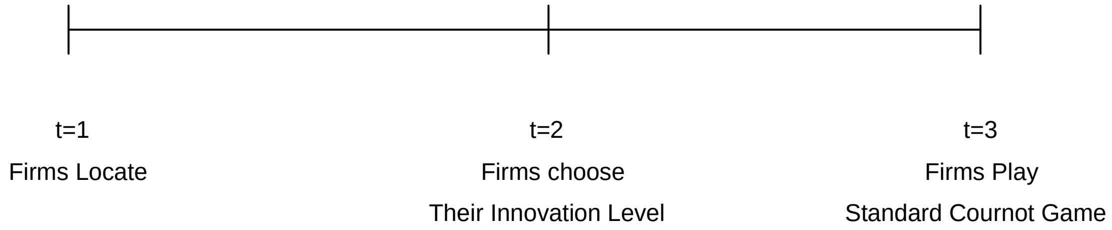
The rest of the chapter is organized as follows. In section 2, theoretical model and methodology is presented which will be analyzed in section 3 utilizing numerical approach. The last section concludes and points out possible extensions of the model as well as research limitations.

3. Model and Methodology

Consider an economy including two separated geographical regions $R_i, i = 1, 2$ but treated as one market. Four firms consisting of two suppliers and two producers from the same industry collaborate via their supply chain in the form that S_i is a supplier of just P_i with $i = 1, 2$. Without loss of generality we assume that upstream suppliers $S_i\,(i = 1, 2)$ produce homogeneous intermediate goods and downstream producers $P_i\,(i = 1, 2)$ produce homogeneous final goods respectively which one unit of intermediate good is required to produce exactly one unit of final good. We investigate two scenarios which in the first one both suppliers are located in the same region, say R_1, and in the other one suppliers act in different regions.

We utilize a three-stage static game with perfect information: In the first stage, firms locate in two regions R_i $(i = 1, 2)$ based on our abovementioned scenarios about suppliers; in the second stage, firms choose their cost-reducing R&D expenditure (Innovation level) X_i for producers and Y_i for suppliers ($i = 1, 2$); in the third stage vertical and horizontal knowledge spillovers exogenously take place given the formation of firms in two regions as well as their innovation efforts and firms compete on standard Cournot market structure to choose the amount of output they will produce strategically.

Figure 1: Sequence of Events



We define here vertical knowledge spillovers as knowledge spillovers between two firms of different stream (Supplier and Producer) via supply chain and can occur between two firms located in the same region β_r or between two firms of different regions β_t , but we assume that regional vertical knowledge spillovers are stronger than the trans-regional vertical one, so $\beta_r > \beta_t$. These exogenous parameters show the proportion of innovation efforts of a firm which might be absorbed by counterparty. Horizontal knowledge spillovers imply spillovers between two firms of a same stream (Two producers or two suppliers) and can happen only when both are located in the same region. We denote it with exogenous parameters $\tilde{\gamma}^p$ for producers and $\tilde{\gamma}^s$ for suppliers ($\tilde{\gamma}^p = \tilde{\gamma}^s = \gamma$ if exist). Moreover we assume that horizontal knowledge spillovers if exist are stronger than vertical one of both types since both producers act as same level firms in the same market, $0 \le \beta_t < \beta_r < \tilde{\gamma}^p = \tilde{\gamma}^s = \gamma \le 1$ (If $\tilde{\gamma}^p$, $\tilde{\gamma}^s$ or both exists). In this setting zero implies occurrence of no spillover and one implies perfect spillovers. Indeed the external effect of firm i's innovation effort is to decrease firm j's unit production cost.

Linear inverse demand function is utilized given by $P = a - bQ$ ($Q = q_1 + q_2$) and $a/b > 0$ shows the size of the market. $Q < a/b, b > 0$. The inverse demand function is useful in deriving the total and marginal revenue functions. Total revenue equals price P times quantity Q or $TR = P*Q = (a-bQ)*Q$. The marginal revenue function is the first derivative of the total revenue function with respect to Q, that is

$MR = a - 2bQ$. The importance of being able to simply calculate MR is that the profit-maximizing condition for firms regardless of market structure is to produce where marginal revenue equals marginal cost MC, that is $MR = MC$.

Our producers as well as our suppliers are supposed to have similar constant unit cost of transforming intermediate goods $\overline{C}_P, \overline{C}_S$ respectively. By innovation efforts in second stage, their unit cost of production is reduced by X_i for producers and Y_i for suppliers. ($i = 1, 2$)

We assume that intermediate goods are sold by suppliers to producers with constant price $\overline{P}$, e.g. based on some long-term contractual commitments. $0 < \overline{C}_P + \overline{P} < a$

Therefore, unit cost of production is of the form $C_i = \overline{C}_P - X_i - \beta_i Y_i - \gamma^p X_j + \overline{P}$ such that

$\beta_i = \begin{cases} \beta_r & \text{if } S_i \text{ and } P_i \text{ are in same region} \\ \beta_t & \text{if } S_i \text{ and } P_i \text{ are in different regions} \end{cases}$, $\gamma^p = \begin{cases} \tilde{\gamma}^p & \text{if } P_1 \text{ and } P_2 \text{ are in same region} \\ 0 & \text{if } P_1 \text{ and } P_2 \text{ are in different regions} \end{cases}$ and

$\gamma^s = \begin{cases} \tilde{\gamma}^s & \text{if } S_1 \text{ and } S_2 \text{ are in same region} \\ 0 & \text{if } S_1 \text{ and } S_2 \text{ are in different regions} \end{cases}$. $(i, j = 1, 2 \ ; \ X_i + \beta_i Y_i + \gamma^p X_j - \overline{P} \le \overline{C}_P)$

Following Qiu (1997), we assume that innovation costs are of the quadratic form $K(X_i) = v_{P_i}(X_i)^2, v_{P_i} > 0$ for producers and $K(Y_i) = v_{S_i}(Y_i)^2$, $v_{S_i} > 0$ for suppliers respectively ($i = 1, 2$) which implies diminishing returns in R&D.

Profit function of the producing firms $i = 1, 2$ will have the form of $\pi_i^p = (a - bQ)q_i - \left(\overline{C}_{P_i} - X_i - \beta_i Y_i - \gamma^p X_j + \overline{P}\right)q_i - v_{P_i}(X_i)^2$ and for suppliers we have $\pi_i^s = \overline{P}q_i - \left(\overline{C}_{S_i} - Y_i - \gamma^s Y_j - \beta_i X_i\right)q_i - v_{S_i}(Y_i)^2$.

Methodology: Whereas solving final equation systems involves sophisticated parametric calculations which make the comparison of final payoff functions almost impossible, numerical approach is applied afterwards. Mathematica will be employed to depict us the role of each parameter of our model as well as the sensitivity of these results upon parametrical changes.

We categorize our parameters into three groups including 1. Market parameters: $a, b, \overline{P}, \overline{C}$ 2. Knowledge spillovers parameter: β_r, β_t, γ and 3. Innovation cost parameter: ν

For the purpose of simplicity we establish three *assumptions* which we release some of them completely or partially afterwards:

Assumption 1: At the first stage of the game -which firms locate- our first producer (P1), first supplier (S1) and second supplier (S2) has chosen their location exogenously based on the framework of our model in section 3; So we are supposed to investigate the location decision of our second producer (P2) in order to answer our research question upon geographical concentration.

Assumption 2: All parameters are considered to be correspondingly homogeneous. Later we release this assumption with respect to innovation's cost parameter ν.

Assumptions 3: Innovation's cost of our producers is assumed to be infinity so they will not invest on any innovation effort: $X_{Pi}^{jk} = 0$ for $i, j, k = 1, 2$. We will relax this assumption completely afterwards.

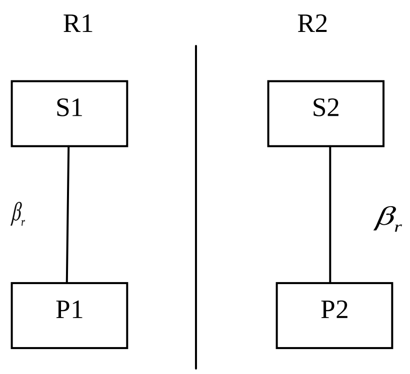
4. Analysis and Findings

In this chapter we analyze our model based on two scenarios which we have established on our model regarding the location decision of suppliers. Throughout we are going to find out the location decision of our producers and the postulated equilibrium. In fact we want to answer this question that under which circumstances knowledge spillovers via supply chain lead us to geographical concentration. Backward induction will be applied to find the SPE of our three-stage static game with perfect information. In each scenario, payoff function of both producers in two different cases will be analyzed parametrically; in the first case of each scenario we assume that both producers are located in different regions while in the second case geographical concentration of producers will be compared.

4.1. First Scenario: Two Suppliers are Located in Different Regions

In this scenario we assume that our suppliers have decided to locate in different regions, say R1 and R2. Consequently based on our model horizontal knowledge spillover between them will not appear in our calculations.

4.1.1. Case 1: Two Producers are Located in Different Regions



At t=3 producers play a standard Cournot duopoly game with the following payoff functions:

$$\pi_{P1}^{11} = (a - bq_{P1}^{11} - bq_{P2}^{11})q_{P1}^{11} - (\overline{C}_P - X_{P1}^{11} - \beta_r Y_{S1}^{11} + \overline{P})q_{P1}^{11} - \nu_{P1}^{11}\left(X_{P1}^{11}\right)^2$$

$$\pi_{P2}^{11} = (a - bq_{P1}^{11} - bq_{P2}^{11})q_{P2}^{11} - (\overline{C}_P - X_{P2}^{11} - \beta_r Y_{S2}^{11} + \overline{P})q_{P2}^{11} - \nu_{P2}^{11}\left(X_{P2}^{11}\right)^2$$

In this notation π_{P1}^{11} is the payoff function of the first producer in the first scenario as well as the first case respectively, for example π_{P2}^{12} shows the payoff of the second producer in the second case of the first scenario.

Finding out the optimal value of these payoff functions lead us to solving the following maximization problem:

$\max\limits_{q_{P1}^{11}} \pi_{P1}^{11}$ for the first producer and $\max\limits_{q_{P2}^{11}} \pi_{P2}^{11}$ for the second one.

By F.O.C. we have:

$$\frac{\partial \pi_{P1}^{11}}{\partial q_{P1}^{11}} = 0 \quad \text{and} \quad \frac{\partial \pi_{P2}^{11}}{\partial q_{P2}^{11}} = 0$$

Nash-Cournot quantities produced by both producers will be reached after some simple calculations,

$$q_{NC1}^{11} = \frac{a - \overline{C}_P + \beta_r (2Y_{S1}^{11} - Y_{S2}^{11}) + 2X_{P1}^{11} - X_{P2}^{11} - \overline{P}}{3b}$$

$$q_{NC2}^{11} = \frac{a - \overline{C}_P + \beta_r (2Y_{S2}^{11} - Y_{S1}^{11}) + 2X_{P2}^{11} - X_{P1}^{11} - \overline{P}}{3b}$$

Consequently optimal payoffs of our producers are:

$$\pi_{P1}^{*11} = \frac{[a - \overline{C}_P + \beta_r (2Y_{S2}^{11} - Y_{S1}^{11}) + 2X_{P2}^{11} - X_{P1}^{11} - \overline{P}]^2}{9b} - v_{P1}^{11} \left(X_{P1}^{11} \right)^2$$

$$\pi_{P2}^{*11} = \frac{[a - \overline{C}_P + \beta_r (2Y_{S1}^{11} - Y_{S2}^{11}) + 2X_{P1}^{11} - X_{P2}^{11} - \overline{P}]^2}{9b} - v_{P2}^{11} \left(X_{P2}^{11} \right)^2$$

At t=2 firms decide on their innovation level X_{Pi}^{11} and Y_{Sj}^{11} as well. $(i, j = 1, 2)$ Payoff functions of suppliers are as follow:

$$\pi_{S1}^{11} = \overline{P}.q_{NC1}^{11} - (\overline{C}_S - Y_{S1}^{11} - \beta_r X_{P1}^{11}) q_{NC1}^{11} - v_{S1}^{11} \left(Y_{S1}^{11} \right)^2$$

$$\pi_{S2}^{11} = \overline{P}.q_{NC2}^{11} - (\overline{C}_S - Y_{S2}^{11} - \beta_r X_{P2}^{11}) q_{NC2}^{11} - v_{S2}^{11} \left(Y_{S2}^{11} \right)^2$$

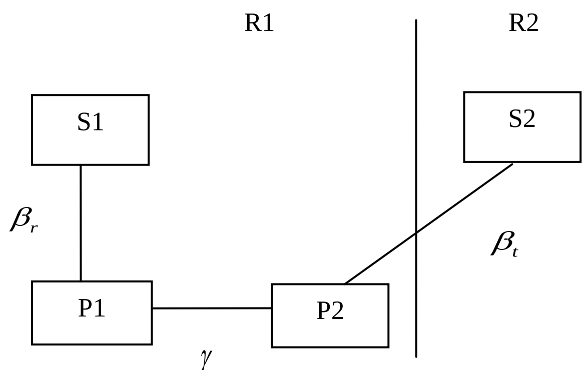
Optimal innovation level of each firm arises from solving four maximization problems strategically as one system; indeed each one is going to maximize its payoff function

as follow: $$\begin{cases} \max\limits_{X_{P1}^{11}} \pi_{P1}^{*11} \\ \max\limits_{X_{P2}^{11}} \pi_{P2}^{*11} \\ \max\limits_{Y_{S1}^{11}} \pi_{S1}^{11} \\ \max\limits_{Y_{S2}^{11}} \pi_{S2}^{11} \end{cases}$$

Subject to four following constraints respectively:

$$\begin{cases} 0 \le \overline{C}_P - X_{P1}^{11} - \beta_r Y_{S1}^{11} + \overline{P} \le a \\ 0 \le \overline{C}_P - X_{P2}^{11} - \beta_r Y_{S2}^{11} + \overline{P} \le a \\ 0 \le \overline{C}_S - Y_{S1}^{11} - \beta_r X_{P1}^{11} \le \overline{P} \\ 0 \le \overline{C}_S - Y_{S2}^{11} - \beta_r X_{P2}^{11} \le \overline{P} \end{cases}$$

4.1.2. Case 2: Two Producers are Located in Same Region



Geographical concentration of producers will be investigated by this case. Similarly, at t=3 producers play a standard Cournot duopoly game with the following payoff functions:

$$\pi_{P1}^{12} = (a - bq_{P1}^{12} - bq_{P2}^{12})q_{P1}^{12} - (\overline{C}_P - X_{P1}^{12} - \beta_r Y_{S1}^{12} - \gamma X_{P2}^{12} + \overline{P})q_{P1}^{12} - \nu_{P1}^{12}\left(X_{P1}^{12}\right)^2$$

$$\pi_{P2}^{12} = (a - bq_{P1}^{12} - bq_{P2}^{12})q_{P2}^{12} - (\overline{C}_P - X_{P2}^{12} - \beta_r Y_{S2}^{12} - \gamma X_{P1}^{12} + \overline{P})q_{P2}^{12} - \nu_{P2}^{12}\left(X_{P2}^{12}\right)^2$$

Maximization of these two payoff functions with respect to relevant quantities as we did in previous case give us Nash-Cournot quantities as follow:

$$q_{NC1}^{12} = \frac{a - \overline{C}_P + 2\beta_r Y_{S1}^{12} - \beta_t Y_{S2}^{12} + 2X_{P1}^{12} - (1-\gamma)X_{P2}^{12} - \overline{P}}{3b}$$

$$q_{NC2}^{12} = \frac{a - \overline{C}_P + 2\beta_r Y_{S2}^{12} - \beta_t Y_{S1}^{12} + 2X_{P2}^{12} - (1-\gamma)X_{P1}^{12} - \overline{P}}{3b}$$

Thus optimal values of our producers' payoff functions are as below:

$$\pi_{P1}^{*12} = \frac{[a - \overline{C}_P + 2\beta_r Y_{S1}^{12} - \beta_t Y_{S2}^{12} + 2X_{P1}^{12} - (1-\gamma) X_{P2}^{12} - \overline{P}]^2}{9b} - v_{P1}^{12}\left(X_{P1}^{12}\right)^2$$

$$\pi_{P2}^{*12} = \frac{[a - \overline{C}_P + 2\beta_r Y_{S2}^{12} - \beta_t Y_{S1}^{12} + 2X_{P2}^{12} - (1-\gamma) X_{P1}^{12} - \overline{P}]^2}{9b} - v_{P2}^{12}\left(X_{P2}^{12}\right)^2$$

Similarly proceeding backward, at t=2 firms decide on their optimal innovation level X_{Pi}^{12} and Y_{Sj}^{12} as well. $(i, j = 1, 2)$ Payoff functions of suppliers are as follow:

$$\pi_{S1}^{12} = \overline{P}.q_{NC1}^{12} - (\overline{C}_S - Y_{S1}^{12} - \beta_r X_{P1}^{12}) q_{NC1}^{12} - v_{S1}^{12}\left(Y_{S1}^{12}\right)^2$$
$$\pi_{S2}^{12} = \overline{P}.q_{NC2}^{12} - (\overline{C}_S - Y_{S2}^{12} - \beta_t X_{P2}^{12}) q_{NC2}^{12} - v_{S2}^{12}\left(Y_{S2}^{12}\right)^2$$

Optimal innovation level of each firm arises from solving four maximization problems strategically as one system; indeed each one is going to maximize its payoff function as follow:

$$\begin{cases} \max\limits_{X_{P1}^{12}} \pi_{P1}^{*12} \\ \max\limits_{X_{P2}^{12}} \pi_{P2}^{*12} \\ \max\limits_{Y_{S1}^{12}} \pi_{S1}^{12} \\ \max\limits_{Y_{S2}^{12}} \pi_{S2}^{12} \end{cases}$$

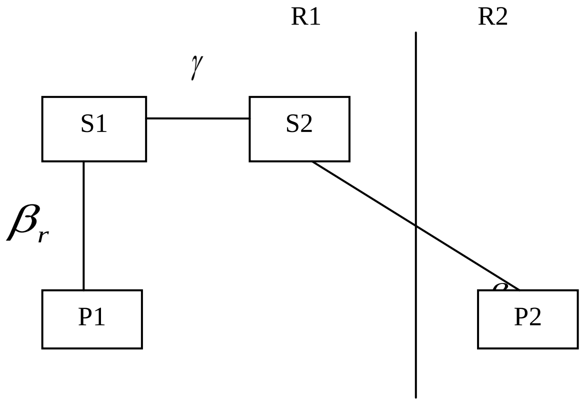
With respect to the following four constraints respectively:

$$\begin{cases} 0 \le \overline{C}_P - X_{P1}^{12} - \beta_r Y_{S1}^{12} - \gamma X_{P2}^{12} + \overline{P} \le a \\ 0 \le \overline{C}_P - X_{P2}^{12} - \beta_r Y_{S2}^{12} - \gamma X_{P1}^{12} + \overline{P} \le a \\ 0 \le \overline{C}_S - Y_{S1}^{12} - \beta_r X_{P1}^{12} \le \overline{P} \\ 0 \le \overline{C}_S - Y_{S2}^{12} - \beta_r X_{P2}^{12} \le \overline{P} \end{cases}$$

4.2. Second Scenario: Two Suppliers are Located in Same Region

Contrary to the first scenario, in the second one whereas our suppliers are located in the same region, say R1, horizontal knowledge spillover between them emerges in both respective cases depicted with parameter γ.

4.2.1. Case 1: Two Producers are Located in Different Regions



Applying backward induction, at t=3 producers play a standard Cournot duopoly game with the following payoff functions:

$$\pi_{P1}^{21} = (a - bq_{P1}^{21} - bq_{P2}^{21})q_{P1}^{21} - (\overline{C}_P - X_{P1}^{21} - \beta_r Y_{S1}^{21} + \overline{P})q_{P1}^{21} - \nu_{P1}^{21}\left(X_{P1}^{21}\right)^2$$

$$\pi_{P2}^{21} = (a - bq_{P1}^{21} - bq_{P2}^{21})q_{P2}^{21} - (\overline{C}_P - X_{P2}^{21} - \beta_t Y_{S2}^{21} + \overline{P})q_{P2}^{21} - \nu_{P2}^{21}\left(X_{P2}^{21}\right)^2$$

Nash-Cournot quantities are the result of maximization process over these payoff functions with respect to $q_{P1}^{21} \,\&\, q_{P2}^{21}$ respectively:

$$q_{NC1}^{21} = \frac{a - \overline{C}_P + 2\beta_r Y_{S1}^{21} - \beta_t Y_{S2}^{21} + 2X_{P1}^{21} - X_{P2}^{21} - \overline{P}}{3b}$$

$$q_{NC2}^{21} = \frac{a - \overline{C}_P + 2\beta_t Y_{S2}^{21} - \beta_r Y_{S1}^{21} + 2X_{P2}^{21} - X_{P1}^{21} - \overline{P}}{3b}$$

After plugging these optimal quantities into payoff functions of producers, following optimal values of them arise:

$$\pi_{P1}^{*21} = \frac{[a - \overline{C}_P + 2\beta_r Y_{S1}^{21} - \beta_t Y_{S2}^{21} + 2X_{P1}^{21} - X_{P2}^{21} - \overline{P}]^2}{9b} - \nu_{P1}^{21}\left(X_{P1}^{21}\right)^2$$

$$\pi_{P2}^{*21} = \frac{[a - \overline{C}_P + 2\beta_t Y_{S2}^{21} - \beta_r Y_{S1}^{21} + 2X_{P2}^{21} - X_{P1}^{21} - \overline{P}]^2}{9b} - \nu_{P2}^{21}\left(X_{P2}^{21}\right)^2$$

Proceeding backward, at t=2 firms decide upon their innovation level X_{Pi}^{21} and Y_{Sj}^{21} as well. $(i, j = 1, 2)$ Profit functions of our suppliers are as follow:

$$\pi_{S1}^{21} = \overline{P}.q_{NC1}^{21} - (\overline{C}_S - Y_{S1}^{21} - \beta_r X_{P1}^{21} - \gamma Y_{S2}^{21})q_{NC1}^{21} - \nu_{S1}^{21}\left(Y_{S1}^{21}\right)^2$$
$$\pi_{S2}^{21} = \overline{P}.q_{NC2}^{21} - (\overline{C}_S - Y_{S2}^{21} - \beta_t X_{P2}^{21} - \gamma Y_{S1}^{21})q_{NC2}^{21} - \nu_{S2}^{21}\left(Y_{S2}^{21}\right)^2$$

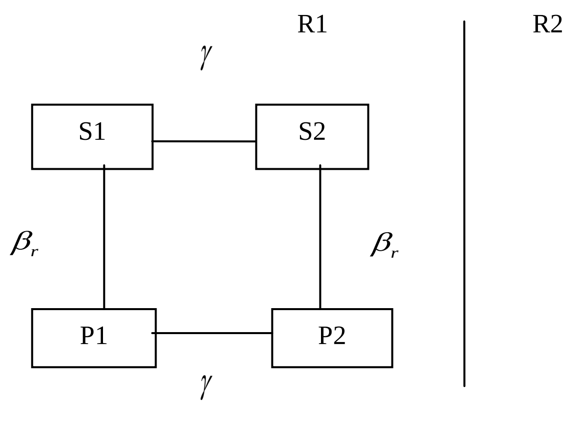
Optimal innovation level of each firm will deduce from maximization of their respective payoff functions strategically as a four-equations-four-unknowns system:

$$\begin{cases} \max\limits_{X_{P1}^{21}} \pi_{P1}^{*21} \\ \max\limits_{X_{P2}^{21}} \pi_{P2}^{*21} \\ \max\limits_{Y_{S1}^{21}} \pi_{S1}^{21} \\ \max\limits_{Y_{S2}^{21}} \pi_{S2}^{21} \end{cases}$$

With respect to the following four constraints respectively:

$$\begin{cases} 0 \le \overline{C}_P - X_{P1}^{21} - \beta_r Y_{S1}^{21} + \overline{P} \le a \\ 0 \le \overline{C}_P - X_{P2}^{21} - \beta_t Y_{S2}^{21} + \overline{P} \le a \\ 0 \le \overline{C}_S - Y_{S1}^{21} - \beta_r X_{P1}^{21} - \gamma Y_{S2}^{21} \le \overline{P} \\ 0 \le \overline{C}_S - Y_{S2}^{21} - \beta_t X_{P2}^{21} - \gamma Y_{S1}^{21} \le \overline{P} \end{cases}$$

4.2.2. Case 2: Two Producers are Located in Same Region



Geographical concentration of producers in the second scenario will be investigated via this case. Incidentally horizontal knowledge spillovers between two producers as well as two suppliers exist in this case which induce flow of knowledge through our four firms depicted by parameters β_r, γ .

By using backward induction, at t=3 producers play a standard Cournot duopoly game with the below mention payoff functions:

$$\pi_{P1}^{22} = (a - bq_{P1}^{22} - bq_{P2}^{22})q_{P1}^{22} - (\overline{C}_P - X_{P1}^{22} - \beta_r Y_{S1}^{22} - \gamma X_{P2}^{22} + \overline{P})q_{P1}^{22} - \nu_{P1}^{22}\left(X_{P1}^{22}\right)^2$$
$$\pi_{P2}^{22} = (a - bq_{P1}^{22} - bq_{P2}^{22})q_{P2}^{22} - (\overline{C}_P - X_{P2}^{22} - \beta_r Y_{S2}^{22} - \gamma X_{P1}^{22} + \overline{P})q_{P2}^{22} - \nu_{P2}^{22}\left(X_{P2}^{22}\right)^2$$

By solving First-Order-Condition equations of both producers as a one system, maximum Nash-Cournot value of our quantities have the following form:

$$q_{NC1}^{22} = \frac{a - \overline{C}_P + 2\beta_r Y_{S1}^{22} - \beta_r Y_{S2}^{22} + 2X_{P1}^{22} - (1-\gamma)X_{P2}^{22} - \overline{P}}{3b}$$
$$q_{NC2}^{22} = \frac{a - \overline{C}_P + 2\beta_r Y_{S2}^{22} - \beta_r Y_{S1}^{22} + 2X_{P2}^{22} - (1-\gamma)X_{P1}^{22} - \overline{P}}{3b}$$

Consequently optimal payoff functions of our producers are as follow:

$$\pi_{P1}^{*22} = \frac{[a - \overline{C}_P + 2\beta_r Y_{S1}^{22} - \beta_r Y_{S2}^{22} + 2X_{P1}^{22} - (1-\gamma)X_{P2}^{22} - \overline{P}]^2}{9b} - \nu_{P1}^{22}\left(X_{P1}^{22}\right)^2$$
$$\pi_{P2}^{*22} = \frac{[a - \overline{C}_P + 2\beta_r Y_{S2}^{22} - \beta_r Y_{S1}^{22} + 2X_{P2}^{22} - (1-\gamma)X_{P1}^{22} - \overline{P}]^2}{9b} - \nu_{P2}^{22}\left(X_{P2}^{22}\right)^2$$

Proceeding backward, at t=2 firms decide on their innovation level X_{Pi}^{22} and Y_{Sj}^{22} as well. $(i, j = 1, 2)$ Payoff functions of suppliers are as follow:

$$\pi_{S1}^{22} = \overline{P}.q_{NC1}^{22} - (\overline{C}_S - Y_{S1}^{22} - \beta_r X_{P1}^{22} - \gamma Y_{S2}^{22})q_{NC1}^{22} - \nu_{S1}^{22}\left(Y_{S1}^{22}\right)^2$$
$$\pi_{S2}^{22} = \overline{P}.q_{NC2}^{22} - (\overline{C}_S - Y_{S2}^{22} - \beta_r X_{P2}^{22} - \gamma Y_{S1}^{22})q_{NC2}^{22} - \nu_{S2}^{22}\left(Y_{S2}^{22}\right)^2$$

Similar to our previous cases, optimal level of innovation of our firms will be resulted by strategically solving a four-equations-four-unknowns system of equations as follow:

$$\begin{cases} \max\limits_{X_{P1}^{22}} \pi_{P1}^{*22} \\ \max\limits_{X_{P2}^{22}} \pi_{P2}^{*22} \\ \max\limits_{Y_{S1}^{22}} \pi_{S1}^{22} \\ \max\limits_{Y_{S2}^{22}} \pi_{S2}^{22} \end{cases}$$

Providing the satisfaction of the four below mention constraints respectively:

$$\begin{cases} 0 \le \overline{C}_P - X_{P1}^{22} - \beta_r Y_{S1}^{22} - \gamma X_{P2}^{22} + \overline{P} \le a \\ 0 \le \overline{C}_P - X_{P2}^{22} - \beta_r Y_{S2}^{22} - \gamma X_{P1}^{22} + \overline{P} \le a \\ 0 \le \overline{C}_S - Y_{S1}^{22} - \beta_r X_{P1}^{22} - \gamma Y_{S2}^{22} \le \overline{P} \\ 0 \le \overline{C}_S - Y_{S2}^{22} - \beta_r X_{P2}^{22} - \gamma Y_{S1}^{22} \le \overline{P} \end{cases}$$

4.3. Findings

4.3.1. Producers Do NOT Invest on any Innovation Effort

In the first phase of our analysis for the purpose of simplicity and based on assumption 3, we ignore any innovation effort of our both producers. Obviously with this assumption in hand horizontal knowledge spillovers between producers will not occur. We will relax this assumption for broader analysis later.

Observation 1: In the first scenario and in the absence of innovation efforts of both producers, the first case which shows the geographical isolation is the equilibrium.

As we have established in the first scenario both suppliers are located in different regions and consequently there is no horizontal knowledge spillover between them. As a result the only channel of innovation's disclosure is through vertical knowledge spillovers characterized by parameters β_r & β_t which $0 \le \beta_t < \beta_r \le 1$. Comparison between two cases of this scenario shows us that the second producer will find it more profitable locating itself in the different region in order to obtain innovation effort of its respective supplier via regional -rather than trans regional- vertical knowledge spillover which will decline its costs more. Obviously the fist producer will prefer the second case over the first one. Because he will compete with a producer who could reduce his costs with the factor $\beta_t < \beta_r$, but it is not equilibrium while second producer will tend to deviate to the first case and locate in different region.

More precisely speaking, we can consider following graphs showed in figure 4.3.1.1 which help us to compare the payoffs of producers in these cases. As depicted in this set of graphs, the first producer clearly prefers the occurrence of second case in which he will obtain more profit from the market while the second producers dominantly prefers the first case getting more payoffs. Suppliers have the same behavior symmetrically.

Observation 2: In the second scenario and in the absence of innovation efforts of both producers, the second case which shows the geographical concentration is the equilibrium.

