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Technology Licensing Strategy Under Asymmetric Beliefs of Supply Reliability

Yunhan Gong

School of Management, Chongqing University of Technology, Chongqing, 400054, China

Abstract: We study the optimal licensing strategy amid the risk of supply chain disruption. Specifically, where an upstream supplier (Licensor, patent-holding firm) licenses technology to another firm (Licensee), so a downstream manufacturer (M) can adopt a dual source purchasing strategy to ensure supply reliability, especially, the estimates of supply reliability among suppliers and manufacturers are inconsistent. Licensor has two licensing strategies: royalty licensing and fixed-fee licensing. Our findings reveal that Licensor will decide which licensing strategy to adopt, considering the fixed fee. In most case, Licensor will decide whether to produce after technology licensing based on estimation conditions, but in case of M and Licensee estimate inconsistently, Licensor will always produce after royalty licensing. Additionally, manufacture will take different procurement strategies based on different estimation situations, especially the estimation of Licensor.

Keywords: Supply reliability, Technology licensing, Dual sourcing, Asymmetric beliefs.

1. Introduction

With the development of economy, an increasing number of enterprises embark on transnational business, leading to more frequent business exchanges among countries. Consequently, the supply chain has become increasingly globalized, accounting for a substantial portion of enterprises' economic activities. However, various unpredictable factors, such as natural disasters or international situation like trade wars, can result in unexpected disruptions to supply chains. Especially in some transnational trade such as global purchasing and sales, business outsourcing, the risk of disruption will be further amplified due to the longer transport distance. Supply chain disruption may be broadly categorized into three categories: (i) supply-related, which occurs when suppliers are unable to fulfill the placed order; (ii) demand related, resulting from sudden fluctuations in customer orders; (iii) miscellaneous risks encompassing unexpected changes in purchasing costs, interest rates, currency exchange rates, safety regulations by government agencies, etc. [1].

In general, supply disruption can significantly impact the business performance of downstream enterprises, causing significant damage to their profitability and leading to shareholder's profit loss and a decline in corporate reputation [2]. Faced the frequent occurrence of supply disruption events and their serious consequences (exemplified by the 2011 Japanese earthquake, which forced many auto parts suppliers to stop production, resulting in Honda, Toyota and other automakers suspending operations for half a year), an increasing number of firms seek solutions.

Dual sourcing is one of the strategies for buyers to deal with the risk of supply chain disruption. Dual (or multi) sourcing, a common supply management strategy, involves the buyer (retailer) purchases from two (or more) suppliers to mitigate the risk of supply chain disruption [3]. Product substitution, an effective demand management strategy, is often used in combination with dual sourcing when multiple sources are unavailable. This combination aims to design supply chains that are more resilient to the high impact of disruption events [4]. Simultaneously, some studies have found that depending on the probability of disruption, either single or dual sourcing can be effective [5]. Dong examines the strategic procurement options of original equipment manufacturers (OEM) in the case of contract manufacturer (CM) intrusion and reliability improvement [6]. Boulaksil et al. investigate the optimization problem of buyer's dual sourcing between inexpensive slow suppliers and expensive fast suppliers [7]. Deligiannis et al. propose a model where a firm sourcing non-storable substitute products from an expensive reliable supplier and a cheap unreliable supplier. They use Bayesian dynamic programming to determine the firm's myopic sourcing policy and partially characterize its optimal sourcing policy. However, existing studies neglect the role of suppliers in dual sourcing, and our research addresses this gap [8].

