The roles of information and communication technology in economic performance

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**THE ROLES OF INFORMATION AND COMMUNICATION
TECHNOLOGY IN ECONOMIC PERFORMANCE**

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The Roles of Information and Communication Technology in Economic Performance

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Executive Summary

In literature, positive contributions of Information and Communication Technology (ICT) to productivity has been found; It is also found that the ICT-using industries benefited most, provided that complementary organizational investment has been carried out in firms. However, the mechanisms at micro level behind this positive link between ICT and productivity in ICT-using industries, as well as those behind the link between the complementary organizational investment and productivity, are not clear. These questions motivate the following studies.

The literature review identifies two major dimensions of ICT impacts on the core activities of the firm. They are (1) the communication and processing of information; and (2) the accumulation and distribution of organizational knowledge. Under the two dimensions, ICT enhances the firm's abilities to create higher value-added in products and services, and thus to improve productivity. Therefore, the firm activities are the keys in turning the advantages of ICT into higher productivity. The following studies contribute present specific models under the two dimensions.

For the first dimension, a model is presented with the firm assumed as an information-processing organization, which is an alternative to markets in coordinating production in markets with demand uncertainty. The model assumes that ICT contributes to the ability of processing information. It shows how this ability determines the performance of the firm in terms of expected profit. Importantly, these results are conditional on the structure of markets. Moreover, improving information processing ability increases firm profitability

as long as market-coordinated production persists elsewhere. Otherwise, it decreases profitability of all firms. Therefore the model provides one illustration why different industries benefit differently from ICT investment. The case studies in this chapter present consistent evidence of this theoretical prediction.

An extension of the model discusses different types of firm coordination of production. The purpose is to further discuss the relation between information processing ability and the choice of firm coordination of production. While vertical firms integrate the production at all stages, horizontal firms integrate either the production of intermediate input or the production of final product. The model shows how the performance of these types of firm differs, under different structure of markets. It also shows how ICT, by improving information processing ability, would change the choice of firm coordination of production.

For the second dimension, an empirical study is conducted to test the hypothesis that ICT increases the importance of tacit knowledge, and therefore motivates industrial clustering, using U.S. data. Results show that the hypothesis is conditional on structural change of the economy towards more knowledge-intensive production and services. The regressions by sector further show that the hypothesis is also conditional on the nature of the cluster, namely whether it is a manufacturing cluster, a services cluster, or a high-tech manufacturing sector. For the services clusters, the tacit knowledge hypothesis is especially true. Whenever the tacit knowledge hypothesis is true, it means more knowledge spill-over within the cluster must be true. In this way, ICT also contributes to performance.

Chapter 1

Introduction

The penetration of Information and Communication Technology (ICT) is ubiquitous. Many terms have been invented to describe this extent of penetration, such as "Information Economy", "New Economy", "Information Society", and "Digital Era". It is exactly due to this ubiquitous penetration that the economic impacts brought about by the ICT are multi-level and multi-facet. And it is increasingly important for economists to answer the questions about to what extent and with what mechanisms does ICT impact the economic performance.

Using the data from four Asian industrialized economies, namely Japan, South Korea, Singapore, and Hong Kong, the following growth accounting study shows that, at economy level, the contribution of ICT to economic growth has become increasingly significant.

Figure 1: Relative contribution of ICT to real GDP growth¹

The relative contribution of ICT is the share of its contribution to real GDP growth, as compared to other factors. After the period of 1991-1995, the contribution of ICT to real GDP growth increased considerably for the four economies. The figure also shows that different economies show different patterns of ICT contribution to economic growth. Such is an observation consistent with the literature. It is therefore asked: what are the key determinants of such differences?

The Solow paradox (1987) stated that "we see computers everywhere except in the productivity statistics". Since then, economists have developed new insights into the economic impacts of ICT:

First, by adjusting the way ICT capital stock is measured, growth accounting studies at both economy level and industry level confirm positive and significant contribution of ICT investment to productivity growth. And its role is beyond capital-deepening. (Jorgenson and Stiroh, 1999; Oliner and Sichel, 2000; Jorgenson, 2001)

Second, it is found that the US economy did better than other industrialized economies in receiving productivity gains from ICT in the late 1990s, and that

¹ Real GDP growth is decomposed according to the following growth accounting formula: $\dot{Y} = \dot{A} + S_{K_{ict}} \times \dot{K}_{ict} + S_{K_{nict}} \times \dot{K}_{nict} + S_E \times \dot{E}$. $\dot{A}$ is the growth rate of total factor productivity (TFP). $S_{K_{ict}}$, $S_{K_{nict}}$, and S_E are the nominal income share of ICT capital stock, non-ICT capital stock, and labor, respectively. $\dot{K}_{ict}$ and $\dot{K}_{nict}$ are the growth rates of real ICT capital stock and real non-ICT capital stock, respectively. $\dot{E}$ is the growth rate of employment. The product of $S_{K_{ict}}$ and $\dot{K}_{ict}$ is the contribution from ICT capital stock. The product is divided by real GDP growth rate to measure the relative contribution of ICT. Source: author's calculation.

this difference is sourced from ICT-using industries rather than ICT-producing industries (van Ark et al., 2002; Lee and Khatri, 2003; Jorgenson and Motohashi, 2005). According to Bloom et al. (2005), the reason is that the US firms, especially multinationals, have more decentralized organization which works better with ICT infrastructure.

Third, industry-level studies show that productivity acceleration in the ICT-using industries accounts for most of the productivity gains of the US in the late 1990s. Moreover, ICT investment appeared to have a lagged effect over productivity growth. This feature is implied by the General Purpose Technology (GPT) hypothesis (Stiroh, 2002; Basu et al., 2003).

Fourth, studies on firms of the ICT-using industries reveal that changes in organizational and work practices are prerequisites for ICT to contribute to firm productivity (Hitt and Brynjolfson, 1996; Brynjolfson and Hitt, 2000; Brynjolfson et al., 2002). This finding is consistent with the prediction of GPT hypothesis, which treats these changes as innovation and investment complementary to ICT. Brynjolfson and Hitt (2003) confirm the lagged effect of ICT investment using firm-level data.

Fifth, empirical evidences of ICT contribution to productivity have not reached complete consensus. For example, in contrast to the other industry-level studies, Gordon (2000) argues that ICT only brings total factor productivity (TFP) acceleration to its own production. Similar conclusion is drawn by Jorgenson and Stiroh (2000). Moreover, Gordon (2004) pointed out that, after 2000, the US ICT investment waned while productivity continued to surge.

In sum, ICT advancement and its penetration not only add into what we do - ICT production, but also change the way that we do everything - ICT application. And that motivates studies to look into micro-level mechanisms. However, many questions remain. For example, since ICT deals with information, in what ways does this functionality matter in firm and industry performance? Are there any other mechanisms at work? And since ICT also changes the way that knowledge is organized, stored, and disseminated, how would these changes contribute to firm and industry performance?

This thesis is produced to look into these questions, therefore contributing to the understandings of the roles of ICT in economic performance. The structure is as the following: Chapter 2 is a literature review, which focuses on firm activities. It is argued that they are the keys in turning the advantages of ICT into higher value added, and therefore higher productivity. The studies that follow Chapter 2 present specific studies to contribute details to this general argument. Chapter 3 models the firm in markets with demand uncertainty. The firm is seen as an information processing organization, which provides an alternative to the market coordination of production. ICT is assumed to lower down the cost of information processing and thus contribute to firm performance. However, the model shows that such contribution is conditional and may not be positive. Chapter 4 extends the model in Chapter 3 further to discuss different types of firm. The main finding is that improving information processing ability would change the internal structure of firms, as well as the choice of type of firm to coordinate production. Chapter 5 is an empirical study which tests the

hypothesis that ICT increases the importance of tacit knowledge², and therefore motivates industrial clustering. In this way, ICT could also contribute to firm and industry performance within the cluster. The study uses the U.S. data. And results imply the hypothesis is conditional on a structural change of the economy towards knowledge intensive economic activities. Chapter 6 concludes.

² The knowledge that cannot be codified is referred to as tacit knowledge, the communication of which requires geographical proximity.

Chapter 2

Literature Review

This literature review provides a structured vision of the roles of ICT in economic performance at micro level. The impacts of ICT on firm activities are emphasized. It is argued that they are the keys in turning the advantages of ICT into higher value added, and therefore higher productivity.

As the economic impacts of ICT are multi-level and multi-facet, issues from the literature are organized in a flow chart as shown in Figure 2. In this review, we focus on the core activities of firms, in which the roles of ICT go beyond simply a capital good.

Figure 2: The economic impacts of ICT on firm activities

Generally speaking, ICT advancement brings changes to firm activities in two dimensions as indicated in Figure 2 by two arrows: (a).The communication and processing of information; and (b).the accumulation and distribution of organizational knowledge. The changes are in terms of the procedure, the costs, and the speed that we conduct these activities. As results, these changes reduce frictions in transactions and resource allocation, improve precision, and enhance flexibility and innovativeness, therefore delivering differentiated products and services with higher value. The observed macro-level productivity acceleration in the New Economy or Information Age is based on these micro-level improvements.

In each dimension, functions of ICT include recording, processing, storing, and distributing information³. In the first dimension, information per se is the centrepiece of the economic activities that follows. ICT brings direct changes to the communication and processing of information in these activities. In the second dimension, ICT brings changes to the way that knowledge is organized, stored and shared within the organization. And organizational knowledge is important intermediate input to the differentiation and innovativeness of products and services.

The discussion that follows will be organized as two categories corresponding to the two dimensions. The discussion focuses on two fundamental questions: (1) where and how does ICT investment contribute to the creation of value; and

³ To demarcate traditional information and communication related technologies and the modern information and communication technology (ICT) concerned in the current studies, Huber (1990) gives three descriptions: “advanced information (and communication) technologies (i) that transmit, manipulate, analyze, or exploit information; (ii) in which a digital computer processes information integral to the user’s communication or decision task; and (iii) that have either made their appearance since 1970 or exist in a form that aids in communication or decision tasks to a significantly greater degree than did pre-1971 forms.”

(2) what are the prerequisites for ICT investment to make significant contribution.

2.1 The Communication and Processing of Information

Two types of firm activities fall under dimension (a): the coordination of economic activities, as indicated by arrow (c); and decision making, for which information reduces uncertainty, as indicated by arrow (d).

2.1.1 Coordination

It is argued that the economy is coordinated by a structured system of information flow, in which market and firms are the two alternative subsystems to coordinate economic activities. Within a firm, the internal structure for coordination and the contents of coordination are significantly affected by ICT.

To begin with, Hayek (1945) points out that the decentralized price system of competitive markets essentially conveys information on both preferences and scarcity of resources to coordinate production and consumption. The information conveyed by prices solves the problems of what to produce, how much to produce, and for whom to produce at individual level, as well as the problem of division and specialization of labor. However, Malmgren (1961) points out that the “trial and error” process by the numerous participants of the markets to arrive at a stable equilibrium is a costly process. This is due to the existence of uncertainty, as well as the difficulties in collecting and communicating information. Stiglitz (2000) further points out that information cost, which is a major component of transaction cost, cannot be ignored.

Because of its existence, neither the markets nor contracts are complete. This is especially true when uncertainty is considered.

Therefore, the unconscious coordination by markets is not likely to be sufficient. For this very reason, multi-person, multi-process firms, which work as an allocating mechanism over the entire set of economic activities between the production and consumption, are necessary complements to market coordination. In fact, if markets were stationary with all information readily available, the price system of markets would be sufficient to coordinate all economic activities. Then services from all factors for production can be traded in markets and there is no reason for a firm to come in to coordinate production. This conclusion is not true reality – firms as defined are everywhere. This is also consistent with the transaction cost argument by Coase (1937). When transactions in the markets are too costly in coordinating multi-stage production, there is incentive to combine a number of activities at different stages of production which are previously connected by short-term transactional contracts in the markets into long-term contracts in firms, so as to save transaction costs (Malmgren, 1961; Van Zandt, 1999).

Stiglitz (2000) further argues that the major component of the transaction costs in the markets is due to imperfect information⁴. And the firms reduces information costs related to finding and making transactions, by consolidating

⁴ If information were perfect, which means that all contingencies could be anticipated, then contracts would be complete at trivial costs. It follows that markets are complete in the sense that all contingencies can be traded at trivial costs. Therefore there is no need for long-term contracts to replace short-term contracts. At any time, in any contingency, contracts could be signed to rearrange the transactions and make sure all stages of production move on smoothly. This is rarely the case in reality. The cost of acquisition of information renders imperfect information, and therefore incomplete contracts, from which incomplete markets are derived. Both incomplete contracts and incomplete markets render significant transaction costs which firms work to save.

production and carrying necessary level of idle capacity to achieve long-term stability (Malmgren, 1961).

For the above reasons, the firm is an information processing structure (DeCanio and Watkins, 1998). The first important use of information is coordination. Information is collected and communicated in order to coordinate economic activities which is consisted of actions across large number of interdependent roles (Galbraith, 1974), whereas coordination could be defined as an improvement in the allocation of resources (arrow (f)).

Specifically, with long-term contracts, firms generate internal information about internal contract prices, techniques of production, market requirements, and managerial know-how to adapt to fluctuations and uncertainties in demand and supply. Such information substitutes for diverged expectations of independent traders when the production procedure is coordinated by the market. In this sense, coordination of production is done within the firm with less information about different intermediate transactions required (Malmgren, 1961).

The structure of a firm to coordinate can be categorizes into three mechanisms (Galbraith, 1974): (1) coordinate by established rules or programs for routine events; (2) use hierarchies to handle events with greater uncertainty on an exception basis – e.g. when non-routine events occur; and (3) set targets or goals, so that employees form task forces to make their own decisions which lead to accomplishment. Choosing the best mechanism of coordination is in fact the design of the organization. It is assumed that managers at the top of hierarchies have limited capacity to process information and make a decision. To handle increasing uncertainties, there are two types of strategies each

containing two methods to design the organization. The first strategy is to reduce the need for information processing by (1) creating slack resources to reduce the amount of information required in handling uncertainties; or (2) creating self-contained tasks as mentioned in the third mechanism raised above. The second strategy is to increase the capacity of information processing of the firm by (1) investing in hierarchical information system; or (2) creating lateral relations between departments with liaison roles in the centre to enhance communication and information processing.

For the effect of ICT on coordination, Porter (1985) points out that ICT creates new linkages between economic activities within and outside of the firm, and therefore enables better coordination. For example, with the help of ICT, firms can have better coordination with buyers and suppliers. This is because “information is the glue that holds together the structure of all businesses” (Evans and Wurster, 1997). Marschak (2004) develops a simple model based on this idea, with the assumption that better ICT brings more information at given costs. The model shows that, if coordination means that all decision makers can use all the information collected by everyone, improved ICT raises the coordination benefit, no matter whether the firm is centralized or decentralized in the communication and processing of information.

ICT also reshapes the work and jobs that are coordinated, as it requires workflow redesign as complementary investment (Brenahan and Trajtenberg, 1991; Basu et al. 2004). Empirical study at industry level by van Ark et al. (2002) also suggests that flexibility in organizing workplace is important in exploiting the advantages of ICT. Bresnahan et al. (2002) points out that ICT is complementary to new workplace organization which includes broader job

responsibilities, due to increased information processing ability of individuals. Therefore, ICT becomes most effective in promoting productivity in the 'New Work Systems' with more decentralized decision making, and more self-managing teams (Brynjolfsson and Hitt, 1998; Dewett and Jones, 2001).

In some cases, business process redesign is required as a complementary investment, as products tend to include more information services and jobs tend to include more information work (Brynjolfsson and Hitt, 1998; Brynjolfsson and Hitt, 2000; Brynjolfsson et al. 2002; Bresnahan et al., 2002). To be more specific, Osorio-Urzua (2008) points out that ICT should be integrated into business processes: firms should, based on their own knowledge, develop their unique ICT solutions integrated with their innovated business processes to create competitive advantages. Earlier study by Evans and Wurster (1997) documents the changes in the business process of the banking industry due to the introduction of ICT systems, and its implications for competitive advantages.