In this scenario horizontal knowledge spillovers between two suppliers which is characterized by γ, exist. Similar to the interpretation of the previous observation, in this scenario our second producer dominantly prefers geographical concentration which depicted in the second case. Consequently he is able to reduce his costs based on the knowledge spillovers factor $\beta_r > \beta_t$ which will not be in the favor of first producer who prefers to be alone in the first region as depicted in the first case. But based on assumption 1 second case of this scenario would be the equilibrium. Although locating of both suppliers is exogenous, their behavior can be interpreted similarly. On the other hand first producer prefers first case in which his competitor is able to share his knowledge with second supplier via trans-regional vertical knowledge spillover that is smaller than regional one.

Figure 4.3.1.2 exhibits the comparison of payoffs of our economic agents in two different cases of this scenario which support above mentioned reasoning.

When R&D efforts of both producers were ignored as we did in this subsection, our observations show strong robustness upon parametrical changes. Broad ranges of parameters have been checked numerically in this part in order to guarantee the final results.

Figure 2
First Scenario: Two Suppliers are located in Different Regions (Yellow: Case1 & Red: Case2)
$(a=100, b=2, \beta_t=0.05, \gamma=0.2, v_{P_1}=v_{P_2}=v_{S_1}=0.7)$

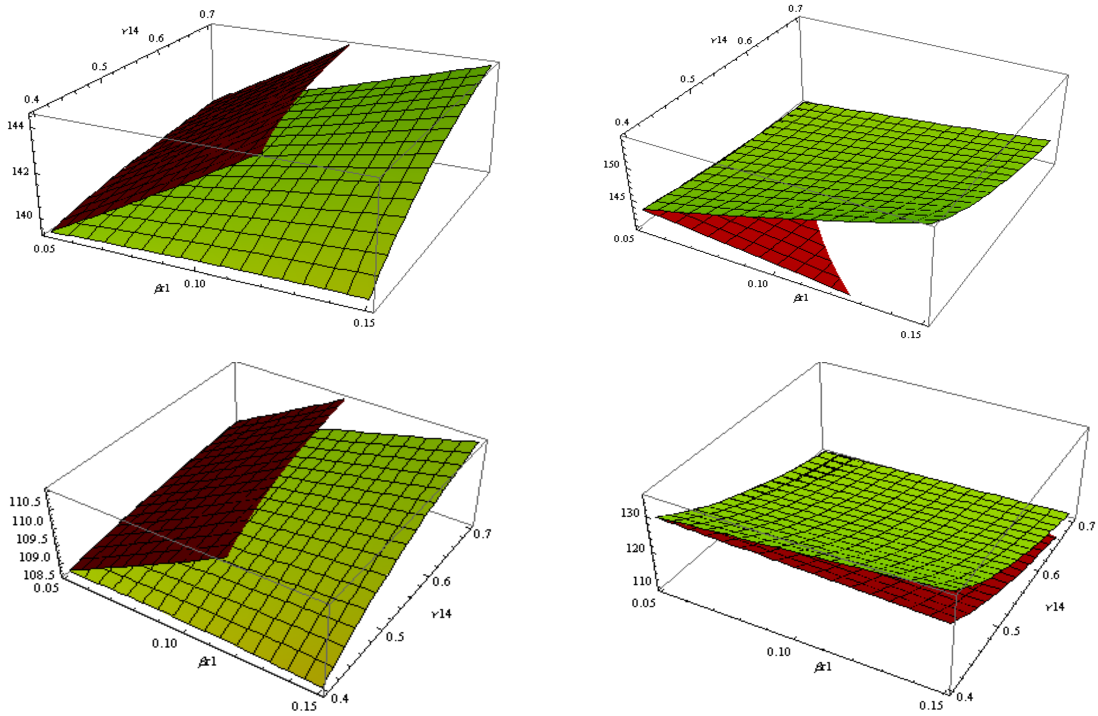
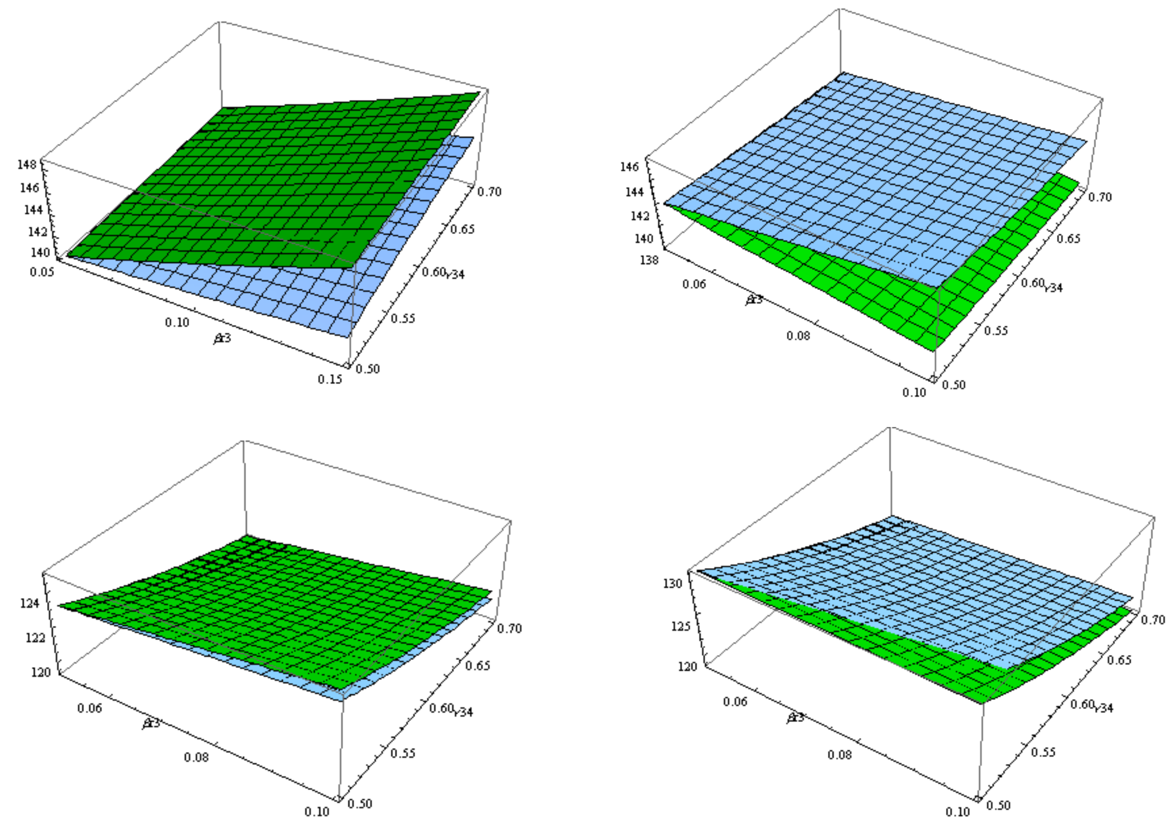


Figure 3
Second Scenario: Two Suppliers are located in Same Region (Green: Case1 & Blue: Case2)
$(a=100, b=2, \beta_t=0.05, \gamma=0.2, v_{P_1}=v_{P_2}=v_{S_1}=0.7)$



4.3.2. Producers Enter Innovation Efforts

In this section we relax assumption 3 and consider the innovation efforts of both producers in our analysis. Obviously in this situation horizontal knowledge spillovers between two producers which characterized by γ will play an important role affecting final outcomes. Furthermore based on assumption 2, horizontal knowledge spillovers between two suppliers as well as two producers are assumed to be homogeneous, that is $\gamma_{suppliers} = \gamma_{producers} = \gamma$.

In the previous section 4.3.1 the results were completely robust with respect to postulated parameters which categorized in section 3 and no deviation from our mentioned equilibrium occurred during numerical analysis and parametric changes, but in this section we examine the robustness and sustainability of our observations according to categorization of our parameters.

Observation 3: In the first scenario and in the presence of innovation efforts of both producers, the second case which shows the geographical concentration is the equilibrium.

Observation 4: In the second scenario and in the presence of innovation efforts of both producers, the second case which shows the geographical concentration is the equilibrium.

4.3.2.1. Comparative Static

In order to realize the effect of each parameter on our outcomes, and supporting the robustness of observations 3 and 4, we investigate comparative static in this subsection. For this purpose two sets of parameters –based on our categorization in section 3- are being fixed and the parametrical effects of the third set are being analyzed. Broad ranges of parameters have been checked in order to ensure us about robustness of our observation upon parametrical changes, but some limited examples could be mentioned here.

4.3.2.1.1. Market Parameters

Providing other parameters are supposed to be fixed, we investigate the effect of our market parameters which characterized by $a, b, \bar{P}, \bar{C}$ on equilibria and location decision of our agents. Utilizing numerical approach we consider the impact of altering the market parameters on equilibrium expressed in observations 3 and 4.

In the first scenario as depicted in figures 4 and 5 second producer prefers second case over the first one implying geographical concentration. Altering the size of the market as well as the unit cost of production and price does not affect the location decision of our producers.

Altering the size of the market indeed just affect the profit value of agents proportionally and has not any effect on location decision of them. Actually paying attention to 'Markup' index of agents in this model clarifies this matter more. In fact any reduction in the size of the market will decline the quantity produced by our agents which cause them to decrease innovation efforts in order to reach marginal profits in the market. Contrary is valid when market size goes up, but whereas our agents doing business in the same market, these changes affect all proportionally.

Similar interpretations could be applied for the second scenario in which all agents dominantly prefer clustering structure over the first case. Figures 6 and 7 confirm our claim.

Comprehensive parametric analysis has been done in this subsection to ensure us upon robustness of observations including broad range of reservation price, market size, unit cost of transforming intermediate goods $\bar{C}$ and different value of intermediate good's price $\bar{P}$.

4.3.2.1.2. Knowledge Spillover Parameters

For the sake of more accurate analysis we arrange a relation between knowledge spillover parameters based on the framework of our model, in which we have assumed that $0 \leq \beta_t < \beta_r < \gamma \leq 1$. Hence we suppose that $\beta_r = \alpha\beta_t = \delta\gamma$ such that $\alpha > 1$ and $0 < \delta < 1$.

In the first scenario second producer would be able to decline its costs from two source of knowledge, its relevant supplier in the different region as well as the first producer in the same region with knowledge spillover factors β_t and γ respectively. Numerical analysis shows that the effect of these two factors is more than the effect of regional vertical knowledge spillover factor β_r alone. Figures 8, 9 and 10 exhibit the different selection of knowledge spillover parameters subject to holding the other parameters fixed. Moreover as depicted in these figures the first producer also prefers second case over the first one which demonstrate his tendency to geographical concentration in which he is able to obtain knowledge from two sources with the factors β_r and γ while his competitor will lose some customers of the common market because of higher costs of production. Thus although the second producer will obtain lower payoff than his competitor he will locate himself near him in order to exploit his innovation efforts which would create better outcome for both of them.

The behavior of our suppliers is a little bit more interesting. The first supplier dominantly prefers the second case over the first one in which he will always have competitive advantage over his rival. He obtains cost-reducing knowledge with two factors β_r and γ while his competitor just can do it via β_t and γ. Our respected figures depict that clearly, but in figure 10 where we have no explicit difference between knowledge spillover parameters β_r, β_t, γ the second producer will also reach more profit in the second case. Consequently our second supplier prefers the symmetric structure of first case when the amount of our knowledge spillover factors is meaningfully different.

In the second scenario all of our agents do agree to compete and collaborate with each other in a cluster, so geographical concentration would be dominantly preferred by them. If second producer chooses the isolated region, directly he could be able just to obtain the knowledge via his relevant supplier with the parameter β_t.

Moreover he will lose the chance to exchange his knowledge with his competitor in the market. When second producer were a stronger innovative firm in the market with higher technology level, this kind of isolation decision might mean more, but in this section based on assumption 2 we have assumed that innovation costs is similar between all agents. We will relax this assumption later. This equilibrium shows strong robustness upon changing the parameters.

4.3.2.1.3. Innovation Cost Parameter

The last group of parameter which we are going to analyze is innovation cost characterized by v and assumed to be homogenous. We will investigate the heterogeneity of this parameter which means different technological level between our agents in the next section.

Following Qiu (1997) we have assumed that innovation cost are of the form $K(X_{Pi}^{jk}) = v(X_{Pi}^{jk})^2$, $v > 0$ and $i, j, k = 1, 2$ for producers as well as $K(Y_{Si}^{jk}) = v(Y_{Si}^{jk})^2$, $v > 0$ and $i, j, k = 1, 2$ for suppliers which implies diminishing returns in R&D.

Figure 14 depicts that in the first scenario if innovation cost is altered homogenously second producer prefers geographical concentration over isolation which is also a preferred situation for the first producer and supplier and our second supplier is somewhat indifferent between two cases.

Providing innovation cost assumed to be homogenous, any increase in this cost enforces our agents to decline R&D efforts which decline their final profit proportionally, but does not affect location decision of them. Inversely high technological firms with lower level of innovation cost will do more R&D activities which decline their total costs and consequently increase the final payoff.

Similarly as depicted in figure 15 in the second scenario all agents prefer to compete and collaborate with each other in the same geographical region.

Figure 4

First Scenario: Two Suppliers are located in Different Regions with a=100, b=2 (Green: Case1 & Red: Case2)

$$(\beta_r = 0.1, \beta_t = 0.05, \gamma = 0.2, \nu_{P_i} = \nu_{S_i} = 0.7)$$

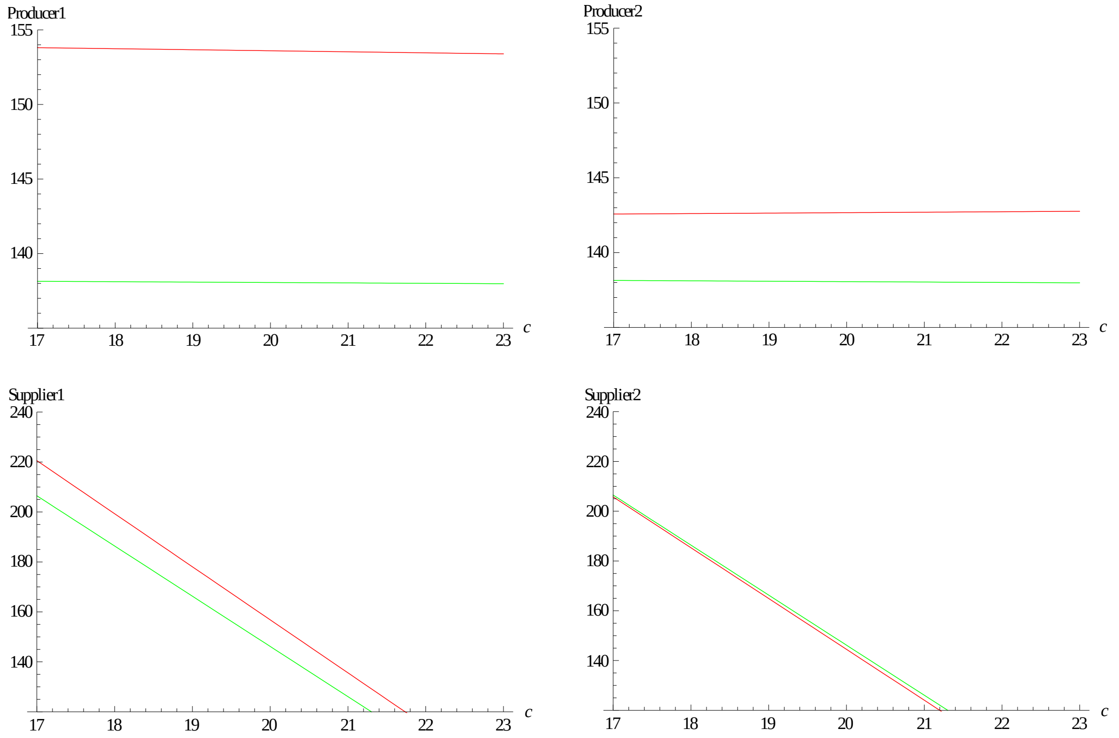


Figure 5

First Scenario: Two Suppliers are located in Different Regions with a=40, b=2 (Black: Case1 & Blue: Case2)

$$(\beta_r = 0.1, \beta_t = 0.05, \gamma = 0.2, \nu_{P_i} = \nu_{S_i} = 0.7)$$

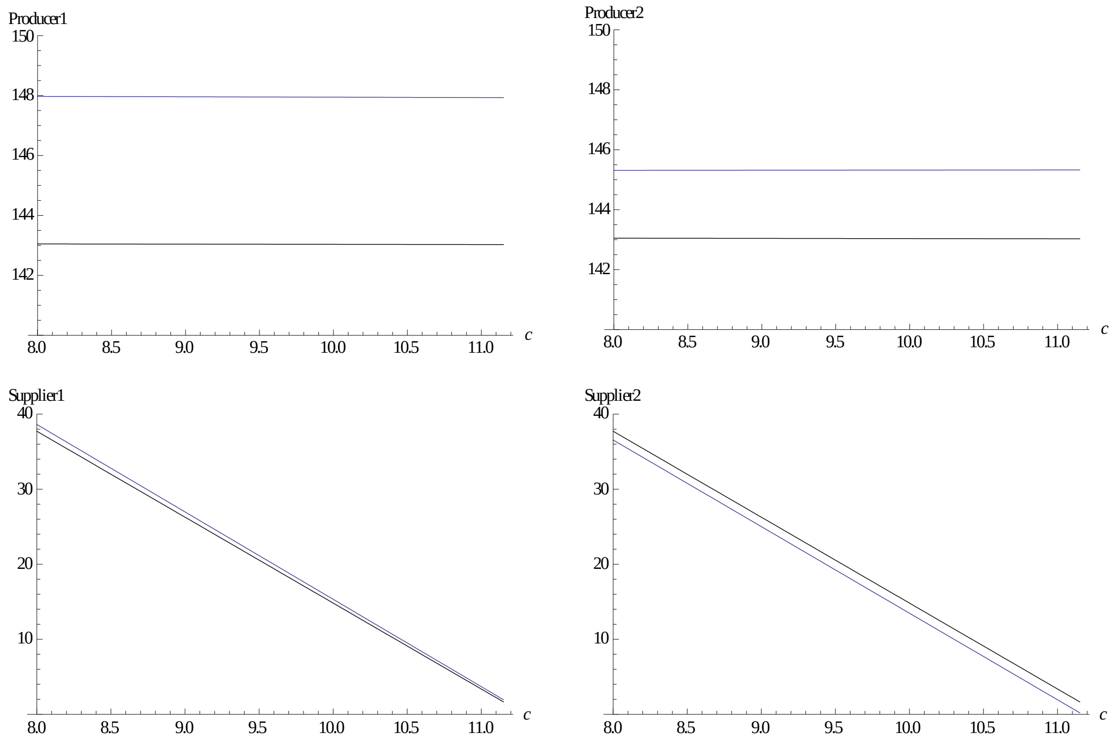


Figure 6

Second Scenario: Two Suppliers are located in Same Region with a=100, b=2 (Green: Case1 & Red: Case2)

$$(\beta_r = 0.1, \beta_t = 0.05, \gamma = 0.2, \nu_{P_i} = \nu_{S_i} = 0.7)$$

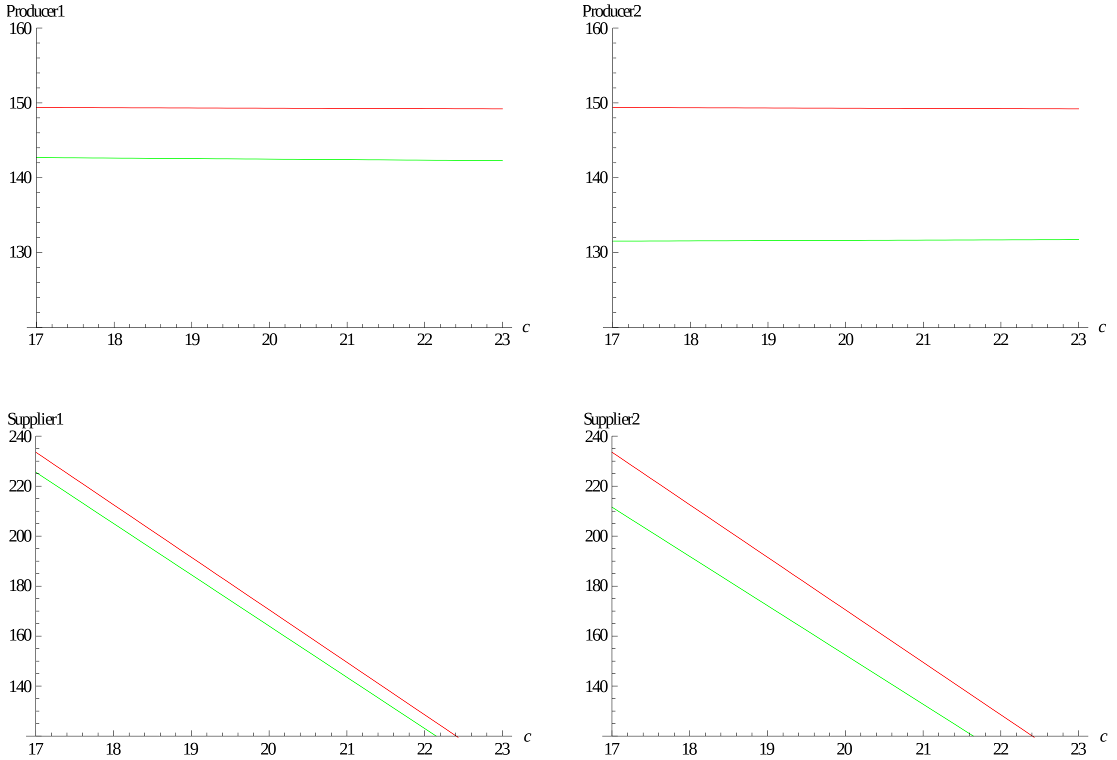


Figure 7

Second Scenario: Two Suppliers are located in Same Region with a=40, b=2 (Black: Case1 & Blue: Case2)

$$(\beta_r = 0.1, \beta_t = 0.05, \gamma = 0.2, \nu_{P_i} = \nu_{S_i} = 0.7)$$

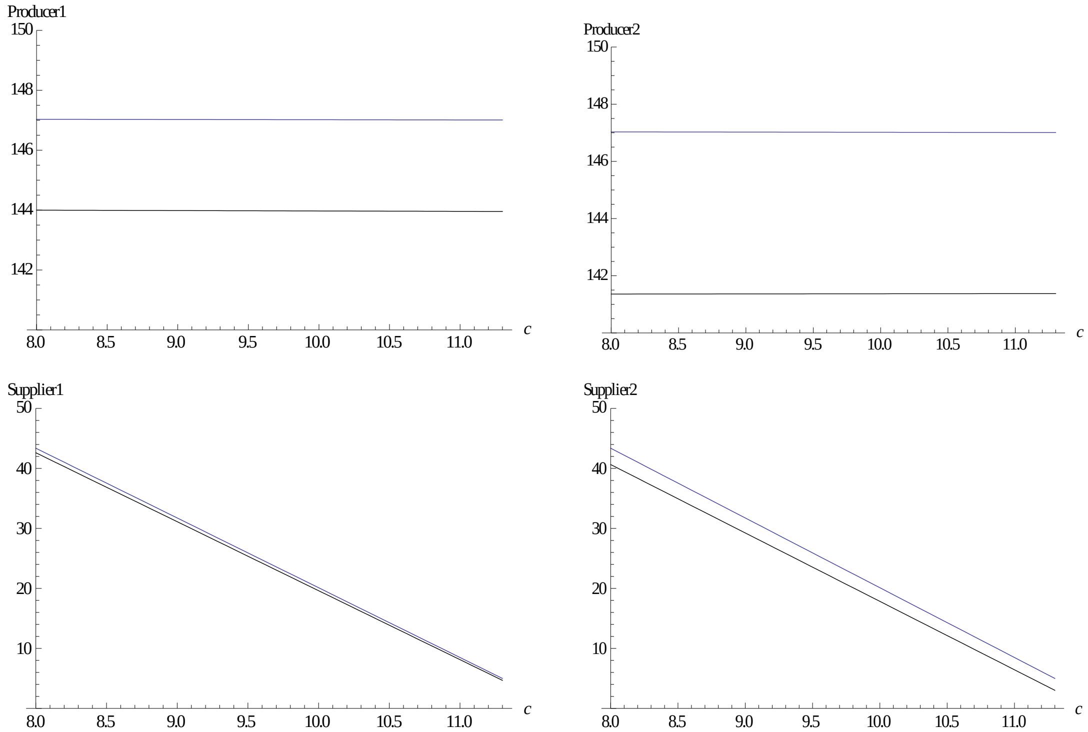


Figure 8

First Scenario: Two Suppliers are located in Different Regions with $\alpha = 2, \delta = 0.5$ (Green: Case1 & Red: Case2)

$(a = 100, b = 2, \overline{P} = 30, \overline{C} = 20, v_{P_i} = v_{S_i} = 0.7)$

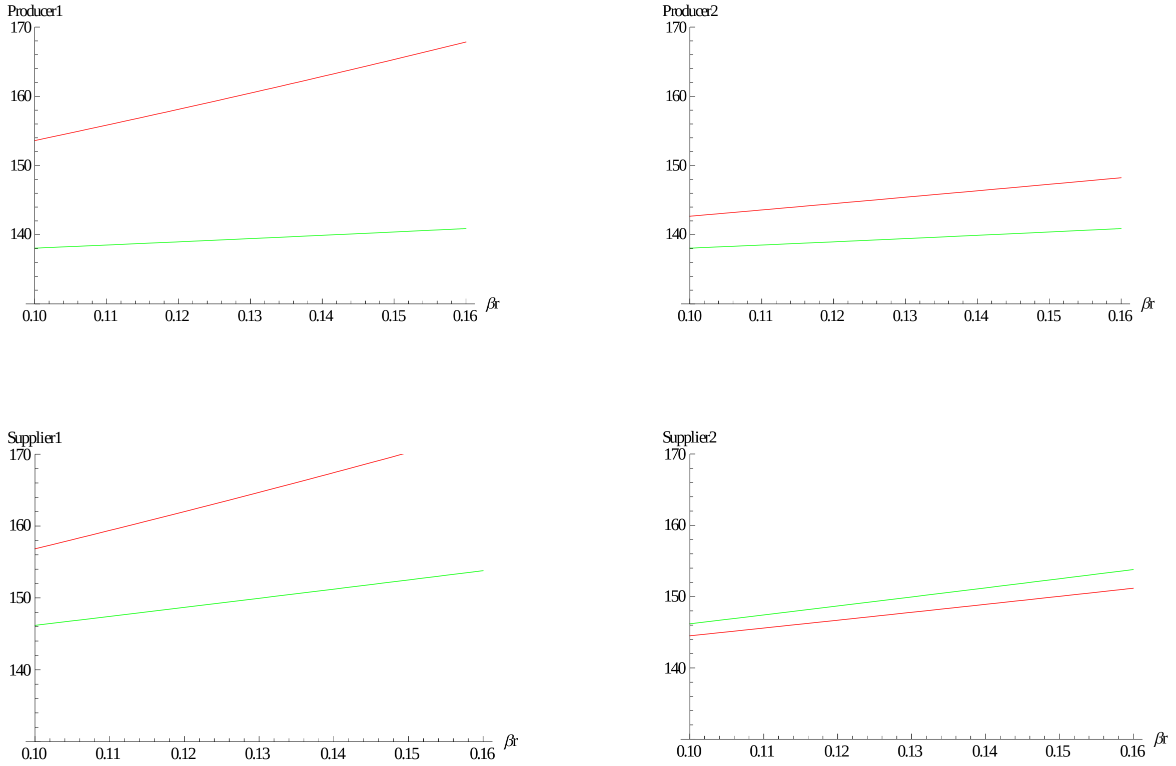


Figure 9

First Scenario: Two Suppliers are located in Different Regions with $\alpha = 1.1, \delta = 0.9$ (Black: Case1 & Blue: Case2)

$(a = 100, b = 2, \overline{P} = 30, \overline{C} = 20, v_{P_i} = v_{S_i} = 0.7)$

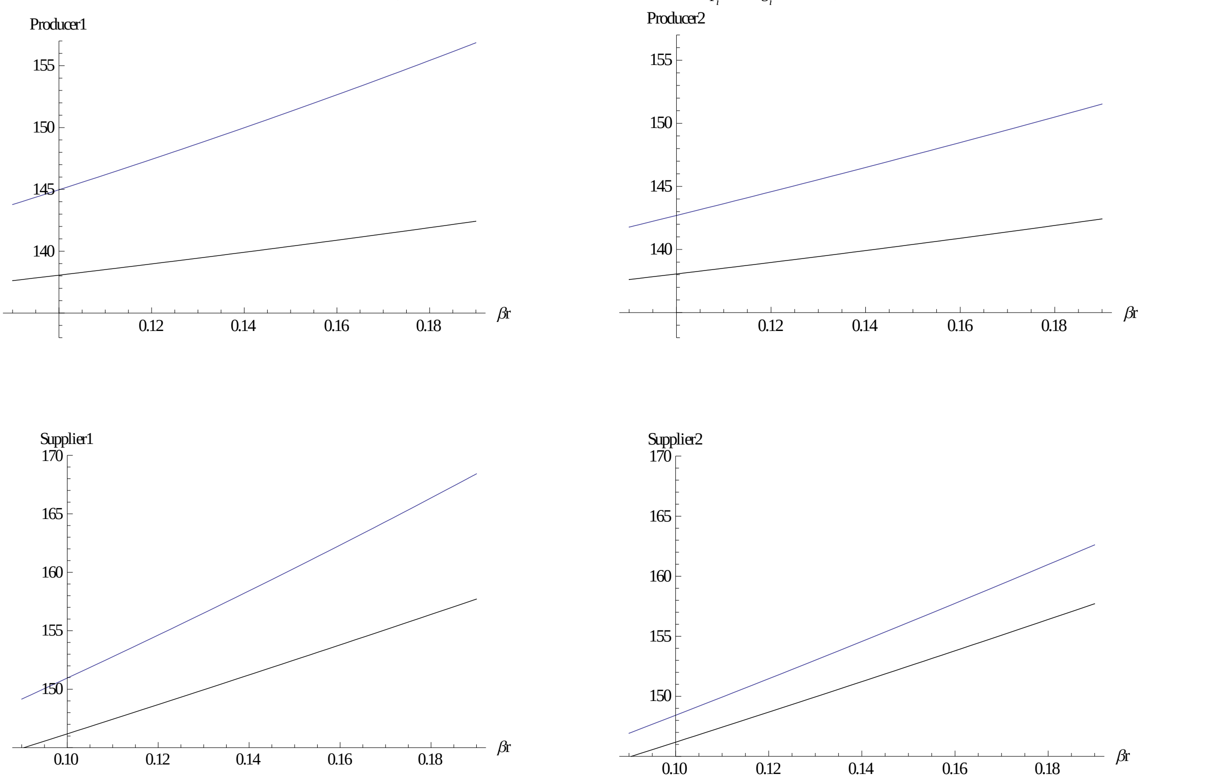


Figure 10

First Scenario: Two Suppliers are located in Different Regions with $\alpha = 5, \delta = 0.33$ (Orange: Case1 & Black: Case2)