For suppliers, considering the dual sourcing strategy applied by manufacture, technology licensing emerges as a feasible approach to mitigating the risk of supply disruptions. In technology licensing, the patent-holding firm licenses the technology of production to another firm, allowing it to produce similar, even homogeneous products. This license confers upon the licensee only the right to use the technology, without transferring ownership. While technology licensing might seem to spawn a formidable competitor for the patent-holding firm, potentially exerting a negative impact. However, there are numerous instances of successful technology licensing in practice. For example, Ford licenses its intellectual property and technology, including diesel fuel regulation modules and passenger-side airbag deactivation switches, to its competitors. Dell, on the other hand, assisted its supplier, Lexmark, in enhancing printer technology in 2002 with innovative cartridge refill software developed by itself. The reason why patent-holding firms are willing to license their technology is that although the licensor creates a competitor who has a negative impact their products sales, they can offset these losses through licensing fees. Secondly, by controlling the licensing fee, the licensor can control the production cost of the licensee, thereby influencing the competitiveness of the licensee. Consequently, the licensee's impact on the licensor is controllable. Finally, after technology licensing, downstream manufacturers have a second supplier, so they can adopt strategic purchasing. In contrast, with no technology licensing, the robustness of the supply chain is quite low. If the sole supplier is disrupted, then the impact of disruption would ripple through the whole supply chain and cause an economic and reputation loss for both the supplier and the manufacturer [9].

Moreover, technology licensing has long been regarded by most high-tech enterprises as a fast and effective means to improve technology and innovative development [10]. Dong and Tang examined technology licensing decisions in a duopoly model with heterogeneous consumers, focusing on quality improvement technologies and quality information disclosure strategies among competing licensors and licensees [11]. Chen and Wang analyzed cost-efficient technology licensing strategies for three manufacturers producing partially substitutable products, they considered four strategies among technology innovators, mid-cost manufacturers, and high-cost manufacturers. Different from the existing research, we view technology licensing as a strategy to address supply disruption and broaden the application scenarios of technology licensing [12].

In reality, upstream supplier and downstream manufacture within the supply chain possess asymmetric levels of information regarding various supply disruptions. Generally speaking, suppliers will have private information about supply disruptions. For example, a supplier may have a deeper understanding of the risk of supply chain disruption than a manufacturer, as well as grasp of the capacity loss resulting from such disruption. In other words, manufacturer and supplier have different perspectives on the risk of supply chain disruption and have their own assessments of the supply chain's reliability, which may be vary. Therefore, when estimating the risk of supply chain disruption, it is crucial to take into account the differing estimations of supply reliability held by manufacturers and suppliers.

Naturally arising research questions are as following:

(1) What is the optimal licensing strategy for Licensor considering different estimate of supply reliability?

(2) What is the optimal production strategy for Licensor under different licensing strategy?

(3) What is the optimal procurement strategy for M given different estimate of supply chain stability?

By solving above questions, we make following contributions

(1) Asymmetric beliefs of supply reliability are considered, which means estimation of supply reliability is different between suppliers and manufactures.

(2) Technology licensing is considered as a coping strategy for supply disruption.

(3) We study the influence of different estimation of supply reliability on technology licensing.

(4) Existing researches on technology licensing are limited to the best licensing strategy, but we study licensor whether to continue production after technology licensing.

The remainder of this paper is organised as follows: Section 2 reviews the related literature. Section 3 presents the model notation and assumptions. In Section 4, we analyse both benchmark model and licensing model. Section 5 presents and compares the numerical results. Finally, Section 6 summarizes our work and outlines the prospect of future work.

2. Literature Review

We will review the relevant literature, including two parts: technology licensing and supply disruption management.

2.1. Supply Disruption Management

Recent research partly focuses on dual sourcing. Tomlin studies two kinds of risk responding strategies when one supplier has the risk of supply disruption in dual-source procurement: diversification strategy before disruption and emergency measure after disruption [13]. Tomlin studies the impact of various factors, including suppliers' supply disruption correlation, product substitutability, demand uncertainty, buyer's risk aversion, on the implementation of dual-source procurement strategy [14]. Additionally, Tomlin examine how the buyer firm's purchasing decision is influenced by updated supplier information in the context of supply disruption risk [15]. Sarkar and Mohapatra investigate the design challenge of optimizing supplier sets amidst supply disruption risk [16]. Giri studies dual-source procurement from a risk-averse buyer's perspective, revealing that the optimal decision is affected by the procurement strategy's risk aversion level [17]. Chen et al. addressed dual-source procurement and inventory management challenges in the face of potential supplier disruptions. This study employed a Bayesian model to capture dynamic information update [18]. Liu and Nagurney employed mean-variance analysis to explore the offshoring problem under exchange rate risk and competition among multiple suppliers [19]. Li et al. conduct a mean-variance analysis of fast fashion supply chains with sales return, studying the coordination between risk-neutral suppliers and multiple risk-averse retailers, they further analyzed the influence of risk-averse level and information symmetry on supply chain coordination [20].