In-between the market coordination and the firm coordination, there is a third institutional alternative – network of agents. It is due to the existence and importance of the following external information: (1) technological changes and other creative destruction; (2) fluctuation in demand and supply; and (3) Shocks on the supply side as well as the demand side (Casson, 1997). These kinds of external information means that a network of firms sometimes is needed to coordinate, in innovating or adopting new technology and business model, in entering or creating new markets, as well as in dealing with fluctuations in markets. The exchange of information (or communication) is the basic function of the network. As a network is a social group with high-trust among members who have similar competence, it ensures the quality of its information flow

(Casson, 1997). The modern Japanese industrial groups, named Keiretsu, are fine examples as networked firms coordinating actions (Miyashita and Russell, 1994). Farnsworth et al. (2007) argue that ICT is redrawing the business borders, encouraging businesses along the value chain to network for timely information to better adjust to changing markets. However, such is not a simple story. According to Bolton and Dewatripont (1994), the efficient structure of a network concerns both the cost of communication and the delay of information processing within it. Further studies on efficient ICT system in the network are needed.

In summary, information is essential in coordinating economic activities. The market and the firm are two basic alternatives to coordinate. ICT improves the coordination of firm directly by lowering the costs of communicating and processing information. Beyond the cost effect, to gain better coordination from ICT investment, organizational investment, which includes both workflow redesign and innovations in business processes, is a prerequisite. Eventually, with better coordination of activities within the firm as well as between firms, the allocation of resources would be more efficient, as indicated by arrow (f). An interesting and important future research topic is, based on the above understandings about ICT and coordination, that how the boundary of the firm would be redefined because of the changes in coordination brought about by ICT.

2.1.2 Decision Making under Uncertainty

This subsection focuses on the second direct use of information – decision making under uncertainty, as indicated by arrow (d) in Figure 2.

Information reduces uncertainty and hence is embedded with decision making, as indicated by arrow (e) (Shannon, 1948; Marschak, 1959; Arrow, 1972; Floridi, 2009). In the following, decision making is discussed as a reaction function to incoming information at a decision node. Our interest, however, is how and what information arrives at a decision node. These two issues are determined by the information processing structure. Therefore, the firm's structure of information processing, and the impact of ICT over this structure are subsequently discussed.

Uncertainty could be measured by the Shannon measure, $H = -\sum p_i \log p_i$, which is a logarithmic function of the probabilities of states of the nature p_i (Shannon, 1948). The quantity of information therefore depends on the information structure⁵, namely the way that the states of nature are partitioned into subgroups. The finer the partitioning, the greater the amount of information is contained by a single piece of signal. When noise embeds with information structure, the amount of information transmitted is measured by Shannon's rate of transmission: $R(i, j) = H(i) - E_j[H(i|j)]$. The second term is the expectation of the capacity of channel H when the state of nature is i and the message j . The cost of information is usually assumed to be proportional to the rate of transmission. (Marschak, 1954; Marschak, 1959; Arrow, 1972; Arrow, 1985; Arrow, 1996)

In reality, information structure depends on the structure of information processing within an organization. Marschak (1954) is the first to formally model the information processing problem within a team consisted of multiple

⁵ Sometimes it is referred to as communication channel, or information instrument.

individual decision-makers. For the team, two problems are to be solved regarding information processing and decision making: one is to choose rules of communication so that appropriate amount of information can be communicated to each member, with minimum cost of communication; the other is to choose rules of action as a function of the information receivable of each member. Arrow (1985) refers to the former as information structure, which is the assignment of signals to agents, and the latter as decision structure which is the choice of decision rules. Our interest is in the former, on which ICT would have impact.

The efficiency of a structure of information processing can be measured by the number of individual processors involved and the delay in processing (Radner and Van Zandt, 1992). Radner (1993) adopts the same measure of efficiency of information processing and analyzes the optimal structure of a hierarchical network of processors with parallel processing at different levels. Both Radner and Van Zandt (1992) and Radner (1993) ignore the cost of communication in an information processing network. Bolton and Dewatripont (1994) discuss the design of efficient communication network within organizations. They find that in order to economize on communication cost, an efficient network of an organization must have a centralized design – pyramidal network. Kennedy (1994) argues that agents differ in processing ability is emphasized. Therefore, the choice between serial structure and parallel structure therefore is a trade-off between specialization and communication costs.

Van Zandt (1999) calls the above mentioned models the ‘constrained-optimal approach’, which explicitly incorporates information processing constraints into computation, communication, and decision problems. It is argued that the

structures of information processing observed in modern firms are the results of incremental learning, imitation, and adaptation over years. It is information processing constraints that lead to hierarchies; meanwhile, costly delay in information processing justifies decentralization.

When a structure of information processing is chosen, performance of the firm is determined by external environment. Barr and Saraceno's (2002) model allows the environment to vary in terms of complexity and instability. The firm is modelled as a learning algorithm which produces hypothesis about the environment based on incoming information. It is found that both performance and optimal size of the firm are determined by complexity and instability of the environment.

Huber (1990) summarizes the following progress in ICT: (1) ICT makes a wider range of detailed information available; (2) ICT enhances expertise involved in each decision making process (also see in Farnsworth et al., 2007); (3) ICT improves collective memory of the organization and the accumulation of organizational knowledge; (4) ICT increases the control and precision of information processing. Therefore, besides cheaper and faster communication and processing of information, it is also implied that ICT increases the precision, timeliness, and innovativeness of decision making, and hence those of resource allocation. These effects are reflected in Figure 2 by arrows (g), (h) and (i).

To model the effect of ICT over the structure of information processing, one can assume that ICT directly brings down the cost of communicating and processing information, as in Marschak (2004). DeCanio and Watkins (1998) take the firm as a network of information processing agents. It is found that

weak information processing ability⁶ demands hierarchical bureaucracy; and improved information processing ability supports ‘flattening’ of the hierarchy. In the case of extremely weak information processing ability, completely decentralized network is superior. Therefore if ICT improves the information processing ability of agents, organizational structure would be affected accordingly. Cukrowski and Fischer’s (2007) model how ICT affects the structure of information processing if it is assumed to bring faster information processing.

In summary, information is valuable resource for decision making. Due to the bounded rationality of individuals, organizations such as firms are needed for information processing. Our discussion focuses on the organizational structure of information processing. The efficiency of this organizational structure is measured by both the cost of communicating and processing information and the delay in processing. The choice of the organization structure conditions on information processing constraints of individuals. It is that information processing constraints that lead to hierarchies; meanwhile, costly delay in information processing justifies decentralization. ICT brings direct impacts on the cost and speed of communicating and processing information. ICT also enhances the information processing ability of individuals. These impacts of ICT generally drive organizational structure towards decentralization in information processing and decision making. Decision making, and hence resource allocation, is then inferred to be improved in terms of its precision,

⁶ Information processing ability depends both on the agent’s intrinsic characteristics in dealing with incoming information and the capacity of communication channels. The two factors determine the speed, cost, and accuracy of information processing. Weak information processing ability is reflected by low speed, high cost, or low accuracy in information processing (DeCanio and Watkins, 1998).

timeliness, and innovativeness, which all add to the quality and value-added of products and services.

2.2 Organizational Knowledge

For the second dimension, as indicated by arrow (b), ICT is identified as facilitating the accumulation, storage, and distribution of organizational knowledge. Such also contribute to changes in market structure.

2.2.1 Knowledge, Tacit Knowledge, and Innovation

The effect of new technology on innovation takes three stages: substitution, diffusion, and transformation. The last stage means that new ways of living and working start emerging because the new technology has widely diffused. ICT is now at its third stage of transforming businesses and society. At this stage, ICT is driving innovation by allowing creative thinking and responsive problem solving (Dutta and Mia, 2007).

Huber (1990) observes and hypothesizes that, as increasingly business processes rely on computer-based activities and transaction-monitoring technologies, there is more frequent development and use of computer-based databases as components of organizational memories. Meanwhile, as internal information processing and knowledge management become standardized, organizations create computer-based expert systems to elicit, store, and distribution organizational knowledge.

The concept of Enterprise 2.0 is a further elaboration of the above idea (McAfee, 2006). It refers to social software which provides platforms for multi-lateral interactions and collaborations within the organization. Such platforms

capture the usually invisible knowledge work within the organization by pooling communications, so that members would share and interact. While users keep tagging and giving feedback to each topic, knowledge gets refined and categorized in the system. It enables each member to tap into the knowledge and expertise of the whole organization for the best or the most suitable solution to problems. Meanwhile, the communication and interaction process also adds to the knowledge pool of the organization. Therefore, successful application of Enterprise 2.0 empowers the organization in flexibility and innovativeness to create differentiated value in products and services, hence adding to competitiveness.

The above can be perceived as codification of the knowledge existing in the organization. Steinmueller (2000) defines the codification of knowledge as the representation of knowledge as codes by the exchange of information. Dewett and Jones's (2001) survey indicates that such is one of the major contributions from ICT to firm performance. Moreover, as Cowan et al. (2000) point out, improvements in ICT permit more faithful reproduction of an increasing range of human capabilities. In this way, ICT also helps the organization convert tacit knowledge embedded with human capital into codified knowledge into the knowledge pool of the organization.

Both explicit knowledge and tacit knowledge are used to “decode, interpret, assimilate, and find novel applications” for incoming information in the form of structured and codified data. Therefore, improvements in the two facilitate innovative problem-solving. However, unique competitive advantages in the sense of technical and business process innovation are built on tacit knowledge, as it is not easily imitated by competitors. Since ICT facilitates accumulation

and dissemination of detailed codified knowledge, the relative importance of tacit knowledge in delivering unique competitive advantages has been growing (Cowan et al. 2000; Quah, 2003; Maier, 2009).

Besides, the study by Osorio-Urzua (2008) explains how ICT directly contributes to innovation, by enhancing the innovation process. This is because the innovation process is essentially a process of searching, testing, analyzing, and managing information about the best solution to a problem or the best market areas for a new solution. Other benefits of ICT to innovation include: (1) decreasing the costs of experimentation and prototyping; (2) increasing the rate of failure and speeding the discovery of sub-optimal alternatives by speeding design-test cycles; (3) empowering customers to become.

These effects facilitate the firms to develop differentiated and even highly customized products and services, as indicated by arrow (l) in Figure 2. And eventually they add to the value of products and services, as indicated by arrow (n). They also change the landscape of market structure of the industry as indicated by arrow (m).

2.2.2 Market Structure

As Porter (1985) points out, ICT improves flexibility and differentiation in products and services. This argument is supported by the previous discussions in both of the two major dimensions of ICT impacts, as indicated by arrow (j) and arrow (l) in Figure 2. These effects thus reshape market structure in many industries.

Outsourcing and offshoring are two additional phenomena facilitated by ICT, both in the manufacturing industries and in the services industries (Melford et al., 2005; Abramovsky and Griffith, 2005).

Besides, ICT also affects geographical concentration of industries. Quah (2003) hypothesizes that as ICT promotes the importance of tacit knowledge, firms in a certain industry are encouraged to cluster geographically so as to acquire tacit knowledge from each other with the advantage of proximity. Cowan et al. (2000) further argues that research activities should also be located in proximity to production operations, which generates tacit knowledge in unique context, providing persistent competitive advantages. One can easily extend this argument to other knowledge intensive service activities, such as marketing, designing, etc. Therefore, it's likely that ICT promotes the clustering of a certain range of industrial value chain.

In summary of the second dimension, ICT facilitates the accumulation and sharing of organizational knowledge including tacit knowledge, by extending sensation and memory of organizations, as well as by providing platforms for multi-lateral interactions and collaborations. It thus facilitates innovative problem-solving, while also directly empowers the innovation process within organizations. These impacts add to the ability of the firm to innovate and differentiate its products and services, therefore contributing to changes in market structure.

2.3 Conclusions

This chapter provides a review on the economic roles of ICT, which go beyond capital goods. The purpose is to clarify the multi-level and multi-facet economic impacts of ICT on firm activities, by distinguishing them from each other, while also drawing links between them. Through this review, the major mechanisms which enable ICT to bring micro-level improvements are identified. It is argued that the core activities of firms are the keys in turning the advantages of ICT into higher productivity observed at industry level and economy level.

Specifically, ICT brings changes to firm activities in two major dimensions: the communication and processing of information, and the accumulation and distribution of organizational knowledge. The changes are in terms of the procedure, the cost, and the speed that these activities are conducted.

For the first dimension, it is understood that the processed information has two direct applications in firm activities: coordination, and decision making.

For coordination, ICT improves effectiveness of coordination of the firm directly by lowering the cost of communicating and processing information; beyond the cost effect, to exploit the most benefit from ICT investment, organizational investment, which includes workflow redesign and innovation on business processes, is a prerequisite. Improvements in coordination means better allocation of resources and higher value-added of products and services.

For decision making, the impact of ICT over structure of information processing is the focus. Since ICT brings lower costs of information processing and communication, higher speed, expanded memory, increased accessibility,

and so on, organizational structure are generally to driven towards decentralization in information processing and decision making. Decision making, and hence resource allocation, is then inferred to be improved by ICT in terms of precision, timeliness, and innovativeness, which all add to the value-added of products and services.

The second dimension, which is the accumulation and distribution of organizational knowledge, identifies ICT as the facilitator to the accumulation, storage, and distribution of organizational knowledge. These would greatly enhance the flexibility and innovativeness of the organization in problem-solving. In addition, ICT directly contributes to the innovation process of organizations.

It is therefore argued that the firm plays a key role in converting the advantages of ICT into higher value-added of products, and therefore higher productivity. The dotted box in Figure 2, which circles the middle of the first dimension and the second dimension, includes the core firm activities. Through firms, the impacts of ICT in various ways fall on two major market outcome: one is the innovated, differentiated products and services, which deliver higher value-added; the other is the change in market structure due to differentiated competitive advantages of firms based on their unique ICT-integrated business processes. The current analysis thus decomposes the firm, which is considered an information processing organization, into its core value-creation activities. A lot more future research can therefore start from here to look into the internal value-creation processes with information and uncertainty involved. This task is pursued in Chapter 3 and Chapter 4 of the thesis. The impact of ICT from the second dimension is also further studied in Chapter 5.

Last but not least, the discussion cannot be finished without mentioning the adequate skills of labor to apply ICT, which is another important prerequisite to reap all the benefits of ICT. Bresnahan et al. (2002) provide evidence that ICT penetration, together with new complementary workplace organization, causes skill-biased technical changes. Since these changes are ICT-based, the skills of workers to work with ICT in depth are emphasized. According to Lanvin and Passman (2008), the penetration of ICT generates 'e-skill' requirement in three categories: ICT user skills for effective application of ICT systems and devices at individual level; ICT practitioner skills for researching, developing, marketing, installing, managing, maintaining, and supporting ICT systems; and e-business skills for exploiting business opportunities facilitated or provided by ICT. Moreover, due to ICT penetration, on the one hand there are more decentralized decision making and more self-managing teams appearing as complementary organization form to ICT, and on the other hand new production processes include more new services and improved service quality. Therefore, besides e-skills, Bresnahan et al. (2002) highlights the demand on cognitive and interpersonal interaction skills of labor. Basu et al. (2004) derive another implication for labor skill using the General Purpose Technology (GPT) theory: complementary workplace re-organization requires high management skill to accomplish. Therefore, higher requirement in e-skills, cognitive and interpersonal interaction skills, and related management skills are necessary to allow full use of ICT.

Chapter 3

The Impact of ICT on Firm: A Model with Demand Uncertainty and Information Processing

This study corresponds to the first dimension of ICT impact on firm performance as proposed in Chapter 2. It adds to the detail of how ICT contributes to coordination in firm production, and how such improves firm performance.

3.1 Introduction

Literature has confirmed that ICT contributes to firm productivity and that organizational investment as a complementary investment to ICT investment is important (Brynjolfsson and Hitt, 2000; Matteucci et al., 2005). But the mechanism that enables ICT to affect firms' productivity is not clear.