$(a = 100, b = 2, \overline{P} = 30, \overline{C} = 20, v_{P_i} = v_{S_i} = 0.7)$

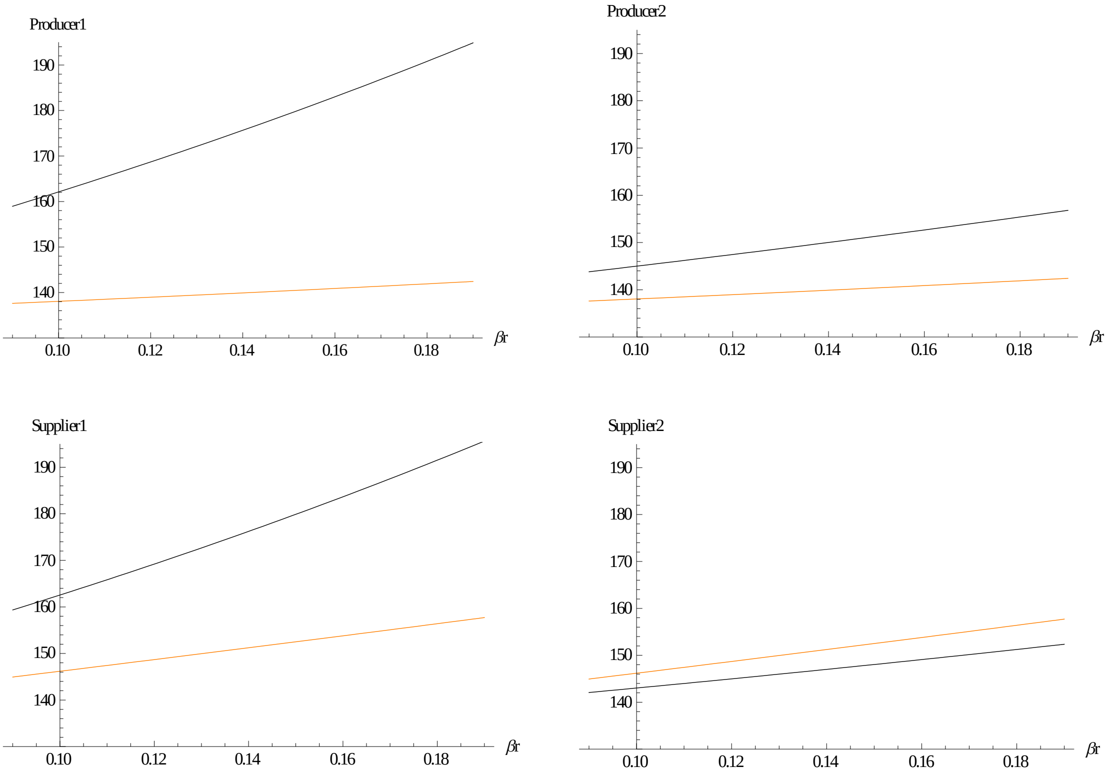


Figure 11

Second Scenario: Two Suppliers are located in Same Region with $\alpha = 2, \delta = 0.5$ (Green: Case1 & Red: Case2)

$(a = 100, b = 2, \overline{P} = 30, \overline{C} = 20, v_{P_i} = v_{S_i} = 0.7)$

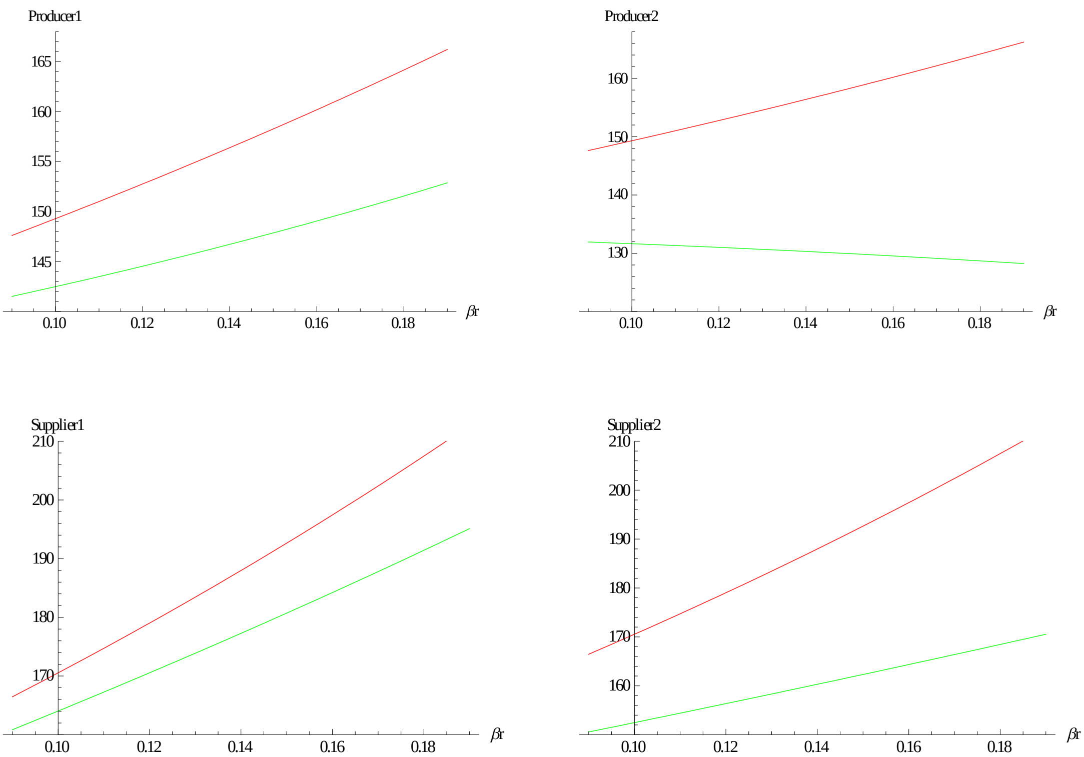


Figure 12

Second Scenario: Two Suppliers are located in Same Region with $\alpha = 1.1, \delta = 0.9$ (Black: Case1 & Blue: Case2)

$(a = 100, b = 2, \overline{P} = 30, \overline{C} = 20, v_{P_i} = v_{S_i} = 0.7)$

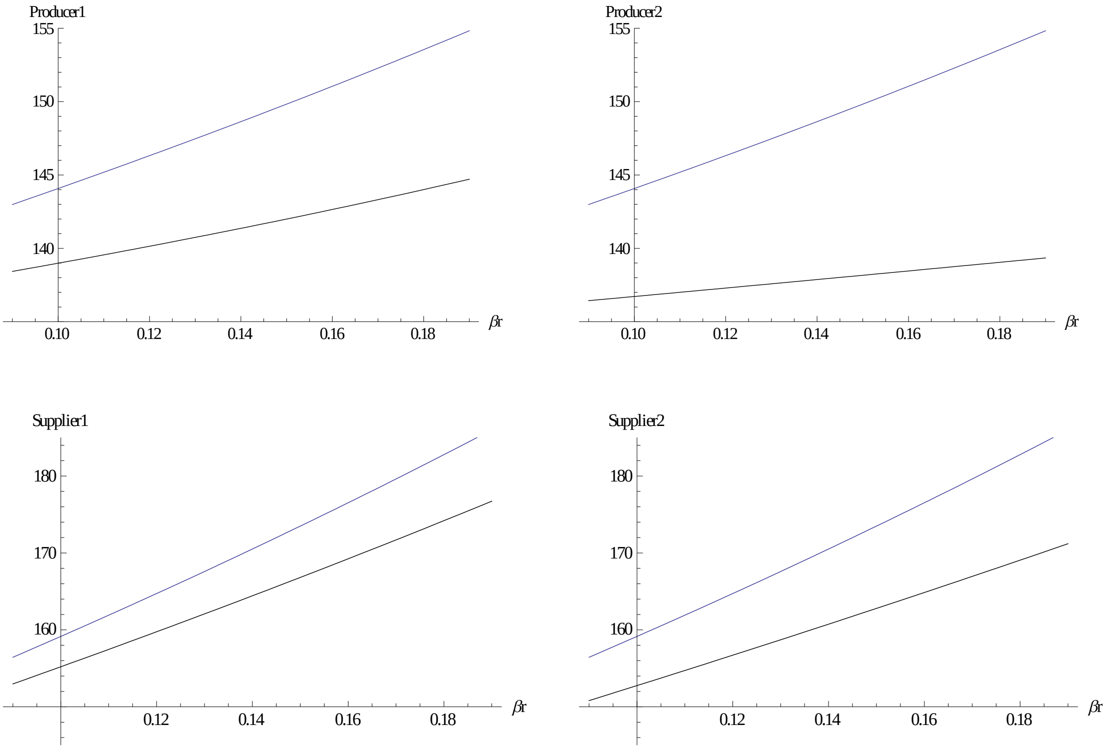


Figure 13

Second Scenario: Two Suppliers are located in Same Region with $\alpha = 5, \delta = 0.33$ (Orange: Case1 & Black: Case2)

$(a = 100, b = 2, \overline{P} = 30, \overline{C} = 20, v_{P_i} = v_{S_i} = 0.7)$

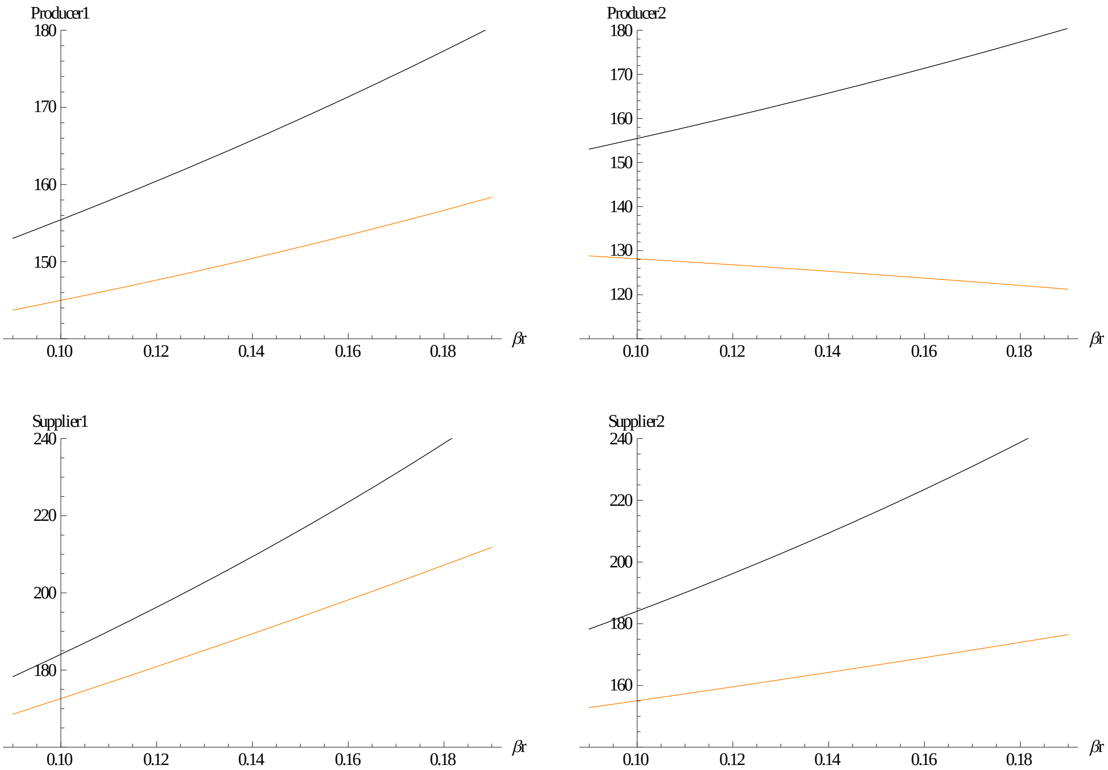


Figure 14

First Scenario: Two Suppliers are located in Different Regions (Green: Case1 & Red: Case2)

$(a = 100, b = 2, \bar{P} = 30, \bar{C} = 20, \beta_r = 0.1, \beta_t = 0.05, \gamma = 0.2)$

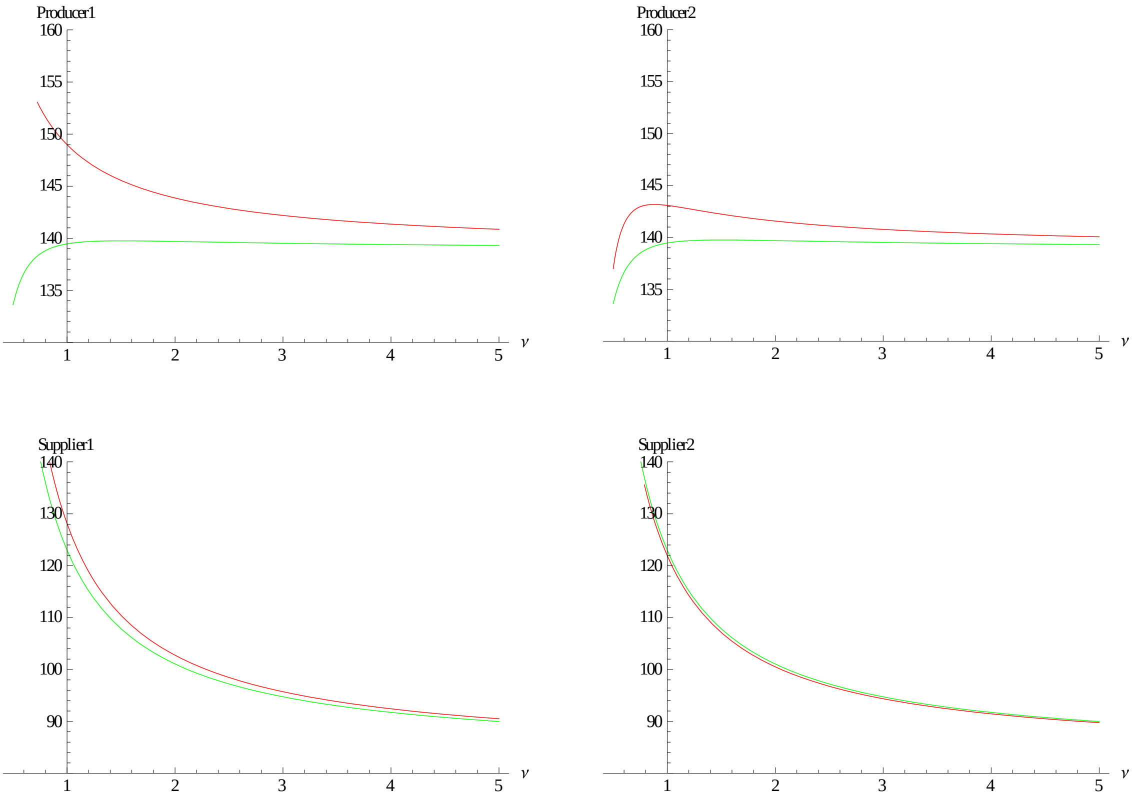
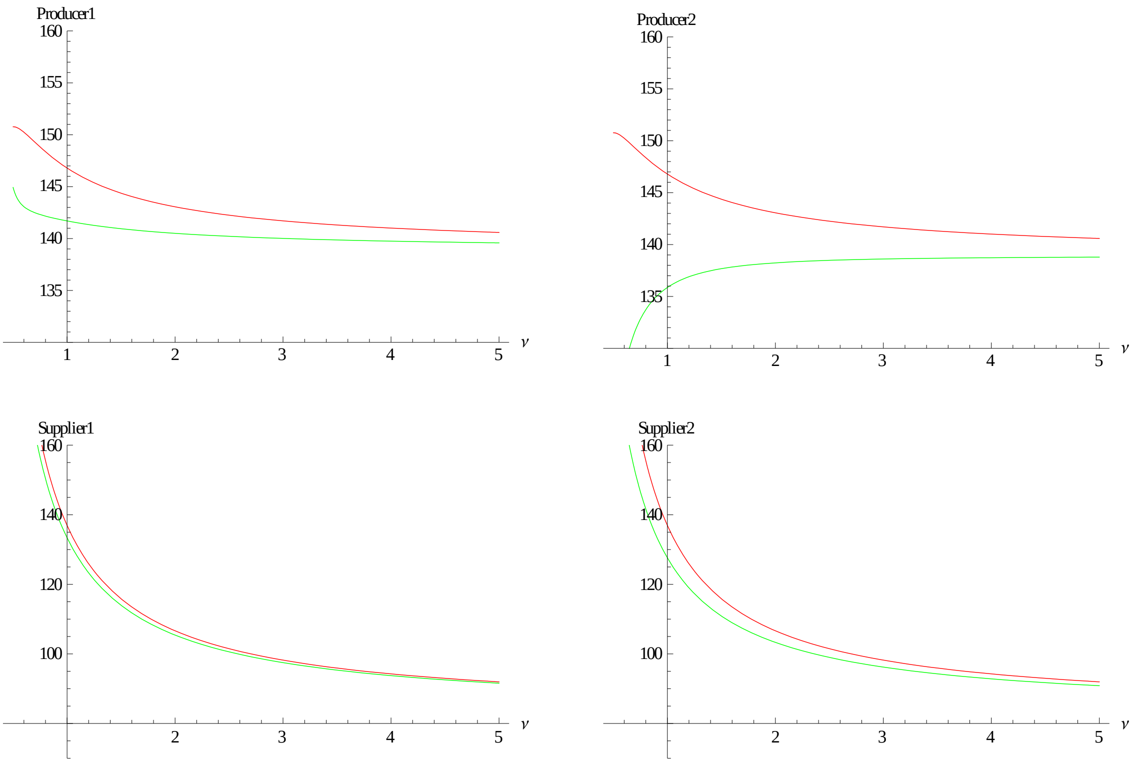


Figure 15

Second Scenario: Two Suppliers are located in Same Region (Green: Case1 & Red: Case2)

$(a = 100, b = 2, \bar{P} = 30, \bar{C} = 20, \beta_r = 0.1, \beta_t = 0.05, \gamma = 0.2)$



4.3.3. Heterogeneity of Innovation Cost

So far we assumed that technological level of our four agents is similar and characterized by homogeneous innovation cost, but in this section we relax assumption 2 partially and investigate the effect of heterogeneous innovation cost on location decision of firms. In fact we move one step toward real world businesses in which companies actually act with different technological level and there are some evidences that these differences can affect the location decision of firms as well. A prominent example in this regard is Microsoft, which became the industry leader after locating in Seattle, which at the time was not a centre for software development (Almazan 2007). For this purpose we consider two different scenarios which may exist and analyze the model accordingly.

4.3.3.1. Innovation Cost is Heterogeneous just among Different Producer-Supplier Pair

In this subsection we suppose that homogenous innovation cost imposes to first supplier and his respected producer in supply chain as well as the second supplier-producer set while we have heterogeneity of innovation cost among these both pairs. So we normalize the innovation cost of second producer and his respected supplier to one while vary the innovation cost of first pair over an interval $\{0.5, 5\}$. The reason of choosing this interval is that innovation costs which are less than half will not satisfy our constraints in optimization problem and amounts more than 5 will decline R&D efforts of firms dramatically such that the impact of knowledge spillovers goes down.

Observation 5: In the first scenario considering conditions of subsection 4.3.3.1, when $v_{P_1} = v_{S_1} < \rho$, second case which shows geographical concentration is the equilibrium, while with $\rho \leq v_{P_1} = v_{S_1}$, first case which shows geographical isolation is the equilibrium such that the exact amount of ρ depends on the value of our parameters.

In the first scenario for our first pair of producer-supplier is always of preference to act within concentration structure because regardless of the technological level of both pair, they obtain knowledge via γ which reduce their cost and increase their final outcome. On the other hand our second pair alters his location decision based on the level of technological differences, that is our second producer when encounter a technological level ρ times higher than his respected rival will find it more profitable to keep his physical distance from him and act in isolation as depicted in the first case to avoid any horizontal information disclosure. Figure 16 demonstrates the schematic results in which $\rho = 1.8$.

Observation 6: In the Second scenario considering conditions of subsection 4.3.3.1, second case which shows geographical concentration is the equilibrium.

Here our second producer dominantly prefers geographical concentration which enables him to receive knowledge from other agents with higher disclosure rate. Figure 17 depicts the result.

4.3.3.2. Heterogeneous Innovation Cost Imposes just on Second Producer

Now we investigate whether a very high-tech firm, that is here our second producer, with low innovation cost choose isolation structure to keep its knowledge capital or not. Hence, homogeneous innovation cost for first producer and both suppliers has been set to five and we change the innovation cost of second producer over the interval $\{0.5, 0.7\}$ parametrically. In fact by setting the innovation cost of other agents to a big value like five, we treat them as low technological level firms. On the other hand we change the innovation cost of our second producer over the interval $\{0.5, 0.7\}$ which implies higher technological level in comparison with other agents. For the sake of more accurate results we consider two different levels of horizontal knowledge spillover $\gamma = 0.2$ and $\gamma = 0.12$ to be more sensitive on the effect of innovation cost. Indeed by choosing $\gamma = 0.12$ rather than $\gamma = 0.2$ we try to investigate the situation of more outward knowledge spillovers' protection.

Observation 7: In the first scenario considering conditions of subsection 4.3.3.2, first case is weakly preferred by the second producer which resulted geographical isolation as equilibrium.

Here our second producer weakly prefers to locate himself far from first producer in order to avoid leakage of information to his rival. Although the results are not strong here and when innovation cost of second producer tend to 0.7 we face some kind of indifference behavior, but dominant preference of second supplier who really makes profit by being alone with his customer might cause some agreements in the real world which commit our first producer to stay in isolation. Figures 18 and 20 show the graphs for $\gamma = 0.2$ and $\gamma = 0.12$, and the result is robust upon parametrical changes.

Observation 8: In the Second scenario considering conditions of subsection 4.3.3.2, second case which shows geographical concentration is the equilibrium.

Although our second producer is more high-tech against other agents but he prefers to stay in concentration structure to benefit from disclosure of knowledge, but our numerical analysis show a weak preferences in this situation. Clearly other agents appreciate his presence near them.

Figure 19 and 21 exhibit the results for $\gamma = 0.2$ and $\gamma = 0.12$ respectively, and the result is completely robust upon parametrical changes.

Figure 16
First Scenario: Two Suppliers are located in Different Regions (Black: Case 1 & Blue: Case 2)
$(a = 100, b = 2, \overline{C} = 20, \overline{P} = 30, \beta_r = 0.1, \beta_t = 0.05, \gamma = 0.2, \nu_{P_2} = \nu_{S_2} = 1)$

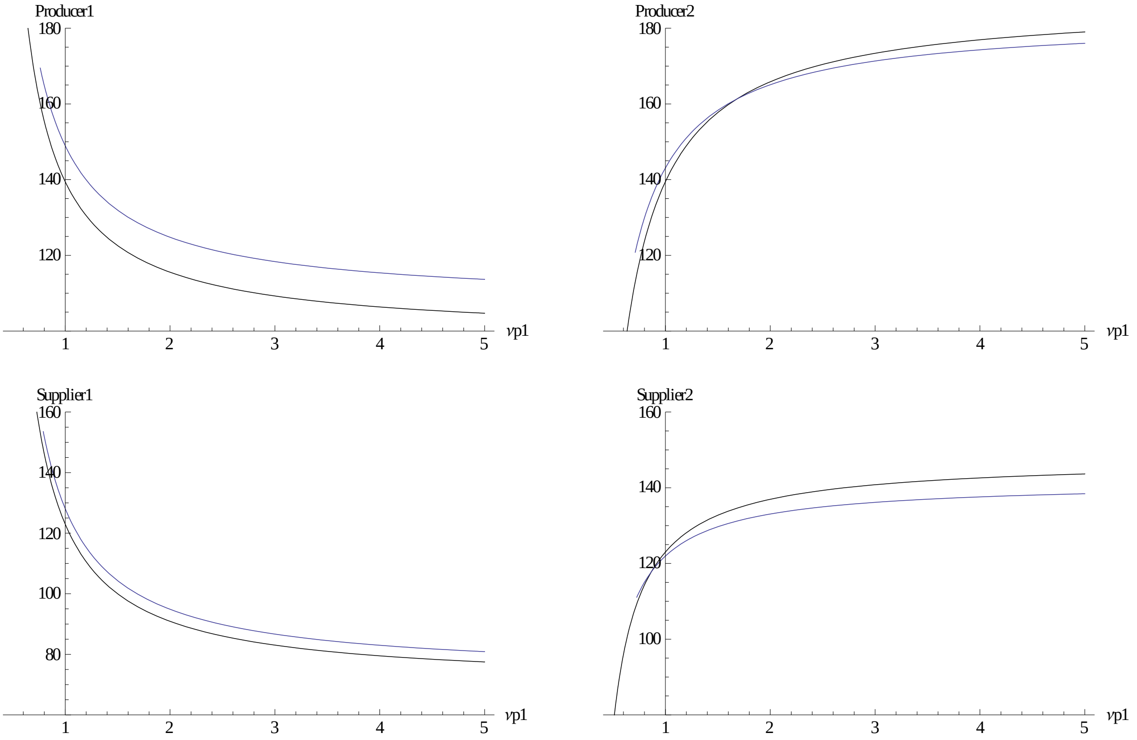


Figure 17
Second Scenario: Two Suppliers are located in Same Region (Black: Case 1 & Blue: Case 2)
$(a = 100, b = 2, \overline{C} = 20, \overline{P} = 30, \beta_r = 0.1, \beta_t = 0.05, \gamma = 0.2, \nu_{P_2} = \nu_{S_2} = 1)$

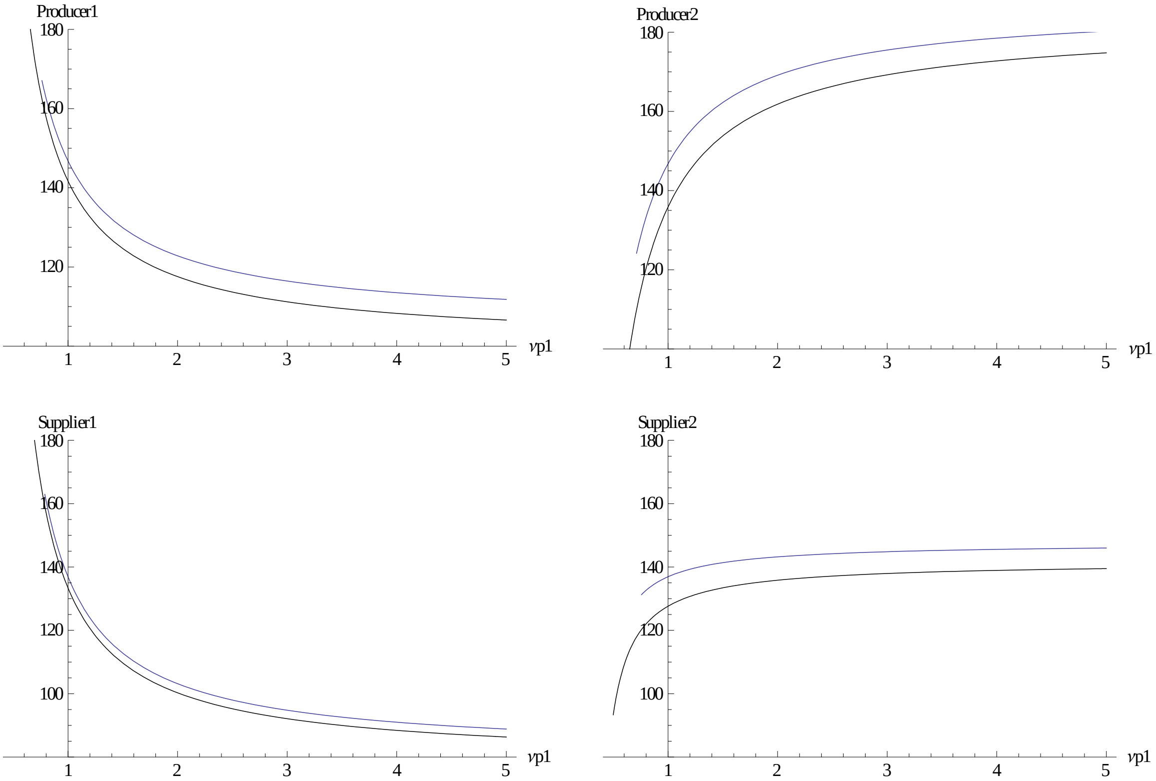


Figure 18

First Scenario: Two Suppliers are located in Different Regions with $\gamma = 0.2$ (Green: Case 1 & Red: Case 2)

$(a = 100, b = 2, \bar{C} = 20, \bar{P} = 30, \beta_r = 0.1, \beta_t = 0.05, v_{P_1} = v_{S_1} = v_{S_2} = 5)$

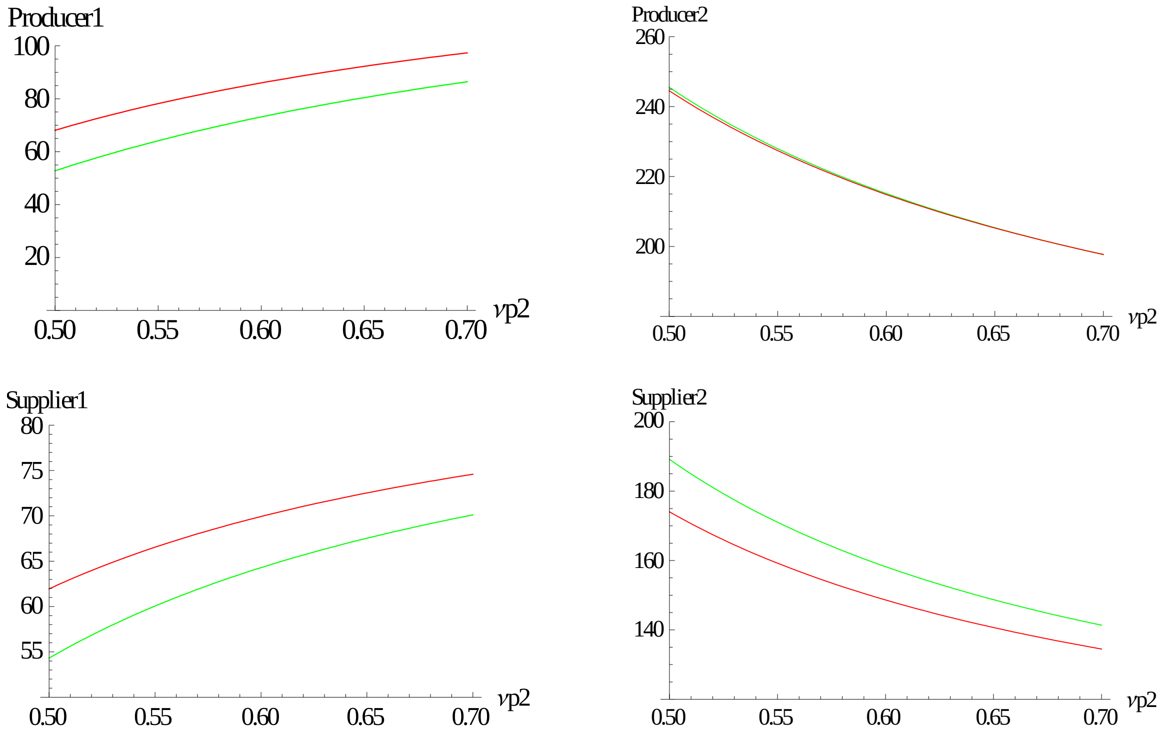


Figure 19

Second Scenario: Two Suppliers are located in Same Region with $\gamma = 0.2$ (Green: Case 1 & Red: Case 2)