Some studies concentrate on uncertainty demand in supply chain risk. Federgruen and Yang study the problem of supplier selection in face of uncertain demand and uncertain supply in an infinite cycle, and presented the optimal strategy of the purchaser [21]. Guo et al. analyze the influence of the two types of supply chain risk on the buyer's optimal ordering decision, emphasizing the importance of accurately identifying the source of supply disruption. They compared scenarios of certain and uncertain demand, considering a setup where buyers faced conventional suppliers with mixed risks of "random interruption and random product" alongside backup suppliers with advance capacity bookings [22]. Lei et al. (2012) investigated optimal procurement contracts amidst demand uncertainty and supply disruption risk, delving into the value of information and the influence of producer strategy [23]. Gheibi and Fay research the optimal sourcing strategy and pricing strategy for retailers in the face of supply disruption, finding it beneficiaL for retailers to order more products from reliable suppliers and less products from unreliable suppliers. Furthermore, they discovered that reducing the price of alternative products when one supplier fails to deliver its products [24]. Li studies the strategies of manufacturers to deal with supply disruption in a market with an unreliable supplier and a reliable and expensive supplier by means of safety inventory or emergency procurement. Based on Pontriagin maximum principle, 11 optimal strategies on how to dynamically and jointly adjust emergency purchase quantity, compensation price and safety stock consumption speed are proposed [25].

Some studies focus on remedial measure following supply disruption. Zeng and Xia design a backup (emergency) procurement revenue sharing contract when the primary supplier had a risk of disruption, they found a Nash equilibrium solution through a decision tree approach, fostering a mutually beneficial partnership between the purchaser and backup supplier [26]. Chen and Yang assume that the main supplier could compensate for the supply through emergency backup purchase after the output risk. They explored the buyer's optimal purchasing strategy and its coordination mechanism in the Starkberg game, considering stochastic market demand with both supplier-dominated and buyer-dominated scenarios [27]. Nejad et al. argue that employing backup suppliers as an emergency ordering strategy to deal with disruption risk is a cost-effective risk management strategy [28]. They developed a decision tool to determine the appropriate response speed of backup suppliers with volume flexibility, enhancing supply chain responsiveness. Critical operational characteristics such as, response time and congestion, are taken into account in the outage scenario. Research shows that congestion is particularly crucial when risk-neutral decision makers develop outage mitigation strategies.

The studies on supply disruption primarily concentrate on the procurement decision of the purchaser, specifically, their coping strategies in the context of varying risk type, capacity constraints, demand uncertainty, and product differentiation. While dual sourcing is considered as a strategy of buyer to deal with supply disruptions, there are few articles study dual sourcing from the perspective of suppliers. Regarding supply reliability, the majority of research assumes a uniform estimation of supply reliability among both the supply and demand sides. Nevertheless, in reality, due to various factors, these estimations often diverge, leading to disparities in the perception of supply reliability.