Other literature focuses on the role of information in firm activities and implies to us that there must be some connection among information processing, organizational structure, ICT investment, and firm performance. (Marschak, 1954; Arrow, 1975; Aoki, 1986; Carter, 1995; DeCanio and Watkins, 1998; Marschak, 2004)

To identify the pattern of connection, one asks why multi-person, multi-process firms exist in a competitive economy. In Malmgren's (1961) view, a firm functions as an allocating mechanism of inputs and outputs. The reason why such allocation is not done by markets, which is supposed to be efficient within traditional settings, is because of the uncertainty and incomplete information⁷ that embed in the real economy. Therefore, firms arise to reduce the information requirement by integrating production procedures, vertically and horizontally. Meanwhile, firms process internal and external information, which gives firms higher expected profit. Internal information regards the production-related variables; and external information regards the environment⁸. Casson (1997) further develops the idea as that firms' internal structure would routinize the processing of external information to be the processing of internal

⁷ Incomplete information here refers to not knowing what everyone else knows (Malmgren, 1961). This is distinguished from the concept of imperfect information, which means not knowing what everyone else has done.

⁸ Malmgren (1961) refers to external information as dependent on the so-called "structure of market".

information, leaving the remaining external information to the entrepreneurs. For the purpose of this paper, we focus on the routine information processing conducted by established firm structure.

To model that firms are endogenously derived out of economic incentive, Yang and Ng (1995) provide a general equilibrium framework. For their purpose, convex production technology is assumed with multi-stage production. Their argument is that firms substitute market in coordinating production procedure where transaction cost is too high. However, they assume an environment with certainty, and the issues of information and coordination are not included.

To introduce uncertainty, Carlton (1978) models a one-product economy with both demand and supply uncertainties. The product is featured in the market by both its price and availability (possibility of obtaining the product from a supplier given a certain price)⁹. In this economy, it is possible that each firm makes a different decision on its production and pricing. It is shown that, with each party trying to maximize its expected profit or utility, given identical production technology and utility function, the economy converges to one combination of price and availability. However, the existence of firms is given exogenously.

Based on the above building blocks, a model of endogenous firms in markets under demand uncertainty would be developed. It assumes that the firm with information processing ability coordinates production in a market with demand uncertainty, and ICT improves its information processing ability. The firm would be rewarded a sustainable source of profit and the profit depends on both

⁹ The idea that price is not the only mechanism to allocate resources is further emphasized by Carlton (1989) and Carlton (1991).

information processing ability and structure of markets. Specifically, the improving information processing ability due to ICT increases firm profitability as long as market-coordinated production persists elsewhere. However, when the improving information processing ability enables enough firms to compete with no market-coordinated production left, it decreases profitability of all firms. The paper thus provides a new perspective on how Information and Communication Technology (ICT) contributes to firm productivity.

The framework of our theory is also applied to the data of the wholesale and retail industry and the finance and insurance industry of 10 OECD countries. The mechanism and the extent that the aggregated firm performance – measured as multi-factor productivity – of the industry is decided by ICT investment is investigated. It is found that the markets of the two industries actually have different structure. From that we infer different patterns of impact from ICT. Interestingly, we do not observe any “first-mover advantage” in ICT investment. Our results suggest that industries in different countries could choose their specific optimal level of ICT investment according to their own market structure – not necessarily the higher the better.

The rest of the chapter is organized as follows. Section 3.2 gives detailed descriptions of the model. Section 3.3 discusses the main findings of the model. Section 3.4 discusses the implications derived from the model. Section 3.5 is devoted to case studies into the finance and insurance industry and the wholesale and retail industry. Section 3.6 concludes.

3.2 The Model

3.2.1 Specialization, Coordination, and Demand Uncertainty

There are one intermediate input M and one final product X in a specific industry. Each individual agent engaged in the industry is endowed with L labor time, which is normalized to one. The agent is capable of producing either of X or M using the following technologies:

$$\begin{aligned} m &= l_M^a \\ x &= m_X^\alpha \cdot l_X^{a(1-\alpha)} \end{aligned} \tag{1}$$

where $a > 1$, $0 < \alpha < 1$.

l_X and l_M denote the portions of individual L devoted into production of X and M respectively, with $l_X \leq 1$, $l_M \leq 1$, and $l_X + l_M = 1$. It is assumed that the technology does not allow labor from different individuals to work in the same procedure. For example $(l_{iM} + l_{jM})^\alpha$ is not viable for individual i and individual j to produce intermediate input M .

Assume that the markets for M and X exist. With the convex production technologies, individuals as producers prefer specializing in producing one product only and trade in the market. Production in the industry could then be coordinated via the intermediate input market for M . A portion of the population in the industry specializes in producing M , while the rest specializes in producing X . The producers of X purchase intermediate input from producers of M , and sell their products in the final product market of X . Individual producer runs his own shop, with only himself employed, to produce and sell products. The labor cost of individual business is then considered as

sunk. The return to labor is the expected revenue of the business. This system is thereafter referred to as a ‘market-coordinated production’ with full specialization.

Demand of both markets is assumed to be random to each shop, and subject to uniform distribution with parameter λs . With imperfect information¹⁰, no buyer knows exactly how many other buyers would go to the same shop as he does; and no producer knows how many buyers would drop by. It leads to availability problem when there are too many buyers and the shop runs out of stock. The availability is defined as the probability that the product demanded is still in stock at the shop, and could be considered as a kind of quality of the product. Namely, the higher the availability is, the better the quality of the product is. The availability of the product is decided by both the demand uncertainty and the output level of the shop¹¹. Competition among shops is about the shops’ policies of price and availability combinations.

In this way, we have deviated from classical assumption of certainty of demand in a limited market. By imposing random distribution of demand with given parameters on shops, the market is in effect assumed to be infinitely large. We are taking the perspective of a typical individual producer in the real economy,

¹⁰ This is due to the setting of our model that consumers decide simultaneously which shop to visit. For each consumer, he doesn’t know what the others have decided. Thus it is imperfect information, rather than incomplete information.

¹¹ This assumption was used by Carlton (1978). The availability issue is incurred by uncertain demand. When realized demand exceeds suppliers’ production level, which is decided according to their expectation, availability is no longer one hundred percent. For such a setting, there are two implicit assumptions. Firstly, production plan is implemented before the demand is realized. Secondly, each consumer enquires with any shop for only once. If the shop runs out of stock, the consumer won’t be able to try another shop. For simplicity of our analysis, the current paper modifies the second assumption into that for each unit of demand, buyer tries only one shop.

as if he is in an infinitely large market and do not have to concern how his behavior changes the overall demand of the market.

3.2.2 Consumer Behavior

Individuals, from either this industry or other parts of the economy, consume the final product X , with an exogenously decided portion of their income to be spent on it. Denote the availability by Q_x ¹². The utility of consuming x units of X is defined as the product of quantity and availability:

$$U \equiv f(x, Q_x) = x \cdot Q_x \quad (2)$$

A typical consumer chooses to,

$$\begin{aligned} \max. \quad & U = x \cdot Q_x \\ \text{s.t.} \quad & P_x \cdot x = I \end{aligned} \quad (3)$$

I is the exogenous income¹³. P_x is the price of X .¹⁴

One can derive an indifference curve of P_x and Q_x , which is linear in this special case, as shown in Figure 3.

When P_x is given, for a certain level of utility, we have:

¹² Formal definition of Q_x will be found in the later subsection for the X -producers' behavior.

¹³ Note that this is not a closed one-industry economy. Rather, the object under study is one specific industry from a multi-industry economy. Consumers come to consume this industry's product with their income each earned from this industry or from other industries. For this reason, income constraint is not an endogenous variable. And thus the utility function is specifically for the consumption of products of this specific industry. This can also be modeled as the following: Let h be the other numeraire good that is consumed. The utility function is $U = h^\mu (x \cdot Q_A^x)^\nu$, with income constraint $h + P_x x = I$. Therefore, this is a classical utility

maximization problem, and there is always a constant portion of the income $\frac{\nu}{\nu + \mu} \cdot I$ spent on

product X . In this paper, for convenience and simplicity, we denote this constant portion of income to be spent on product X as I .

¹⁴ Availability can be seen as quality of the product. For this reason, the X -producer does not necessarily consume his own product, as he may well produce and sell high quality product, but consume low quality product, according to his preference. Thus what he cares about, as the m producers do as well, is the monetary revenue he receives from the market.

$$U_0 = \frac{I}{P_X} \cdot Q_X \Rightarrow P_X = \frac{I}{U_0} \cdot Q_X \quad (4)$$

Let $\beta_X = \frac{U_0}{I}$, we have:

$$P_X(Q_X) = \frac{Q_X}{\beta_X} \quad (5)$$

Later it will be shown that β_X is both a measure of consumer welfare status and a measure of producer's market power, in the equilibrium.

Figure 3: Indifference curve of the consumers in the $P_X - Q_X$ space

3.2.3 The Individual X -Producers' Decision

An X -producer faces random demand with a uniform distribution, which could be described by parameter λ_X . The probability density function is $\phi_{\lambda_X}(k) = \frac{1}{\lambda_X}$,

$k \in [0, \lambda_X]$, where k denotes the realization of random demand at each shop.

The larger the parameter λ_X is, the greater the volatility in terms of variance in the market is.

Suppose that the X -producer buys m_X units of the intermediate input. With full specialization, his output level is $m_X^\alpha \cdot L^{\alpha(1-\alpha)}$. As L is normalized to one, the output level of each X -producer is m_X^α . The X -producer needs to decide optimally how many units of m_X to purchase from the market.

The revenue function of a typical X -producer is:

$$\pi = \begin{cases} P_X k, & \text{if } k \leq m_X^\alpha \\ m_X^\alpha P_X, & \text{if } k > m_X^\alpha \end{cases} \quad (6)$$

To maximize his expected revenue, the X -producer decides the optimal output level and price according to:

$$\begin{aligned} \max. E(\pi_X) &= \left[\int_0^{m_X^\alpha} P_X k \phi_{\lambda_X}(k) dk + \int_{m_X^\alpha}^{\lambda_X} m_X^\alpha P_X \phi_{\lambda_X}(k) dk - P_M m_X \right] Q_M \\ \text{s.t. } U_{P_X} &= \frac{I}{P_X} Q_X \geq U^* \end{aligned} \quad (7)$$

P_M is the price of the intermediate input M , and Q_M is the availability of it in the intermediate input market. $Q_X = F_{\lambda_X}(k < m_X^\alpha) \times Q_M$ is the availability of X product at the shop, where $F_{\lambda_X}(k < m_X^\alpha) = \int_0^{m_X^\alpha} \phi_{\lambda_X}(k) dk$ is the cumulative density function.

The constraint condition means that the X -producer needs to offer a combination of price and availability that delivers a utility which is at least as high as the average level in the market.

This is because, for a given $E_0(\pi_x)$, there are multiple possible combinations of price and availability along the iso-revenue curve as shown in Figure 4. Producers compete with each other by shifting to the iso-revenue curve that is the closest to a given level of consumer utility, which is described by the given indifference curve. A specific combination of price and availability is chosen when the two curves are tangential to each other.

Therefore, the indifference curve of the consumer imposes a pricing rule for the producers. The firms have to accept it to make consumers indifferent in choosing any combination along the curve. Otherwise, if the firm sets an arbitrary pricing rule and chooses the corresponding combination of price and availability (Point A in Figure 5), other producers can always find another combination along the iso-revenue curve to offer a higher utility level (From point A to Point B in Figure 5)¹⁵.

Figure 4: Iso-revenue curve and the indifference curve of consumer

¹⁵ Note that in this $P_x - Q_x$ space, $U_1 > U_0$, since at U_1 one always have lower price for the same availability. On the other hand, $E(\pi_x)$ gets larger as the iso-revenue curve shifts up.

Figure 5: An arbitrary pricing rule

Therefore, the indifference curve of the consumers' utility imposes a pricing rule on the X -producers, so that consumers are indifferent between any combination of price and availability along the indifference curve. The equilibrium in this market is decided by both the iso-revenue curve and the indifference curve.

To find the equilibrium, rewrite the expected revenue of the X -producer into an iso-revenue curve in terms of P_X and Q_X at any $E_0(\pi_X)$

$$P_X = \frac{\frac{E_0(\pi_X)}{Q_M} + P_M m_X}{\int_0^{m_X^\alpha} k \phi_{\lambda_X}(k) dk + \int_{m_X^\alpha}^{\infty} m_X^\alpha \phi_{\lambda_X}(k) dk} \quad (8)$$

P_M and Q_M are to be decided in the intermediate input market, which the subsequent section discusses.

3.2.4 The Individual M - Producers' Decision

Let k denote the realized per shop random demand on M . A typical M - producer faces random demand which is subject to uniform distribution parameterized by λ_M , such that $\phi_{\lambda_M}(k) = \frac{1}{\lambda_M}$ is the probability density function, $k \in [0, \lambda_M]$. Parameter λ_M describes the maximum demand to a shop. The precondition for the M - producer to fully specialize in producing M is: $\lambda_M \geq 1$. Otherwise, given that an M - producer knows that the maximum demand coming to him is less than one, there is no incentive to full specialization in producing M , which gives an output level at $1^a = 1$.

The revenue for a typical M - producer is:

$$\pi = \begin{cases} P_M k, & \text{if } k \leq 1 \\ P_M, & \text{if } k > 1 \end{cases} \quad (9)$$

The M -producer maximizes the following expected revenue:

$$\begin{aligned} \max . E(\pi_M) &= \int_0^1 P_M k \phi_{\lambda_M}(k) dk + \int_1^{\lambda_M} P_M \phi_{\lambda_M}(k) dk \\ \text{s.t. } E(\pi_X | (P_M, Q_M)) &\geq E^*(\pi_X) \end{aligned} \quad (10)$$

The constraint condition states that the combinations of P_M and Q_M should make the X -producers indifferent at a market-average level.

Figure 6: Fixed availability of the M -product and the indifference curve of the X -producers

In this market, as shown in Figure 6, the availability of the product is fixed at $Q_M = F_{\lambda_M}(k \leq 1)$. The price of the product depends on the equilibrium. In effect, the only decision for the M -producer to make is whether to stay in the industry at the equilibrium.

3.2.5 The Equilibrium of Market-Coordinated Production

Bearing in mind that we have identical consumers and producers assumed, for the market-coordinated production, the following statement is proposed.

Proposition 1: As a stable equilibrium, producers in either market produce at the same output level to offer the same availability, and sell their product at the same price.

Deneckere and Peck (1995) provide an excellent summary of the existence of equilibrium condition for Carlton (1978), which our model bases on. It shows that when demand uncertainty is given, as well as given increasing marginal cost of production, the model with firms predetermining its capacity and

availability of the product has equilibrium. Take the X -producer as an example. Suppose that the equilibrium $(\overline{P}_X, \overline{Q}_X)$ is achieved, and one producer disobeys it. If he simply raises its price, it results in no purchase from the consumers, although they drop by due to the random distribution of demand. Otherwise, he can offer a higher Q_X with a higher P_X . According to Figure 5, it means that this new combination is either on the right of $(\overline{P}_X, \overline{Q}_X)$ on the original iso-revenue curve, or in the area which is on the right of $(\overline{P}_X, \overline{Q}_X)$ and above the original iso-revenue curve (otherwise he renders himself on a lower iso-revenue curve). Neither is acceptable to the consumers as long as there is curvature in the iso-revenue curve because it renders lower utility. This curvature as described in the figure is assured by the decreasing marginal product of the intermediate input ($\alpha < 1$). Similarly, moving to the left-hand-side area of the equilibrium point is for the same reason not viable. Thus, the equilibrium is stable at least in its neighbourhood. A proof can be found in the appendix A.

The other important property of the equilibrium is:

$$E(\pi_X) = E(\pi_M) = w \quad (11)$$

where w is an exogenously decided opportunity cost of labor. This is due to that there is no fixed cost of entry and labor is indifferent between working in this industry and in the rest of the economy. In the following, w is normalized to one. Then, according to Eq.(10),

$$P_M = \frac{1}{\int_0^1 k \phi_{\lambda_M}(k) dk + \int_1^{\lambda_M} \phi_{\lambda_M}(k) dk} \quad (12)$$

Now both P_M and Q_M are decided by λ_M . According to Eq.(8) and Eq.(11), the iso-revenue curve of the X -producer is:

$$P_X = \frac{\frac{1}{Q_M} + P_M m_X}{\int_0^{m_X^\alpha} k \phi_{\lambda_X}(k) dk + \int_{m_X^\alpha}^{\infty} m_X^\alpha \phi_{\lambda_X}(k) dk} \quad (13)$$

Putting this equation into Eq. (4) and assuming $I = 1$ we have:

$$U = \frac{\int_0^{m_X^\alpha} k \phi_{\lambda_X}(k) dk + \int_{m_X^\alpha}^{\infty} m_X^\alpha \phi_{\lambda_X}(k) dk}{\frac{1}{Q_M} + P_M m_X} \cdot F_{\lambda_X}(k < m_X^\alpha) \times Q_M \quad (14)$$

Let $\alpha = \frac{1}{2}$. Maximizing the utility in Eq. (14) will solve for m_X^* , in terms of λ_M and λ_X . It is described by Figure 7. m_X^* increases as λ_M and λ_X increases, which means markets are expanding.