$(a = 100, b = 2, \bar{C} = 20, \bar{P} = 30, \beta_r = 0.1, \beta_t = 0.05, v_{P_1} = v_{S_1} = v_{S_2} = 5)$

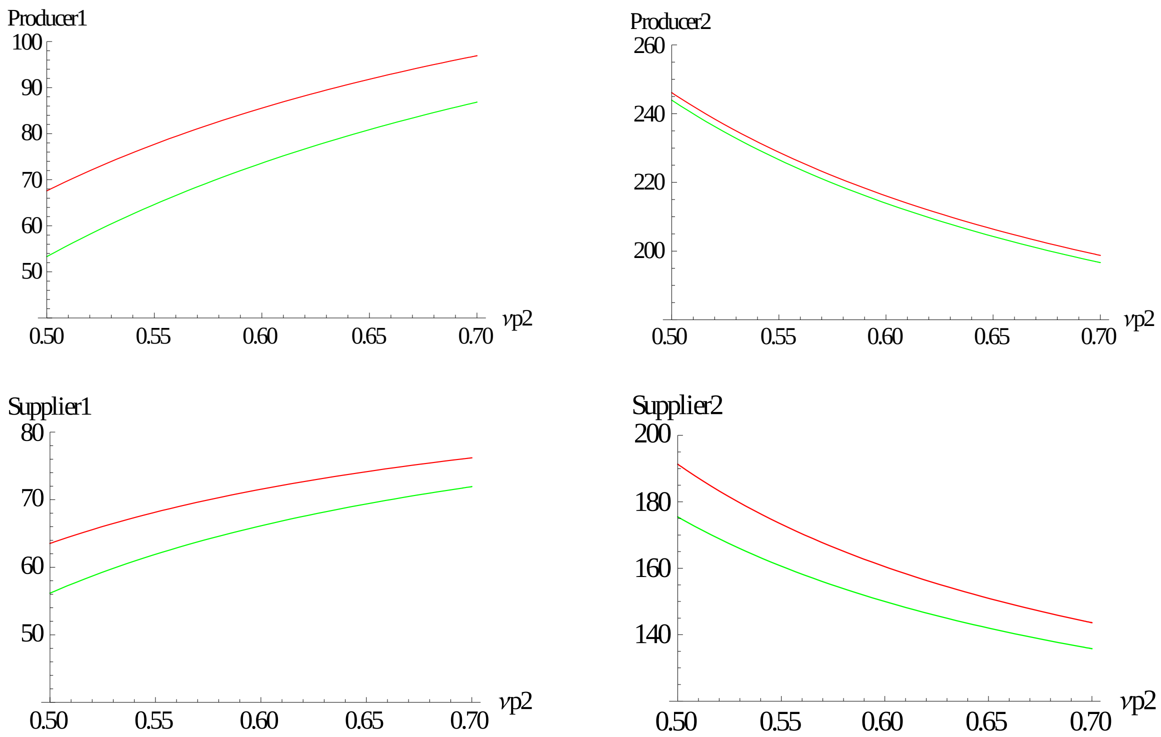


Figure 20

First Scenario: Two Suppliers are located in Different Regions with $\gamma = 0.12$ (Black: Case 1 & Blue: Case 2)

$(a = 100, b = 2, \bar{C} = 20, \bar{P} = 30, \beta_r = 0.1, \beta_t = 0.05, v_{P_1} = v_{S_1} = v_{S_2} = 5)$

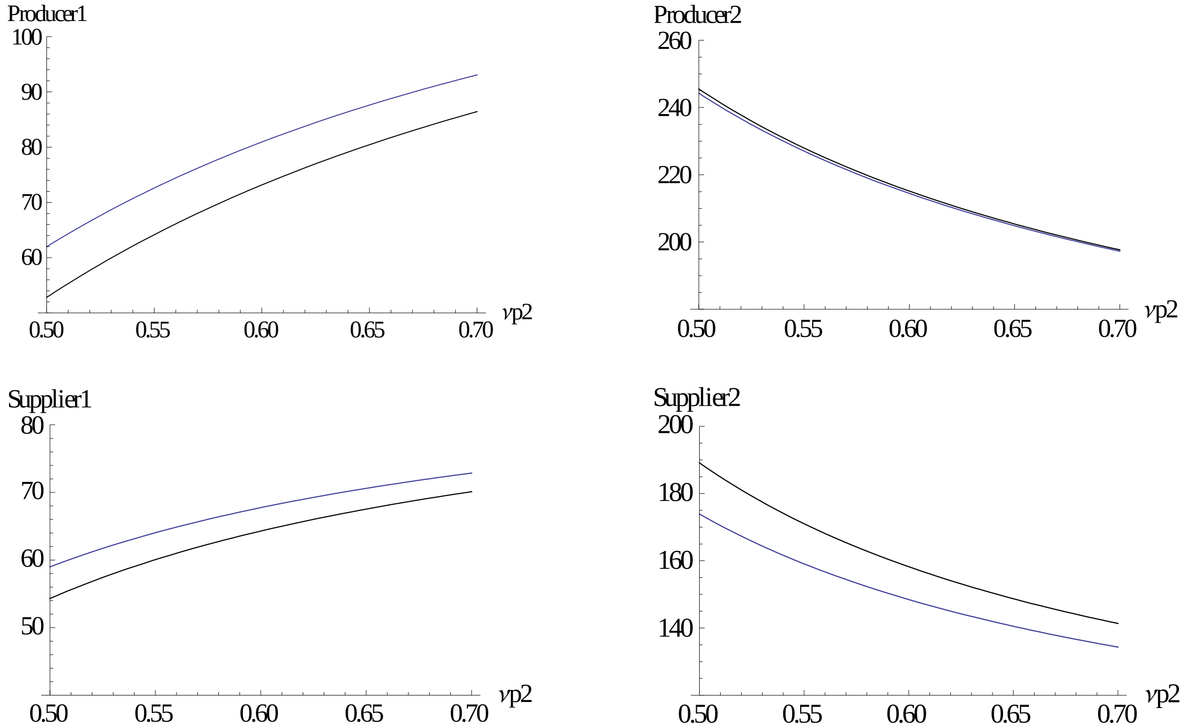
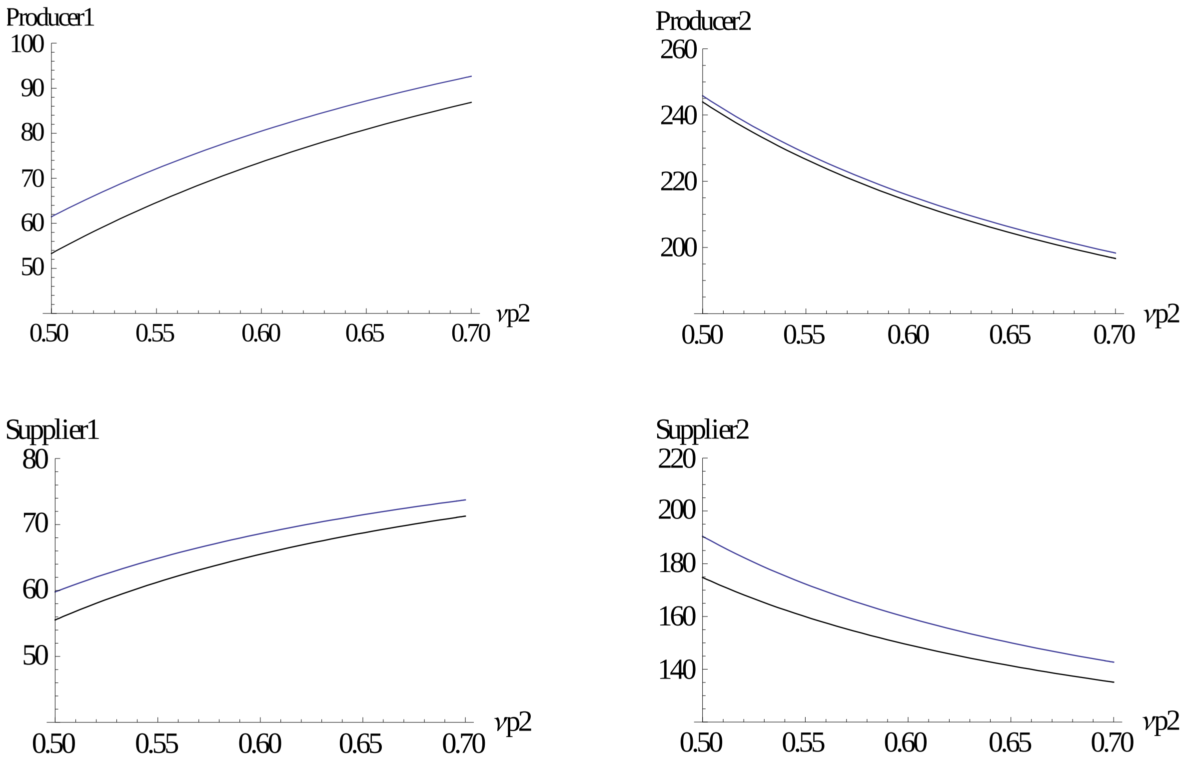


Figure 21

Second Scenario: Two Suppliers are located in Same Region with $\gamma = 0.12$ (Black: Case 1 & Blue: Case 2)

$(a = 100, b = 2, \bar{C} = 20, \bar{P} = 30, \beta_r = 0.1, \beta_t = 0.05, v_{P_1} = v_{S_1} = v_{S_2} = 5)$



5. Conclusion

Knowledge as a source of competitive advantage plays a vital role in nowadays business affairs such that in many cases affects the location decision of firms directly. Particularly, when we consider the location decision of innovative technology-based companies, the issue becomes more significant.

In this research we tried to answer the question that under which circumstances vertical knowledge spillover via supply chain lead us to geographical concentration which Porter (1998) named it cluster.

For this purpose a three-stage game theoretic model based on the inspiration of existing model in the literature of innovation, knowledge spillovers and economic geography has been established to empower us analyzing the subject more accurate. In our model we distinguished vertical knowledge spillover which occurs between a producer and its respected supplier from horizontal one happening between two firms of the same stream of the market. Moreover different technological level of our players was analyzed separately. Numerical approach with the utilization of Mathematica is applied to solve our strategic optimization problem.

Results show that based on the selected values of parameters, imposed assumptions, and designed scenarios, different location decision might be made in which firms act within clusters or isolation. Observations 1-8 express the results which have been supported by graphs induced from our programming. Because of having reliability on our observations, broad ranges of parameters have been examined in order to guarantee the robustness of equilibrium outcomes.

A main limitation of this paper which leads the research to enter numerical analysis was the mathematically complicated nature of final equations. This made the comparison between different scenarios completely intractable. Another limitation was the number of scenarios that we have considered that is more probable scenarios could enrich the results.

Finally it might be useful to mention that different approaches can be applied to extend this work. Altering or relaxing each of our established assumptions in section

3 would open a new door, e.g. specific designed scenarios upon disposal of our supplier, assuming exogenous knowledge spillovers, can be developed. Moreover we have assumed that each producer is able just to provide his intermediate goods from his respected supplier and also each supplier can sell it only to his respected producer which would be an appropriate aspect of extension.

Chapter 2

Strategic Technology Choice and Capacity Investment Decision: The Role of Salvage Market

This essay examines the effect of salvage market on strategic technology choice and capacity investment decision of two firms that compete on the amount of output they produce under demand uncertainty. A game theoretic model applies such that in the first stage firms choose their production technology between two alternatives: modular production process (flexible technology) or unified production process (inflexible technology). Then at the second stage they decide on the amount of capacity investment: flexible firm makes decision about general and specific components' capacity and inflexible firm just about unified component (final product). One stage forward both enter the primary market in which demand is uncertain and play a duopoly Cournot game on the amount of quantity they manufacture and finally at the last stage, flexible firm will be able to sell its unsold general components in the secondary market (salvage market) with a deterministic price. Solving optimization problems of the model results

in intractable equations which lead us to employ numerical studies considering a specific probability distribution to observe equilibrium behavior of competing firms. Broad range of parameters with respect to established relationships among them have been examined in order to cover all the possible economically reasonable scenarios. Findings are expressed explicitly in the form of observations where we demonstrate that with symmetric parameterization there is a unique symmetric Nash equilibrium in which both firms choose inflexible technology while applying asymmetric parameters has the potential to form two types of equilibrium when 1. Both firms choose inflexible technology or 2. Only one firm chooses flexible technology. Moreover it is shown that there is a specific unified cost threshold that could shift the equilibrium of the game. Finally we discuss on the case that there is no equilibrium and mention some managerial implications of the model.

1. Introduction

Intensive competition in global market and product-differentiation strategies of firms force the companies to make their investment decisions in more uncertain environment than before. Uncertainty about the size of the market for potential product and the purchasing behavior of consumers affect the strategic technology choice and capacity investment decision of firms. Actually operation managers try to minimize supply-demand mismatches by considering all available options in the competitive context before choosing their production line technology and decide on their capacity investment. On the other hand in some industries of developing countries there are large demands for unsold components of some industries in developed countries. In fact developing countries could play the role of salvage market for some companies that encounter low demand realization in the competitive market. Supplying residual general components of some products with prices lower than total cost although implies negative numbers in bottom line of financial statements of a company, has the potential of covering some greater loss. Consequently, investment on a modular production line that can further assemble a general and specific component of the final product create the opportunity to respond to the probable demand for unsold components in secondary market. Moreover it can equip the firm with a production technology to hedge against demand uncertainty. Obviously firm should pay more for extra desirability.

In this paper we explore how the existence of a secondary non-sale capacity market (which we call it salvage market) for unsold general components of a producer affects its strategic technology choice and respected capacity investment decision considering demand variability in the primary market. Our point of departure is the Goyal and Netessine (2007) three-stage model of technology, capacity investment and production games. They show that how a monopolist and duopolist respond to a given flexibility premium. Moreover in contrast with common belief, they conclude that flexibility is not always the best response to competition such that flexible and dedicated technologies may coexist in equilibrium. They consider two firms that invest in two products and compete with each other in two markets. We introduce salvage market with specific characteristics to their model in which the flexible firm who invests in more expensive technology is able to resell its residual general components with loss. Indeed we focus on the strategic decisions of two producers upon choosing modular versus unified production line. Modular production line (flexible technology) is designed to assemble general and specific components with higher total cost but can be used as strategic weapon in the presence of demand uncertainty by postponing the production process. On the other hand unified production line (inflexible or dedicated technology) manufactures the final product without any assembly phase with lower total cost and can be used as commitment device for the producer which ensures the customers of receiving certain amount of goods regardless of the demand realization in the primary market. Furthermore flexible firm will be able afterwards to enter the salvage market reselling its residual general components with loss, the advantage that does not exist for inflexible producer.

In order to solve the model we have been obliged to apply numerical approach because of intractability of our final equations and integrals. Moreover uniform distribution function is assumed for handling our demand uncertainty. Under symmetric parameterization we demonstrate that there is a unique symmetric Nash equilibrium such that both producers decide on choosing inflexible (or dedicated) technology and produce the final product via unified production process. In addition optimal capacity and profits of firms are strictly increasing in mean and standard deviation of the demand intercepts. Under asymmetric parameterization we reach two types of equilibria such that whether both firms choose inflexible technology or just one firm chooses the flexible technology. There is a threshold unified cost around which equilibrium can shift. Disequilibrium also can emerge under some range of parameterization such that we show equilibrium in pure strategies for capacity investment fails to exist if the degree of demand variability exceeds a threshold level. The point is that this range of parameters is far from real-world business considerations.

This paper contributes to the available outstanding literature on manufacturing flexibility and production technology by studying the effect of the existence of a non-sale-capacity market which we call it salvage market (or secondary market B) on the technology choice and capacity investment decision of firms that compete under demand uncertainty. We think that it is worthwhile to investigate this uncovered area of the literature via a separated study.

The remainder of this paper is organized as follows. In part 2 we briefly review the available related literature in OM and IO. Section 3 explains the basic general model, and §4 deals with the methodology of solving our problem. In section 5 we report and discuss the findings of our extensive numerical studies plus managerial implication of this setting, and §6 concludes this paper. Technical appendix at the end of the paper details the calculation of the model and respected assumptions.

2. Literature Review

Seminal papers in the field of industrial economics and operation management deal with this subject. Production and pricing postponement strategies of producers with respect to revelation of uncertain demand are at the heart of these researches, some investigate just the monopolistic scenario and others consider duopoly competition.

Chod and Rudi (2005) investigated the effect of resource flexibility and responsive pricing for a monopolist doing business in two markets. By using normal distribution in their paper, they show that capacity investment and respected profit are increasing in demand variability, a result that consistently exists in our competitive setting too. Considering market competition, Anupindi and Jiang (2008) endogenize capacity investment, production and pricing decision in their competitive model and evaluate the interplay between the timing of demand realization and production decision of firms with different capabilities. They also establish the strategic equivalence of price and quantity competitions when firms are flexible. Moreover in their model they characterize equilibria considering two different kinds of demand uncertainty: additive and multiplicative. In our model we deal with additive shock only. Reynolds and Wilson (2000) did their research on the context of symmetric Bertrand-Edgeworth competition and analyzed investment and pricing incentives of firms under demand variability. In their model firms decide on production level ex ante demand realization while price decision occurs ex post demand revelation. They show that if the extent of demand variation exceeds a threshold level then a symmetric equilibrium in pure strategies does not exist, a result that also observable in our findings.

Anand and Girotra (2007) investigate the strategic perils of delayed differentiation and its effect on consumer surplus and welfare. They demonstrate that in the presence of either entry threat or competition, these strategic effects can diminish the value of delayed differentiation (versus early differentiation). In their model they let the producers to decide on the timing of customization freely considering distribution center (DC). Fine and Pappu (1990) evaluate tactical and strategic usage of flexible manufacturing system (FMS) under market competition. Tactical as it helps firm to respond quickly to variation in demand within a market or to decrease the level of inventory and strategic as it equips the firm with a tool to defend its own market and to enter the markets of its less flexible rival. Actually in their two-firm repeated-game model, flexibility serves as a mechanism to prevent market entry by having the potential power of attacking to the competitor’s markets (grim strategy). Indeed they show how the availability of FMS can make firms worse off.

McCabe (2011) in its empirical study evaluates the reliability factors for salvage value of photovoltaic (PV). He expressed that as PV system prices become less expensive, the salvage value can be increasingly important in life cycle economic calculations. He concludes that there is a healthy resale market for PV modules that should be recognized in project level economic evaluation and as systems costs become lower and lower (because of competition), salvage value has more significant ramifications.

Cachon and Koek (2007) explain how to estimate a salvage value of an unsold order. They pointed a quote that describes the economics of selling fashion ski apparel, as faced by Sport Obermeyer: "units left over at the end of the season were sold at a loss that averaged 8% of the … price." They believe that choosing a fixed salvage value is questionable and its pricing depends on the amount of left inventory.

3. The Model

Consider an economy in which two firms indexed by i and j, $i, j = 1, 2$ and $i \neq j$ producing a homogenous final product. Both firms are assumed to be risk neutral and maximize their expected profits considering the actions of respected rival. Based on the production process technology a single firm chooses, it will be able to produce the final product via whether the unified process or the modular process.

Choosing unified production process enables a firm to manufacture the final product with lower costs and also can be interpreted as a strategic commitment device whereby a firm commits to bring a certain quantity to market (Anupindi, Jiang 2008). On the other hand, choosing modular production process implies that a firm invests on a more expensive technology which empowers it to manufacture the final product with higher costs by producing a general component – which can be used in other products- assembled sequentially with a specific component which is specialized for certain product based on the demand information of the market.

Following the terminology of Anupindi and Jiang (2008), we assume that the firm invests on unified production process is inflexible (N) and the one chooses the modular process is flexible (F) as well. Also we assume that a firm cannot invest in flexible and inflexible technologies simultaneously.

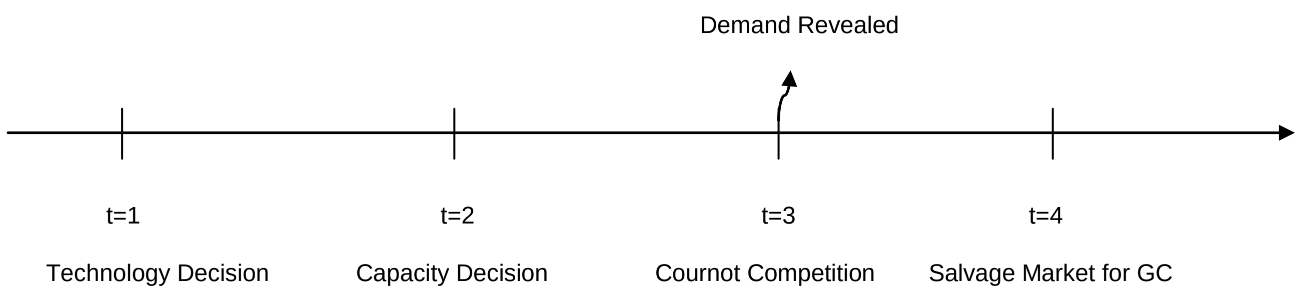
Flexible firm will be able to postpone its production ex post realization of demand which implies more effective reaction to the volatility of market; so it needs to tradeoff the higher costs of flexibility and its ability to hedge against demand uncertainty. On the other hand, inflexible firm commits to produce a certain amount of final good ex ante revelation of demand.

We consider two separated markets here: Market A and market B in which our firms could compete with each other. Market A is the primary market in which demand is uncertain and regardless of the technology choice of our firms, they compete on the quantity of final output in it. (Cournot duopoly competition) Market B is the secondary market with deterministic demand for the general component of the final product which can be produced only by the firm chooses the flexible technology. In fact inflexible firm cannot enter this market. Clearly speaking, there is no demand for the final product or specific component in market B. Price is also set beforehand less than unit cost of general component procurement.

This paper contributes to the available outstanding literature on manufacturing flexibility and production technology by studying the effect of the existence of a non-sale-capacity market which we call it salvage market (or secondary market B) on the technology choice and capacity investment decision of firms that compete under demand uncertainty.

A four-stage game theoretic model is applied such that in the first three stages, our firms play a simultaneous-move non cooperative game with complete information.

Figure 1: Four-Stage Static Game



In the first stage $t=1$, each firm can invest either in a flexible technology (F) that enables it to manufacture both general and specific components - which later can be assembled and sold in market A or supplies the general component with known price to market B - or an inflexible technology (N) which allows the firm to produce and supply the final product with lower production costs and higher commitment to market A.

Following Goyal and Netessine (2007), three subgames can potentially emerge:

1. Mixed subgame in which one firm invests in flexible and its rival in inflexible technology denoted by m. ((F,N) or (N,F))
2. Flexible subgame in which both firms invest in flexible technology and have the opportunity to supply the general component in market B, denoted by f. (F,F)
3. Inflexible subgame in which both firms choose inflexible technology and the game lasts until the end of the third stage, denoted by n. (N,N)

The superscript expresses the subgame which our firm plays denoted by m, f or n. Moreover to differentiate firms from each other, the firm index i, j appears in the subscript as well.

In the second stage $t = 2$, each firm invests either in a production capacity of the final product via the unified production process when it adopts inflexible technology or in general and specific components' capacities when it chooses flexible one considering the point that general component can be sold separately in market B. Subscripts g and s refer to general and specific components respectively. Moreover subscript u refers to the final product which is manufactured via unified process.

We denote all capacities by X, e.g. X_{gi}^{m} is the capacity of the general component which can be produced by firm i when its rival chooses inflexible technology. (Mixed subgame)

Capacity investment is costly and we let these costs to differ by firms. We assume that the cost of purchasing general and specific resources be c_{gi} and c_{si} per unit respectively and the cost of the inflexible resources be c_{ui} per unit for firm i. We let the total costs of producing a unit of the final product via the modular process to be $C_{Mi} = c_{gi} + c_{si}$ while for the unified process to be $C_{Ui} = c_{ui}$ and so $C_{Ui} < C_{Mi}$. For the sake of simplicity, we ignore the assembly cost of general and specific component and assume that it is sunk in c_{gi} and c_{si}.

The expected optimal payoff of the firm is denoted by Π, so e.g. Π_{Mi}^{m} denotes the expected profit of firm i that compete with firm j in the mixed subgame and invests in two general and specific components via the modular production process technology with capacities X_{gi}^{m} and X_{si}^{m}.

In the third stage $t = 3$, firms play a Cournot duopoly game on the quantity of final product they manufacture denoted by q. This decision is ex post because at the time of production, the firm is better aware of the market demand information.

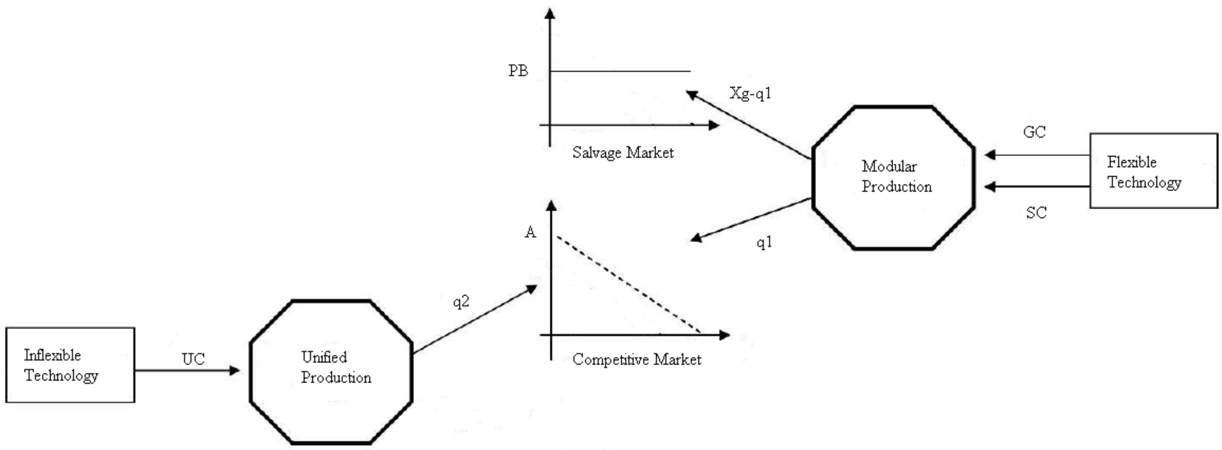
The linear inverse demand function for the final product which is supplied to market A is $P_A\left(A_A, Q_A\right) = A_A - Q_A$ in which $Q_A = q_{iA} + q_{jA}$ is the total quantity of the final product supplied to the primary market by our firms combined. (Cournot competition model with linear demand function) and P_A is price of the final product in market A which is assumed to be nonnegative. Subscript A refers to the primary market A.

Demand uncertainty appears in the intercepts of the linear inverse demand function, $A_A \in \Re_+$ which draws from a continuous distribution function F with density function f The mean and variance of the marginal distribution is denoted by μ_A and σ_A^2 respectively.

We denote profit in the Cournot game by π and E represent the expectation operator with respect to the random variable A_A. Following Goyal and Netessine (2007), marginal cost of production in this stage is normalized to zero. We consider this cost in our capacity decision stage.

Finally in the last stage $t = 4$, the firm that has chosen the flexible technology can enter the secondary market B and supplies its unsold general components as a price taker with the deterministic price less than the unit procurement cost of general component which is $P_{Bi} < c_{gi}$. Consistent with Roller and Tombak (1990, 1993), modular production process is a prerequisite for entering the secondary market. Figure 2 which is inspired by Anand and Girotra (2007) visually summarizes the explained procedure.

Figure 2: Modular vs. Unified Production Process



3.1. Problem Formulation

Based on the technology choice of our firms which we categorized as three different subgames, this stage could contain zero, one or two player as well. We denote payoff in market B by V which is revenue minus costs there.

Following Fine and Pappu (1990) and Roller and Tombak (1990, 1993), we can simply show the technology choice of the firms in a strategic-form game by a 2×2 matrix as depicted in following page. Matrix entries represent profits in the second-stage capacity game. Backward induction is applied to capture the subgame perfect Nash equilibrium (SPNE) of this model. Hence we move by analyzing from the last stage $t=4$ considering all three possible subgame of the technology choice of our firm. The optimization problem for a firm i that chooses modular production process technology (Flexible firm) for any strategic choice of its competitor j is:

<u>Stage 4: Secondary Market for General Component</u>

$\nu_i = \max_{q_{iB}} [q_{iB}.P_{Bi}]$ Such that $0 \le q_{iB} \le \left(X_{gi} - q_{iA}\right)$

Stage 3: Cournot Duopoly Competition

$\pi_{Mi} = \max_{q_{iA}} \left[\left(A_A - q_{iA} - q_{jA}\right).q_{iA} + \nu_i\right]$ Such that $0 \le q_{iA} \le \min\left[X_{gi}, X_{si}\right]$

Stage 2: Capacity Decision Investment

$\Pi_{Mi} = \max_{X_{gi}, X_{si}} \left[E\left(\pi_{Mi}\right) - c_{gi}.X_{gi} - c_{si}.X_{si}\right]$ Such that $X_{gi}, X_{si} \ge 0$

The optimization problem for a firm i that chooses unified production process technology (Inflexible firm) for any strategic choice of its competitor j is:

Stage 4: Secondary Market for General Component

$\nu_i = 0$

Stage 3: Cournot Duopoly Competition

$\pi_{Ui} = \max_{q_{iA}} \left[\left(A_A - q_{iA} - q_{jA}\right).q_{iA}\right]$ Such that $0 \le q_{iA} \le X_{Ui}$

Stage 2: Capacity Decision Investment

$\Pi_{Ui} = \max_{X_{ui}} \left[E\left(\pi_{Ui}\right) - c_{ui}.X_{ui}\right]$ Such that $X_{ui} \ge 0$

Figure 3: The Strategic-Form of the Technology Game

		Firm j F	Firm j N
Firm i	F	Π^f_{Mi}, Π^f_{Mj}	Π^m_{Mi}, Π^m_{Uj}
	N	Π^m_{Ui}, Π^m_{Mj}	Π^n_{Ui}, Π^n_{Uj}

4. Methodology

In order to solve the model and find the technology choice as well as optimal capacity investment decision of each firm, we proceed by considering each subgame of the model. Backward induction is applied to find the optimal payoff of each probable subgame which afterwards will be located as entries of our mentioned matrix to analyze the equilibria of the model. For the sake of simplicity, we make two assumptions and establish a lemma as follows:

Assumption 1: We assume that both firms enter the game, choose a production technology and make a positive capacity investment which implies that $P(A_A, 0) \geq c'_M(0)$ for any realization of demand.