2.2. Technology Licensing

For technology licensing, some researches have studied the connection between external innovators and technology licensing. Bagchi and Mukherjee study the issue of technology licensing decisions in differentiated oligopolistic markets, focusing on the impact of product differentiation and product market competition on external innovators' technology licensing decisions [29]. They concluded that, across a range of product differentiation, with a sufficient number of potential licensees, both innovators and society tend to prefer production commission licensing to fixed-fee licensing, regardless of whether Cournot or Bertrand competition applies. Wang and Shin discuss the influence of three types of contracts between upstream suppliers and downstream companies on upstream technology investment levels. Their study showed that when upstream investment costs are high, revenue sharing contracts can effectively coordinate supply chain [30]. Aydin and Parker investigated how downstream companies in the technology supply chain select different levels of upstream technology and explored the impact of the consumer market environment on technology supply pricing [31]. Mooi and Wuyts investigate the problem of bilateral moral hazard in technology licensing through agency theory [32]. Their research found that both upstream monitoring (i.e., licensee monitoring licensor) and downstream monitoring (i.e., licensee monitoring licensee) indicate the influence of licensee's experience in licensing on licensee. Zhang et al. analyzed and contrasted three types of license contracts: fixed-fee license, royalty license, and two-part AD valorem license [33]. They evaluated these contracts based on the profit, consumer surplus, and social welfare of the patent holder, and analyzed the optimal license contract for the patentee in the Court duopoly market, considering quality improvement innovation.

Some researches have also focus on relationship between internal innovators and technology licensing. Hu et al. studied the open or closed technology strategies of competitive firms, and the results indicated that open technology may constitute an equilibrium and attract supplier investment, despite the risk of intensifying future competition [34]. Duchene et al. studied how internal innovators can reduce the entry threat of potential market competitors by using a lower production royalty licensing strategy [35]. Their research revealed that the purpose of preventing potential market competitors from entering the market is to sign in the unfavorable terms of the potential entrants' entry into the market in the lower production royalty license agreement. This strategic licensing decision results in a more concentrated market and lower prices. Additionally, the low-cost production royalty licensing strategy benefits not only innovators but also enhances social welfare. Colombo and Filippini analyze the issue of two-part licensing decisions [36]. They explore decisions based on aggregate price royalty and those based on per-unit royalty in a differential duopoly Bertrand competitive market where the innovator is also a downstream producer. The study further concluded that internal innovators are more inclined to make two-part licensing decisions based on per-unit offer, this preference stems from the fact that two-part licensing based on aggregate price is more likely to lead to a pure aggregate price licensing outcome. Under price competition, two-part royalty licensing based on per-unit offer is more strategic than two-part licensing based on aggregate price. However, the social welfare of the two-part commission license based on the per-unit payment is lower than that of the two-part license based on the total price. Li and Qing develop a game theory model exploring technology licensing and parallel imports in a scenario where a leading manufacturer in a developed country (high market) can license its innovative technology to a manufacturer in a developing country (low market) [37]. In a separate study, Li et al. investigated how technology suppliers can optimize the design of licensing contracts when the information about the licensee's demand potential for products in the high-tech supply chain is incomplete [38]. The result shows that the optimal contract structure changes with the change of demand potential under the condition of asymmetric demand information.

Other researches have combined network externality to study technology licensing. Kulatilaka and Lin investigate three licensing options for an innovative company in the network product market: fixed-fee, royalty, and two-part licensing [39]. Lin and Kulatilaka analyze the influence of network externalities and market size on technology licensing strategies of internal licensors, and showed that when network externalities are large, fixed licensing strategies are superior to variable licensing strategies, and vice versa, variable licensing strategies are superior. When network externalities are moderate, the selection of licensing strategies should also consider the influence of market size [40]. Lerner and Tirole et al. argue that if the network externality is strong and the transfer cost is high, innovators who occupy a disadvantageous position will have a strong incentive to implement open source licensing [41]. Sun and Xie analyze four technology commercialization strategies of innovators under network externalities: Prior art monopoly market, licensing low-end technology, product line expansion and the combination of licensing and product line expansion [42]. The research shows that when the network externality is strong, the free license strategy is superior to the product line expansion strategy. When the cost of low-end technology products is lower or the quality is higher, the paid license is better than the free license. In addition, when the network externality is strong, the fixed license strategy is superior to the extracted license strategy.