It follows that P_X^* is also in terms of λ_M and λ_X , as described by Figure 8. As the final product market expands, price would initially fall and then rise. An expanding intermediate input market would push up the price of the final product. Such is due to the low availability of the intermediate input that is incurred.

Figure 7: Intermediate input purchase of the X -producers in terms of λ_X and λ_M

Figure 8: Price of the final product X in the equilibrium in terms of λ_X and λ_M

And the consumers' welfare status is described by β_X^* , which is also in terms of λ_X and λ_M , as shown by Figure 9. It is observed that to obtain high utility for consumers, the markets should not expand too much.

Figure 9: Welfare status and pricing condition measured as β_x in terms of λ_x and λ_M

Note that β_x also stands for the market power of the producers to charge a certain price for certain availability (Eq.(5)). So when β_x^* is high, it stands for low market power of the producers and high welfare level of the consumers. It depends on the exogenously given random behavior of demand.

3.2.6 Firm Production

Following Malmgren (1961), the firm as a multi-person and multi-process mechanism of allocating inputs and outputs is described by Figure 10. The firm is assumed to have no advantages in terms of production technology or retail channels.

Figure 10: The structure of a firm

As illustrated by Figure 10, a firm hires individuals from the labor market to specialize in the producing either M or X . The production and supply of M is pooled together, and then distributed to X -producers of the firm. The production and supply of X is assumed done at individual shops. The shops are independent and do not communicate with each other. The only difference between the firm production and the market-coordinated production is that a labor market replaces the intermediate input market. To do this, a firm processes the information of supply and use of the intermediate input within the firm.

At each X -shop of the firm, the expected revenue is:

$$P_{Xf} \left[\int_0^{m_f^\alpha} k \phi_{\lambda_X}(k) dk + m_f^\alpha \int_{m_f^\alpha}^{\lambda_X} \phi_{\lambda_X}(k) dk \right] \quad (15)$$

The firm is to maximize its expected profit, when there are i shops.

$$\begin{aligned}
\max .E(\pi_f) &= \sum_i P_{Xf} \left[\int_0^{m_f^\alpha} k_i \phi_{\lambda_x}(k_i) dk_i + m_f^\alpha \int_{m_f^\alpha}^{\lambda_x} \phi_{\lambda_x}(k_i) dk_i \right] - w \times i \times (m_f + 1) - C(i \cdot (m_f + 1)) \\
s.t. \frac{I}{P_{Xf}} \cdot F_{\lambda_x}(k < m_f^\alpha) &\geq U^*
\end{aligned} \tag{16}$$

$C(\cdot)$ is the cost of processing the information to run such an organization, with $C' > 0$, $C'' > 0$. Assume that C takes the functional form of $C(i \cdot (m_f + 1)) = \theta \cdot i^2 \cdot (m_f + 1)^2$, in which θ reflects the level of information processing ability. Low value of θ represents high information processing ability.

w is the wage that firm pays to its employees. The wage w that the firm needs to offer is $w = E(\pi_x) = E(\pi_M)$, which makes individual labor indifferent between taking a job and running his own individual shop. Appendix B provides proof.

When there are few firms in the industry, and the market-coordinated production is still dominating the economy, firms can take the welfare status as given at β_x^* , which is decided at the equilibrium of the market-coordinated production. Such is the constraint condition for the maximization of its profit. Therefore, the price that the firm charges is:

$$P_{Xf} = \frac{Q_{Xf}}{\beta_x^*} \tag{17}$$

With firm coordination of production, availability of the product is $Q_{xf} = F_{\lambda_x}(k < m_f^\alpha)$, since uncertainty in the supply of intermediate input is eliminated. Therefore, the iso-profit curve of the firm is:

$$E_0(\pi_f) = \sum_i \frac{Q_{xf}}{\beta_x^*} \left[\int_0^{m_f^\alpha} k_i \phi_{\lambda_i}(k_i) dk_i + m_f^\alpha \int_{m_f^\alpha}^{\infty} \phi_{\lambda_i}(k_i) dk_i \right] - w \times i \times (m_f + 1) - C(i \cdot (m_f + 1)) \quad (18)$$

The firm decides its optimal supply of intermediate input M to each shop, as well as its optimal number of final product shops to run. By maximizing Eq.(18), m_f^* can be solved at $\alpha = \frac{1}{2}$, in terms of λ_x only (Figure 11).

Compared with m_x^* for individual X -producers, m_f^* monotonically increases with respect to λ_x only. Such is due to that the firm has avoided the uncertainty in the supply of intermediate input.

However, i^* is solved in terms of both λ_M and λ_x , as described by Figure 12. This is due to that β_x^* , which decides the price that the firm can charge with any given availability of the product, is determined by both λ_M and λ_x in the market-coordinated production.

Figure 11: Plotting m_f^* in terms of λ_x

Figure 12: Plotting i^* , with $\theta=0.1$ as given

3.3 Information Processing Ability and Entrepreneurship

The firm's decisions made above lead to the following expected profit:

$$E(\pi_f)^* = \sum_i \frac{Q_{Xf}^*}{\beta_X^*} \left[\int_0^{m_f^{*\alpha}} k_i \phi_{\lambda_1}(k_i) dk_i + m_f^{*\alpha} \int_{m_f^{*\alpha}}^{\infty} \phi_{\lambda_1}(k_i) dk_i \right] - w \times i^* \times (m_f^* + 1) - C(i^* \cdot (m_f^* + 1)) \quad (19)$$

Therefore, the expected profit can be written in terms of λ_M and λ_X with a given θ as shown in Figure 13. With some combinations of λ_M and λ_X the expected profit is zero, meaning that a firm production is not viable there. With other combinations of λ_M and λ_X , positive expected profit is obtained with firm production. Therefore, it is observed that, given sufficiently low value of θ , the firm makes positive expected profit is conditional on the structure of markets as described by λ_M and λ_X .

Figure 13: Plotting $E(\pi_f)^*$ when $\theta = 0.1$

Proposition 2: Ceteris paribus, the firm's expected profit depends on both λ_M in the intermediate input market and λ_X in the final product market. The two parameters describe the structure of the two markets.

Corollary: When the value of θ varies, its impact on the expected profit depends on the structure of markets as described by λ_X and λ_M .

Thus our model has shown that how information processing ability contributes to firm profitability, conditional on the structure of markets. Next we want to

know what if many such firms exist so that market-coordinated production no longer dominates.

So far our conclusions are based on the assumption that there are few firms in the industry, and the market-coordinated production is still dominating the economy. In the subsequent discussion, we allow β_x to be exogenous and different from the β_x^* determined by the equilibrium of the market-coordinated production. So that given λ_x and λ_M , values of β_x and θ would determine the sign and scale of the expected profit of the firm.

Assume that the industrial population is N , and the information processing ability θ is initially a natural gift which distributes randomly among the industrial population, with each individual assigned a value of θ . Put them into an ordered sequence as $\Theta = (\theta_1, \theta_2, \theta_3, \dots, \theta_N)$. Starting with a critical θ_n in the sequence which is low enough to enable a firm, individuals with a value of θ lower than θ_n can start up firms. Such describes entrepreneurship in the industry.

Suppose that the sequence Θ is low enough so that all production of this industry is engaged in firm coordination of production. Then market-coordinated production no longer provides benchmark β_x for the industry. Instead, β_x is subject to the competition among firms in the final product market. The mechanism of competition in the product market works in a way similar to that of Ricardian theory of land rent. Given λ_x and λ_M , with the

opportunity cost of labor given exogenously as 1, the consumer's utility offered by the marginal firm determines the benchmark β_x for the industry.

The marginal firm is the firm which has a θ_n value that satisfies the following equations:

$$i(\theta_n) = \frac{\frac{1}{\beta_x^{**} \cdot \lambda_x} \left[m_f - \frac{m_f^{\frac{3}{2}}}{2\lambda_x} \right] - (m_f + 1)}{2\theta_n (m_f + 1)^2} \geq 1 \quad (20)$$

$$\sum_{j=1, \dots, n} i(\theta_j) \cdot (m_f + 1) = N - n \quad (21)$$

$$E(\pi_f)_n = i(\theta_n) \cdot \frac{1}{\beta_x^{**}} \cdot \left(\frac{m_f}{\lambda_x} - \frac{m_f^{\frac{3}{2}}}{2\lambda_x^2} \right) - i(\theta_n) \cdot w \cdot (m_f + 1) - \theta_n \cdot i^2(\theta_n) \cdot (m_f + 1)^2 = w \quad (22)$$

Eq.(20) states that the firm size cannot be smaller than 1. Eq.(21) says that production of the industry is completely conducted by firms, with no more market-coordinated production. Eq.(22) states that the owner of the marginal firm has to be able to compensate his opportunity cost, which is equivalent to the market wage. The three equations determine a specific pair of (β^{**}, θ_n) , which defines the marginal firm. The rest of the firms in the industry with lower θ values therefore make positive expected profit greater than the opportunity cost of labor.

As the sequence of Θ shifts to lower values, say due to ICT investment, the optimal size of existing firms increases, and the original marginal firms will be driven out of the market. It is predicted that the consumers will enjoy higher

utility as firms compete in the final product market to push up the value of β^{**} , until Eq.(22) is true for the new marginal firm. In this process, the expected profit of the existing firms and productivity of the industry would be impaired by the improvement in θ value, as β^{**} keeps increasing. Therefore, when the industry is fully engaged in firm coordination of production, further improvement in θ will improve consumer welfare but impair firm profitability.

To sum up, the structure of the markets has fundamental effect in deciding to what extent information processing ability can improve profitability of firms and productivity of the industry. If ICT applies to improve information processing ability, it increases profitability of firms and productivity of the industry until it comes to the point when all production is engaged in firm production. After that point, further improvement in information processing ability impairs profitability and productivity due to intensified competition.

The subsequent section examines whether the impacts of information processing ability on firm performance in the real economy are as predicted in the model. Two service industries, which are close to our assumptions in many ways, are selected as case studies. Specifically, they are the *wholesale & retail industry* and the *finance and insurance industry*.

First, production technology of these industries is plain and open to anyone. No one could claim a patent on the design or organization of a store, nor could anyone claim patent on an investment tool tailored for customers. Second, there exist many individually run retail shops, as well as many self-employed financial agents. Third, demand in the markets do appear random to a certain extent. Fourth, both the labor and the final product market are relatively

competitive in the two industries, which means that market power can hardly be the source of sustainable profit. Fifth, neither of them is perfectly competitive with homogeneity embedded. We do observe that different prices are charged for services with different quality. Sixth, according to empirical studies (van Ark, 2002), these two industries do benefit substantially from ICT advancement and investment in the U.S., which is a result that could be predicted by our model. For these reasons, we use the two industries as our subjects.

3.4 Case Studies

In this section, a cross-country industry-level panel data analysis is conducted. The wholesale and retail industry and the finance and insurance industry are the subjects. The sample includes data of the two industries from the United States, the United Kingdom, Japan, Germany, Italy, Australia, South Korea, Denmark, Finland, and Austria, covering the period from 1980 to 2005. Data is collected from the EU-KLEMS database, the OECD.stats database, and statistics bureaus of the respective countries.

Combining the theoretical frameworks of growth accounting approach and our model, the following is established. For an industry i ,

$$Y_i = A_i \times F_i(K_i, N_i) = A_i \times K_i^\rho \times E_i^{1-\rho} \quad (23)$$

where Y_i is the real output of the industry, K_i is capital stock, E_i is employment, and A_i is total factor productivity.

Let P_i be the price of the product. The nominal output is,

$$P_i \times Y_i = P_i \times A_i \times K_i^\rho \times E_i^{1-\rho} \quad (24)$$

The decomposition of the growth rate of the nominal output is,

$$g_{P_i \times Y_i} = g_{P_i} + g_{A_i} + \rho \cdot g_{K_i} + (1 - \rho) \cdot g_{E_i} \quad (25)$$

We want to look at the growth of nominal value-added per labor hour rather than real value-added per labor hour for two reasons: Firstly, it is technically difficult to distinguish how much the growth of value in current price of a service is due to quality improvement and how much of that is due to inflation¹⁶. A measure of real value-added could thus be biased in reflecting the value created by service industries. Secondly, the purpose of the study is the firms' ability to generate profit (rather than the ability to produce), which is not a homogeneous function of prices of degree one.

The growth rate of the nominal value-added per labor hour is defined as,

$$g_{P_i \times Y_i} - g_{H_i} = g_{P_i} + g_{A_i} + \rho \cdot g_{K_i} + (1 - \rho) \cdot g_{E_i} - g_{H_i} \quad (26)$$

where g_{H_i} is the growth rate of labor hour.

Let $glph_i = g_{P_i \times Y_i} - g_{H_i}$. The following is established:

$$glph_i = \alpha \cdot INF + \rho \cdot g_{k_i} + (1 - \rho) \cdot glq_i + g_{A_i} \quad (27)$$

where k_i is the capital per labor hour, and glq_i is the measure of growth of labor quality defined as $g_{E_i} - g_{H_i}$ (Jorgenson and Stiroh, 2000). INF is the general inflation rate of the economy, which is used to proxy for g_{P_i} with

¹⁶ SNA93 provides detailed information.

$g_{P_i} = \alpha \cdot INF$. This treatment is necessary since it is difficult to accurately estimate the price for a service, and the overall inflation data is readily available.

g_{A_i} is the growth rate of industrial total factor productivity, which is the key variable that we use to measure the aggregate firm performance in the industry.

To examine this hypothesis, we run the regression of g_{A_i} against the following explanatory variables, as implied by our theoretical model: (i). Growth of ICT capital stock of the industry, measured as g_{IT_i} , to control for the cost of information; (ii). Growth of level of labor compensation in the very industry, measured as g_{ILCPH_i} , which controls increases in wage level; (iii). Average firm size of the industry, measured as FZ_i . The regressions are designed to find evidence that θ impacts economic performance of firms in the way that our model predicts, with wage level and firm size controlled.

Therefore, after g_{A_i} is estimated from Eq.(27), we have,

$$g_{A_i} = \beta_1 g_{IT_i} + \beta_2 g_{ILCPH_i} + (\beta_3 FZ_i) + u_{ij} + \varepsilon_i \quad (28)$$

where u_{ij} is fixed country effect of country j .

As total factor productivity data for each industry in each country is readily available from the EU-KLEMS database which uses growth accounting method, we also run regressions Eq.(29) against this data to check if the results from the above are reliable, as a robustness test.

$$g_{TFP_i} = \beta_1 g_{IT_i} + \beta_2 g_{ILCPH_i} + (\beta_3 FZ_i) + u_{ij} + \varepsilon_i \quad (29)$$

3.6.1 The Wholesale and Retail Industry

Figure 14 describes the mean and standard deviation of some key variables relevant. It can be observed that the industry in different economies follow different patterns of growth. The U.S. wholesale and retail industry relies more on the growth of ICT capital stock: a relatively stable and high growth in ICT drives median level of growth of nominal labor productivity. The industry of Japan relies more on significant labor quality improvement, while its growth of labor compensation is among the lowest. The industry of U.K. and Korea has low ICT growth, low labor quality growth, while industrial labor compensation grows relatively faster.

Figure 14: Key variables of the wholesale and retail industry

By pooling the countries together in a panel regression, the pattern for this wholesale and retail industry becomes clear (Table 1).