Assumption 2: We assume that price is nonnegative for any realization of demand.

Lemma 1: The flexible firm avoids the excess supply of specific components which exists no demand for it in the salvage market B that is $X_{Si} \leq X_{gi}$ or $\min\left[X_{Si}, X_{gi}\right] = X_{Si}$.

Based on the model described in previous section, we establish the Lagrangian function of firms in each of mentioned three subgames. Maximization problems are solved using first-order Kuhn-Tucker conditions, but whereas demand is uncertain when firms involve capacity investment decisions, we should consider different states. Each state could happen according to the different probable realization of market size shown by A. Hence backward induction approach implies that firms encounter expected profit functions in capacity investment game. Expectation operator leads us to integrals with the boundaries which are functions of capacities and this fact makes our calculation really messy and almost intractable. To simplify the problem we try to specify the probability distribution function of our random variable which appears in the intercept of linear inverse demand function and therefore uniform distribution function F with density $f(A)$ is chosen.

$$f(A) = \begin{cases} \frac{1}{M}, & 0 \leq A \leq M \\ 0, & Otherwise \end{cases}$$

Also we add a symmetry assumption between both firms on respected costs' and also salvage market price' parameters. (See assumptions TA.3 and TA.4 in appendix)

Whereas these assumptions did not reach us to some gentle equations, we employ an extensive numerical study to find out the strategic behavior of our agents. For this purpose, a wide range of plausible parameters' values chosen to represent realistic scenarios from the real-world businesses. These parameters include costs (general and specific component for flexible firm and unified component for inflexible one shown respectively by c_g , c_s and c_u), price of the residual general component of flexible firm in salvage market notated by P_B and finally M that is a finite positive sufficiently large number such that if demand realization were on the upper bound of probability distribution, all capacities are bounded. Here M has an important interpretation which is inherently in the nature of uniform distribution. Actually the mean and variance of uniform distribution simply are $\mu = \frac{M}{2}$ and $\sigma^2 = \frac{M^2}{12}$ respectively which means that the mean and variance of the random variable A (Reservation price of the market) is increasing in M . For each parameter combination, we calculated the equilibrium under assumed subgames and determined capacities and profits. The numerical study consists of a large amount of instances resulting from every possible combination of the values listed in Table 1. Detailed calculation of mathematical stuff is put simply in technical appendix.

Table 1: Parameter Values Used in Numerical Study

Parameter	Values
Demand Distribution	Uniform
M	(3,120)
μ	$\frac{M}{2}$
σ^2	$\frac{M^2}{12}$
c_u	(1,10]
c_g	(0.75,10]
c_s	(0.75,10]
P_B	(0.5,10)
Parameters' Relations:	$P_B < c_g, c_u < c_g + c_s$

5. Findings

The main part of our analysis contains the technology game in which both firms make decision between modular and unified manufacturing process that afterwards affects the capacity investment decision of them. Seminal papers including Goyal and Netessine (2007) or Chod and Rudi (2005), despite of some differences in modeling, tried to avoid numerical analysis in this phase and therefore imposed some additional assumptions to ease the analytical discussion. For example Goyal and Netessine (2007) assume that each firm produces to capacity called it *clearance*. Numerical approach to solve and analyze of this problem considering a specific distribution function is a missing part of literature that we are going to cover here. In order to preclude any uncovered set of parameters and results, we were obsessive in examining the parameters. For the purpose of having comprehensive results, also we investigate some sets of parameters which exist numerically but could be interpreted hard economically.

For implementing numerical method, first we choose a reference starting point and then apply incremental approach based on the assumed relationship between parameters, also try to investigate extreme values of them. Optimal capacities and respected maximum profits of producers subsequently are put in the matrix of technology game depicted in figure 3. In this phase probable equilibrium of the game can be found out by comparing some explicit numbers representing the firms' optimal profit. For detailed mathematical steps refer to technical appendix.

5.1. Best Reply Functions

In this subsection we are going to characterize the best reply functions of our producers in the capacity investment game. Lemmas 2-4 characterize the best response functions of both firms. Proofs are put in the technical appendix.

Lemma 2: In flexible subgame of the capacity investment game where both firms choose modular production process, optimal capacities are characterized by best response functions as follows:

$$-c_{s_i} - c_{g_i} + 0.25M + 1.5P_B - \frac{0.75P_B^2}{M} - X_{si} + \frac{P_B \cdot X_{si}}{M} - \frac{2.25X_{si}^2}{M} + \frac{4X_{si}X_{sj}}{M} - \frac{X_{sj}^2}{M} = 0, \quad for\ firm\ i$$

$$-c_{s_j} - c_{g_j} + P_B - \frac{P_B \cdot X_{si}}{M} - \frac{2X_{si}^2}{M} + \frac{4P_B X_{sj}}{M} + \frac{4X_{si}X_{sj}}{M} - \frac{2X_{sj}^2}{M} = 0, \quad for\ firm\ j$$

Lemma 3: In inflexible subgame of the capacity investment game where both firms choose unified production process, optimal capacities are characterized by best response functions as follows:

$$-c_{u_i} + \frac{M}{2} - 2X_{ui} + \frac{1.5X_{ui}^2}{M} - X_{uj} + \frac{2X_{ui}X_{uj}}{M} + \frac{X_{uj}^2}{M} = 0, \quad for\ firm\ i$$

$$-c_{u_j} + \frac{M}{2} - X_{ui} + \frac{X_{ui}^2}{2M} - 2X_{uj} + \frac{2X_{ui}X_{uj}}{M} + \frac{2X_{uj}^2}{M} = 0, \quad for\ firm\ j$$

Lemma 4: In mixed subgame of the capacity investment game where one firm chooses modular production process while the competitor chooses unified one, optimal capacities are characterized by best response functions as follows: (without loss of generality we assume firm i is flexible and firm j is inflexible)

$$-c_{g_i} - c_{s_i} + P_B + \frac{M}{2} - 2X_{si} + \frac{6P_B X_{si}}{M} + \frac{(-2P_B - 2X_{si})\cdot X_{si}}{M} + \frac{9X_{si}^2}{2M} - X_{uj} + \frac{2X_{si}X_{uj}}{M} + \frac{-P_B^2 - 2P_B X_{si} - X_{si}^2 + X_{uj}^2}{M} = 0, \quad for\ firm\, i$$

$$-c_{uj} + \frac{M}{2} - X_{si} + \frac{X_{si}^2}{2M} - 2X_{uj} + \frac{2X_{si}X_{uj}}{M} + \frac{2X_{uj}^2}{M} = 0, \quad for\ firm\ j$$

Optimal capacities afterwards should be plugged in respected profit functions to lead us toward equilibria.

5.2. Symmetric Parameterization

Here we start our analysis by assuming symmetry in parameters such that both firms face similar cost of capacities in symmetric subgames (F,F) and (N,N). Moreover in flexible subgame each should sell the rest of their general component in salvage market with a fixed predetermined price P_B. (See assumption TA.4 in technical appendix) Figure 4 shows the pair of parameters for each producer that is considered as inputs of numerical solution.

Figure 4: Symmetric Parameterization

		Firm j: F	Firm j: N
Firm i	F	(c_s, c_g, P_B, M) (c_s, c_g, P_B, M)	(c_s, c_g, P_B, M) (c_u, M)
	N	(c_u, M) (c_s, c_g, P_B, M)	(c_u, M) (c_u, M)

Observation 1: Under symmetric parameterization condition, the unique equilibrium of the technology game is the subgame (N,N) that is both firms choose inflexible technology and produce the final product via unified production process. Moreover

this is a symmetric equilibrium such that both choose same amount of capacity investment that is $x_{Ui}^{*n} = x_{Uj}^{*n}$ which leads to the same optimal profits $\Pi_{Ui}^{*n} = \Pi_{Uj}^{*n}$.

Observation 2: Optimal capacity and respected profits of firms are strictly increasing in mean $\mu = \frac{M}{2}$ and variance $\sigma^2 = \frac{M^2}{12}$ of the demand intercept and strictly decreasing in the cost of unified component c_u. (Figures 5 and 6 depict the result for specific amount of parameters.)

Choosing inflexible technology (or unified production process here) can be interpreted as a strategic device whereby a firm commits to bring certain quantity to market. Actually the firm benefits more from the value of this commitment rather than any flexibility premium it may obtain from the capability to postpone production (Anupindi, Jiang 2008). Our first observation is also consistent with the result of Anupindi and Jiang (2008) that is when $\mu = \frac{M}{2} > c_u$ and distribution $F(.)$ has IGFR (Increasing Generalized Failure Rate) property, which uniform distribution has, there exist unique symmetric equilibrium capacity of a firm in a symmetric inflexible duopoly.

The second observation is different from the finding of Goyal and Netessine (2007) that capacity decisions do not depend on variance of demand intercepts. In fact this happens because of the nature of specific probability distribution we choose (Uniform distribution) and also relaxing a tough assumption of that seminal paper that was each firm produces to capacity. The main reason is inherent in the characteristics of uniform distribution such that any change in M causes the simultaneous changes in mean and also variance of demand intercepts (Figure 7).

Although in uniform distribution mean and variance are both the function of one variable, here M, but as it is shown in figure 7, for $M > 6$ variance becomes greater than mean and for $M > 3$ raises with higher rate than mean. It implies two effects which are happening with increment of M simultaneously: First, an increase in the amount of dispersion escalates the probability of both high and low demand realizations and second, a more attractive mean of market size.

Figure 5: Optimal Capacity Investment in Inflexible Subgame

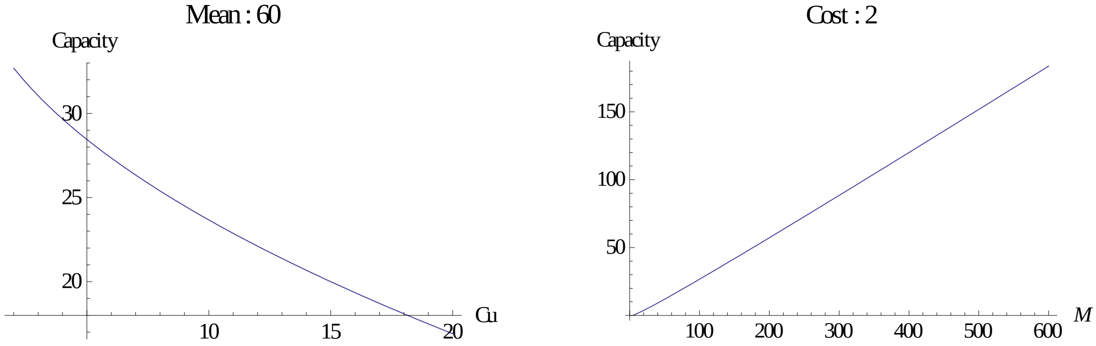
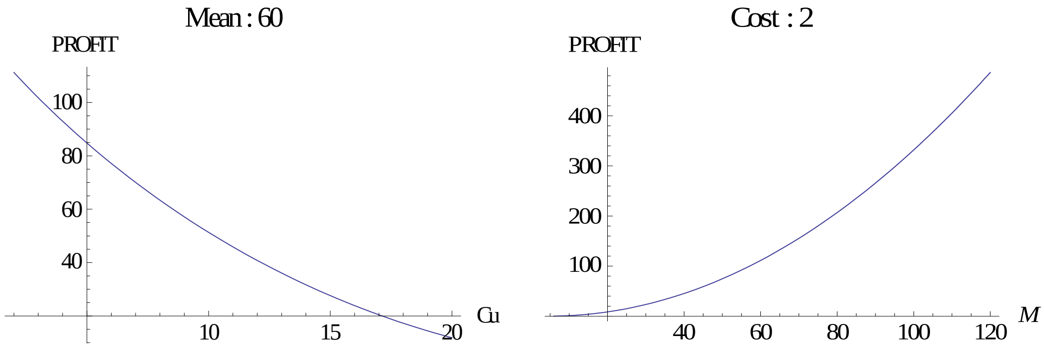


Figure 6: Optimal Profit in Inflexible Subgame

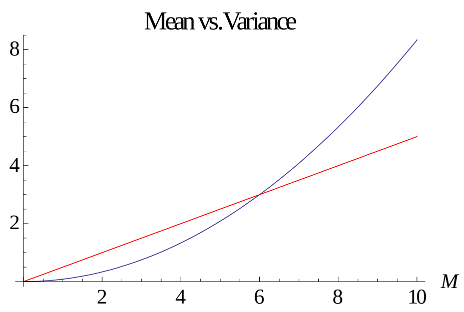


As it shown in figure 7 the first effect is stronger for $M > 6$ and vice versa. The first effect implies more uncertainty which intuitively might support the usage of flexible technology and the second effect reinforces the investment on inflexible production line in order to commit to a larger market with lower production cost. Furthermore higher variance and uncertainty spells that for some specific demand realizations, the market clearing price will be zero and so the firm faces some non-sale capacities that in the case of being flexible producer, will be able to enter salvage market and sell the general components with loss. Consequently both firms confront a complex trade-off which has a route in demand uncertainty and cost of producing unified component. Numerical analysis explicitly shows that both firms dominantly prefer to choose inflexible technology and (N, N) is the unique equilibrium of the technology game.

Moreover firms should take into consideration that choosing flexible technology, within this symmetric parameterization setting, needs two conditions to be more profitable decision: first, the competitor also should play F and second the firm should invest more rather than its rival on capacity; otherwise you encounter a big loss. Thus playing F has an incredible threat for each manufacturer which leads to the subgame (N, N). Indeed this situation is a kind of prisoner's dilemma game.

In the next subsection we run numerical method by considering kinds of asymmetry in some parameters of our established model.

Figure 7: Mean & Variance of Uniform Distribution



5.3. Asymmetric Parameterization

Here we relax the assumption of having symmetric parameterization and let our firms obtain their technologies with different investment costs. We can reasonably imagine a case in which both producers having access to similar inflexible technology but they can have different technological level of flexible modular production line. Actually we have implicitly assumed that flexible production strategy is a newer higher technological option that tries to strategically convince stakeholders to invest on it in order to reap more profits from the uncertain demand in the market in comparison with the available inflexible one which is accessible for all firms with same investment cost. Thus in this section we try to scrutinize the scenario that both firms encounter symmetric investment costs when choosing inflexible technology $c_{ui} = c_{uj}$ but asymmetric flexible technological level $c_{gi} \neq c_{gj}$. Figure 8 summarizes the respected parameters' consideration.

Figure 8: Asymmetric Parameterization

		Firm j	
		F	N
Firm i	F	(c_{si}, c_{gi}, P_B, M) (c_{sj}, c_{gj}, P_B, M)	(c_{si}, c_{gi}, P_B, M) (c_u, M)
	N	(c_u, M) (c_{sj}, c_{gj}, P_B, M)	(c_u, M) (c_u, M)

Observation 3: Depending on the relative cost of technologies and the upper bound of random variable M , it is possible to have two types of equilibrium which is 1. Both firms are inflexible (N, N) or 2. Only one is flexible $\{(F, N)$ or $(N, F)\}$.

Observation 4: There is a threshold cost of manufacturing the final product via unified production process $c_u^{Threshold}$, after which the firm with access to higher flexible technological capability (smaller c_M) finds it more profitable to alter its strategic technology choice from inflexible technology to flexible one which results in asymmetric equilibrium $\{(F, N)$ or $(N, F)\}$.

Observation 5: For sufficiently small amount of M relative to capacity costs, there is a unique Nash equilibrium for this game that is both firms choose inflexible technology (N, N) .

Observation 6: For sufficiently large amount of M relative to capacity costs, there is whether a unique Nash equilibrium for this game that is both firms chooses inflexible technology (N, N) or there is no pure strategy Nash equilibrium.

In this setting two factors actually have significant effects on strategic decisions of our players: first, the perception of producers about the parameter M which implies the maximum possible realization of our random variable A (intercepts of the inverse demand function). It is basically the art of marketing research activities of a company to estimate properly this influential parameter which appears in mean and also variance of the random factor and afterwards affects the strategic decision of firm and also plays role in determination of the amount of capacity investment and respected profits. Second, relative capacity costs of two rival firms which explicitly can change their strategic technology choice.

Moreover as we are working with uniform distribution in this setting, M at the same time clarifies two facts about the market: first, higher M spells more attractive mean of the price reservation. Second, an increase in M increases the likelihood of both high and low demand realizations that is although higher M motivates the producer to take the flexible modular production line but simultaneously increases the threat of higher loss because of very low demand realization and this kind of analysis is reinforced with usage of uniform distribution as we allocate same probability to each level of demand realization. Actually this is the main reason that we face disequilibrium in sufficiently large value of M with respect to capacity costs in some sets of parameters (Observation 6). On the other hand lower M implies less volatile market which decreases the motivation of investment in more expensive flexible technology such that in sufficient small values of M with respect to capacity costs (N, N) is the unique Nash equilibrium of the game (Observation 5).

Consistent with Anupindi and Jiang (2008) we encounter a threshold unified cost -which can be changed with respect to M and modular costs- that whenever $c_u < c_u^{Threshold}$, both firms choose inflexible technology and (N, N) is the unique Nash equilibrium of the game, but otherwise the firm with access to higher flexible technological level (lower c_M) finds it more profitable to invest on flexible production line. This results in the formation of asymmetric equilibrium $\{(F, N)$ or $(N, F)\}$ (Observations 3 and 4). Also it should be pointed out that when one manufacturer decides on this strategic move from symmetric inflexible choice to asymmetric flexible one, in some ranges of M it increases the profits of both firms and make them better off. This result depends critically on M such that with higher M the inflexible firm should invest less on capacity and makes less profit in comparison to its flexible rival. Actually higher M causes more marginal benefit for flexible firm which we intuitively expect.

In our setting as we focus on the effect of salvage market on strategic choice of producers and since the flexible firm is able to sell its unsold general components with predetermined price less than its cost there $P_B < c_g$, so in our parameterization we have weighted the modular cost with concentration on c_g rather than c_s and avoided the investigation of extreme scenarios that the main part of the total modular cost exist in specific components such that $c_s \gg c_g$. In fact in this case as the revenue of flexible firm in salvage market becomes subtle, there will be no motivation on choosing more expensive modular production line which implicitly bypasses the attraction of our salvage market.

Also it can be observed from numerical studies that the most amount of investment on capacities takes place in the symmetric flexible subgame in which both producers rely on their ability to sell their residual general components in salvage market with loss. Obviously here the firm that access to higher flexible technology (lower c_M) gets more profit. Although we have assumed that our firms are risk neutral this behavior shows a level of risk taking that is firms hope to face high demand realization in order to obtain more profit. As shown in figure 6 profit is convex and increasing with respect to demand uncertainty which also reinforce the idea of risk seeking behavior of producers. Moreover in this case and in the presence of uniform distribution, in higher M, risk of facing loss (negative profit) is also high. These are the main reasons that banned the existence of symmetric flexible equilibrium (F, F) as with low M it is not attractive to invest on more expensive less probable modular production technology and in sufficiently large range of M in comparison with inflexible unified technology, it is risky to take flexible technology while the higher standard deviation the larger probability of facing very low demand realization.

Example 1: (Observation 3, 4) Consider an economic situation in which both firms deal with these amount of parameters: maximum possible realization amount of demand intercept is considered $M = 24$, fixed price of the residual general component in the salvage market is $P_B = 1$, and costs of producing final product via modular and unified production process for firm i, j are expressed as following two scenarios:

Scenario 1: $c_{gi} = 1.1,\ \ c_{gj} = 1.5,\ \ c_{si} = c_{sj} = 1,\ \ c_{ui} = c_{uj} = 2$

Scenario 2: $c_{gi} = 1.1,\ \ c_{gj} = 1.5,\ \ c_{si} = c_{sj} = 1,\ \ c_{ui} = c_{uj} = 1.75$

Actually compare to second scenario, in the first scenario we have assumed that our first producer, here firm i, have access to higher level of flexible technology relative to inflexible one. Based on lemmas 2-4 and after calculation of optimal capacity investment decision of producers, optimal profits of them are depicted in figure 9 and 10 as follows.

Figure 9: Optimal Profits (Scenario 1)

Firm i \ Firm j	F	N
F	$\Pi^f_{Mi} = 0.76$ $\Pi^f_{Mj} = 7.5$	$\Pi^m_{Mi} = 15.04$ $\Pi^m_{Uj} = 13.44$
N	$\Pi^m_{Ui} = 31.77$ $\Pi^m_{Mj} = 11.33$	$\Pi^n_{Ui} = 13.57$ $\Pi^n_{Uj} = 13.57$

Figure 10: Optimal Profits (Scenario 2)

Firm i \ Firm j	F	N
F	$\Pi^f_{Mi} = 0.76$ $\Pi^f_{Mj} = 7.5$	$\Pi^m_{Mi} = 14.22$ $\Pi^m_{Uj} = 14.47$
N	$\Pi^m_{Ui} = 33.71$ $\Pi^m_{Mj} = 10.85$	$\Pi^n_{Ui} = 14.38$ $\Pi^n_{Uj} = 14.38$

As shown in above mentioned figures, in the first scenario we have asymmetric equilibrium of (F, N) while in the second scenario both firms choose inflexible technology and (N, N) is equilibrium (Observation 3). Indeed there is a threshold cost of manufacturing the final product via unified production process $c_u^{Threshold}$, here a number between 1.75 and 2.0, after which the firm with access to higher flexible technological capability (smaller c_M) chooses modular production process (Observation 4). □

Example 2: (Observation 5) In this example consider the case in which both firms estimate a small value for maximum possible realization of our random variable that is $M = 8$, price in the secondary market is assumed to be constant $P_B = 1$ and costs of producing final product via modular and unified production process for firm i, j are expressed as follows: $c_{gi} = 1.1,\ c_{gj} = 1.5,\ c_{si} = c_{sj} = 1,\ c_{ui} = c_{uj} = 2.1$. Optimal profits of producers are shown in figure 11. As you see in the cost structure of this example, intuitively for firm i is better to invest on flexible technology because first, there is no cost advantage in choosing unified production line and second it can react more accurately to demand uncertainty in the primary market. But on the contrary because of the important role of M we will see that under competition it prefers to choose inflexible technology and (N, N) is the unique Nash equilibrium. □

Example 3: (Observation 6) Now consider the case in which both firms estimate a large value for maximum possible realization amount of demand intercept that is $M = 50$, price in the salvage market is fixed to $P_B = 1$ and costs of producing final product via modular and unified production process for firm i, j are expressed as follows: $c_{gi} = 1.1,\ c_{gj} = 1.5,\ c_{si} = c_{sj} = 1,\ c_{ui} = c_{uj} = 2.05$. Optimal profits of producers are shown in figure 12. As it can be induced from the matrix, there exists no pure strategy Nash equilibrium in this setting of parameters in which firm i has access to a higher technological level of modular production line. A technology which is approximately imposes same costs in comparison of employing unified production line. (If we decrease the unified cost from 2.05 there is a threshold cost under which (N, N) is the unique Nash equilibrium of the game) □

Figure 11: Optimal profits (Example 2)

Firm i \ Firm j	F	N
F	$\Pi^f_{Mi} = NA$ $\Pi^f_{Mj} = NA$	$\Pi^m_{Mi} = 0.41$ $\Pi^m_{Uj} = 0.97$
N	$\Pi^m_{Ui} = 1.57$ $\Pi^m_{Mj} = 0.05$	$\Pi^n_{Ui} = 0.44$ $\Pi^n_{Uj} = 0.44$

Figure 12: Optimal profits (Example 3)

Firm i \ Firm j	F	N
F	$\Pi^{f}_{Mi} = 18.7$ $\Pi^{f}_{Mj} = 127.2$	$\Pi^{m}_{Mi} = 79.17$ $\Pi^{m}_{Uj} = 73.27$
N	$\Pi^{m}_{Ui} = 171.4$ $\Pi^{m}_{Mj} = 69.7$	$\Pi^{n}_{Ui} = 74.17$ $\Pi^{n}_{Uj} = 74.17$

5.4. Managerial Implication

Intensive competition in free market and product-differentiation strategies of firms force the companies to make their investment decisions in more uncertain environment than before. Uncertainty about the size of the market for potential product and the purchasing behavior of consumers affect the strategic technology choice and capacity investment decision of firms. Considering minimum supply-demand mismatches plus investment costs enter the strategic decision making process of CEOs.

For this purpose managers take into consideration the possibility of using flexible technology which enables them to customize the final product based on the request of consumers and also avoid huge inventory costs. They can reduce the production lead time and wait more to obtain updated near-to-real information about the consumers demand. This strategy has its own disadvantageous, for instance could affect the long term contracts of the firm with its suppliers or direct customers such that the firm could not commit to sell a specific quantity of raw materials or bring a certain amount of the final product to the market and it may cause the reduction in long-run profits. Moreover access to this kind of modular production lines has more investment costs that should be considered beforehand.

As shown in our results choosing flexible technology is not always the best strategic choice of a company, rather, in the presence of competition and uniform probability distribution, in more cases firms avoid of taking that. Actually managers should characterize carefully a complex set of parameters such as investment costs, distribution function of the random variable (intercepts of the inverse demand function) and its respected elements. Here we try to focus on a specific situation that was not investigated in previous literatures such that the flexible producer is able to enter a secondary less attractive market to sell its unsold general components. Indeed these residual general components are the result of low demand realization.

Incidentally managers should be obsessive in determination of influential parameters since they can shift the equilibrium of the game and affect capacity investment as well as firm's profit. For example as it was shown, asymmetry in the flexible costs could convince a CEO to choose a different production technology from its rival or high enough estimation of M could adversely influence strategic decision of firms because of disequilibrium outcome.

Finally it was discussed in this research that the existence of a salvage market which might be ignored in some strategic-level decisions like technology choice could be important. Basically it is an opportunity to encourage managers to take more risk under uncertain market demand structure.

6. Conclusion

In this paper we present a model to focus on the effect of the existence of a non-sale capacity market (salvage market) on strategic technology choice and capacity investment decision of two firms that compete under stochastic price-dependant demand structure. Actually we take a different approach toward the concepts of flexible production technology and product postponement. Our model is inspired by seminal previous research in this field like Goyal & Netessine (2007) and Anupindi & Jiang (2008). In this setting each firm involves in three non-cooperative games: technology game (flexible vs. inflexible), capacity investment game (general, specific and unified components) and finally duopoly Cournot game on the amount of quantity. We assumed that flexible firm has the permission to enter the salvage market to ameliorate its excess investment in general components that could occur because of low demand realization. The model is presented in general form, but as it could be followed in technical appendix some simplifying assumptions were essential for solving purposes. Assuming uniform distribution function also did not help us arriving to explicit tractable destination, thus numerical analysis considering broad range of parameters is applied.

We show that depending on the specific values of the problem parameters, three equilibria including (N,N), (F,N) and (N,F) could arise. It was discussed that under symmetric problem parameterization, (N,N) is the unique Nash equilibrium of the game, but in asymmetric setting it is possible to have asymmetric equilibrium in which only one firm chooses flexible technology. In fact the flexible firm proves the effect of salvage market in strategic-level decision of managers who encouraged by this secondary market to invest on more expensive but better adjusted production line. Moreover we show in asymmetric case there is a unified cost threshold that can shift the equilibrium of the game. Also the important role of maximum possible market price reservation M is discussed extensively and it is demonstrated that capacity investment and profit of firms are increasing in M. Disequilibrium also appears as a result of some specific asymmetric parameterization. Contrary to the common opinion that flexibility is always a competitive advantage against rivals in uncertain markets, it is shown here that the existence of salvage market could convince the managers to employ it just under some specific conditions.

Several limitations affect the findings of this paper. Uniform distribution is the maximum entropy probability distribution for a random variable that has no constraint except its support interval while in real-world businesses, firms with extensive market research activities has some knowledge about the demand behavior of consumers. Moreover sufficiently large amount of M under asymmetric problem parameterization eventuate disequilibrium that could restrict the prediction power of our model, even considering the point that large value of M with respect to investment costs implies very high price reservation that within some range of M seems not very logical. Furthermore setting a fixed price for salvage market is a little bit tough assumption that could be revised in further extension. Development of web-based platforms like eBay, Amazon, or other second hand online markets besides considering large scale salvage markets could be a motivation for further study in this field. Revision the structure of our salvage market, considering two products in primary market, add partial flexibility by letting firms to choose simultaneously flexible and inflexible technologies have the potential of further research.

Technical Appendix

Here, the solutions to the production and the capacity games as well as the effect of our salvage market for non sale general components of flexible firm are explained considering assumptions 1, 2 and lemma 1. For these purposes three different subgames - as perfectly done by Goyal and Netessine (2007) - are considered and respected optimization problems as well as the solving approach will be established. Moreover, in this section, the intractable final equations for finding capacities and firm profits which lead me to apply numerical analysis are shown.

Moreover in last phase of problem solving, we need some specific assumptions in order to simplify the sophisticated closed expressions which will appear at second stage of our model. Consequently we will impose two more assumptions first on the type of distribution function of demand uncertainty and second on symmetric consideration of our agents. Symmetric assumption will be relaxed partially later on. Note that primarily we solve the model generally without these assumptions in order to 1. Justify the usage of recent assumptions and numerical method and 2. Let the interested scholar to trace the raw equations and do further probable extensions.

Assumption TA.3: We assume that demand uncertainty appears in the intercepts of the linear inverse demand function which draws from a *uniform* distribution function F with density function f as follow:

$$f(A) = \begin{cases} \frac{1}{M}, & 0 \le A \le M \\ 0\ , & Otherwise \end{cases}$$

Note that M is a finite positive sufficiently large number such that if demand realization were on the upper bound of probability distribution, all capacities would be bounded. With this setting in hand, the mean and variance of this specific distribution are respectively as follows:

$\mu = \frac{M}{2}$, $\sigma^2 = \frac{M^2}{12}$.

