Innovation Internalization in Technology-Intensive Supply Chains

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As new products in a range of industries, from automobiles to machine tools to life sciences, become intelligent and networked, technology and intellectual property play an increasingly important role in enhancing the sales and mediating the relationships among supply chain entities. Such Technology-Intensive Supply Chains (TISC), in which technological innovation critically determines the margins and power/leadership of the supply chain, pose a variety of new research questions that have not been considered in the classical research on technology-neutral supply chains. A large fixed investment in upstream R&D is often needed to develop the technological capabilities and this investment must be recouped one way or other, possibly through royalty payments from downstream supply chain entities.

Smartphones are notable examples of TISC driven by innovation in processor and networking technologies (such as LTE). Upstream technology suppliers such as Qualcomm and Ericsson often decide to charge royalties for the use of their patented technologies in end products and a key question arises as to whether these royalty payments should be based on the wholesale price of the subsystem containing the technology, which is called smallest sellable unit (SSU), or the retail price of the end product. While the latter is equivalent to a revenue sharing contract, which is known to better coordinate supply chains, policy makers
in some countries such as China discourage high-tech firms from implementing such a policy of charging a royalty based on the retail price (Mozur and Hardy 2015\textsuperscript{1}).

In this paper, we focus on modeling and analyzing TISC to specifically understand the pattern of innovation investment decisions and the impacts on firm and supply chain profits. To do so, we must go beyond traditional price-quantity supply chains - by incorporating different types of qualities at various levels of the supply chain to model innovation-driven value addition in TISC with different royalty schemes. We construct a unified model where technology and component quality decisions are linked to price and quantity decisions to serve a market of heterogeneous customers. Our modeling and analysis produce actionable insights for managing TISC.

We consider innovative products that comprise a sub-system with a key technology/intellectual property and a component from a three-tier supply chain. The quality of the end-product is the technology quality determined by the Tier 2 “innovator,” as depicted in Figure 1, multiplied by the component quality, determined the Tier 0 manufacturers, representing that the end-product has little value without either part. A monopoly innovator in Tier 2 achieves the technology innovation by investing a fixed amount of capital in R&D. Examples of such upstream technology innovations include LTE networking or battery charging intellectual

\footnote{Mozur, Paul, Quentin Hardy. 2015. China hits Qualcomm with fine. The New York Times}
Special suppliers in Tier 1 embed the technology into a sub-system. We allow the innovator to be Tier 1 firm as well and to have sales revenue in addition to royalty revenue streams. Two “manufacturers” in Tier 0 develop the sub-system into finished products by adding components. They compete through product quality differentiation and price for two vertically-differentiated market segments similar to Moorthy and Png (1992)\(^2\).

To focus on the impact of different royalty schemes on quality investment decisions and profits in TISC, we consider that the innovator licenses the technology through a simple royalty contract, which specifies the royalty rate (percentage) and the royalty base. If the base is a consumer product shown in Figure 1(a), manufacturers pay royalties depending on the retail prices. If the royalty base is the sub-system (SSU) as in Figure 1(b), then suppliers pay royalties based on the wholesale prices that Tier 1 charges to Tier 0 firms. Between supply chain entities, simple wholesale price contracts are employed. We characterize each firm’s optimal decisions and compare profits (surplus) under two different royalty schemes.

We find that the retail price base royalty, in Figure 1(a), does not always better co-ordinate the supply chain as shown in Table 1. Specifically, if the consumer market is largely homogeneous, the innovator is better off under the wholesale price base (SSU) royalty scheme, which is uncommon in technology-neutral supply chains. This is because the downstream Tier 0 manufacturers invest more under SSU-based royalty scheme, and develop


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<th>Royalty Base</th>
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<td>Wholesale Price (SSU)</td>
<td>Innovator Society Consumer Mft2</td>
<td>Innovator Consumer Mft2</td>
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<td>Retail Price</td>
<td>Innovator</td>
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Table 1: Royalty Base Preferences of Supply Chain Entities
higher quality products, which leads to higher quality products and generates more royalty profits to the innovator. In contrast, when the consumer market is highly differentiated, the innovator’s profit is higher under the retail price base since its increase in technology investment outweighs the decrease in downstream manufacturers’ investment due to the royalty. Although the manufacturer’s profits and consumer surplus follow the similar pattern, each entity may prefer one over the other royalty scheme at the same market circumstance as illustrated in Table 1. Our finding sheds light on relevant managerial insights for the recent conflicts between Qualcomm and China. In particular, if Chinese consumer market is largely homogeneous with majority of low-value segment consumers and little high-value segment consumers, then SSU-based royalty scheme can be more beneficial for all entities in the supply chain as well as consumers than retail price base royal schemes which is similar to current royalty schemes employed by Qualcomm.