Table 1: Regression results of the wholesale and retail industry

Regression	(1)	(2)	(3)	(4)
Method	OLS	OLS	OLS	OLS
Observations	104	104	104	104
Regressand:	Resid_gtfp	gtfp	Resid_gtfp	gtfp
Regressors:				
gitph	0.09**	0.10**	0.12**	0.12**
gitph(-1)	-	-	-0.06	-0.03
gilcph	0.40**	0.40**	0.38**	0.39**
fz	-1.64	9.14**	-0.78	9.62**
C	-0.02	-0.11**	-0.03	-0.11**
Fixed country	Yes	Yes	Yes	Yes
Fixed period	None	None	None	None
R-squared	0.38	0.50	0.39	0.50
Prob (F-statistic)	0.00	0.00	0.00	0.00
Durbin-Watson statistic	1.88	2.16	1.88	2.18

* 10% significant; ** 5% significant.

Regression results from Eq.(28) and Eq.(29) are very similar. The results reveal two findings: First, ICT capital stock, which reduces the cost of information processing, has a positive impact on the aggregate performance of firms; Second, growth in labor compensation and firm size both have positive impact on the aggregate performance of firms. According to our theory, this implies that, given a certain β_x value, a lower θ has enabled more firms to join in and at the same time has pushed the optimal firm size higher, therefore improving the performance of the whole industry. In other words, ICT investment brings additional room for expansion to the industry.

Figure 15: The effects of decreasing θ numbered as 1, 2, and 3

Figure 15 illustrates the three simultaneous effects numbered as 1, 2, and 3, of the decreasing cost of information processing:

- (1) As Θ shifts down, more firms enter the industry. Such improves productivity of the industry and improves profitability of existing firms.
- (2) Lower value of θ has the effect of pushing up the optimal firm size. Therefore this is a positive effect.
- (3) As Θ keeps shifting down, the industry could eventually come to the stage that all production is engaged in the firm production. From this moment on, β_x is no longer decided by the market-coordinated production, and starts to increase as firms start to compete to provide the consumers with higher utility. Further decrease in Θ will increase the size of existing firms, but lower down the profitability of firms as well as productivity. Thus this is a negative effect.

According to the above theory, the generally positive effects of ICT investment over the wholesale and retail industry keeps happening as long as the market coordinated production still dominates.

3.6.2 The Finance and Insurance Industry

Figure 16 presents the different growth patterns of the finance and insurance industry of each economy. For example, ICT growth of the finance and insurance industry in the U.S. is among the highest, accompanied by low labor quality growth and median level labor compensation growth; Yet the nominal labor productivity growth is in the median-low zone. Data on its firm size

shows that the industry has the largest average size among all economies in the sample and it is declining over the years. The U.K. and Australia cases are different. They have relatively high ICT accumulation, negative labor quality growth, and relatively high labor compensation growth. These features give them significant improvement in the aggregate performance of firms.

Figure 16: Key variables of the finance and insurance industry

Table 2: Regression results of the finance and insurance industry

Regression	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Method	GLS	OLS	OLS	GLS	OLS	OLS	OLS	OLS
Observations	65	65	65	64	64	228	228	228
Regressand:	Resid_ gtfp	gtfp	gtfp	Resid_ gtfp	Resid_ gtfp	gtfp	gtfp	gtfp
Regressors:								
gitph	0.14*	-	-	0.15*	0.07	-0.06*	-	-
		0.03	0.01				0.07*	0.08*
gitph(-1)	-	-	-	-0.12	-0.05	-0.00	0.00	0.00
gilcph	-0.20	0.22	0.16	-0.22	-0.02	0.26**	0.28*	0.29*
		*					*	*
fz	-2.51**	-	-	-1.96	-0.34	-	-	-
		1.43	0.29					
C	0.10	0.08	0.02	0.09	0.01	0.01	0.02	0.01
Fixed	Yes	Yes	Non	Yes	None	Yes	None	Yes
country			e					
Fixed period	None	Non	Yes	None	Yes	None	Yes	Yes
		e						
R-squared	0.13	0.19	0.37	0.17	0.24	0.17	0.16	0.24
Prob (F- statistic)	0.39	0.14	0.23	0.29	0.88	0.00	0.06	0.01
Durbin- Watson statistic	2.65	2.40	1.89	2.66	2.44	1.73	1.57	1.72

* 10% significant; ** 5% significant.

The following is observed from the regression results in Table 2: First, when firm size is controlled, growth of ICT capital stock has positive impact, otherwise the impact of growth of ICT capital stock turns significantly negative. Such implies that this market is saturated with firm production, and further improvement in information processing ability intensifies competition and thus puts marginal firms out of business. Second, the growth of labor compensation in the industry has positive impact on the performance of firms; Third, period fixed effect is more suitable for this industry, rather than fixed country effect.

Recall Figure 15, the following explains the case of the finance and insurance industry: growth in ICT capital stock reduces the cost of information processing, pushing up the optimal firm size, and also enabling more entry of firms into the industry. However, unlike the case of the wholesale and retail

industry, it leads to lower firm performance if the markets are dominated by firm production and firms compete to raise β_x . The rising labor compensation in the industry also keeps driving out firms at the margin, thus alleviating such competition and having positive contribution to firm performance. To sum up, in the case of the finance and insurance industry, in contrast to the previous one, the effect of ICT generally turns negative because the intensity of competition in this industry is already large enough. Evans and Wurster (1997) documented the impact of ICT on the value chain of the banking industry in the 1990s. They observed that ICT intensifies competition and imposes smaller firm size. Such is consistent with our conclusions.

Fixed country effect in our regressions displays ambiguous results. In the wholesale and retail industry, fixed effect for a certain country has different signs in regressions applying Eq.(28) and Eq.(29). Applying Eq.(28), the U.S. has positive fixed effect, yet it is neither unique nor the most significant one. Applying Eq.(29), the U.S. fixed effect is actually negative. In the finance and retail industry, the U.S. fixed effect is always negative, while other countries' fixed effect being positive or negative. Therefore, no unique country effect, especially “first-mover advantage” to the U.S., is found.

3.5 Conclusions

This chapter aims at investigating how the information and communication technology (ICT) improves firm performance, so as to improve the performance of the industry. For this purpose, a model of firm in an industry with demand uncertainty is developed.

The model is a partial equilibrium analysis for a certain industry existing in a broader economy, where there are other industries elsewhere. The industry has two stages of production, for the intermediate input M and the final product X respectively. There is convex production technology openly available for all producers in the industry, which provides incentive for specialization. Market transaction of the intermediate product is one way to coordinate the specialized production, with each specialized producers running their own shops to sell. Such is referred to as market-coordinated production.

Consumers of product X come from all industries including the current one, with a certain portion of their total income. Demand uncertainty, which is subject to uniform distribution, exists for the markets of both products. This leads to availability issue of the products from one shop, which is in terms of probability of obtaining the products.

A firm featured as an organization with multi-person and multi-stage production is the other alternative to coordinate the production. It employs labor from the labor market, and uses the same production technology to produce both intermediate input and final product. It sells its final product at individual shops. The only difference between firm production and market-coordinated production is that, a firm has the production process organized by processing the information of demand and supply of the intermediate input. However, information processing is a costly process. ICT is assumed to improve information processing ability and lower down the cost.

Via the model, we understand that the cost of information processing has its impact on firm performance, conditional on the structure of the markets in

terms of the level of demand uncertainty. Importantly, the improving information processing ability increases firm profitability as long as market-coordinated production persists elsewhere. However, when the improving information processing ability enables enough firms to compete with no market-coordinated production left, it decreases profitability of all firms.

To test if these theoretical predictions apply to real economy, the paper conducts case studies on the wholesale and retail industry, and the finance and insurance industry. Choosing service industries to examine our model prediction is basically for the convenience of analysis, as the service industries fit our model assumptions in many ways.

It is found that ICT investment has different patterns of impact over the two service industries. In the wholesale and retail industry, ICT investment brings positive impact to the aggregated firm performance by increasing the optimal firm size and allowing more firms to enter, which means more production is done by firm coordination rather than market coordination. In the finance and insurance industry, the market is likely to be saturated with firm production. As intensity of competition is already high between firms, lower information cost further intensifies it by increasing the size of the existing ones while putting marginal firms into close. The remaining firms will continue to compete by offering consumers higher utility, which gradually pushes up β_x and therefore lower the profitability of each firm. Therefore the effect of ICT investment is generally negative in the finance and insurance industry.

Last but not least, we learn from the fixed country effect coefficients that it is unlikely that there is a first-mover advantage attached to any single economy in

ICT investment. Rather, different economies could adjust their ICT investment strategies according to the development stage with corresponding market structure of the specific industry. This is because that ICT investment does not necessarily and automatically bring better industrial performance – therefore not necessarily the higher the better. In other words, many other factors, especially intensity of market competition, should be taken into consideration in policy-making.

Chapter 4

The Impact of Information Communication Technology on the Coordination of Production

4.1 Introduction

In Chapter 3, it is shown that conditional on the structure of the markets, by improving information processing ability, Information and Communication Technology (ICT) contributes to profitability of firms. Additionally, when the market has reached the point that the production is all coordinated by firms, it intensifies competition between firms, resulting in higher welfare to consumers, but lower profitability to firms.

The firms in Chapter 3 are assumed to vertically integrate production. However, in many cases, an industry has more choices over the types of firm coordination. There could be both horizontally integrated firms and vertically integrated firms in an industry with multiple stages of production. The question asked in this chapter is whether ICT would have impacts on the choice of the types of firm coordination. For this purpose, we further extend the model built in Chapter 3.

There have been studies investigating the coordination of production in an industry with multiple stages of production. Yang and Ng (1995) model the firm production as endogenously emerging from market-coordinated two-stage production, which has the specialized individual labor coordinated by trade. The paper provides discussion on different types of internal organization of a firm. However, the paper is based on the idea of transaction cost, and therefore does not discuss information processing. Carter (1995) presents a model to discuss the performance of a firm with different organizational structure to process information. Uncertainty in both production and sales is assumed.

However, the cost of information processing, which is modelled as organizational cost, is assumed to be fixed. Carlton (1979) models a two-stage industrial value chain with demand uncertainty. The model shows the incentive for downstream firms to acquire upstream firms for vertical integration of production. However, firms are assumed to exist exogenously in the model. And it focuses on vertical integration only.

Based on the ideas and understandings above about the firm coordination of production, our model considers a two-stage production with demand uncertainty. To coordinate production, cost of information processing and different types of internal structure of firms are considered. The building blocks are also borrowed from other studies including Malmgren (1961), Carlton (1978), and Carlton (1989). Literature review on these studies as well as those related to ICT has been discussed in Chapter 3, and hence not repeated here.

4.2 The model

4.2.1 Production Technology and Demand Uncertainty

This model considers one industry of an economy, which has two stages of production. Let M denote the intermediate input and X denote the final product to be consumed. Consumers come from the whole economy, with an exogenous budget to spend on X .

A convex production technology which applies to individual labor only is assumed. Each individual has one unit of labor endowment, i.e. $l = 1$. For product M , the production function is $m = A_M \cdot (l_M)^a$, where m is the quantity of output, l_M is the portion of individual's labor used in producing M , A_M is

the exogenously given Total Factor productivity (TFP), and $a > 1, l_M \leq 1$. When $l_M = 1$, which means full specialization in producing M , we have $m = A_M$. For product X , the production function is $x = A_X \cdot (m_X)^\alpha \cdot (l_X)^a$, where x is the quantity of the output, m_X is the intermediate input used in producing X , l_X is the portion of individual's labor used in producing X , A_X is the exogenously given TFP, and $a > 1, \alpha < 1, l_X \leq 1$. When $l_X = 1$, which means full specialization in producing X , we have $x = A_X \cdot (m_X)^\alpha$.

Demand for each shop selling either product is assumed to be uncertain. The demand follows truncated normal distributions from zero to positive infinity. For the market of M , it is a distribution with μ_M as the mean, and $\sigma_M = 1$ as the variance. For the market of X , it is a distribution with μ_X as the mean, and $\sigma_X = 1$ as the variance. μ_M and μ_X describe the structure of the markets, and are assumed to be given.

Classical assumption about consumer behavior claims that there is a given maximum demand, and the demand is a function of price only. In other words, price is the only variable to clear the market. The current model deviates from this classical assumption. The market is seen as unlimited to individual producers, with given structure described by μ_M or μ_X . Moreover, following Carlton (1989), both price and queuing are the tools to clear the market. In this model, with uncertain demand, the realized demand to a shop could be higher than, equal to, or lower than the capacity of a shop. Therefore, 'queuing' is realized as 'availability', which is a probability that the shop has the stock when demand comes.

It is assumed that consumers take into account both the quantity and the availability of the final product. Let Q_x denote the availability. Consumers maximize the following utility:

$$U = h^\rho + (Q_x \cdot x)^\rho \quad (30)$$

where h is the consumer's wealth or a numeraire good for consumption with price equal to one. Budget constraint for the consumer is:

$$h + P_x \cdot x = I \quad (31)$$

where P_x is the price of product X , and I is the exogenous income of the consumer.

Taking the price P_x and availability Q_x of product X as given, the optimal quantities are:

$$x^* = \frac{I \cdot P_x^{\frac{1}{\rho-1}}}{Q_x^{\frac{\rho}{\rho-1}} + P_x^{\frac{\rho}{\rho-1}}} \quad (32)$$

$$h^* = \frac{I \cdot Q_x^{\frac{\rho}{\rho-1}}}{Q_x^{\frac{\rho}{\rho-1}} + P_x^{\frac{\rho}{\rho-1}}} \quad (33)$$

Therefore, the maximized utility is:

$$U^* = \left(\frac{I \cdot Q_X^{\frac{\rho}{\rho-1}}}{Q_X^{\frac{\rho}{\rho-1}} + P_X^{\frac{\rho}{\rho-1}}} \right)^\rho + \left(\frac{I \cdot P_X^{\frac{1}{\rho-1}} \cdot Q_X}{Q_X^{\frac{\rho}{\rho-1}} + P_X^{\frac{\rho}{\rho-1}}} \right)^\rho \quad (34)$$

It follows that to make the consumers indifferent between any combinations of P_X and Q_X , at any given utility level, P_X and Q_X satisfy the following equation:

$$U_0(P_X, Q_X) = \left(\frac{I \cdot Q_X^{\frac{\rho}{\rho-1}}}{Q_X^{\frac{\rho}{\rho-1}} + P_X^{\frac{\rho}{\rho-1}}} \right)^\rho + \left(\frac{I \cdot P_X^{\frac{1}{\rho-1}} \cdot Q_X}{Q_X^{\frac{\rho}{\rho-1}} + P_X^{\frac{\rho}{\rho-1}}} \right)^\rho \quad (35)$$

In the $P_X - Q_X$ space, the indifference curve is upward sloping and concave as shown in Figure 17.

Figure 17: The indifference curve in the $P_X - Q_X$ space

4.2.2 The Market-coordinated Production

Assume that both the market of intermediate input and market of final product exist. Production and consumption can then be coordinated by market transactions, with individuals specializing in producing either X or M , and then selling the products at their own shops.

For an individual X -producer, given his capacity at $A_X \cdot (m_X)^\alpha$, let k be the realized demand to his shop. His sales revenue π is,

$$\pi = \begin{cases} P_X \cdot k, & \text{if } k \leq A_X \cdot (m_X)^\alpha \\ P_X \cdot A_X \cdot (m_X)^\alpha, & \text{if } k > A_X \cdot (m_X)^\alpha \end{cases} \quad (36)$$

By specializing in producing X , his problem is reduced to maximizing his expected revenue.

Given the price P_M and availability Q_M of the intermediate input from the market, the availability of his product is $Q_X = Q_M \cdot F_{\mu_X}(k \leq A_X \cdot (m_X)^\alpha)$, which depends on m_X . His maximization problem is,

$$\max E(\pi_X) = [P_X \cdot \int_0^{A_X \cdot (m_X)^\alpha} k \cdot \phi_{\mu_X}(k) dk + P_X \cdot A_X \cdot (m_X)^\alpha \cdot \int_{A_X \cdot (m_X)^\alpha}^{\infty} \phi_{\mu_X}(k) dk - P_M \cdot m_X] \cdot Q_M \quad (37)$$

The producer chooses an m_X to maximize expected revenue. For a given level of expected revenue, there are multiple possible combinations of P_X and m_X .