Assumption TA.4: We assume that both producers compete within symmetric context in which symmetric costs are imposed on them in all different subgames and states, that is:

$c_{gi} = c_{gj} = c_g$, $c_{si} = c_{sj} = c_s$, $c_{ui} = c_{uj} = c_u$.

Moreover they sell their residual general components in second market B with the same price as:

$p_{Bi} = p_{Bj} = p_B$.

Section TA.1-TA.3 contains the proof of lemma 2-4 which expressed in part 5.1.

TA.1.The Flexible Subgame

Assume that both firms invest in flexible technology (modular production process) which enables them to manufacture both general and specific components and consider the last stage of the game in which both sell their remaining general components in the secondary market B.

The optimal quantity of general component supplied to the second market and the respected profit for our firms can be calculated trivially which leads us to:

For firm i we have: $q_{iB}^* = X_{gi} - q_{iA}$ and $v_i^* = \left(X_{gi} - q_{iA}\right) \cdot p_{Bi}$. Similarly for firm j: $q_{jB}^* = X_{gj} - q_{jA}$ and $v_j^* = \left(X_{gj} - q_{jA}\right) \cdot p_{Bj}$.

It means that it is optimal for both firms to sell all their remaining general components in the second market with the specific price which is smaller than the unit procurement cost of their general component.

Proceeding backward, at the third stage both firms play a standard Cournot duopoly game on the amount of quantity they produce. The optimization problem can be formulated using Lagrange multipliers as follows:

$$\max_{q_{iA}} L_{Mi}^{f}\left(\lambda_i, q_{iA}\right) = \left[\left(A_A - q_{iA} - q_{jA}\right) \cdot q_{iA} + \left(X_{gi} - q_{iA}\right) \cdot P_{Bi}\right] + \lambda_i \left(X_{si} - q_{iA}\right)$$

Solving of this equation for both firms considering the Lagrange multipliers and also the slack variables lead us to three different states: First state represents the set of demand realizations in which no firm is capacity-constrained (Capacity is NOT binding); Second state represents the set of demand realization such that both firms are capacity-constrained (Capacity is binding for both producers) and finally in the third state one firm is capacity-constrained but the rival is not (Capacity is binding for firm i but is not binding for firm j). As a matter of notation we use s_i for positive integer i showing our different states.

In each state, the Cournot duopoly game can be solved and the first-order Kuhn-Tucker conditions are as follows:

$$A_A - 2q_{iA} - q_{jA} - P_{Bi} - \lambda_i = 0,$$

$q_{iA} + \eta_i = X_{si}$, (Where η_i is the slack variable)

$$\lambda_i \cdot \eta_i = 0$$

Note that we suppose all the quantities are positive and also as the objective function is concave, Kuhn-Tucker necessary conditions are sufficient as well.

For firm j we have same formulas with the Lagrange multiplier and the slack variable indexed as λ_j, η_j.

State 1: Capacity Is NOT Binding

In this state we have interior solutions, our Lagrange multipliers are zero and positive slack variables exist that is $\lambda_i = \lambda_j = 0$ and $\eta_i, \eta_j > 0$. Under these conditions the optimal quantity levels are as follows:

$$q_{iA}^{*} = \frac{A_A + P_{Bj} - 2P_{Bi}}{3}, \quad q_{jA}^{*} = \frac{A_A + P_{Bi} - 2P_{Bj}}{3}, \quad P_A = \frac{A_A + P_{Bi} + P_{Bj}}{3}.$$

For quantities to be nonnegative we should have two following inequalities:

$$A_A \geq 2P_{Bi} - P_{Bj}, \quad A_A \geq 2P_{Bj} - P_{Bi}.$$

Moreover the optimal profit of our firms can be expressed as below:

$$\pi_{Mi}^{*f} = (1/9)\left(A_A - 2P_{Bi} + P_{Bj}\right)^2 + P_{Bi}X_{gi}$$

$$\pi_{Mj}^{*f} = (1/9)\left(A_A - 2P_{Bj} + P_{Bi}\right)^2 + P_{Bj}X_{gj}$$

State 2: Capacity Is Binding for Both Firms

In this state we have binding solutions, our Lagrange multipliers are positive and slack variables equal to zero such that $\lambda_i, \lambda_j > 0$ and $\eta_i = \eta_j = 0$. Solving for quantities of both producers, we have:

$$q_{iA}^* = X_{si}, \; q_{jA}^* = X_{sj}, \; P_A = A_A - X_{si} - X_{sj}.$$

Based on our first assumption, quantities are positive in this state. For price to be nonnegative (Assumption 2) we should have the following inequality: $A_A \geq X_{si} + X_{sj}$.

Optimal profit functions of our firms can be formulated as follow:

$$\pi_{Mi}^{*f} = (A_A - X_{si} - X_{sj}) \cdot X_{si} + (X_{gi} - X_{si}) \cdot P_{Bi}$$

$$\pi_{Mj}^{*f} = (A_A - X_{si} - X_{sj}) \cdot X_{sj} + (X_{gj} - X_{sj}) \cdot P_{Bj}$$

State 3: Capacity Is Binding for Just One Firm

Without loss of generality we assume that the capacity for our first manufacturer (Firm i) is binding but it is not binding for the second one (Firm j). In this state we have binding solution for the first firm with positive Lagrange multiplier and zero slack variable and interior solution for the second one with zero Lagrange multiplier and positive slack variable as well that is $\lambda_i > 0, \eta_i = 0$ for firm i and $\lambda_j = 0, \eta_j > 0$ for firm j. Solving for quantities, we obtain:

$$q_{iA}^* = X_{si}, \; q_{jA}^* = \frac{A_A - X_{si} - P_{Bj}}{2}, \; P_A = \frac{A_A - X_{si} + P_{Bj}}{2}.$$

According to our assumptions, for quantities to be positive we should have $A_A \geq X_{si} + P_{Bj}$ and for price non-negativity we have $A_A \geq X_{si} - P_{Bj}$ that is $A_A \geq X_{si} \pm P_{Bj}$.

Optimal profit functions are also determined as follows:

$$\pi_{Mi}^{*f} = \left(\frac{A_A - X_{si} + P_{Bj}}{2}\right) \cdot X_{si} + \left(X_{gi} - X_{si}\right) \cdot P_{Bi}$$

$$\pi_{Mj}^{*f} = \left(\frac{A_A - X_{si} + P_{Bj}}{2}\right) \cdot \left(\frac{A_A - X_{si} - P_{Bj}}{2}\right) + \left(X_{gj} - \frac{A_A - X_{si} - P_{Bj}}{2}\right) \cdot P_{Bj}$$

Proceeding backward, at the second stage both firms make capacity investment decisions. In flexible subgame which we consider now, it means that both should determine the level of investment on general and specific components based on the expectation of profit on the market A considering the existence of secondary market B. According to lemma 1, Profit functions of our firms are as follows:

$$\Pi_{Mi} = \max_{X_{gi}, X_{si}} \left[E\left(\pi_{Mi}^{*f}\right) - c_{gi} \cdot X_{gi} - c_{si} \cdot X_{si}\right]$$ Such that $0 \le X_{si} \le X_{gi}$.

$$\Pi_{Mj} = \max_{X_{gj}, X_{sj}} \left[E\left(\pi_{Mj}^{*f}\right) - c_{gj} \cdot X_{gj} - c_{sj} \cdot X_{sj}\right]$$ Such that $0 \le X_{sj} \le X_{gj}$.

The optimization problem of our firms can be formulated using Lagrange multipliers as follows:

$$\max_{X_{gi}, X_{si}} L_{Mi}^{f}\left(\lambda_i, X_{gi}, X_{si}\right) = E\left(\pi_{Mi}^{*f}\right) - c_{gi} \cdot X_{gi} - c_{si} \cdot X_{si} + \lambda_i \left(X_{gi} - X_{si}\right)$$

$$\max_{X_{gj}, X_{sj}} L_{Mj}^{f}\left(\lambda_j, X_{gj}, X_{sj}\right) = E\left(\pi_{Mj}^{*f}\right) - c_{gj} \cdot X_{gj} - c_{sj} \cdot X_{sj} + \lambda_j \left(X_{gj} - X_{sj}\right)$$

In each state, the first-order Kuhn-Tucker conditions are as follows:

$$E\frac{\partial \pi_{Mi}^{*f}}{\partial X_{gi}} - c_{gi} + \lambda_i = 0, \quad E\frac{\partial \pi_{Mi}^{*f}}{\partial X_{si}} - c_{si} - \lambda_i = 0,$$

$$X_{si} + \eta_i = X_{gi}, \quad \eta_i . \lambda_i = 0.$$

And similarly for firm j we have:

$$E\frac{\partial \pi_{Mj}^{*f}}{\partial X_{gj}} - c_{gj} + \lambda_j = 0, \quad E\frac{\partial \pi_{Mj}^{*f}}{\partial X_{sj}} - c_{sj} - \lambda_j = 0,$$

$$X_{sj} + \eta_j = X_{gj}, \quad \eta_j . \lambda_j = 0.$$

Since we have assumed $P_B < c_g$ for any firm which enters the second market B, so we do not have any interior solution and $\lambda_i, \lambda_j \neq 0$ as well as slack variables equal to zero, that is $X_s = X_g$ for both firms in this subgame. It implies that it is optimal for our firms to invest on equal capacity of both general and specific components.

After some simple calculations for firm i we have:

$$c_{gi} - \lambda_i = \int_{S_1} P_{Bi} f(A)dA + \int_{S_2} P_{Bi} f(A)dA + \int_{S_3} P_{Bi} f(A)dA$$

$$c_{si} + \lambda_i = \frac{\partial}{\partial X_{si}} \left(\int_{s1} \pi_{Mi}^{*f} f(A)dA + \int_{s2} \pi_{Mi}^{*f} f(A)dA + \int_{s3} \pi_{Mi}^{*f} f(A)dA \right)$$

And for the second flexible firm j we obtain:

$$c_{gj} - \lambda_j = \int_{S_1} P_{Bj} f(A)dA + \int_{S_2} P_{Bj} f(A)dA + \int_{S_3} P_{Bj} f(A)dA$$

$$c_{sj} + \lambda_j = \frac{\partial}{\partial X_{sj}} \left(\int_{s1} \pi_{Mj}^{*f} f(A)dA + \int_{s2} \pi_{Mj}^{*f} f(A)dA + \int_{s3} \pi_{Mj}^{*f} f(A)dA \right)$$

In above equations $\lambda_i = \lambda_j = \lambda = c_g - P_B$ because Lagrange multipliers here specify the difference between the prices of residual general components in salvage market and its respective costs.

Based on the conditions of each state of each subgame we have different lower bound and upper bound for our integrals that is:

For state 1: $LB = \max\left[2P_{Bi} - P_{Bj}, 2P_{Bj} - P_{Bi}\right]$, $UB = \min\left[3X_{si} - P_{Bj} + 2P_{Bi}, 3X_{sj} - P_{Bi} + 2P_{Bj}\right]$

For state 2: $LB = \max\left[X_{si} + X_{sj}, 3X_{si} - P_{Bj} + 2P_{Bi}, 2X_{sj} + X_{si} - P_{Bi} + 2P_{Bj}\right]$, $UB = M$

For state 3: $LB = \max\left[X_{si} + P_{Bj}, 3X_{si} - P_{Bj} + 2P_{Bi}\right]$, $UB = 2X_{sj} + X_{si} + P_{Bj}$

Because the boundaries of the integrals are themselves functions of the capacities of our two firms, differentiating the first-order conditions does not result in tractable equations. Consequently we need to specify some assumptions about the probability distribution of random variable and enter numeric analysis. For the sake of simplicity we have established assumptions 3 and 4 which mentioned above.

Note 1: Whereas lower and upper bound of integrals –as shown above- need a starting assumption about the relationship between X_{si} and X_{sj}, so without loss of generality we assume that $X_{si} \leq X_{sj}$.

Note 2: Since our optimization problems contain maximizing our desired parameters including capacities and profits, and whereas we encounter multiple solutions in solving best reply functions of two firms, second-order condition applies to screen the proper outcomes.

Note 3: All the above mentioned assumptions and regulations with some notation modification apply to other subgames as well.

After finding optimal capacities, optimal profit can be easily calculated by plugging-in these capacities in objective functions of each firm.

According to all above mentioned assumptions, implementing the first-order condition for both firms leads us to the following equations. Optimal capacities could be calculated by solving these two-equations-two-unknowns system for two firms respectively:

$$c_s + c_g - P_B = \frac{\partial}{\partial X_{si}}\left(\int_{P_B}^{3X_{si}+P_B} \left(\frac{(A-P_B)^2}{9} + P_B \cdot X_{si} \right) \cdot \frac{1}{M} dA + \int_{3X_{si}+P_B}^{2X_{sj}+X_{si}+P_B} (A - X_{si} - X_{sj}) \cdot X_{si} \cdot \frac{1}{M} dA + \int_{2X_{sj}+X_{si}+P_B}^{M} \left(\frac{A - X_{si} + P_B}{2} \right) \cdot X_{si} \cdot \frac{1}{M} dA \right)$$

$$c_s + c_g - P_B = \frac{\partial}{\partial X_{sj}}\left(\begin{array}{l} \int_{P_B}^{3X_{si}+P_B} \left(\frac{(A-P_B)^2}{9} + P_B \cdot X_{sj} \right) \cdot \frac{1}{M} dA + \int_{3X_{si}+P_B}^{2X_{sj}+X_{si}+P_B} (A - X_{si} - X_{sj}) \cdot X_{sj} \cdot \frac{1}{M} dA \\ + \int_{2X_{sj}+X_{si}+P_B}^{M} \left(\left(\frac{A - X_{si} + P_B}{2} \right) \cdot \left(\frac{A - X_{si} - P_B}{2} \right) + \left(X_{si} - \frac{A - X_{si} - P_B}{2} \right) P_B \right) \cdot \frac{1}{M} dA \end{array} \right)$$

After some calculations, best reply functions of firms will be as follow:

$$-c_s - c_g + 0.25M + 1.5P_B - \frac{0.75P_B^2}{M} - X_{si} + \frac{P_B \cdot X_{si}}{M} - \frac{2.25X_{si}^2}{M} + \frac{4X_{si}X_{sj}}{M} - \frac{X_{sj}^2}{M} = 0$$

$$-c_s - c_g + P_B - \frac{P_B \cdot X_{si}}{M} - \frac{2X_{si}^2}{M} + \frac{4P_B X_{sj}}{M} + \frac{4X_{si}X_{sj}}{M} - \frac{2X_{sj}^2}{M} = 0$$

Solving these two equations result in intractable messy large outcomes which convince us moving to numerical analysis. Actually we reach 4 sets of outcomes, but it includes complex answers as well as some outcomes which are minimum optimal amounts that should be screened via second-order condition.

TA.2.The Inflexible Subgame

In this subsection suppose that both firms invest in inflexible technology which enables them to produce the final product via the unified production process. Choosing this technology is a barrier to enter the secondary market B which has sufficient demand for general component of the final product. Consequently there will be no payoff for our firms in the fourth stage and so we start by analyzing the third stage in which they compete in market A on the quantity of the final product (Cournot duopoly competition).

The optimization problem based on our model and by considering the Lagrange multiplier can be formulated as follow:

$$\max_{q_{iA}} L_{Ui}^{n}\left(\lambda_i, q_{iA}\right) = \left(A_A - q_{iA} - q_{jA}\right) \cdot q_{iA} + \lambda_i \left(X_{Ui} - q_{iA}\right)$$

Solving of this equation for both firms considering the Lagrange multipliers and also the slack variables lead us to three different states as before: First state represents the set of demand realizations in which no firm is capacity-constrained (Capacity is NOT binding); Second state represents the set of demand realization such that both firms are capacity-constrained (Capacity is binding for both producers) and finally in the third state one firm is capacity-constrained but the rival is not (Capacity is binding for firm i but is not binding for firm j).

The first-order Kuhn-Tucker conditions for these states are as follows:

$A_A - 2q_{iA} - q_{jA} - \lambda_i = 0$,

$q_{iA} + \eta_i = X_{Ui}$, (η_i Is the slack variable)

$\lambda_i \cdot \eta_i = 0$.

We suppose that all the quantities are positive and also as the objective function is concave, Kuhn-Tucker necessary conditions are sufficient as well.

For firm j we have same formulas with the Lagrange multiplier and the slack variable indexed as λ_j, η_j.

State 1: Capacity Is NOT Binding

In this state we have interior solutions, our Lagrange multipliers are zero and positive slack variables exist that is $\lambda_i = \lambda_j = 0$ and $\eta_i, \eta_j > 0$. Under these conditions the optimal quantity levels are as follows:

$$q_{iA}^* = \frac{A_A}{3}, \; q_{jA}^* = \frac{A_A}{3}, \; P_A = \frac{A_A}{3}.$$

For quantities and price to be nonnegative we should have following inequality: $A_A \geq 0$

The optimal profit of our firms also can be expressed as below:

$$\pi_{Ui}^{*n} = \frac{A_A^2}{9}$$

$$\pi_{Uj}^{*n} = \frac{A_A^2}{9}$$

State 2: Capacity Is Binding for Both Firms

In this state we have binding solutions, our Lagrange multipliers are positive and slack variables equal to zero such that $\lambda_i, \lambda_j > 0$ and $\eta_i = \eta_j = 0$. Solving for quantities of both producers, we have:

$$q_{iA}^* = X_{Ui}, \; q_{jA}^* = X_{Uj}, \; P_A = A_A - X_{Ui} - X_{Uj}.$$

Based on our first assumption, quantities are positive in this state. For price to be nonnegative (Assumption 2) we should have the following inequality:

$$A_A \geq X_{Ui} + X_{Uj}$$

Optimal profit functions of our firms can be formulated as follow:

$$\pi_{Ui}^{*n} = \left(A_A - X_{Ui} - X_{Uj}\right) \cdot X_{Ui}$$

$$\pi_{Uj}^{*n} = \left(A_A - X_{Ui} - X_{Uj}\right) \cdot X_{Uj}$$

State 3: Capacity Is Binding for Just One Firm

Without loss of generality we assume that the capacity for our first manufacturer (Firm i) is binding but it is not binding for the second one (Firm j). In this state we have binding solution for the first firm with positive Lagrange multiplier and zero slack variable and interior solution for the second one with zero Lagrange multiplier and positive slack variable as well that is $\lambda_i > 0, \eta_i = 0$ for firm i and $\lambda_j = 0, \eta_j > 0$ for firm j. Solving for quantities, we obtain:

$$q_{iA}^{*} = X_{Ui}\,,\quad q_{jA}^{*} = \frac{A_A - X_{Ui}}{2}\,,\quad P_A = \frac{A_A - X_{Ui}}{2}\,.$$

For quantities and price to be positive we should have $A_A \geq X_{Ui}$.

Optimal profit functions are also determined as follows:

$$\pi_{Ui}^{*n} = \left(\frac{A_A - X_{Ui}}{2}\right) \cdot X_{Ui}$$

$$\pi_{Uj}^{*n} = \left(\frac{A_A - X_{Ui}}{2}\right)^2$$

Proceeding backward, at the second stage both firms make capacity investment decisions. In this subsection since our both firms are inflexible, indeed they should determine the level of investment on producing the final product which has demand only in market A. Profit functions of our firms are as follows:

$$\Pi_{Ui} = \max_{X_{Ui}} \left[E\left(\pi_{Ui}^{*n}\right) - c_{ui} \cdot X_{Ui} \right] \text{ Such that } X_{Ui} \geq 0$$

$$\Pi_{Uj} = \max_{X_{Uj}} \left[E\left(\pi_{Uj}^{*n}\right) - c_{uj} \cdot X_{Uj} \right] \text{ Such that } X_{Uj} \geq 0$$

The optimality conditions for both firms in this stage are as follows based on the first-order condition:

$$\frac{\partial \Pi_{Ui}}{\partial X_{Ui}} = 0\,,\quad \frac{\partial \Pi_{Uj}}{\partial X_{Uj}} = 0\,.$$

That is:

$$E\frac{\partial \pi_{Ui}^{*n}}{\partial X_{Ui}} - c_{ui} = 0\,,\quad E\frac{\partial \pi_{Uj}^{*n}}{\partial X_{Uj}} - c_{uj} = 0\,.$$

So for our firms we have:

$$c_{ui} = \frac{\partial}{\partial X_{Ui}} \left(\int_{s_1} \pi_{Ui}^{*n} f(A)dA + \int_{s_2} \pi_{Ui}^{*n} f(A)dA + \int_{s_3} \pi_{Ui}^{*n} f(A)dA \right)$$

$$c_{uj} = \frac{\partial}{\partial X_{Uj}} \left(\int_{s_1} \pi_{Uj}^{*n} f(A)dA + \int_{s_2} \pi_{Uj}^{*n} f(A)dA + \int_{s_3} \pi_{Uj}^{*n} f(A)dA \right)$$

Based on the conditions of each state of each subgame we have different lower bound and upper bound in which our integrals have been defined that is:

For state1 we have: $LB = 0$, $UB = \min\left[3X_{Ui}, 3X_{Uj}\right]$

For state 2 we have: $LB = \max\left[3X_{Ui}, 2X_{Uj}+X_{Ui}, X_{Ui}+X_{Uj}\right]$, $UB = M$

For state 3 we have: $LB = 3X_{Ui}$, $UB = 2X_{Uj} + X_{Ui}$

Similarly, according to all above mentioned assumptions, implementing the first-order condition for both firms leads us to the following equations. Optimal capacities could be calculated by solving these two-equations-two-unknowns system for two firms respectively:

$$c_u = \frac{\partial}{\partial X_{ui}}\left(\int_0^{3X_{ui}} \frac{A^2}{9}\cdot\frac{1}{M}dA + \int_{3X_{ui}}^{2X_{uj}+X_{ui}} \frac{A-X_{ui}}{2}\cdot X_{ui}\cdot\frac{1}{M}dA + \int_{2X_{uj}+X_{ui}}^{M}\left(A-X_{ui}-X_{uj}\right)\cdot X_{ui}\cdot\frac{1}{M}dA\right)$$

$$c_u = \frac{\partial}{\partial X_{uj}}\left(\int_0^{3X_{ui}} \frac{A^2}{9}\cdot\frac{1}{M}dA + \int_{3X_{ui}}^{2X_{uj}+X_{ui}} \left(\frac{A-X_{ui}}{2}\right)^2\cdot\frac{1}{M}dA + \int_{2X_{uj}+X_{ui}}^{M}\left(A-X_{ui}-X_{uj}\right)\cdot X_{uj}\cdot\frac{1}{M}dA\right)$$

Best reply functions of firms then will be as follow:

$$-c_u + \frac{M}{2} - 2X_{ui} + \frac{1.5X_{ui}^2}{M} - X_{uj} + \frac{2X_{ui}X_{uj}}{M} + \frac{X_{uj}^2}{M} = 0$$

$$-c_u + \frac{M}{2} - X_{ui} + \frac{X_{ui}^2}{2M} - 2X_{uj} + \frac{2X_{ui}X_{uj}}{M} + \frac{2X_{uj}^2}{M} = 0$$

After finding optimal capacities, optimal profit can be easily calculated by plugging in these capacities in objective functions of each firm.

TA.3.The Mixed Subgame

Without loss of generality, suppose that firm i chooses the flexible technology which enables it to produce the final product via the modular process with manufacturing both general and specific components while its rival, firm j chooses the inflexible technology and unified production process which equips it with commitment device. So with this setting firm i has the opportunity to supply its remaining general components in the secondary market B with the given price less than the unit procurement cost of general component.

At the last stage the optimal quantity of general component supplied to the second market and the respected profit for the flexible firm can be calculated as before which leads us to:

For firm i we have: $q_{iB}^{*} = X_{gi} - q_{iA}$ and $v_i^{*} = \left(X_{gi} - q_{iA}\right) \cdot P_{Bi}$. But for firm j we have $v_j = 0$.

It means that it is optimal for the flexible firms to sell all its remaining general components in the second market with the specific price.

Proceeding backward, at the third stage both firms play a standard Cournot duopoly game on the amount of quantity they produce.

The optimization problem for the flexible firm i can be formulated using Lagrange multipliers as follows:

$$\max_{q_{iA}} L_{Mi}^{m}\left(\lambda_i, q_{iA}\right) = \left[\left(A_A - q_{iA} - q_{jA}\right) \cdot q_{iA} + \left(X_{gi} - q_{iA}\right) \cdot P_{Bi}\right] + \lambda_i \left(X_{si} - q_{iA}\right)$$

And for the inflexible firm j we have:

$$\max_{q_{jA}} L_{Uj}^{m}\left(\lambda_j, q_{jA}\right) = \left(A_A - q_{jA} - q_{iA}\right) \cdot q_{jA} + \lambda_j \left(X_{Uj} - q_{jA}\right)$$

Solving of these equations for both firms considering the Lagrange multipliers and also the slack variables lead us to three different states: First state represents the set of demand realizations in which no firm is capacity-constrained (Capacity is NOT binding); Second state represents the set of demand realization such that both firms are capacity-constrained (Capacity is binding for both producers) ; In the third state the flexible firm is capacity-constrained but its inflexible competitor is not (Capacity is binding for flexible firm i but is not binding for inflexible firm j). This subgame implies (F, N) combination which we investigate it here. The reverse case (N, F) in which the inflexible firm binds sooner will be skipped in order to avoid similar calculations.

In each state, the Cournot duopoly game can be solved and the first-order Kuhn-Tucker conditions are as follows:

For the flexible firm i we have:

$$A_A - 2q_{iA} - q_{jA} - P_{Bi} - \lambda_i = 0,$$

$q_{iA} + \eta_i = X_{si}$, (η_i Is the slack variable here.)

$\lambda_i \cdot \eta_i = 0$.

And for the inflexible firm j we have:

$A_A - 2q_{jA} - q_{iA} - \lambda_j = 0$,

$q_{jA} + \eta_j = X_{Uj}$, (η_j Is the slack variable)

$\lambda_j \cdot \eta_j = 0$.

We suppose that all the quantities are positive and also as the objective functions are concave, Kuhn-Tucker necessary conditions are sufficient as well.

State 1: Capacity Is NOT Binding

In this state we have interior solutions, our Lagrange multipliers are zero and positive slack variables exist that is $\lambda_i = \lambda_j = 0$ and $\eta_i, \eta_j > 0$. Under these conditions the optimal quantity levels are as follows:

$\overset{*}{q}_{iA} = \frac{A_A - 2P_{Bi}}{3}$, $\overset{*}{q}_{jA} = \frac{A_A + P_{Bi}}{3}$, $P_A = \frac{A_A + P_{Bi}}{3}$.

For quantities and price to be nonnegative we should have following inequality: $A_A \geq 2P_{Bi}$

The optimal profit of our firms also can be expressed as below:

$$\pi_{Mi}^{*m} = \left(\frac{A_A - 2P_{Bi}}{3}\right) \cdot \left(\frac{A_A + P_{Bi}}{3} - P_{Bi}\right) + X_{gi} \cdot P_{Bi}$$

$$\pi_{Uj}^{*m} = \left(\frac{A_A + P_{Bi}}{3}\right)^2$$

State 2: Capacity Is Binding for Both Firms

In this state we have binding solutions, our Lagrange multipliers are positive and slack variables equal to zero such that $\lambda_i, \lambda_j > 0$ and $\eta_i = \eta_j = 0$. Solving for quantities of both producers, we have:

$\overset{*}{q}_{iA} = X_{si}$, $\overset{*}{q}_{jA} = X_{Uj}$, $P_A = A_A - X_{si} - X_{Uj}$.

For price to be nonnegative we should have: $A_A \geq X_{si} + X_{Uj}$

The optimal profits of our firms also are also as follows:

$$\pi_{Mi}^{*m} = \left(A_A - X_{si} - X_{Uj}\right) \cdot X_{si} + \left(X_{gi} - X_{si}\right) \cdot P_{Bi}$$

$$\pi_{Uj}^{*m} = \left(A_A - X_{si} - X_{Uj}\right) \cdot X_{Uj}$$

State 3: Capacity Is Binding for the Flexible Firm and Not Binding for the Inflexible Firm

We assume that the capacity for our first manufacturer (Firm i) is binding but it is not binding for the second one (Firm j). In this state we have binding solution for the first firm with positive Lagrange multiplier and zero slack variable and interior solution for the second one with zero Lagrange multiplier and positive slack variable as well that is $\lambda_i > 0, \eta_i = 0$ for firm i and $\lambda_j = 0, \eta_j > 0$ for firm j. Solving for quantities, we obtain:

$$q_{iA}^{*} = X_{si}\,,\quad q_{jA}^{*} = \frac{A_A - X_{si}}{2}\,,\quad P_A = \frac{A_A - X_{si}}{2}\,.$$

For quantities and price to be nonnegative we should have following inequality: $A_A \geq X_{si}$

The optimal profit of our firms also can be expressed as below:

$$\pi_{Mi}^{*m} = \left(\frac{A_A - X_{si}}{2}\right) \cdot X_{si} + \left(X_{gi} - X_{si}\right) \cdot P_{Bi}$$

$$\pi_{Uj}^{*m} = \left(\frac{A_A - X_{si}}{2}\right)^2$$

Proceeding backward, at the second stage our firms decide on the level of capacity investment. Flexible firm's decision involves determining the level of investment on general and specific components while the inflexible firm makes decision on the level of producing the final product via the unified process. Profit functions of our flexible and inflexible firms are respectively as follows:

$$\Pi_{Mi} = \max_{X_{gi}, X_{si}} \left[E\left(\pi_{Mi}^{*m}\right) - c_{gi} \cdot X_{gi} - c_{si} \cdot X_{si}\right] \text{ Such that } 0 \leq X_{si} \leq X_{gi}$$

$$\Pi_{Uj} = \max_{X_{Uj}} \left[E\left(\pi_{Uj}^{*m}\right) - c_{uj} \cdot X_{Uj}\right] \text{ Such that } X_{Uj} \geq 0$$

The optimization problem for the flexible firm i can be formulated using Lagrange multiplier as follows:

$$\max_{X_{gi}, X_{si}} L_{Mi}^{m}\left(\lambda_i, X_{gi}, X_{si}\right) = E\left(\pi_{Mi}^{*m}\right) - c_{gi} \cdot X_{gi} - c_{si} \cdot X_{si} + \lambda_i \left(X_{gi} - X_{si}\right)$$

But for firm j considering first-order condition we have: $\frac{\partial \Pi_{Uj}}{\partial X_{Uj}} = 0$

In each state, the first-order Kuhn-Tucker conditions for first firm are as follows:

$$E\frac{\partial \pi_{Mi}^{*m}}{\partial X_{gi}} - c_{gi} + \lambda_i = 0, \quad E\frac{\partial \pi_{Mi}^{*m}}{\partial X_{si}} - c_{si} - \lambda_i = 0.$$

And for firm j we have: $E\frac{\partial \pi_{Uj}^{*m}}{\partial X_{Uj}} - c_{ui} = 0$.