Most Researches regard technology licensing as a solution to technological innovation, cost reduction or product differentiation. However, only a few consider it as a way to address possible supply disruption.

3. Assumption

We consider patent holder supplier(S1) as an international supplier, possesses the core technology of the product, and produces key components for the downstream manufacturer M. Subsequently, M sells the final product in the domestic market. S1 can ensure produce successfully, but it is still subject to logistics risks (e.g. natural disasters, international environment). The patent holder is considering licensing its technology to Licensee(S2), a domestic firm, to ensure supply chain stability. In practice, there are two technology licensing strategies: royalty licensing and fixed-fee licensing. Under the royalty licensing strategy, S2 must pay S1 for each unit of product sold. On the other hand, the fixed-fee licensing strategy involves one-time payment by S2 to S1 for the right to produce the product, regardless of actual production or sales quantity. Once technology licensing is successful, both S1 and S2 could become supplier of M, and operate in a competitive environment.

Given the inherent uncertainty surrounding supply, S1, S2 and M will have their own estimations of supply reliability (i.e. the probability of successful delivery) during trading transactions. Aligning with Gurnani, we assume that these estimations are not confidential, both buyers and sellers know each other's reliability estimation [43].

4. Technology Licensing When Manufacture and S1 Estimate Inconsistently

In this case, M has a same estimation of supply chain reliability with S2, but has an inconsistent one with S1.

4.1. Royalty Licensing

In royalty licensing, we found that manufacture will decide the procurement strategy depends on the specific estimation. Specially the procurement strategy of manufacture pays more attention to the self-estimation of S1. Because when Licensor's estimation is low, S1 lacks confidence and may deal with orders negatively, so M does not purchase any products from S1 in order to avoid potential risks.

After the technology licensing, S1 finds that M purchases products from it under certain conditions, that is, S1 has a risk of no order. Therefore, S1 will decide whether to produce after technology licensing according to the actual situation. If S1 does not produce, S1 gets the profit from the royalty licensing fee, and S2 gets all orders from M. Further, S1's production strategy is related on M's estimation. When M's estimation is high, relatively speaking, S1's estimation is low, witch means S1 is lack of confidence, so S1 will not product after royalty licensing when M's estimation is high.

4.2. Fixed-fee Licensing

Under a fixed-fee licensing, S1 charges S2 a fixed-fee. Fixed-fee occurs before production and is independent of production quantity, wholesale price and supply reliability. Manufacture's procurement strategy is similar to that in 4.1, which is when S1 has a low estimation of its own supply reliability, M will not order any products from S1 in order to avoid negative treatment from S1.

For S1, production strategy is when M has a high estimation of supply reliability but that of S1 is low, S1 decides to no longer produce, and charges licensing fees as profits. When M's estimation of supply reliability is not high enough and that of S1 is high S1 to quit from the market.

5. Technology Licensing When M and S2 Estimate Inconsistently

In this case, M has a same estimation of supply chain reliability with S1, but has an inconsistent one with S2.

5.1. Royalty Licensing

In royalty licensing, we found that procurement decision of M is determined by M's estimations of S1 and S2. As S2 is geographically closer to M, M is more inclined to place orders with S2 because of its natural competitive advantages (such as supply efficiency, information communication and after-sales service) compared with S1, when M has a high enough estimation of supply reliability of S2 to meet M'2 expectation, it will not order any products from S1, even if S1 and M have the same estimation. Naturally, M will not procure anything from S1 when M has a low estimation of S1. In short, S1 will get orders only when S1 is obviously more reliable than S2.

Also, S1 can decide whether to continue to produce. However, S1 will always produce after royalty licensing when M and S2 have inconsistent estimations of supply reliability. The reason is that S1 has less no-order risk at this time, so it is profitable for S1 to enter the market right now. At the same time, under the royalty licensing, the licensing fee of S1 is related to the order quantity of S2, if S1 quits the market, the situation of S2 is difficult to predict due to double marginalization and inconsistency between S2 and M, so S1 cannot obtain relatively stable licensing fees.