Therefore, one can find an iso-revenue curve of $E_0(\pi_X)$ in the P_X - Q_X space as the following:

Figure 18: Iso-revenue curve of the individual X -producer

For an individual M -producer, given his capacity at A_M , let k be the realized demand to his shop. His sales revenue π is,

$$\pi = \begin{cases} P_M k, & \text{if } k \leq A_M \\ A_M P_M, & \text{if } k > A_M \end{cases} \quad (38)$$

The availability of his product is $Q_M = F_{\mu_M}(k \leq A_M)$. By specializing in producing M , his problem is reduced to maximizing his expected revenue.

$$\max .E(\pi_M) = P_M \cdot \int_0^{A_M} k \cdot \phi_{\mu_M}(k) dk + P_M \cdot A_M \cdot \int_{A_M}^{\infty} \phi_{\mu_M}(k) dk \quad (39)$$

At the equilibrium of the market-coordinated production, two conditions hold. First, the expected revenue of the individual M -producers equals that of the individual X -producers. Otherwise the market-coordinated production fails as no one would specialize in the production that earns less. Second, in the absence of fixed cost and other entry barrier, the expected revenue of the

individual producers equals the opportunity cost of his labor, due to competition. Let the opportunity cost of labor be w , which is the wage that could be earned elsewhere in the economy. Figure 19 shows the equilibrium of the market-coordinated production.

Figure 19: Equilibrium of the market-coordinated production: X -product market

Figure 19 shows that, although producers prefer higher expected revenue $E'(\pi_X)$ and consumers prefer higher utility level U' , competition between producers would push the expected revenue to be equal to wage level w . In this case, the highest utility level achievable would be U^* . Therefore, the M -producer's pricing is:

$$P_M = \frac{w}{\int_0^{A_M} k \cdot \phi_{\mu_M}(k) dk + A_M \cdot \int_{A_M}^{\infty} \phi_{\mu_M}(k) dk} \quad (40)$$

with Q_M fixed at $F_{\mu_M}(k \leq A_M)$.

For the X -producer, given his choice of m_X , his pricing is:

$$P_X = \frac{\frac{w}{Q_M} + P_M \cdot m_X}{\int_0^{A_X \cdot (m_X)^\alpha} k \cdot \phi_{\mu_X}(k) dk + A_X \cdot (m_X)^\alpha \cdot \int_{A_X \cdot (m_X)^\alpha}^{\infty} \phi_{\mu_X}(k) dk} \quad (41)$$

Therefore, both P_X and Q_X can be written in terms of m_X . The equilibrium of the market-coordinated production can be solved by maximizing utility with respect to m_X .

4.2.3 Firm Production

Another way to coordinate production is to integrate the production into a firm. The firm coordination requires information processing. For instance, the information about what to produce and how much to produce needs to be processed, and signals need to be sent to each employee so as to coordinate. In this model, this is completed by paying a cost of information processing. The amount of the cost depends on the information processing ability of the firm, which is described by a parameter θ . ICT investment is assumed to improve information processing ability and gives a lower value of parameter θ .

A variety of types of firms are introduced into this model to coordinate production. A vertically integrated firm integrates both the two stages of production; a horizontally integrated firm integrates only one stage of production. A horizontally integrated firm that specializes in producing M is referred to as an M -firm, whereas a horizontally integrated firm that specializes in producing X is referred to as an X -firm.

Vertically Integrated Firm

A vertically integrated firm has the following structure:

Figure 20: The internal structure of a vertically integrated firm

As illustrated by the figure above, the firm hires labor to produce the intermediate input M and pools the output together for distribution to the next stage of production. The firm then chooses the optimal amount of intermediate input M to be used by each labor in producing the final product X . The final product X as output is again pooled together for distribution to its shops. It is assumed that no additional cost is incurred to run the shops. The firm needs to decide the optimal capacity of each shop.

Suppose that the firm hires L_M to produce the intermediate input, L_X to produce the final product, and runs i_V shops. Its objective function is:

$$\max E(\pi_{vf}) = i_V \cdot P_X \cdot \left[\int_0^{\frac{L_X \cdot A_X \cdot m_X^\alpha}{i_V}} k \cdot \phi_{\mu_X}(k) dk + \frac{L_X \cdot A_X \cdot m_X^\alpha}{i_V} \cdot \int_{\frac{L_X \cdot A_X \cdot m_X^\alpha}{i_V}}^{\infty} \phi_{\mu_X}(k) dk \right] - (L_M + L_X) \cdot w - \theta \cdot (L_M + L_X)^2 \quad (42)$$

$E(\pi_{vf})$ denotes the expected profit of the firm. Wage paid is assumed to be the same as the opportunity cost of labor. The last term of the equation accounts for the cost of information processing. It is assumed to be a quadratic form of the employment size of the firm.

The firm has iso-profit curves in the $P_X - Q_X$ space denoted by $E(\pi_{vf})$ in Figure 21, which is different from the iso-revenue curves of the individual producers denoted by $E(\pi_X)$.

Figure 21: Iso-profit curve of the vertically integrated firm

Therefore, as shown in Figure 21, taking the utility level of the consumers as given from the equilibrium of market-coordinated production, the firm can choose a different combination of P_X and Q_X to maximize its expected profit. In this figure, it is the tangent point B of $E(\pi_{vf})$ and U^* . Therefore, the firm maximizes its expected profit with respect to L_M , L_X , m_X , and i_V .

Horizontally Integrated M -firm

A horizontally integrated M -firm has the following internal structure:

Figure 22: The internal structure of a horizontally integrated M -firm

The firm hires labor to specialize in producing the intermediate input M , and pools the output for distribution to its shops. Suppose that the firm hires L_M to produce the intermediate input, and runs i_M shops. Its objective function is:

$$\max .E(\pi_{mf}) = i_M \cdot P_M \cdot \left[\int_0^{\frac{A_M \cdot L_M}{i_M}} k \cdot \phi_{\mu_M}(k) dk + \frac{A_M \cdot L_M}{i_M} \cdot \int_{\frac{A_M \cdot L_M}{i_M}}^{\infty} \phi_{\mu_M}(k) dk \right] - L_M \cdot w - \theta \cdot L_M^2 \quad (43)$$

The task for the horizontal M -firm is to maximize the expected profit while making the individual X -producers, who are the customers, indifferent. It has iso-profit curves in the P_M - Q_M space. The X -producers, with other conditions given, would also have iso-revenue curves in the space. This is shown in Figure 22.

Figure 23: Iso-profit curve of the horizontally integrated M -firm

Point A in Figure 23 is the original equilibrium of the market-coordinated production, in which the individual M -producers with capacity fixed at A_M level are supplying intermediate input M . The horizontally integrated M -firm, with the constraint on the capacity of each shop removed, is free to choose any other combinations of P_M and Q_M to supply. Therefore, the tangent point B of the iso-profit curve $E^*(\pi_{mf})$ of the firm and the iso-revenue curve $E^*(\pi_x) = w$ of the individual X -producer is optimal choice.

However, the shape of the iso-revenue curve of the individual X -producer depends on the combination of P_x and Q_x determined as the equilibrium in the final product market. Therefore, an additional condition is imposed on the horizontally integrated M -firm. Namely, the utility derived from the P_M and Q_M offered by the firm should be higher than or equal to the utility available in the equilibrium of market-coordinated production. Under these constraints, the firm maximizes its expected profit with respect to L_M and i_M .

Horizontally Integrated X -firm

A horizontally integrated X -firm has the following internal structure:

Figure 24: The internal structure of a horizontally integrated X -firm

The firm purchases intermediate input M from the market, hires labor to specialize in producing the final product X , and pools the output for distribution to its shops in the final product market. Suppose that the firm hires L_X to produce the intermediate input, and runs i_X shops. Its objective function is:

$$\begin{aligned} \max . E(\pi_{xf}) = & [i_X \cdot P_X \cdot \left(\int_0^{i_X} k \cdot \phi_{\mu_X}(k) dk + \frac{L_X \cdot A_X \cdot m_X^\alpha}{i_X} \cdot \int_{\frac{L_X \cdot A_X \cdot m_X^\alpha}{i_X}}^{\infty} \phi_{\mu_X}(k) dk \right) - P_M \cdot L_X \cdot m_X] \cdot Q_M \\ & - L_X \cdot w - \theta \cdot L_X^2 \end{aligned} \quad (44)$$

The horizontally integrated X -firm has the advantage of choosing the optimal capacity at each shop. As shown in Figure 25, it has iso-profit curve $E^*(\pi_{xf})$ in the $P_X - Q_X$ space different from the iso-revenue curve $E^*(\pi_X) = w$ of the individual X -producer under market-coordinated production.

Figure 25: Iso-profit curve of the horizontally integrated X-firm

It maximizes its expected profit by choosing the iso-profit curve $E^*(\pi_{xf})$ which is tangent at point B with the indifference curve U^* of consumers given by the equilibrium of market-coordinated production. Therefore, it chooses the corresponding optimal L_X and i_X .

4.3 Numerical Solutions

Due to the complexity in the utility function and the distribution function in this model, explicit solutions are not available for the decision variables of the various types of producers. However, numerical solutions can still be obtained.

To do so, a few parameters are predefined with specific values. Let $\rho = 0.5$, $\alpha = 0.5$, $w = I = 100$, $A_M = 50$, $A_X = 10$, and $\mu_M = 50$. The model is solved with different μ_X and different θ values. μ_X describes the structure of the final product market. θ describes information processing ability, which is determined by ICT. The purpose is to investigate how the two determine the coordination of production and profitability of firms.

The equilibrium of market-coordinated production is as shown in Table 3.

Table 3: Equilibrium of market-coordinated production with various structure of the final product market

μ_X	P_M	Q_M	m_X	P_X	Q_X	U^*
10	2.0161	0.5	2	20.4	0.5000	10.1218
20	2.0161	0.5	5	10.5	0.4954	10.2331
30	2.0161	0.5	11	7.4	0.4996	10.3318
40	2.0161	0.5	18	5.9	0.4962	10.4115
50	2.0161	0.5	28	5.1	0.4991	10.4753
60	2.0161	0.5	39	4.6	0.4964	10.5209
70	2.0161	0.5	53	4.4	0.4987	10.5535
80	2.0161	0.5	68	4.2	0.4965	10.5728
90	2.0161	0.5	86	4.1	0.4984	10.5837
100	2.0161	0.5	106	4.1	0.4992	10.5862
110	2.0161	0.5	127	4.1	0.4982	10.5838
120	2.0161	0.5	151	4.2	0.4990	10.5769
130	2.0161	0.5	176	4.3	0.4981	10.5674
140	2.0161	0.5	204	4.4	0.4988	10.5558
150	2.0161	0.5	233	4.5	0.4979	10.5429

It is worth of noting that as μ_X increases, which means the market expands for the X -producers, prices of the final product first decreases, and then increases. Accordingly, utility of the consumer first increases, but then decreases. The threshold is around $\mu_X = 100$. This is because in an expanding market with demand uncertainty, on the one hand, the cost of production could be shared by more consumers; on the other hand, the marginal product of the intermediate input for individual X -producers decreases, which raises the cost of production. When the market is relatively small, the former effect dominates, therefore the price would fall. When the market is relatively large, the latter effect dominates, therefore the price would increase.

Next we consider various types of firm production with $\theta = 1$. Table 4 describes the behavior of the vertically integrated firm.

Table 4: The vertically integrated firm under various structure of the final product market

μ_x	P_x	Q_x	i_v	$E^*(\pi_{vf})$
10	36.558	0.97	1499	2.49E+05
20	20.118	0.99	436	7.42E+04
30	14.383	1	203	3.46E+04
40	11.618	1	120	2.08E+04
50	10.059	1	81	1.44E+04
60	9.175	1	60	1.13E+04
70	8.630	1	48	9.53E+03
80	8.337	1	40	8.69E+03
90	8.179	1	35	8.27E+03
100	8.144	1	31	8.22E+03
110	8.178	1	29	8.38E+03
120	8.277	1	27	8.75E+03
130	8.417	1	26	9.25E+03
140	8.594	1	25	9.89E+03
150	8.8	1	24	1.06E+04

It is observed that as the final product market expands, the expected profit of the firm first declines, and then rises after the threshold of $\mu_x = 100$. Before the threshold, according to Table 3, the productivity of individual X -producer under market-coordinated production increases with μ_x . Therefore, the relative advantage of the firm production weakens and the profitability decreases. After the threshold, the firm production gains increasing advantage due to the declining marginal product of intermediate input to individual X -producer under market-coordinated production.

Table 5 describes the behavior of the horizontally integrated M -firm.

Table 5: The horizontally integrated M -firm under various structure of the final product market

μ_X	P_M	Q_M	P_X	Q_X	i_M	U^{**}	$E^*(\pi_{mf})$
10	154	1	40.8	1	3467	10.1218	1.32E+07
20	64	1	21.0032	0.9909	1413	10.2332	2.19E+06
30	32	1	14.0103	0.9477	683	10.3327	5.10E+05
40	20	0.98	11.5517	0.9725	416	10.4124	1.86E+05
50	14	0.97	9.6237	0.9458	278	10.4799	8.29E+04
60	11	0.96	8.8865	0.9531	209	10.5226	4.67E+04
70	9	0.95	8.1902	0.9335	163	10.5545	2.83E+04
80	8	0.97	8.0889	0.9633	138	10.5787	2.05E+04
90	7	0.95	7.8586	0.947	116	10.5854	1.43E+04
100	6	0.91	7.3991	0.9038	94	10.5932	9.23E+03
110	6	0.96	7.8743	0.9566	92	10.59	9.05E+03
120	6	1	8.3335	0.9933	89	10.5792	8.71E+03
130	5	0.9	7.624	0.8965	70	10.5716	5.17E+03
140	5	0.93	8.0182	0.9239	70	10.5604	5.11E+03
150	5	0.95	8.4685	0.9461	69	10.5438	5.06E+03

In this case, there are two interesting observations. First, with the horizontally integrated M -firm production, consumer utility is higher than in the case of a vertically integrated firm. This is because the way that the horizontally integrated M -firm maximizes its profit, as shown in Figure 23. Second, as the final product market expands, the expected profit and the size of the firm constantly decrease.

Table 6 describes the behavior of the horizontally integrated X -firm, if it purchases intermediate input from the individual M -producers in the intermediate input market.

Table 6: The horizontally integrated X -firm with intermediate input purchased from individual M -producers

μ_X	P_X	Q_X	i_X	$E^*(\pi_{xf})$
10	18.468	0.49	23546	5.07E+05
20	10.161	0.5	2205	4.53E+04
30	7.192	0.5	470	8.16E+03
40	5.809	0.5	145	1.99E+03
50	5.03	0.5	51	498.5416
60	4.588	0.5	19	120.4979
70	4.315	0.5	6	19.7709
80	4.169	0.5	1	1.2923
90	NA	NA	0	0
100	NA	NA	0	0
110	NA	NA	0	0
120	4.139	0.5	1	1.7401
130	4.209	0.5	3	9.928
140	4.297	0.5	4	31.1754
150	4.4	0.5	6	70.489

For this type of firm, as the final product market expands, like the vertically integrated firm, its expected profit and firm size decrease first and then increase. However, the firm cannot exist under certain structure of the final product market.

Table 7 describes the behavior of the horizontally integrated X -firm, if it purchases intermediate input from the horizontally integrated M -firms in the intermediate input market.

Table 7: The horizontally integrated X -firm with intermediate input purchased from horizontally integrated M -firms

μ_X	P_X	Q_X	i_X	$E^*(\pi_{xf})$
10	36.558	0.97	24	794.5868
20	20.118	0.99	10	222.305
30	14.383	1	12	378.275
40	11.386	0.98	13	437.0515
50	9.758	0.97	16	640.241
60	8.808	0.96	18	808.487
70	8.199	0.95	20	1.10E+03
80	8.087	0.97	26	1.90E+03
90	7.771	0.95	28	2.24E+03
100	7.411	0.91	29	2.45E+03
110	7.851	0.96	39	4.66E+03
120	8.277	1	48	7.63E+03
130	7.575	0.9	42	5.58E+03
140	7.993	0.93	52	8.79E+03
150	8.360	0.95	60	1.23E+04

As is observed from the table, the behavior of this type of firm is very different.