So for the flexible firm we have:

$$c_{gi} - \lambda_i = \int_{s_1} P_{Bi} f(A)dA + \int_{s_2} P_{Bi} f(A)dA + \int_{s_3} P_{Bi} f(A)dA$$

$$c_{si} + \lambda_i = \frac{\partial}{\partial X_{si}}\left(\int_{s1} \pi_{Mi}^{*m} f(A)dA + \int_{s2} \pi_{Mi}^{*m} f(A)dA + \int_{s3} \pi_{Mi}^{*m} f(A)dA + \right)$$

And for the inflexible firm we have:

$$c_{uj} = \frac{\partial}{\partial X_{Uj}}\left(\int_{s_1} \pi_{Uj}^{*m} f(A)dA + \int_{s_2} \pi_{Uj}^{*m} f(A)dA + \int_{s_3} \pi_{Uj}^{*m} f(A)dA\right)$$

Based on the conditions of each state of each subgame we have different lower bound and upper bound in which our integrals have been defined that is:

For state 1: $LB = 2P_{Bi}$, $UB = \min\left[3X_{si} + 2P_{Bi}, 3X_{Uj} - P_{Bi}\right]$

For state2: $LB = 2X_{Uj} + X_{si}$, $UB = M$

For state 3: $LB = \min\left[3X_{si} + 2P_{Bi}, 3X_{Uj} - P_{Bi}\right]$, $UB = 2X_{Uj} + X_{si}$

Hence according to all above mentioned assumptions, implementing the first-order condition for both firms leads us to the following equations. Optimal capacities could be calculated by solving these two-equations-two-unknowns system for two firms respectively:

$$c_s + c_g - P_B = \frac{\partial}{\partial X_{si}}\left(\int_{2P_B}^{3X_{si}+2P_B}\left(\frac{A-2P_B}{3}\left(\left(\frac{A+P_B}{3} - P_B\right) + X_{si} \cdot P_B\right)\right) \cdot \frac{1}{M} dA + \int_{3X_{si}+2P_B}^{2X_{uj}+X_{si}}\left(\frac{A-X_{si}}{2}\right) \cdot X_{si} \cdot \frac{1}{M} dA + \int_{2X_{uj}+X_{si}}^{M}\left(A - X_{si} - X_{uj}\right) \cdot X_{si} \cdot \frac{1}{M} dA\right)$$

$$c_u = \frac{\partial}{\partial X_{uj}}\left(\int_{2P_B}^{3X_{si}+2P_B}\left(\frac{A+P_B}{3}\right)^2\cdot\frac{1}{M}dA+\int_{3X_{si}+2P_B}^{2X_{uj}+X_{si}}\left(\frac{A-X_{si}}{2}\right)^2\cdot\frac{1}{M}dA+\int_{2X_{uj}+X_{si}}^{M}\left(A-X_{si}-X_{uj}\right)\cdot X_{uj}\cdot\frac{1}{M}dA\right)$$

Best reply functions of firms then will be as follow:

$$-c_g - c_s + P_B + \frac{M}{2} - 2X_{si} + \frac{6P_B X_{si}}{M} + \frac{\left(-2P_B-2X_{si}\right)\cdot X_{si}}{M} + \frac{9X_{si}^2}{2M} - X_{uj} + \frac{2X_{si}X_{uj}}{M} + \frac{-P_B^2-2P_B X_{si}-X_{si}^2+X_{uj}^2}{M} = 0$$

$$-c_u + \frac{M}{2} - X_{si} + \frac{X_{si}^2}{2M} - 2X_{uj} + \frac{2X_{si}X_{uj}}{M} + \frac{2X_{uj}^2}{M} = 0$$

Finally after finding optimal capacities, maximum profit can be calculated by plugging in these capacities in objective functions of each firm. □

Chapter 3

Supply Chain Configuration under Information Sharing

This essay examines the effect of information sharing on supply chain configuration where the market characterized by demand uncertainty. A dynamic multi-stage game theoretic model with incomplete information is employed to capture the sequence of events. Our supply chain consists of two suppliers with exogenous wholesale prices and two retailers, the incumbent and the entrant, with asymmetric demand information. Informed incumbent prefers to conceal its private information from the entrant in order to reap more profits in the market. The channel of information flows is only through the first supplier and the incumbent can supply just from him, but the entrant is free to choose its proper supplier considering the point that the second supplier is uninformed. Our analytical model demonstrates that how the mean demand of the market, wherein our retailers compete, and its relation with the relative wholesale price of the suppliers play crucial role in equilibrium determination. Our results show under which circumstances separation and pooling equilibrium could occur in some range of demand variation. It is also shown that the entrant sometimes prefers to avoid information acquisition by choosing the second supplier and playing Cournot instead of Stackelberg which is more profitable for him in some occasions.

1. Introduction

Several industries and businesses follow differentiation strategies in order to attract the potential customers and overcome their rivals. Moreover proper implementation of this strategy requires a good knowledge of the market and sophistication of consumer demand which is costly and time-consuming. Hence access to private information about the actual demand of a specific market, particularly today, is a *competitive advantage* in competition that should be *managed* by CIOs. Controlling the channels of information leakage has become an important part of information management and business intelligence. Furthermore several competitors work with common players in their supply chain which potentially could share their economic information with their rivals-intentionally or unintentionally. Zhang and Li (2006) mentioned that several managers have concerns about the leakage of crucial information from suppliers to their rivals. This prospect leads to control over all signals that a competitor might ascribe from our ordinary course of business such as quantity ordering to common suppliers. Consequently information imperatives should be considered in our profit function and be treated strategically.

In this chapter we explore the effect of information sharing on supply chain configuration in the market characterized with demand uncertainty. Indeed we examine how information considerations could affect the operational activities of firms. Our dynamic multi-stage supply chain signaling game includes four potential players, two suppliers (wholesalers) and two manufacturers (retailers), which will be configured based on informational and operational imperatives. At the beginning of the game, the first supplier which assumed to be the exclusive supplier of the incumbent (first retailer) decides whether to accept the entrant (second retailer) or not. Then the incumbent that have private information about market demand, places his quantity order strategically, while is aware of the first supplier's decision. Acceptance of the entrant implies that the incumbent could lose its competitive edge (private information). Hence the incumbent has strong incentive to conceal the updated information from the first supplier while ordering. At the third stage, the entrant chooses its proper supplier. If he chooses the first supplier (and the first supplier in stage one accepted him), the incumbent's order information will reveal to him. Finally both retailers compete on the quantity they launch to the market (Cournot duopoly competition). Price and profits are determined consequently.

This research contributes to the available outstanding literature in IO and strategic information management by studying the existence of a second supplier (with different wholesale price) on determination of the game's equilibria and further supply chain configuration. In fact it investigates analytically the effects of relative wholesale prices (of two suppliers) and demand uncertainty's elements on supply chain disposition. We have tried to equip all the agents of the game with crucial incentives to have interesting scenarios. Actually we model the incumbent's incentive of information sharing, the first supplier's incentive of information leakage and also the entrant's incentive for information acquisition and their effects on order quantities of retailers and acceptance decision of first supplier which configure the supply chain. Four propositions and six Lemmas explicitly depict the results of this research which come out of the optimization problems of the game. Results show that how the additional second supplier affects the equilibia of the game and under some circumstance neutralizes the temptation of information acquisition. The results fill the gap of literature in this field. We also discuss about the scenario of exclusive supply contract (ESC) between the first supplier and the incumbent. Moreover the paper studies the effects of price differences between two suppliers. Several questions arise to answer in this study as for which constellations of demand uncertainty and wholesalers' relative price, the entrant chooses informed supplier and for which constellations of them, informed wholesaler accepts entrant's ordering? Is it possible for the incumbent to preclude information leakage? Does the entrant acquire information in equilibrium? What is the role of second supplier on the entrant's decision?

The remainder of this chapter is organized as follows. In part 2 we briefly review the available related literature in IO and information management. Section 3 explains the basic general model and §4 deals with analysis and results. Finally, section 5 concludes this essay.

2. Literature Review

Several papers published in recent years have investigated the effect of information management on operation management. Indeed these studies focus on the trade-off between C-suits (CIO vs. COO[1]) of companies, the incentive of “minimum information leakage” versus the incentive of “maximum operational profits”. The rationale behind these papers including ours is to model the incentives of all active agents in supply chain, wherein a company works, and try to optimize this *internal* trade-off considering all *external* strategic determinants.

Early papers on information sharing, studied the motivation of oligopolistic firms for information sharing. Gal-Or (1985), considering oligopolistic market characterized with demand uncertainty, concluded that no information sharing is the unique Nash equilibrium of the game. She modeled demand uncertainty with normal distribution function. Ziv (1993) designed a mechanism by which the firm will reveal the true value of its private information and this truthful revelation is its optimal reply. He showed that under some circumstances, information sharing’s benefit is more than signaling costs.

Li (2002) pointed to two effects of vertical information sharing in two-level supply chain: direct and indirect effect. They showed that indirect effect (or leakage effect) motivates the retailers to conceal the demand information and reveal the cost information. Lee and Whang (2000) mentioned several examples of firms in supply chain that make profits by information sharing. They also empirically stated that the distribution of these benefits among players is asymmetric. Moreover different types of shared information were explained in their paper, e.g. inventory, sales, demand forecast, order status and production schedule. Our work deals with demand information.

[1] Chief Information Officer (CIO) vs. Chief Operation Officer (COO)

Anand and Goyal (2009) *explicitly model firm's incentives to acquire, share and disseminate demand information, and their impact on order quantities and sale*. They consider one common supplier and two horizontally competing retailers. This seminal paper actually is the pillar of strategic information management. They have endogenized information acquisition decision of the incumbent retailer (with private information) in their model. Moreover their supply chain contains an exclusive supplier which our model tries to extend it to two suppliers with different wholesale prices.

Several scholars have contributed to this exquisite paper. Kong et al. (2012) study how the potential of revenue sharing contracts, which can be offered by supplier to two retailers, can favor information sharing through the supply chain and decline the destructive effects of information imperatives on operational one. In fact they have investigated the impacts of changing the wholesale price contract of Anand and Goyal (2009) to revenue sharing contract. They showed that this alteration motivates the supplier not always to leak the private demand information of the incumbent in equilibrium. This could result in higher benefits for all players of the supply chain even the uninformed entrant.

Özer et al. (2011) approached information sharing in supply chain considering cooperation and trust between different parties. They based their analytical model on laboratory findings that firms in supply chain cooperate even in the absence of contracts. Partial trust is also permitted in their model contrary to the available literatures. Ha et al. (2011) considered two competing supply chains each consists of one supplier and one retailer, with production technologies show diseconomies of scale. They show that information sharing benefits a supply chain under large production diseconomies, less intense competition, and less accurate information. For modeling diseconomies of scale they assume to have quadratic production cost. Two different types of competition (Bertrand & Cournot) are analyzed in this paper.

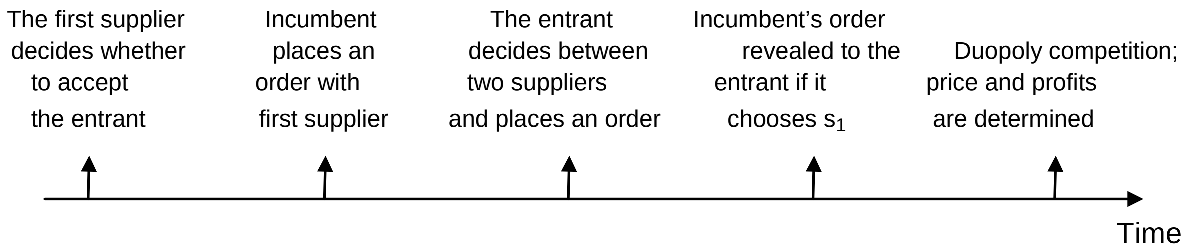
3. The Model

Inspired by Anand and Goyal (2009), consider a supply chain consisting of two retailers and two suppliers in which two retailers compete on the quantity they produce in a market characterized by demand uncertainty. One retailer is incumbent and due to long presence in the market has access to private information about demand. The other retailer is an uninformed entrant that is eager to realize the demand information. Based on some long-term contractual imperatives, incumbent restricted to supply its product from first supplier, but the entrant endogenously decides between two suppliers. Final product supplied from two different suppliers is assumed to be perfect substitutable. We index the four players- the incumbent, the entrant, the first supplier and the second supplier, by i, e, s_1, s_2 respectively. All firms are risk neutral and aim to maximize their own expected profits.

Game Theoretic Model. According to Gibbons (1992) we study a dynamic (multi-stage) supply chain game of incomplete information between four players. More specifically speaking, a signaling game sequentially happens between retailers through their quantity ordering from suppliers.

Sequence of Events. The sequence of events is as follows: 1. The first supplier decides whether to accept entrant's potential order -which implies the leakage of demand information to it, or not; 2. The incumbent retailer (Stackelberg leader) - due to its private information about market demand, places an order with the first supplier, knowing that it will leak this information to the entrant (Stackelberg follower) if it accepts the entrant. Indeed the incumbent tries to strategically manage its private information via its ordering process. This might result in ordering distortion and supply chain inefficiency; 3. Then the entrant decides between two suppliers and places its order; 4. Here if the entrant chooses the first supplier then the incumbent's order information will be shared with it by s_1, and finally 5. All ordered quantities are launched to the market, and price and profits are realized due to duopoly competition. (See figure 1)

Figure 1: The Sequence of Events

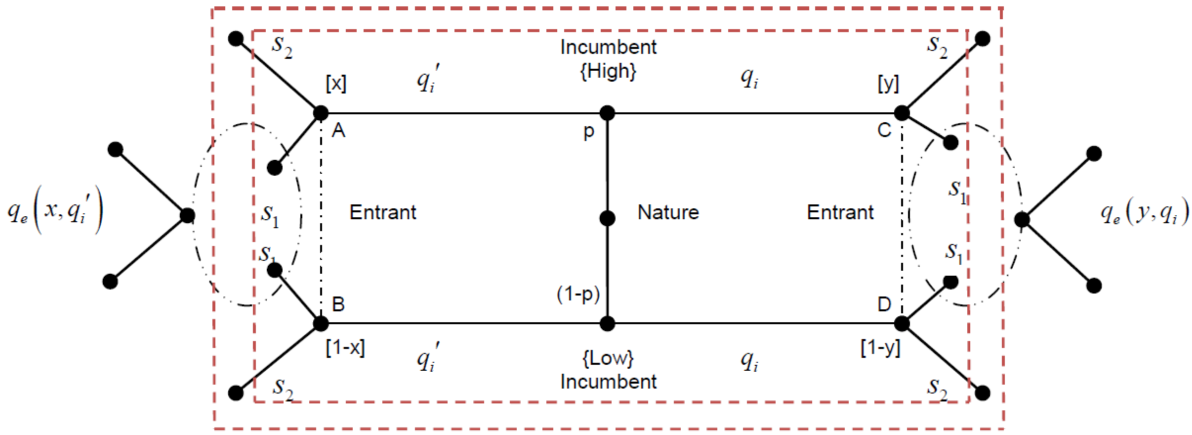


Demand Structure. We assume an inverse demand function that is linear and downward-sloping which implies that it arises from utility-maximizing behavior of customers with quadratic additively separable utility function (Singh and Vives (1984)). Uncertainty occurs in the intercepts of inverse demand function characterized specifically by $P(Q) = \tilde{A} - Q$ where $Q = q_i + q_e$ is the total quantity launched to the market by orders of both incumbent (q_i) and entrant (q_e). We assume a *binary support* for random variable $\tilde{A}$ that can take two values: a high value A_H with probability p and a low value A_L with probability $(1-p)$ such that $0 < A_L < A_H$. We denote the mean demand by $\mu = pA_H + (1-p)A_L$. These priors are common knowledge between all players at the beginning of the game. We assume that the transactions between suppliers and retailers are governed by wholesale price contract. Wholesale price is assumed to be fixed exogenously and indexed by W_1 and W_2 for first and second suppliers respectively. Also we assume that both suppliers have no capacity constraints to supply the retailers' orders and also we avoid partial ordering between suppliers. Consistent with Anand and Goyal (2009) also we consider $\theta = (A_H - W_1)/(A_L - W_1)$, as a proxy for demand uncertainty as showed by the coefficient of variation. Contrary to Anand and Goyal (2009) we do not normalize wholesale price to zero and therefore this price appears in the formulation of parameter θ.

Extensive Form Representation of the Signaling Game. In this setting the incumbent is the *sender* (informed agent), the entrant is the *receiver* (uninformed player), *type* space is $T = \{High, Low\}$ and $t \in T$ is a specific type of the sender, $m = q_i \in [0, \infty)$ is the *message* or signal that sender sends form a set $M(t)$, and $a = q_j \in [0, \infty)$ is the *action* or response that receiver chooses from a set $A(m)$. (See figure 2 and 3)

Solution Concept. Whereas we employ a dynamic game of incomplete information, Perfect Bayesian Nash Equilibria (PBNE) will be derived in terms of information and material flows. (Gibbons (1992))

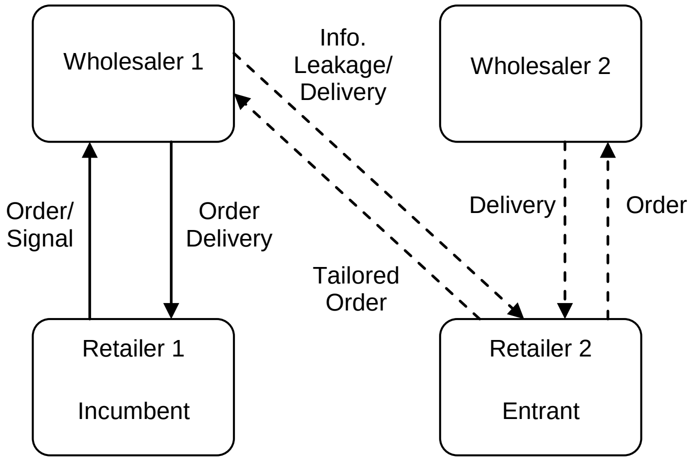
Figure 2: Extensive Form of Signaling Game



Contribution. This model is similar to that of Anand and Goyal (2009) with some alteration and extensions: First, another supplier s_2 is also available in the supply chain which could affect the decision making process of entrant and first supplier. Indeed we have eliminated the monopolistic role of first supplier. Second, following this extension, the entrant decision of choosing its proper supplier becomes endogenous variable in the model. Third, this setting assumes that incumbent receives demand signal, if any, by default, i.e. information acquisition is not a decision variable (contrary to Anand and Goyal (2009)) and finally, the decision to leak or not leak information is made ex-ante rather than ex-post by first supplier, i.e., before the demand signals is obtained (contrary to Anand and Goyal (2009)).

Research Questions. This study is going to answer the following questions. For which constellations of demand uncertainty about $\tilde{A}$ and wholesalers' relative price W_1 / W_2, entrant chooses informed supplier and for which constellations of them, informed wholesaler accepts entrant's ordering?

Figure 3: Potential Supply Chain Configuration



4. Analysis

As depicted in figure 1, the first supplier, the incumbent and the entrant, each, should choose among two decisions: the first supplier should decide whether to accept the entrant or not ('Accept' or 'Not Accept'), the incumbent's decision is its ordering strategy ('Separation' or 'Pooling')[2], and finally the entrant's decision is to choose among two suppliers ('First Supplier' or 'Second Supplier'). Second supplier here will

[2] *Pooling* strategy implies that both types of the incumbent order the same quantity from the supplier to conceal the leakage of demand information. By choosing *Separation* strategy the high-type incumbent and the low-type incumbent order separate amount of quantity based on different level of demand realization. Hence the supplier also becomes aware of the updated information.

enter the game just in two cases: when the first supplier does not accept the entrant and so it must procure from the second supplier, or when the first supplier accepts the entrant but it is more profitable for it to choose the second supplier. Hence potentially we could have 8 different scenarios although some of them are infeasible or inefficient which are listed as follow:

Table 1: Potential Equilibria

	Scenario	Remark
1	(Accept, Separation, First Supplier)	-
2	(Accept, Separation, Second Supplier)	-
3	(Accept, Pooling, First Supplier)	-
4	(Accept, Pooling, Second Supplier)	Not Optimal for Incumbent
5	(Not Accept, Separation, First Supplier)	Infeasible
6	(Not Accept, Separation, Second Supplier)	-
7	(Not Accept, Pooling, First Supplier)	Infeasible
8	(Not Accept, Pooling, Second Supplier)	Not Optimal for Incumbent

As can be seen in table 1, we have potentially 4 equilibrium candidates which will be analytically discovered in next sections. Obviously when the first supplier decides not to accept the entrant it is not feasible to have two scenarios regardless of the incumbent's strategy (Scenarios 5 and 7). Moreover when the first supplier does not accept the entrant, there is no rational incentive for the incumbent to take the pooling strategy as it causes operational distortion while there is no channel for information leakage. Thus the 8th scenario is not optimal for the incumbent. Finally when the entrant chooses s_2 then separation will not be optimal for the incumbent and so the 4th scenario is ignored.

Incidentally the relationship between wholesale prices of two suppliers leads to clearer potential equilibria. Indeed if $W_1 \leq W_2$ then the first supplier offers lower wholesale price plus (weakly) higher information to the entrant which make him very attractive in the entrant's viewpoint. On the other hand if $W_1 > W_2$ then the second supplier offers lower price to the entrant but cannot add any updated information to the prior belief of the entrant while the first supplier is able to do that. In fact in this case there is a real trade-off between lower price and more information for the entrant which affects the incumbent's ordering strategy. The following table categorizes the remaining 4 scenarios:

Table 2: Potential Equilibria with Wholesale Price Consideration

2.1	If $W_1 \leq W_2$	Remark
1	(Accept, Separation, First Supplier)	-
2	(Accept, Separation, Second Supplier)	-
3	(Accept, Pooling, First Supplier)	-
4	(Not Accept, Separation, Second Supplier)	-

2.2	If $W_1 > W_2$	Remark
1	(Accept, Separation, First Supplier)	-
2	(Accept, Separation, Second Supplier)	-
3	(Accept, Pooling, First Supplier)	Not Optimal for Entrant
4	(Not Accept, Separation, Second Supplier)	-

As shown in above mentioned tables, if $W_1 \leq W_2$ and the first supplier accepts the entrant then the only incentive for the entrant to choose s_2 is the higher cost of information acquisition. In fact as it will be explained later, there is a threshold that affects the decision of the entrant between two suppliers. Here we have 4 equilibrium candidates.

Furthermore as depicted in table 2.2 if $W_1 > W_2$ then the only reason for the entrant to choose the first supplier is more precise demand information. So in the case of choosing pooling strategy by the incumbent there would be no rational incentive for the entrant to work with the first supplier, hence the 3rd scenario goes out. Here we have 3 equilibrium candidates.

For the sake of simplicity and tractability we impose two assumptions as below:

Assumption 1: If the first supplier accepts the entrant, it will leak the updated information.

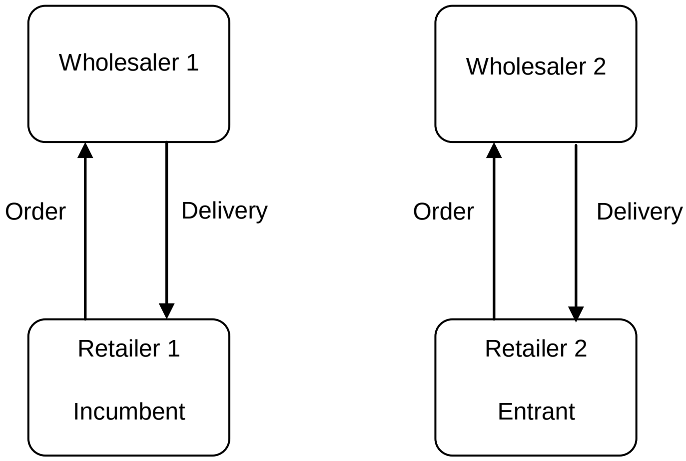
Assumption 2: Wholesale prices are sufficiently high as both retailers (The incumbent and the entrant) will tend to sell all the received intermediate goods. This means that assembly costs of the retailers are low enough compared to W_1, W_2.

In the next section we consider the first supplier's decision as *given* in order to have a benchmark analysis in hand. For this purpose we assume that based on long term business relationship between the first supplier and the incumbent, there is *exclusivity* in contractual terms such that the first supplier commits not to leak the updated information to the entrant. Thus the first event in the game is solved beforehand. Details are as follow.

4.1. Exclusive Supply Contract

As benchmark analysis, we consider the existence of *exclusive supply contract* (Anand and Goyal (2009)). In this case the first supplier is precluded from information leakage to entrant based on some fixed contractual terms. That is the supplier makes an *ex ante* credible commitment not to leak the incumbent's order quantity to the entrant. Hence the incumbent, aware of this term, takes the *separation* strategy and has no concern upon truthful ordering. Moreover the entrant must procure its order from second supplier. Indeed the game between the incumbent and the entrant is a static simultaneous-move game with incomplete information in which the incumbent sends its order to first supplier and the entrant to the second one (See figure 4). The point is that the incumbent at the ordering time knows the exact realization of demand while the entrant orders just based on his prior belief. Solving this game leads us to following results.

Figure 4: Supply Chain Configuration with Exclusivity



Proposition 1: Under exclusive supply contract between the first supplier and the incumbent (Non-Leakage), if $3A_L + 2(W_2 - 2W_1) \geq \mu$, then the order quantities of the high-type incumbent, the low-type incumbent and the entrant respectively are,

$$q_{iH}^{ESC} = \frac{1}{2}A_H - \frac{1}{6}\mu + \frac{1}{3}(W_2 - 2W_1) \;,\; q_{iL}^{ESC} = \frac{1}{2}A_L - \frac{1}{6}\mu + \frac{1}{3}(W_2 - 2W_1) \;,\; q_e^{ESC} = \frac{1}{3}(\mu - 2W_2 + W_1).$$

Moreover suppliers and retailers earn the following expected profits:

$$\pi_{s_1}^{ESC} = \frac{1}{3}(\mu - 2W_1 + W_2).W_1 \quad \text{(First Supplier)}$$

$$\pi_{s_2}^{ESC} = \frac{1}{3}(\mu - 2W_2 + W_1).W_2 \quad \text{(Second Supplier)}$$

$$\Pi_{iH}^{ESC} = \left[\frac{1}{2}A_H - \frac{1}{6}\mu + \frac{1}{3}(W_2 - 2W_1)\right]^2 \quad \text{(High type incumbent)}$$

$$\Pi_{iL}^{ESC} = \left[\frac{1}{2}A_L - \frac{1}{6}\mu + \frac{1}{3}(W_2 - 2W_1)\right]^2 \quad \text{(Low type incumbent)}$$

$$\Pi_{e}^{ESC} = \left[\frac{1}{3}(\mu - 2W_2 + W_1)\right]^2 \quad \text{(Entrant)}$$

Proof: When due to contractual terms, the first supplier commits *ex ante* not to leak the updated demand information from incumbent to entrant, optimal order quantities results from solving a simultaneous-move game with incomplete information. Profit functions of high-type incumbent, low-type incumbent and entrant which should be maximized are as follows:

$$\Pi_{iH} = \max_{q_{iH}} \left(A_H - q_{iH} - q_e \right) q_{iH} - W_1 q_{iH}$$
$$\Pi_{iL} = \max_{q_{iL}} \left(A_L - q_{iL} - q_e \right) q_{iL} - W_1 q_{iL}$$
$$\Pi_e = \max_{q_e} \left(p.\left(A_H - q_{iH} - q_e \right) q_e + (1-p).\left(A_L - q_{iL} - q_e \right) q_e \right) - W_2 q_e$$

Optimal order quantities are simply the answers of the first order conditions. Moreover $q_{iL}^{ESC} \geq 0$ is the participation constraint which guarantees the entry of incumbent and entrant to the market which results in $3A_L + 2\left(W_2 - 2W_1\right) \geq \mu$. This inequality also covers the price non-negativity condition that is $3A_L + 2\left(W_1 + W_2\right) \geq \mu$. Suppliers' profits can be calculated easily with equations $\pi_{s_1}^{ESC} = W_1.\left(pq_{iH}^{ESC} + (1-p) q_{iL}^{ESC} \right)$ and $\pi_{s_2}^{ESC} = W_2.\, q_e^{ESC}$. Retailers' profits also have been obtained by plugging optimal quantities into profit functions as shown above. □

Here the sequence of events is such that the first supplier based on exclusive contract with the incumbent does not accept the entrant's order which is common knowledge between all players. Due to that commitment, the incumbent truthfully reveals its order based on its updated demand information and so there is no operational distortion. The entrant afterwards has no other choice rather than doing business with second supplier. Finally after order delivery from suppliers, both retailers enter the market and compete on the amount of output. According to the first proposition, incumbent's order quantity depends on the actual realization of demand, posterior belief, which is known to it at ordering time while the entrant should maximize its expected profit and demand mean reveals in its optimal order quantity. In fact the entrant's ordering decision is based on his prior belief (demand mean). Here with the assumption of exclusivity, the incumbent does not encounter any informational distortion such that separation strategy and maximizing operational profit are in its interest.

4.2. Effect of Price Differences

Here we consider two different cases with respect to wholesale prices of the suppliers, establish the (dis)incentives of the players and seeking the equilibrium of the whole game.

4.2.1. The First Supplier Offers Lower Price $(W_1 \leq W_2)$

Under this price setting the entrant's incentives in choosing S_1 are lower wholesale price plus (weakly) higher information. Indeed even if the incumbent chooses pooling strategy, then the entrant can supply its goods with lower cost and its prior beliefs if it is accepted by S_1. Actually there could be potentially two incentives for the entrant to choose the second supplier: First reason in working with S_2 could be the non-acceptance of S_1 and second one refers to the cost of information acquisition. As we will show in second proposition, under some circumstances it is more profitable for the entrant not to choose the first supplier and enter the market with its prior belief. In this case it can produce Cournot quantity instead of Stackelberg one.