5.2. Fixed-fee Licensing

In fixed-fee licensing, M will not buy anything from S1 when M has a high estimation of supply reliability of S2 or a low estimation of supply reliability of S1 and S2. As mentioned in section 5.2, S2 has a natural competitive advantage, S1 will get order only when S1 is obviously more reliable than S2.

Further, S1 will not produce after fixed-fee licensing when the self-estimation of S1 and reliability estimation of S2 by M are both high. This seems hard to understand, since S1 has no significant competitive disadvantage. We believe that the reason is that S1 cannot control production cost of S1 through fixed fee, so S1 will gradually be at a disadvantage in competition with similar reliability due to S2's advantage mentioned in section 5.2. In addition, when the supply reliability of both sides is similar, fierce competition will occur, and both sides will reduce their wholesale prices to gain more market share, which will eventually lead to the decline of product profits.

6. Technology Licensing When Estimation of M Is Inconsistent with That of S1 and S2

In this case, M has an inconsistent estimation of supply with S1 and S2. However, the reliability estimation of S1 and S2 by M is the same, that is, M believes that the probabilities of successful delivery by S1 and S2 are the same.

6.1. Royalty Licensing

In royalty licensing, we found that when this estimation is high, M will not buy any products from S1, because M's reliability estimation of S2 is high enough to meet M's expected profit, S2 will obtain all orders from M. This is because reliable supplier S2 can satisfied the expect of M.

After technology licensing, S1will decide whether to continue production. In simple terms, when M has a high estimation of the whole supply chain, S1 will not produce after royalty licensing. Because S1 believes that it has no significant competitive advantage compared with S2, and if S1 enters the market will lead to fierce competition. In order to obtain more orders, S1 and S2 will lower their wholesale prices, and finally, their profits will decline.

6.2. Fixed-fee Licensing

In fixed-fee licensing, when M's estimation of the supply reliability of whole supply chain is high, M will not buy any products from S1 in order to avoid potential risks, which is similar to royalty licensing.

For S1, there is a complicated situation. First, when M has a low estimation of supply reliability but S1 has a high estimation of itself, S1 will not produce, because the potential risk caused by high estimation divergence. Second, when M has a high estimation of supply reliability and S1 has a low or high enough estimation of itself, S1 will not continue to produce products. Because low self-estimation will make a high risk of no-order, and high self-estimation will lead to fierce competition.

7. Conclusion

We assume that the patent holder licenses another supplier to address a potential supply risk, and both the manufacturer and the supplier estimate the reliability of supply due to the risk of supply disruption. We model the supply chain under different estimation situations and study the different coping strategies of suppliers and manufacturer. We find that manufacture will take different procurement strategies based on different estimation situations, especially the estimation of Licensor. Moreover, under most estimation situation, Licensor will not produce after technology licensing in some certain conditions. But Licensor will always produce after royalty licensing when M and Licensee have inconsistent estimation of supply reliability.

This paper is helpful to promote the research of supply chain risk. Most of the previous research focusing on supply chain risk did not pay attention to asymmetric beliefs of supply reliability, and carried out research on the same reliability. Moreover, it is feasible by default when the manufacturer adopts dual source purchasing. We assume that the supply reliability estimation of the upstream and downstream of the supply chain is inconsistent, and assumes that the manufacturer can only conduct dual-source purchase after the supplier's technology licensing, so as to combine the supply disruption and technology licensing, and consider various situations where the reliability estimation is different.

In the future work, we can be expanded from the following aspects. First, we can explore this study under information asymmetry, this is an interesting idea. Second, we can consider the case where supplier or manufacture claims a fake reliability of supply in order to gain trust or exaggerate themselves. Finally, we assume that the supply disruption is completely, and it is feasible to consider the license contract under the partial disruption.

Disclosure Statement

No potential conflict of interest was reported by the authors.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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