As the final product market expands, its expected profit and firm size decrease first, but then immediately turn to increase, at $\mu_X = 20$.

The above observations raise a natural question: which type of firm coordination will dominate under different structure of the final product market?

Figure 26 reveals the answer to this question.

Figure 26: A comparison of the expected profit of different types of firms ($\theta = 1$)

In this figure, horizontal X -firm type 1 stands for the horizontally integrated firm purchasing intermediate input from individual M -producers. Horizontal X -firm type 2 stands for the horizontally integrated firm purchasing intermediate input from horizontally integrated M -firms.

The following can be observed from Figure 26. First, when μ_x is smaller than 120, the expected profit of a horizontally integrated M -firm is always higher than that of a vertically integrated firm. It would have no incentive to invade into the downstream of the industrial value chain to become vertically integrated firm. When μ_x becomes greater than 120, there is the incentive. Second, when μ_x is smaller than 140, the expected profit of a horizontally integrated X -firm type 2 is lower than a vertically integrated firm. It would always have the incentive to invade into the upstream of the industrial value chain to become vertically integrated firm. Third, when μ_x is smaller than 50, a

horizontally integrated X -firm would be better off by purchasing intermediate input from individual M -producers.

These observations mean that, given that a firm has information processing ability as described by $\theta = 1$, when μ_x is smaller than 120, it would choose to be horizontally integrated M -firm; when μ_x is between 120 and 140, it would choose to be vertically integrated firm; when μ_x is greater than 140, it would choose to be horizontally integrated X -firm, if intermediate input is available from other horizontally integrated M -firms.

Then we would like to see if ICT, by lowering the value of θ , would give any impact on the choice of coordination of production. For this purpose, we simulated two additional scenarios to determine the impact of decreasing θ . We choose the two scenarios as $\theta = 0.5$ and $\theta = 0.1$ respectively.

It turns out that for all three types horizontally integrated firms, as θ decreases to its original $y\%$, it increases both expected profit and firm size by $\frac{1}{y\%}$ times, regardless of the structure of the final product market. However, this is not true in the case of vertically integrated firm, as shown in Figure 27.

Figure 27: The impact of θ on the expected profit of the vertically integrated firm

It is observed that as μ_x increases, a decreasing θ has accelerated expansionary effect over the expected profit of the vertically integrated firm. Moreover, this acceleration effect happens at the threshold of $\mu_x = 100$, when the declining expected profit starts to rise again. Combining the observation from Figure 26, this means that if θ further decreases to a certain point, vertically integrated firm production is the choice for firm coordination of production when $\mu_x \geq 100$.

Therefore, the results of this model are consistent with those of chapter 3, which claimed that the impact of θ over firm performance is conditional on the structure of the markets. Moreover, this model further reveals that θ has impacts on the choice of firm coordination of production, also conditional on the structure of markets. The implication is that, by improving information processing ability, ICT has impacts on the choice of firm coordination of production.

4.4 Conclusions

This chapter serves two purposes. One is to verify the theoretical findings in chapter 3 in more general settings. The other is to look for the impact of ICT on the choice of firm coordination of production.

An industry with two stages of production is assumed to exist in an economy with many other industries. In this industry, there is one intermediate input M and one final product X . There exogenously exists demand uncertainty in the markets of both products. For this reason, availability of the product becomes an important feature of the product. These assumptions basically describe an unlimited market with observed demand uncertainty, which producers face. Such markets are cleared not only by prices, but also by availability in this model. If the two-stage production is completed by individual producers hiring themselves to produce and running their shops to sell, it is called a market-coordinated production. If the production is conducted by a firm which has an internal structure to coordinate the labor hired and specialized in the production of the two products, it is called firm coordination of production. For the firm to run such an internal structure to coordinate, information processing ability is required. This is modelled as paying the cost of information processing. In this model, a firm could either be a horizontally integrated firm to produce one of the two products or be a vertically integrated firm to produce both of them and sell the final product.

Numerical solutions shows that the profitability of a firm with information processing ability, which is described by parameter θ , is conditional on the

structure of the markets. The structure of the markets are described by μ_x and μ_M , which are the parameters of the distribution of uncertain demand. The better the information processing ability, the lower the value of θ is. ICT is assumed to improve information processing ability and contribute to lower value of θ . It is shown that for all types of firm production, lower value of θ leads to higher profitability, as long as market-coordinated production still exists elsewhere in the markets.

More interestingly, the numerical results of the model shows that the structure of the markets determines the choice of firm production among different available types, with a given value of θ . When θ decreases, the growth of expected profit and firm size of a vertically integrated firm accelerates. Therefore, the improving information processing ability due to ICT does change the internal structure of firms, and meanwhile changes the choice of firm coordination, conditional on the structure of markets.

Chapter 5

Industrial Clustering and the Information and Communication

Technology – the Tacit Knowledge Hypothesis

This chapter contributes additional detail to how Information and Communication Technology (ICT) facilitates decision making, by raising the importance of tacit knowledge. This effect is included in arrow (e) of Figure 2. This hypothesized effect motivates industrial clustering, and changes the market structure (Quah, 2003) (arrow (j) and arrow (m) of Figure 2). Eventually, the knowledge spill-over in industrial clusters, together with other benefits of clustering, promote productivity in the cluster.

5.1 Introduction

Economists have a long history of studying geographical concentration of industries: industrial agglomeration and industrial cluster. Theories that use the term “industrial agglomeration” refer to the geographical concentration of firms of the same industry. More recently, as Porter (1998) argues, geographical concentration is more often about the clustering of interconnected companies from various industries. Therefore, it is referred to as “industrial cluster”.

Our study contributes to the understanding of the role of ICT in industrial clustering. In this study, empirical evidence is provided to the hypothesis that ICT promotes industrial clustering, by raising the importance of tacit knowledge in forging competitive advantages of firms. Since the role of ICT to be discussed focuses on knowledge, we begin with a literature review on the issue. The idea that knowledge is a key factor in the phenomenon of

geographical concentration of industries can be traced back to theories of industrial agglomeration.

Industrial Agglomeration and Knowledge Spill-over

As summarized in the literature (Glaeser et al., 1992; Falck and Heblich, 2007), Alfred Marshall introduced the concept of industrial districts. He found that industries agglomerate around specific locations to take the advantage of three types of external economies of scale: (1) economies resulting from access to a common labor market and shared public goods; (2) economies from saved transportation and transaction costs; and (3) economies resulting from knowledge spill-over within the industry, which is mainly due to the geographical proximity.

The MAR (Marshall-Arrow-Romer) externality refers to the third type of external economies of scale of industrial agglomeration mentioned above. It concerns knowledge spill-over between firms in the agglomerated industry. Such externality is considered by neoclassical endogenous growth models as the major “engine of growth” (Romer, 1986).

Industrial Clustering and Knowledge Spill-over

Porter (1998) defines clusters as the “geographic concentrations of interconnected companies; specialized suppliers; service providers; firms in related industries, and associated institutions (for example, universities, standard agencies, and trade associations) in particular fields that compete but also cooperate.” Like in the MAR externality argument, Porter (1998) argues

that knowledge spill-over in relatively specialized and geographically concentrated industrial clusters stimulates growth.

Porter distinguishes the factors which drive industrial clustering as key factors and non-key factors. Key factors, or specialized factors, in production are created in a dynamic process. The key factors include skilled labor, infrastructure, and capital. Location factors such as raw material and unskilled labor are seen as non-key and inherited. Once a cluster forms because of these factors, especially the key factors, it influences competitiveness in the following ways: (1) it improves the productivity of the firms within the cluster, thereby leading to process innovation; (2) it drives innovation within the cluster, thus fostering the product cycles of the industry; and (3) it stimulates new businesses, which foster the product lifecycle and probably further promote new industry lifecycle. Knowledge spill-over is cleared embedded with (2) and (3).

Jacobs (1969) emphasizes that the most important knowledge transfers come from the outside of the core industry. It is the variety and diversity of geographically proximate industries rather than geographical specialization that promotes innovation and growth. The idea is that the crucial externality in clusters (cities) is the cross fertilization of ideas across different lines of work. Accordingly, knowledge spill-over effect is greater in industrial cluster than in industrial agglomeration.

The “skill-biased technological change” is an additional reason that knowledge spill-over motivates geographical concentration. It creates immense demand on skilled labor and hence knowledge. However, knowledge in the form of human capital – also referred to as tacit knowledge – is relatively immobile. The tacit

knowledge is sticky knowledge, which constantly circulates and accumulates within a geographically concentrated community's social network by face-to-face communication and informal meetings (Stanley and Helper, 2003).

A few other theories specify the details of the pattern that knowledge spill-over affects geographical concentration. Stanley and Helper (2003) summarize the empirical studies and find that the relative importance of the above mentioned factors for industrial clustering, including knowledge spill-over, varies across different industries and time periods. For example, according to Duranton and Puga (2002), clustering near sources of technical knowledge is likely to be particularly important in young or "infant" industries, where cutting edge information is not yet widely known and face-to-face interaction is necessary for learning. When the industry is more mature and critical early innovations have spread, firms may relocate to optimise transportation costs and save on wages.

Therefore, knowledge spill-over is a major motivation for industrial clustering. Next, we find out how ICT contributes to it.

The Effects of ICT on Geographical Concentration

There is no controversy on that ICT facilitates outsourcing and offshoring, by lowering the cost of communication and information processing. Therefore, it has negative effects over industrial clustering. However, it may not necessarily be the dominant force.

Quah (2003) hypothesizes another mechanism that ICT affects industrial clustering. To begin with, ICT brings down the cost of codifying, processing, storing, as well as transmitting information and knowledge. The knowledge that cannot be codified is referred to as tacit knowledge. Since codifiable information and knowledge, except for tacit knowledge, could be cheaply available due to ICT, competitive advantages cannot be built on them, but rather on tacit knowledge. The spill-over of tacit knowledge require physical proximity and fact-to-face interaction among skilled labor. Meanwhile, tacit knowledge embeds on human capital, which is relatively immobile. Hence, firms are motivated to concentrate geographically so as to take the advantage of proximity to acquire tacit knowledge. In the following, this is referred to as “the tacit knowledge hypothesis”.

Malmberg and Maskell (1997) and Antonelli (1998) provide more detail on Quah’s (2003) argument. It is argued that the process of problem-solving of a firm requires both tacit knowledge and codified knowledge. When codified knowledge becomes easily available, the importance of tacit knowledge increases as complementary good. Besides internal knowledge resources, firms seek for external sources of knowledge to build their competitive advantages. Since there is market failure for the exchange of knowledge, firms form social networks to conduct barter trade in knowledge. Specially, in the case of tacit knowledge, firms need not only social networks but also geographical proximity. Therefore, the increasing importance of tacit knowledge encourages industrial clustering.

Empirical Evidence from Literature

Glaeser et al. (1992) provide evidence that intra-industry knowledge spill-over is less important for growth than spill-over across industries, particularly in fairly mature cities. Stanley and Helper (2003) find that firms that are located in the industrial clusters are more productive and also lose less work to foreign competitors from lower-wage regions. It is also found that firms that report learning valuable ideas (tacit knowledge) from informal contacts with other firms are more productive. However, this communication is just as likely to be with faraway firms as with nearby firms. Otto et al. (2005), using Netherlands' data, find that, spatially, high ICT growth co-locates with high labor productivity and the effect of ICT is more than capital deepening.

Unfortunately, there is no evidence in literature to show the direct linkage between tacit knowledge, ICT, and industrial clustering. In fact, if tacit knowledge hypothesis is true, the above stories would become a consistent one: ICT promotes the importance of tacit knowledge, therefore motivating clustering; Clustering delivers competitive advantages, therefore higher productivity to the firms in the cluster; Therefore, ICT co-locates with higher productivity.

Motivations of This Study

The current study investigates the pattern that ICT impacts on industrial clustering in the United States. On the one hand, one can predict that ICT contributes negatively to industrial clustering, since ICT provides high capacity communication channels to distant customers, suppliers, and partners. On the

other hand, as argued by Malmberg and Maskell (1997), Antonelli (1998) and Quah (2003), one predicts that the effect of ICT on tacit knowledge contributes positively to industrial clustering. Whether the impact of ICT over industrial clustering is positive or negative depends on which effect is dominating. A significantly positive contribution from ICT to industrial clustering would support the tacit knowledge hypothesis.

To do this, we first identify the pattern of industry clusters in the economy by using the Input-Output tables of the United States and applying the factor analysis method proposed by Feser and Bergman (2000). Then we match the detailed employment data of industries at each county, which is provided in the County Business Pattern dataset, to the pattern identified. Glaeser et al. (1992) propose using employment data as a measure of industrial clustering of a certain region. Our study goes further to build a measure of industrial clustering at the economy level. We also apply the pattern to ICT capital stock data from the EUKLEMS database, so as to obtain the measure of ICT capital stock of each cluster. Regression analysis is then applied to find out the impacts of ICT capital stock of the cluster over the measure of industrial clustering.

The results show that the hypothesized tacit knowledge effect is significant after a structural change in the economy towards the “knowledge economy”, which involves more knowledge intensive production and services. Moreover, whether or not such is at work also depends the nature of the cluster, namely whether the cluster is a traditional manufacturing cluster, a service cluster, or a high-tech manufacturing cluster.

For the rest of the chapter, section two describes our data and the methods of constructing measures. Section three reports our regression models and their results. Section four concludes.

5.2 Data Analysis

The Pattern of Industrial Clusters

The 1997 U.S. “use table” of the Input-Output tables contains 484 six-digit level industries, of which 483 industries have non-trivial data. The 2002 U.S. use table of the Input-Output tables contains 418 six-digit industries, of which 416 industries have non-trivial data. The use table provides information on the purchases and sales of intermediate inputs – in terms of both products and services – among all industries. The information reveals the linkage of industries and therefore enables us to identify different industrial clusters.

Following the methodology of Feser and Bergman (2000), for each entry in the commodity-industry matrix, we calculate a purchase share in total purchase of

the industry as $\frac{x_{ij}}{p_j}$, and a sales share in total sales of the commodity as $\frac{y_{ij}}{s_i}$.

x_{ij} indicates industry j’s purchase of intermediate input i in industry j’s total purchase p_j . y_{ij} indicates industry i’s sales of intermediate input i to industry j in industry i’s total sales s_i . The computation gives two matrices: a purchase share matrix X and a sales share matrix Y.

For each column of X and Y, four pairs of correlation coefficients can be calculated. They are $r(x_i, x_j)$, $r(y_i, y_j)$, $r(x_i, y_j)$, and $r(y_i, x_j)$. For each pair

of industry, pick up the largest one of the four correlation coefficients and we have an $N \times N$ matrix, where N is the number of industries in the use table with non-trivial entries. Each column of this matrix describes the pattern of relative linkage between the column industry and all other industries.

A principal components factor analysis with varimax rotation on this matrix identifies the latent factors with eigenvalues greater than one. Each factor represents an industrial cluster. In the 1997 case, we have 41 clusters identified. In the 2002 case, we have 35 clusters identified. According to the matrix of factor loadings, primary industries (group of industries with factor loadings greater than or equal to 1) and secondary industries (group of industries with factor loadings smaller than 1 and greater than 0.8) that consist the clusters can be identified. The results are presented as Appendix C.

According to the tables in Appendix C, considerable structural changes have taken place in the U.S. economy. Specifically, iron and steel related products manufacturing was the most important industrial cluster in 1997, while in 2002 it became number three. Due to technological advancement, internal links among industries also changed significantly. Information and communication technology (ICT) products and aerospace product and parts manufacturing used to be two separated clusters in 1997: factor 4 and factor 35 respectively. In 2002, they became one cluster and appeared as the most important industrial cluster in the U.S. economy. Meanwhile, professional services, health care and other personal services firmly remain as the second cluster in both 1997 and 2002.

It is also worth of noting that the NAICS industrial classification systems behind the two use tables are different. The purpose of such revision, according

to BEA, is due to the structural changes that happened in the U.S. economy. Therefore, systematic difference in the two industrial clustering patterns is expected.