On the other hand the first supplier's incentive is to deliver higher volume of intermediate goods to the retailers in order to maximize its profit. Hence acceptance of the entrant is in his interest. Moreover the incumbent's incentive in both demand states is to persuade the entrant that the demand is low to reach more profit in the market. Pooling strategy is an equipment of the incumbent to threat the S_1 not to accept the entrant. The question here is that how *credible* this threat is. Actually if the incumbent pools (the worst scenario for S_1 in this case), then how the sum of the orders of both retailers *in comparison with* the scenario of non-acceptance of the entrant by S_1 will be. The other point is that when demand variation is high, pooling strategy is too costly for the high-type incumebnt. In fact if S_1 knows that the incumbent separates then he will always accept the entrant. As can be seen in following propositions and lemmas, the relative amount of the suppliers' wholesale price $\left(W_1/W_2\right)$ and mean demand μ play crucial roles here which could convince S_1 not to accept the entrant or could affect the entrant's decision in choosing among two suppliers and information acquisition.

4.2.1.1. Separating Equilibrium

Here we consider a potential equilibrium where the incumbent's order quantity depends on the demand states (High or Low). Thus if the first supplier accepts the entrant then the entrant will have perfect demand information as well prior to his ordering decision.[3] Hence under this scenario a *Stackelberg* sequential move game with complete information occurs in which the incumbent is the leader and the entrant is the follower.

For future references we establish the following lemma that states the optimal quantities of Stackelberg game for our mentioned inverse demand system. For brevity, the proof has been skipped.[4]

Lemma 1: If the first supplier S_1 accepts the entrant, the incumbent separates and the entrant chooses the first supplier S_1, then the SPNE outcomes (quantities and profits) of the respected *Stackelberg game with complete information* are as follows:

$$q_i^{*Stackelberg} = \left(\tilde{A}-W_1\right)\Big/2 \quad ; \quad q_e^{*Stackelberg} = \left(\tilde{A}-W_1\right)\Big/4$$

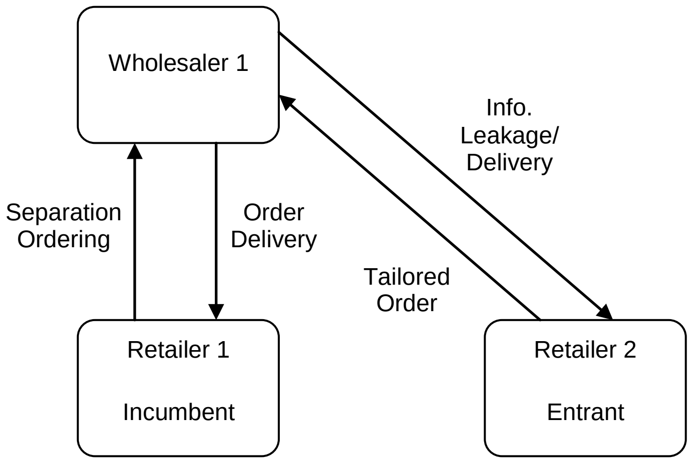
$$\pi_i^{*Stackelberg} = \left(\tilde{A}-W_1\right)^2\Big/8 \quad ; \quad \pi_e^{*Stackelberg} = \left(\tilde{A}-W_1\right)^2\Big/16$$

[3] If the first supplier accepts the entrant then the entrant will access to the actual demand information and also cheaper goods. Since the incumbent orders first, so the entrant plays the role of the follower.

[4] The idea of putting this Lemma here is inspired by Anand and Goyal (2009). The detailed proof can be found in the technical appendix of Anand and Goyal (2009) and also several game theoretic books, i.e. Gibbons (1992).

Referring to figure 3, the supply chain configuration due to this scenario (Accept, Separation, First Supplier) can be depicted as the following figure.

Figure 5: Supply Chain Configuration of Lemma 1



As explained earlier in the separating equilibrium, the entrant has perfect demand information and realizes the demand state correctly. Consequently based on the figure 2, in the extensive form of the resulted game the entrant infers the realized demand, updates its prior belief and knows on which node of the signaling game stands.

In order to find the equilibrium, firstly we investigate the choice of entrant among two suppliers. Considering incentives, it is obvious that the entrant will choose more profitable supplier. Next Lemma describes the entrant's decision.

Lemma 2: Under separation equilibrium and when $W_1 \leq W_2$, if $\mu \leq 8W_2 - 7W_1$ then the entrant chooses the first supplier S_1. Otherwise it chooses the second supplier S_2.

Proof: The entrant will choose S_1 *if and only if* $\Pi_e^{s_1} \geq \Pi_e^{s_2}$, otherwise it chooses the second supplier. As a matter of notation, $\Pi_e^{s_1}$ implies the entrant's profit by choosing the first supplier. If the entrant chooses the second supplier, regardless of the reason (Its own decision or non-acceptance of S_1), then its profit- based on proposition 1- is:

$$E\left(\Pi_e^{s_2}\right)=\left[\frac{1}{3}\left(\mu-2W_2+W_1\right)\right]^2$$

For calculating the expected $\Pi_e^{s_1}$, the entrant faces the following maximization problem based on its prior belief:

$$E\left(\Pi_e^{s_1}\right)=p.\max_{q_{eH}}\left[\left(A_H-q_{iH}^*-q_{eH}\right)q_{eH}-W_1.q_{eH}\right]+\left(1-p\right).\max_{q_{eL}}\left[\left(A_L-q_{iL}^*-q_{eL}\right)q_{eL}-W_1.q_{eL}\right]$$

In order to solve the above optimization problem we need the optimal amount of the incumbent's quantity in both demand state. The expected profit of the entrant by choosing the first supplier is:

$$E\left(\Pi_e^{s_1}\right)=\left[\frac{1}{4}\left(\mu-W_1\right)\right]^2$$

Solving inequality $\Pi_e^{s_1}\geq\Pi_e^{s_2}$ leads us to the below result:

$\mu\leq 8W_2-7W_1$. □

Lemma 3: The first supplier always *accepts* the entrant, if separation equilibrium outcome occurs after acceptance.

Proof: Comparing the fist supplier's profit in two cases (acceptance and non-acceptance) concludes the result. We have:

If the first supplier accepts the entrant, its profit is as follow:

$$\pi_{s_1}^{accept}=p.\left(W_1\,.\,q_{iH}^*+W_1\,.\,q_{eH}^*\right)+\left(1-p\right).\left(W_1\,.\,q_{iL}^*+W_1\,.\,q_{eL}^*\right)$$

But in the case of non-acceptance we have:

$$\pi_{s_1}^{not-accept}=p.\left(W_1\,.\,q_{iH}^*\right)+\left(1-p\right).\left(W_1\,.\,q_{iL}^*\right)$$

It is trivial to show that $\pi_{s_1}^{accept}\geq\pi_{s_1}^{not-accept}$. □

According to above mentioned Lemmas, now, we are well equipped to establish the second proposition which describes the separation equilibrium. Before that, as in

Anand and Goyal (2009), we should consider the entrant's belief as a part of PBNE. The entrant's belief structure is as follow:

$$\Pr_e\left(\tilde{A}=A_H\right)=\begin{cases}1, & \text{if the first Supplier accepts and } q_i > q_{iL}^* \\ 0, & \text{if the first Supplier accepts and } q_i \le q_{iL}^*\end{cases}$$

In separation strategy, the major incentive of the incumbent is to signal the entrant that the demand state is low. This could be beneficial when the difference between high and low demand states is *small enough* (this term is quantified via parameter $\theta=\left(A_H-W_1\right)/\left(A_L-W_1\right)$). Actually the incumbent tries to manage the entrant's belief. On the other hand, the entrant's belief is increasing in the order quantity of incumbent. This issue will appear as an *incentive compatibility constraint* in our optimization problem such that the high-type incumbent has an incentive to mimic the low-type. The inverse one is not reasonable. The following proposition characterizes the separation equilibrium. Here, capacities have been chosen by retailers, but quantities still not.

Proposition 2: A separating Perfect Bayesian Nash Equilibrium exists and is as follow:

i. If $\mu \le 8W_2-7W_1$:

- The first supplier S_1 accepts the entrant.
- The incumbent orders:

  $q_{iH}^*=\left(A_H-W_1\right)/2$, if demand is high

  $q_{iL}^*=\left(A_L-W_1\right)/2$, if demand is low and $\theta \ge 3$

  $q_{iL}^*=\dfrac{2A_H-A_L-W_1-\sqrt{\left(A_H-A_L\right)\left(3A_H-A_L\right)-2W_1\left(A_H+A_L\right)}}{2}$, if demand is low and $\theta<3$

- The entrant chooses the first supplier S_1 and orders:

  $q_{eH}^*=\left(A_H-W_1\right)/4$, if $\Pr_e\left(\tilde{A}=A_H\right)=1$

  $q_{eL}^*=\left(A_L-W_1\right)/4$, if $\Pr_e\left(\tilde{A}=A_H\right)=0$ and $\theta \ge 3$

  $q_{eL}^*=\dfrac{3A_L-2A_H-W_1+\sqrt{\left(A_H-A_L\right)\left(3A_H-A_L\right)-2W_1\left(A_H+A_L\right)}}{4}$ if $\Pr_e\left(\tilde{A}=A_H\right)=0$ & $\theta<3$

Consistent with its belief that:

$$\Pr_e\left(\tilde{A}=A_H\right)=\begin{cases}1, & \textit{if the first Supplier accepts and } q_i > q_{iL}^* \\ 0, & \textit{if the first Supplier accepts and } q_i \le q_{iL}^*\end{cases}$$

ii. If $\mu > 8W_2 - 7W_1$:

- The first supplier S_1 accepts the entrant.
- The incumbent orders:

  $q_{iH}^* = \frac{1}{2}A_H - \frac{1}{6}\mu + \frac{1}{3}(W_2 - 2W_1)$, if demand is high

  $q_{iL}^* = \frac{1}{2}A_L - \frac{1}{6}\mu + \frac{1}{3}(W_2 - 2W_1)$, if demand is low

- The entrant chooses the second supplier S_2 and orders:

  $q_e^* = \left(\mu - 2W_2 + W_1\right)/3$, consistent with its belief that $\Pr_e\left(\tilde{A}=A_H\right)=p$

Proof: We use Lemmas 1-3 in our calculation. The proof is similar to that of Anand and Goyal (2009), adjusted to our model with two suppliers.

<u>Part One</u>: Based on Lemma 2 we know that under which circumstances the entrant will choose among two suppliers. So if $\mu \le 8W_2 - 7W_1$ the entrant chooses the first supplier S_1. Also in Lemma 3 we have shown that the first supplier always accepts the entrant. Hence under separation strategy, the incumbent determines its order quantity by simultaneously solving the following maximization problem:

The low-type incumbent solves:

$$\Pi_{iL} = \max_{q_{iL}}\left(A_L - q_{iL} - q_{eL}^*\left(q_{iL}\right)\right)q_{iL} - W_1.q_{iL}$$

Such that $\left(A_H - q_{iL} - q_{eL}^*\left(q_{iL}\right)\right)q_{iL} - W_1.q_{iL} \le \left(A_H - W_1\right)^2/8$

And the high-type incumbent solves:

$$\Pi_{iH} = \max_{q_{iH}} \left(A_H - q_{iH} - q_{eH}^*\left(q_{iH}\right)\right) q_{iH} - W_1 . q_{iH} \quad \text{(Unconstrained)}$$

Note: The low-type incumbent has not any incentive to mimic the high-type one, while the high-type tries to convince the entrant that the demand state is low. Thus the maximization problem of the low-type incumbent has a constrained which guarantees that off-equilibrium profit is not higher than equilibrium profit. (Incentive Compatibility Constraint)

Moreover the entrant faces the following maximization problem:

$$q_{eL}^*\left(q_{iL}\right) = \arg\max_{q_{eL}} \left(A_L - q_{iL} - q_{eL}\right) q_{eL} - W_1 .\, q_{eL} = \left(A_L - q_{iL} - W_1\right)/2$$
$$q_{eH}^*\left(q_{iH}\right) = \arg\max_{q_{eH}} \left(A_H - q_{iH} - q_{eH}\right) q_{eH} - W_1 .\, q_{eH} = \left(A_H - q_{iH} - W_1\right)/2$$

Considering $\theta = \left(A_H - W_1\right)/\left(A_L - W_1\right)$, the rest of the proof for part one is similar to Anand and Goyal (2009). In our proof the wholesale price appears in calculation and change the final order quantity.[5]

<u>Part Two</u>: Based on Lemma 2 we know that if $\mu > 8W_2 - 7W_1$ then the entrant chooses the second supplier. This choice does not update the prior belief of the entrant. The proof of this part is similar to the proof of proposition 1. In this scenario although the first suppler accepts the entrant, information acquisition is not valuable for the entrant and it prefers to enter the market using its prior belief. □

As can be seen in proposition 2, when demand variation is high enough, here $\theta \geq 3$, it is too costly for the incumbent to manipulate its order quantity. Truthful revelation of the demand state is in his interest. Thus if the entrant chooses the first supplier, the real demand state will be transferred thereafter. Indeed when $\theta \geq 3$ the difference between high and low demand realization is as so high such that the high type incumbent avoids mimicking the low type. In this case if the entrant procures from S_1

[5] The proof of the first part is very similar Anand and Goyal (2009, Technical Appendix). Here contrary to them, based on different modeling and the existence of second supplier, we consider positive wholesale prices which slightly affect the results.

then the game will be the Stackelberg with complete information as discussed in Lemma 1.

On the other hand, when demand variation is low enough, here $\theta < 3$, it is valuable for the incumbent to manipulate its ordering to convince the entrant upon low demand realization. The point is that the entrant is also aware of this thinking and behaves strategically. So when demand is high, the high type incumbent orders truthfully as before but the low type incumbent should ensure the entrant that demand is really low. Hence the incumbent should order a quantity strictly less than $q_{iL}^{*} = \left(A_L - W_1\right)/2$ to convince the entrant that the demand is low. Otherwise the entrant might infer $q_{iL}^{*} = \left(A_L - W_1\right)/2$ as an ordering of the high type incumbent mimicking low type. Thus when demand state is low and $\theta < 3$, then the low type incumbent prefers to order $q_{iL}^{*} = \left[\left(2A_H - A_L - W_1 - \sqrt{\left(A_H - A_L\right)\left(3A_H - A_L\right) - 2W_1\left(A_H + A_L\right)}\right)/2\right] < \left[\left(A_L - W_1\right)/2\right]$.

The other issue is the existence of the threshold which determines the choice of entrant among two suppliers. As shown in Lemma 2, the entrant will not choose the first supplier if $\mu > 8W_2 - 7W_1$. This implies that information acquisition for the entrant is a strategic decision and entering the market with prior belief could be his best reaction. Indeed when $\mu > 8W_2 - 7W_1$ the entrant produces based on Cournot which is higher compared to Stackelberg follower. Also it can sell its product with higher price which concludes higher benefit. But the incumbent (as potential Stackelberg leader) and the first supplier face the opportunity cost of not having the entrant in their desirable supply chain configuration as shown in figure 5. By considering the condition $\mu > 8W_2 - 7W_1$, the first supplier can leverage the choice of entrant by decreasing its wholesale price W_1 (which we take it exogenous in the model). Indeed by decreasing the wholesale price W_1 the range of choosing S_1 by the entrant expands which could be profitable for S_1.

4.2.1.2. Pooling Equilibrium

In this subsection we consider a potential equilibrium where the incumbent chooses pooling strategy such that the incumbent's order quantity is independent of demand state. Hence the entrant cannot update his prior belief. Indeed, here, the only reason for the entrant in choosing s_1 is the lower wholesale price of it in comparison with s_2, that is $W_1 \leq W_2$.

As it was discussed in table 2.1, under pooling equilibrium, the first supplier already has accepted the entrant. In fact if s_1 does not accept the entrant then there will be no incentive for the incumbent to pool. So (Not Accept, Pooling, Second Supplier) will not happen in equilibrium as it is not optimal for the incumbent. Moreover as we have shown in proposition 2, when the difference between high and low demand realization is high enough ($\theta > 3$), then it is too costly for the incumbent to pool and mimic the other type. Hence pooling equilibrium is feasible for smaller range of θ which will be determined precisely later. So the question is that under which circumstances the first supplier accepts the entrant when the threat of pooling is credible. Following lemma deals with this situation.

Lemma 4: Under the pooling equilibrium, if $\mu \leq 2A_L - W_1$ then the first supplier s_1 *accepts* the entrant. Otherwise it will reject the entrant.

Proof: Similar to the proof of Lemma 3, comparing the fist supplier's profit in two cases (acceptance and non-acceptance) concludes the result. We have:

If the first supplier accepts the entrant, its profit is as follow:

$$\pi_{s_1}^{accept} = W_1 \cdot \left(q_{ip}^* + q_{ep}^*\right)$$

q_{ip}^* and q_{ep}^* can be calculated based on the proof of the next proposition. To be mentioned here, we have:

$$q_{ip}^* = A_L - \left(\mu + W_1\right)/2$$
$$q_{ep}^* = \left(3\mu - 2A_L - W_1\right)/4$$

By plugging these two quantities into the profit function of the first supplier we reach:

$$\pi_{s_1}^{accept} = \left(W_1 / 4\right)\left(\mu + 2A_L - 3W_1\right) \quad (*)$$

But in the case of non-acceptance we have:

$$\pi_{s_1}^{not-accept} = p.\left(W_1 \,.\, q_{iH}^{*}\right) + \left(1-p\right).\left(W_1 \,.\, q_{iL}^{*}\right)$$

Separation quantities of the incumbent can be obtained from proposition 2, so here we get:

$$\pi_{s_1}^{not-accept} = \left(W_1 / 2\right)\left(\mu - W_1\right) \quad (**)$$

By comparing (*) and (**) we conclude:

$\pi_{s_1}^{accept} \geq \pi_{s_1}^{not-accept}$ iff $\mu \leq 2A_L - W_1$. □

As corollary of above mentioned Lemma it can be stated that the probability of accepting the entrant by S_1 is *decreasing* with respect to the probability of high demand realization p. (The proof is simply achieved by limit the inequality when p tends to zero)

Now we should find out range of quantity in which the incumbent has incentive to pool. As we discussed before, the low type incumbent has no incentive to mimic the high type. Hence the optimal quantity of the low type incumbent in pooling equilibrium determines the upper bound of (or maximum amount of) the pooling interval ($q_{iP}^{\max}$). On the other hand the high type incumbent has reasonable incentive to mimic the low type and conceal the real demand state, but the question is that '*down to which amount?'* Indeed the high type incumbent pools when it would make more profit than the case of ordering a high enough quantity which can reveal his type to the entrant. Thus the minimum order quantity that the high type incumbent prefers to pool determines the lower bound of (or minimum amount of) the pooling interval ($q_{iP}^{\min}$). Obviously the lower bound should be smaller or equal to the upper bound of the interval. This trivial condition specifies the range of θ in which pooling equilibrium exists.

In pooling equilibrium, the belief structure of the entrant which is an essential part of the PBNE determination, based on Anand and Goyal (2009), is as follow:

$$\Pr_e\left(\tilde{A}=A_H\right)=\begin{cases}1, & \text{if the first Supplier accepts and } q_i > q_{iP}^{\max} \\ p, & \text{if the first Supplier accepts and } q_{iP}^{\min} \le q_i \le q_{iP}^{\max} \text{ , or} \\ & \text{if the first Supplier does not accept} \\ 0, & \text{if the first Supplier accepts and } q_i < q_{iP}^{\min}\end{cases}$$

Next Lemma formalizes the above mentioned discussion:

Lemma 5: A pooling equilibrium, if exists, should belong to the interval $\left[q_{iP}^{\min}, q_{iP}^{\max}\right]$ where:

$$\begin{cases} q_{iP}^{\max} = A_L - \left(\mu + W_1\right)/2 \\ q_{iP}^{\min} = A_H - \left(\mu + W_1\right)/2 - \left(1/2\right)\sqrt{\left(A_H-\mu\right)\left(3A_H-\mu\right) - 2W_1\left(A_H+\mu\right)} \end{cases}$$

Proof: The upper bound of the interval will be determined by the optimal order quantity of the low type incumbent because the low type never prefers to pool on a quantity more than q_{iP}^{*L}. In fact if he orders more than this optimal quantity, the entrant might ascribe it as a high demand realization signal which is not favorable for the incumbent. For finding q_{iP}^{*L} we have to solve the following maximization problem:

$$\Pi_{iL}^{P} = \max_{q_{iP}}\left(A_L - q_{iP} - q_{eP}^{*}\left(q_{iP}\right)\right).q_{iP} - W_1.q_{iP}$$

Since the entrant cannot realize the exact demand state, he should stick to his prior and solve the following optimization problem:

$$\Pi_{e}^{P} = \max_{q_{eP}}\left(p.\left(A_H - q_{iP} - q_{eP}\right).q_{eP} + \left(1-p\right).\left(A_L - q_{iP} - q_{eP}\right).q_{eP}\right) - W_1.q_{eP}$$

First-Order-Conditions lead us to the optimal quantity of the entrant and also low type incumbent which specifies the *upper* bound of the interval in Lemma 5. Both optimal quantities are shown below:

$$q_{eP}^{*}\left(q_{iP}\right)=\left(\mu-q_{iP}-W_1\right)/2$$

$$q_{iP}^{\max}=q_{iP}^{*L}=A_L-\left(\mu+W_1\right)/2$$

Plugging the optimal quantity of the low type incumbent q_{iP}^{*L} into the entrant's equation reach us to: $q_{eP}^{*}=\left(3\mu-2A_L-W_1\right)/4$

In order to find out the lower bound of the interval we should consider the incentive of the high type incumbent who prefers to mimic the low type to affect the entrant's order. Indeed the high type incumbent will pool as long as the profit of pooling dominates the profit of truthful revelation. So the high type incumbent solves the following inequality:

$$\left(A_H-q_{iP}-q_{eP}^{*}\left(q_{iP}\right)\right).q_{iP}-W_1.q_{iP}\geq\underbrace{\max_{q_{iH}>q_{iP}^{*}}\left(A_H-q_{iH}-q_{eH}^{*}\left(q_{iH}\right)\right).q_{iH}-W_1.q_{iH}}_{\left(A_H-W_1\right)^2/8}$$

After some manipulation on the inequality and find out the two roots of the resulted formula will get us to the lower bound of the interval as below:

$$q_{iP}^{\min}=A_H-\left(\mu+W_1\right)/2-\left(1/2\right)\sqrt{\left(A_H-\mu\right)\left(3A_H-\mu\right)-2W_1\left(A_H+\mu\right)}\qquad\square$$

Existence condition of a pooling equilibrium is similar to Anand and Goyal (2009) and will be got by solving the inequality $q_{iP}^{\min}\leq q_{iP}^{\max}$. The alterations are the positive amount of wholesale price- which changes the formulation of θ such that $\theta=\left(A_H-W_1\right)/\left(A_L-W_1\right)$-and also the threshold (Shown in Lemma 2) after which the entrant chooses the second supplier. Working with the second supplier leads to separation equilibrium.

Lemma 6: The pooling equilibrium *exists* if demand uncertainty proxy parameter θ and mean demand μ obey the following inequalities simultaneously:

$\theta\leq\left(3+2p-p^2\right)/\left(1+4p-p^2\right)$ where p is the probability of high demand realization;

And

$\mu \le \min\{(8W_2 - 7W_1),(2A_L - W_1)\}$ which causes that first, S_1 accepts the entrant and second, the entrant chooses the first supplier S_1.

Otherwise there is no pooling equilibrium and the incumbent prefers to separate its ordering.

Proof: By solving $q_{iP}^{\min} \le q_{iP}^{\max}$ (As done in Anand and Goyal (2009)) we reach the first inequality of θ. The second inequality on μ has been proven in Lemma 2. □

The following proposition characterizes the pooling equilibrium when $W_1 \le W_2$:

Proposition 3:

- If $\mu \le \min\{(8W_2 - 7W_1),(2A_L - W_1)\}$ & when $\theta \le (3+2p-p^2)/(1+4p-p^2)$, a pooling Perfect Bayesian Nash Equilibrium exists and is as follow:

I. The first supplier S_1 accepts the entrant.

II. The incumbent orders: $q_{iP}^{*} = A_L - (\mu + W_1)/2$

III. The entrant chooses the first supplier S_1 and orders: $q_{eP}^{*} = (3\mu - 2A_L - W_1)/4$

Consistent with its belief that:

$$\Pr_e\left(\tilde{A} = A_H\right) = \begin{cases} 1, & \textit{if the first Supplier accepts and } q_i > q_{iP}^{\max} \\ p, & \textit{if the first Supplier accepts and } q_{iP}^{\min} \le q_i \le q_{iP}^{\max} \textit{, or} \\ & \textit{if the first Supplier does not accept} \\ 0, & \textit{if the first Supplier accepts and } q_i < q_{iP}^{\min} \end{cases}$$

where $q_{iP}^{\min} = A_H - (\mu + W_1)/2 - (1/2)\sqrt{(A_H - \mu)(3A_H - \mu) - 2W_1(A_H + \mu)}$

- Otherwise, If $\mu \leq \min\{(8W_2 - 7W_1), (2A_L - W_1)\}$, $\theta \leq (3+2p-p^2)/(1+4p-p^2)$ or both does not hold, there is no pooling equilibrium and firms behave as proposition 2.

Proof: Proofs of Lemmas 2, 4, 5 and 6, actually lead us to the outcomes of this proposition. □

As shown in proposition 3, when the incumbent chooses pooling equilibrium (and it exists), the entrant obtains no additional demand information and should stick to its prior. The point is that this pooling should be beneficial for the incumbent. This issue is determined by the condition on θ. Indeed when θ is high it is too costly for the high type incumbent to mimic the low type and separation will occur.

The other important point is preconditions for existence of pooling equilibrium. In fact information acquisition should be profitable for the entrant which is captured by $\mu \leq 8W_2 - 7W_1$. Moreover the first supplier accepts the entrant as long as the profit he would make from acceptance (besides the threat of pooling strategy) dominates the choice of non-acceptance. This also causes to impose a restriction on mean demand that is $\mu \leq 2A_L - W_1$. Hence $\mu \leq \min\{(8W_2 - 7W_1), (2A_L - W_1)\}$ is the necessary condition for existence of any pooling equilibrium.

4.2.2. The Second Supplier Offers Lower Price $(W_2 < W_1)$

Under this pricing regime, the only incentive of the entrant for choosing S_1 is its potential updated information. It implies that if the incumbent pools on its quantity ordering, then the entrant will choose the cheaper wholesaler in equilibrium. As we have shown in table 2.2, if $W_1 > W_2$ we could have potentially three possible equilibria where in two cases, the first supplier accepts the entrant and the incumbent separates. Hence the exact equilibrium will be determined by the decision choice of the entrant among two wholesalers. Whereas the second supplier offers more attractive price, we have a real trade-off for the entrant between higher levels of demand information (which could be obtained by choosing S_1) and lower price of the product (which is offered by S_2). This decision will configure our supply chain. Also as we have explained in Lemma 3, under separation, the first supplier S_1 always accepts the entrant (in equilibrium). Hence only two equilibrium candidates remain. As significant calculations have been done so far, we go directly to state the result.

Proposition 4: If $\mu \leq 8W_2 - 7W_1$ and $0.875 \leq \frac{W_2}{W_1} \leq 1$, then in equilibrium, the first supplier S_1 accepts the entrant, the incumbent separates and the entrant prefers S_1. The optimal quantities of the players and the belief structure of the entrant are as stated in the first part of proposition 2. Otherwise if one or both of above mentioned conditions does not hold, then in equilibrium, the first supplier S_1 accepts the entrant, the incumbent separates and the entrant chooses the second supplier S_2 that offers lower price. The optimal quantities of the players and the belief structure of the entrant are as stated in the second part of proposition 2.

Proof: The proof is similar to the methods we have followed in Lemmas 1-3 and proposition 2. The added condition on the relative amount of wholesale prices stems from the fact that $W_1 > W_2$ which causes the imposition of inequality $0 \leq \mu \leq 8W_2 - 7W_1$. In previous subsection as $W_1 \leq W_2$, the mean demand was always positive but here in order to have non-negative mean demand we should have $0 \leq 8W_2 - 7W_1$. This leads us to a condition on wholesale prices $\frac{7}{8} = 0.875 \leq \frac{W_2}{W_1} \leq 1$. □

As expresses in proposition 4, when the entrant has access to a supplier with lower price, the range of relative wholesale price W_2 / W_1 is more restricted. In fact if the price of S_2 is much lower than S_1 such that the condition $0.875 \leq \left(W_2 / W_1\right)$ would not hold, then the entrant will ignore the updated demand information and work with the second supplier.

5. Conclusion

In this essay we presented a model to investigate the strategic effects of information sharing on supply chain configuration with vertical structure. We considered a typical supply chain containing two suppliers (wholesalers) that could potentially supply intermediate (final) goods to two manufacturers (retailers), an incumbent and an entrant. The incumbent is assumed to do business only with the first supplier (potential channel of information leakage from incumbent to entrant) while the entrant is free to choose its supplier strategically. A dynamic multi-stage game of incomplete information between these four economic agents was employed: The first supplier starts the game by his decision upon (none) acceptance of the entrant followed by the quantity order decision of the incumbent, then the entrant decides between two suppliers and places his order (considering their wholesale price and updated information) and finally, both retailers play a Cournot duopoly game on the amount of quantity they launch to the market characterized by demand uncertainty. Our model contributed to the literature in IO and strategic information management by considering a second supplier which gives a degree of freedom to the entrant in choosing its supplier. Methodologically, a signaling game was applied to model the strategic interactions of players. Hence, Perfect Bayesian Nash Equilibrium (PBNE) has been derived in terms of information and material flows.

We showed that how the difference between wholesale prices W_1, W_2, the elements of mean demand $\mu = p.\, A_H + (1-p).\, A_L$, and also the range of demand variation $\theta = (A_H - W_1)/(A_L - W_1)$, select an equilibrium from the set of candidates. Moreover it was demonstrated that information acquisition is not always desirable for an uninformed entrant and how the entrant prefers to trade off between price and information, playing Cournot or Stackelberg. Furthermore existence of pooling equilibrium for sufficiently small demand variation confirms the significant role of strategic information management whereby the incumbent is able to keep its competitive advantage and preclude the leakage of information. Add a second supplier to the seminal model of Anand and Goyal (2009), actually empowers us to involve the first supplier more actively. This extension gives the entrant an opportunity to choose its own supplier endogenously. In addition, the existence of pooling equilibrium besides the separation one implies that more accurate demand information (in the form of lower θ) enables the incumbent to conceal its private information while less accuracy leads to truthful ordering and neutralize the asymmetric dominancy.

Our model dealt with exogenous wholesale prices which restrict the role of suppliers. Further research can endogenize the pricing of suppliers in the model. Indeed price competition between two suppliers makes the research more interesting and realistic. Moreover we imposed a restriction on choice of the incumbent between suppliers which can be released in oncoming works. Partial supply also can be investigated. Finally for the sake simplicity we avoided to examine the level of information quality which is worth examining.

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