The clusters are categorized into three broad sectors: manufacturing, services, and high-tech manufacturing. The categorization facilitates us to visualize that the U.S. economy has undergone significant structural changes, moving towards knowledge-intensive production and services. Grosben and Potter (2003) and Mann and Kirkegaard (2006) also confirm that the U.S. economy had experienced structural changes after 2001.

Accordingly, the dataset is divided into two periods: 1998 - 2002 which applies the 1997 pattern, and 2003 - 2006 which applies the 2002 pattern.

A Measure of Industrial Clustering

The U.S. County Business Pattern (CBP) is the data of industrial activities at county level. It records the employment, number of establishments, and so on, of each six-digit level industry in the county. From 1998 onwards, CBP datasets are based on the NAICS industrial classification systems. From 1998 to 2002, it applies NAICS 1997; from 2003 to 2006, it applies NAICS 2002. The datasets include 51 states/district of the U.S.

Following Glaeser et al. (1992), we use employment data from CBP to measure the geographical concentration of industries. To build a measure of industrial clustering at economy level: First, we match industries of the county into different clusters. Second, employment of the industries in one cluster are summed together to get the total employment of the cluster in each state. Third,

for each cluster, we identify the largest ten states in terms of the employment of the cluster in the state, an employment share over total employment of the cluster is calculated for each of the ten states. Fourth, an HHI index is calculated as the measure of industrial clustering, using these shares.

It is interesting to note that our analysis on CBP data also reflects structural change in the U.S. economy. Using the data generated in the first step mentioned above, we can identify the first three most important clusters existing in each county, in terms of its employment share in the total employment of the county. Applying the categorization of clusters in Table 11 and Table 12, we can count the frequency that the clusters of the three sectors show up in our sample. Table 8 summarizes the data.

Table 8: Sub-groups of the CBP data

Period/Group	Manufacture	Service	High-tech
1998-2002	37.78%	57.52%	4.71%
2003-2006	18.30%	52.37%	28.69%

According to Table 8, the majority of the clusters are service clusters, in both periods. The portion of manufacturing clusters shrinks as we move from 1998-2002 dataset to 2003-2006 dataset, while the portion of high-tech manufacturing clusters rises. The structural change as mentioned earlier is also reflected in CBP dataset.

A Measure of ICT Capital Stock

For each cluster, we estimate its ICT capital stock. ICT capital stock data at industry level is obtained from the EU-KLEMS database. A weighted summation scheme is used, as usually found in growth accounting practices:

$$K_j = \sum \alpha_{ij} \times K_{ij}$$

where value-added of the industry i as a share in the total value-added of the cluster j is used as the weight:

$$\alpha_{ij} = \frac{VA_i}{\sum VA_j}$$

As the EU-KLEMS database provides data up to year 2005, we test the hypothesis that there is a one-year lag in the impact of ICT investment (Basu and Fernald, 2006). Therefore, the data is divided into two groups: 1997-2001 and 2002-2005.

Figure 28 and Figure 29 provides brief descriptions of the data.

Figure 28: Growth of ICT capital stock 1997-2001

Figure 29: Growth of ICT capital stock 2002-2005

It is observed that ICT investment of the service clusters are among the highest. ICT investment of the traditional manufacturing clusters such as wood processing, textile, apparel, leather, and agriculture are the lowest. This is true for both periods.

Other Control Variables

Meanwhile, there are many other possible factors which drive clustering, for example, specialized talents, natural resources, infrastructure, transportation, special technology used by the cluster, and scale of product market. To capture these effects, besides introducing fixed effect model, we also introduce three other control variables. They are mgdp, mroad, and nonict. mgdp is a measure for the concentration of real GDP in relevant states. mroad is a measure for the concentration of transportation. nonict is a measure for the non-ICT investment of the cluster.

The estimation of mgdp and mroad is similar to the estimation of industrial clustering. For the states indentified with the highest share of employment in the cluster, its share of real GDP in the economy and share of road miles in the nation are calculated. An HHI index is then calculated using the data. The estimation of nonict is similar to the estimation of ICT capital stock.

5.3 Regression Model and Results

It is hypothesized that ICT, by increasing availability and bringing cheaper transmission of codifiable information and knowledge, makes tacit knowledge more important and more valuable. Tacit knowledge has two important features: One is that it is usually attached to either human capital or organizational capital; the other is that it is either too expensive or against the interest of the holder to codify and spread the knowledge, even with the help of ICT. Industrial clustering facilitates the spill-over of tacit knowledge in many ways. Most importantly, it forms a local network of firms which facilitates the creation and exchange of tacit knowledge, via face-to-face interaction (Malmberg and Maskell, 1997; Antonelli, 1998; Stanley and Helper, 2003). Therefore, the increasing importance of tacit knowledge due to ICT motivates the clustering of certain industries, despite that the advancing ICT facilitates outsourcing by lowering the costs of communication (Quah, 2003).

To verify if the hypothesized impact of ICT is dominating the other effects, the following regression model is applied:

$$\text{cluster}_{jt} = C + \beta_1 \cdot \text{ict}_{jt} + \beta_2 \cdot \text{mgdp}_{jt} + \beta_3 \cdot \text{mroad}_{jt} + \beta_4 \cdot \text{nonict}_{jt} + i \cdot \alpha_i + \varepsilon_{jt}$$

Hausman tests for the fitness of random effect model consistently reject the null hypothesis, indicating that there is correlation between regional effect and the explanatory variables. Therefore, fixed-effect model applies. Additionally, to deal with potential heteroskedasticity problem, general least square (GLS) method is applied.

Table 9 presents regression results for all clusters in the two periods.

Table 9: Regression results for all clusters in both periods

MODEL	(1)		(2)		(3)	
PERIOD	1998- 2002	2003- 2006	1998- 2002	2003- 2006	1998-2002	2003- 2006
ICT (t-statistics)	-8.48E- 09* (-1.72)	5.43E- 08** (3.59)	-9.87E- 09* (-1.89)	4.04E- 08** (2.48)	-1.97E- 08** (-3.65)	4.22E- 08** (2.46)
MGDP (t-statistics)	-	-	0.018 (0.29)	0.32** (3.48)	-0.01 (-0.25)	0.33** (3.47)
MROAD (t-statistics)	-	-	-0.09 (-0.92)	1.12** (2.84)	-0.06 (-0.62)	1.11** (2.83)
NONICT (t-statistics)	-	-	-	-	3.59E- 08** (2.75)	4.33E-09 (0.15)
C	0.05	0.05	0.05	0.03	0.05	0.02
FIXED EFFECT	YES	YES	YES	YES	YES	YES
GLS	YES	YES	YES	YES	YES	YES
D-W STAT	2.15	2.20	2.10	2.08	2.16	2.12
R-SQUARED	0.99	0.99	0.99	0.99	0.99	0.99

Table 10 presents regression results for the three sectors in the two periods.

Table 10: Regression results for clusters by sector in both periods

SECTOR PERIOD	MANUFACTURING		SERVICES		HIGH-TECH	
	1998-2002	2003-2006	1998- 2002	2003-2006	1998- 2002	2003- 2006
ICT (t-statistics)	-1.48E-07** (-2.18)	-1.37E-07 (-0.70)	-1.08E-08 (-0.92)	1.04E-07** (4.32)	-3.03E-08** (-2.24)	-1.56E-08 (-0.05)
MGDP (t-statistics)	0.18* (1.97)	0.30** (2.71)	0.15 (0.40)	-0.95 (-1.45)	-0.21 (-0.90)	-1.09* (-1.83)
MROAD (t-statistics)	-0.21 (-1.54)	0.79 (1.48)	0.003 (0.004)	12.85** (4.32)	0.14 (0.42)	8.82** (3.09)
NONICT (t-statistics)	2.69E-08 (0.47)	-9.10E-08** (-2.08)	1.98E-09 (1.30)	-1.63E-07** (-2.17)	-5.66E-08 (-0.76)	3.94E-06** (4.22)
C	0.05	0.03	0.04	-0.08	0.06	-0.09
FIXED EFFECT	YES	YES	YES	YES	YES	YES
GLS	YES	YES	YES	YES	YES	YES
D-W STAT	2.04	2.19	2.56	1.89	1.87	2.42
R-SQUARED	0.99	0.99	0.99	0.98	0.99	0.99

In Table 9, the coefficient of ICT capital stock is significantly negative in the period of 1998-2002. However, the coefficient of this variable is significantly positive in the period of 2003-2006. These results are robust in all three model specifications in the table.

In Table 10, the coefficients of ICT capital stock in the period of 1998-2002 are negative for all three sectors, although they are significant only for the manufacturing sector and the high-tech sector. On the contrary, in the period of 2003-2006, the coefficients for manufacturing and high-tech, which are significantly negative in the previous period, are now insignificant; and the coefficient for services which is insignificant in the previous period now becomes significantly positive.

Therefore, we have observed a shift in pattern. In the first period, a significantly negative impact of ICT over clustering means the effect that ICT facilitates distant connection with customers, suppliers, and partners is dominating. In the second period, a significantly positive impact of ICT over clustering means that the tacit knowledge hypothesis is at work and dominates. Meanwhile, evidence shows that the U.S. economy has undergone structural change in the two periods towards knowledge-intensive production and services. Therefore, it is argued that the tacit knowledge hypothesis is true and ICT does facilitate industrial clustering when knowledge economy dominates. Moreover, the tacit knowledge hypothesis is especially true for the services sector.

The data we have in hand can also reveal some dynamics of clustering and ICT investment within a cluster, and we can take a further look at the differences between different services clusters. The data of two typical service clusters are represented in Figure 30 and Figure 31.

Figure 30: Clustering and ICT investment of the professional services cluster

Figure 31: Clustering and ICT investment of the financial cluster

It is observed that for the professional services cluster, clustering and ICT investment are increasing both before and after the structural change of the economy, although interrupted by the burst of IT bubble around 2000-2001. The correlation of clustering and ICT investment is as high as 0.87. However, the financial cluster looks quite different: clustering was decreasing before the structural change of the economy, and after that increasing steeply. The correlation between the two variables is therefore only 0.48 across the two periods. Such observations imply that future studies on the dynamics of the two variables in a specific service cluster and the reasons for the differences between clusters would be very interesting topics.

5.4 Conclusions

This study tests the hypothesis that ICT investment increases the importance of tacit knowledge, and therefore promotes industrial clustering, using U.S. data.

To do that, a national pattern of industrial clusters is obtained based on factor analysis of the U.S. input-output table. Based on that information, clusters in each county and each state are identified, using the County Business Pattern data. An HHI index is generated using the data of employment share of the cluster of the state.

The data of ICT capital stock of each cluster is estimated using the EU-KLEMS database. Additionally, three other control variables are introduced to control effects from other factors which contribute to clustering. They are non-ICT capital stock, concentration of GDP, and concentration of transportation.

During the process of data analysis, we observe evidence which implies that the structure of the U.S. economy has changed significantly from the period of 1998-2002 to the period of 2003-2006. Skill-based services, together with high-tech manufacturing are becoming dominant industrial clusters in the U.S. economy, indicating a structural change of the economy towards knowledge-intensive production and services.

Our regression results show that it is exactly after the structural change in the U.S. economy that the hypothesized positive impact of ICT over clustering became dominant. It is therefore reasonable to argue, based on these facts and observations, that the tacit knowledge hypothesis is conditional on the structural change of the economy towards more knowledge-intensive production and services. The regressions by sector further show that the hypothesis is also conditional on the nature of cluster, namely whether it is a manufacturing cluster, a service cluster, or a high-tech sector. For the services sector, the tacit knowledge hypothesis is especially true.

Our results are not surprising. A greater portion of knowledge-intensive production and services in the economy would certainly impose greater emphasis on proper and timely acquisition of tacit knowledge, as complementary input to codifiable information and knowledge, to create competitive advantages for firms (Malmberg and Maskell, 1997; Antonelli, 1998; Huang et al., 1999). If ICT augments the supply of codifiable information and knowledge, more complementary tacit knowledge is required.

Last but not least, three arguments from literature provide implications on a positive relation between the tacit knowledge hypothesis and productivity. First, it is generally argued that agglomeration economies promote productivity in the region (Glaeser et al., 1992; Ciccone and Hall, 1996; Lall et al., 2001; Rosenthal and Strange, 2001). Second, among the many economies of geographical concentration, knowledge spill-over is considered the most important in the formation of modern industrial clusters (Cooke, 2002). Such spill-over facilitates adoption of new technology, and in this way directly contributes to productivity (Bekes et al., 2009). Third, industrial clusters promote firm productivity (Porter, 1998; Stanley and Helper, 2003). Therefore, it is safe to argue that the hypothesized effect of ICT on industrial clustering is positively related to productivity.

Chapter 6

Conclusions

The thesis looks into the mechanisms at micro level behind the positive link between ICT and productivity in ICT-using industries, as well as those behind the link between the complementary organizational investment to ICT and productivity. From this perspective, the roles of ICT in economic performance beyond being a capital good are discussed.

The literature review reveals two dimensions of impacts of ICT on the core activities of the firm. They are (1) the communication and processing of information; and (2) the accumulation and distribution of organizational knowledge. As a matter of fact, ICT lowers the cost of information processing and communication. Beyond the cost effect, it changes the way that people, as well as organizations, are connected and organized; and it also reshapes work content, workflow, the accumulation and distribution of organizational knowledge, and even the entire business process. As a result, ICT increasingly drives firms towards decentralized organizational structures. These changes make information processing, decision making, resource allocation, and innovation process more efficient, and eventually lead to increases in the value-added of products and services. These impacts are the major sources of productivity improvement documented in empirical studies. Therefore, the firm activities are the keys in turning the advantages of ICT into higher productivity.

Following the first dimension, in an industry with two-stage production and demand uncertainty, the firm is modeled as an information processing organization, which provides an alternative to the market coordination of production. The firm outperforms the market by making a positive expected

profit, due to its information processing ability. Via the model, we understand that the cost of information processing has its impact on firm performance, conditional on the structure of the markets in terms of the level of demand uncertainty. Importantly, the improving information processing ability increases firm profitability as long as market-coordinated production persists elsewhere. However, when the improving information processing ability enables enough firms to compete with no market-coordinated production left, it decreases profitability of all firms. Case studies based on this model further show that firm performance in an industry depends critically on the market structure – intensity of competition. ICT generates improvements in performance under relatively low intensity of competition. Under high intensity of competition, its impact could be negative. This might be the theoretical explanation to why ICT generates productivity acceleration in some ICT-using industries while not in the others.

In an extension to the above model, different types of firm coordination of production are discussed. Vertical firms integrate the production of both two stages; horizontal firms integrate the production of either the intermediate input or the final product. It is shown how the performances of these types of firm differ, with information processing ability and structure of markets given. It is also shown that improving information processing ability would change the choice of firm coordination of production, conditional on the structure of markets. The implications for the welfare status of consumers are different as well.

Following the second dimension, another mechanism that ICT could affect industrial organization and productivity is investigated. The study is an

empirical test of the hypothesis that ICT increases the importance of tacit knowledge, and hence motivates industrial clustering. Industrial clustering is generally recognized in the literature as beneficial to competitiveness and productivity for the group of firms clustered. The results show that it is exactly after the structural change in the U.S. economy that the hypothesized positive impact of ICT over clustering became dominant. It is therefore reasonable to argue, based on these facts and observations, that the tacit knowledge hypothesis is conditional on structural change of the economy towards more knowledge-intensive production and services. The regressions by sector further show that the hypothesis is also conditional on the nature of cluster, namely whether it is a manufacturing cluster, a service cluster, or a high-tech sector. For the services sector, the tacit knowledge hypothesis is especially true.

By now, we see that the forces of ICT turn out to be no mystery, but as Shapiro and Varian put it: it's still the principles of economics at work. Specifically, one could say that it is all about improving our ability to create higher value-added in products and services, and thereby enhancing our competitiveness. These enhanced abilities are in terms of precision, timeliness, and innovativeness in coordination and decision making, hence in resource allocation; flexibility and innovativeness in business process; and knowledgeability of organizations. Therefore, as we have seen from the literature review and the specific studies that follow, there are multiple mechanisms at work on the firm activities that enable ICT in bringing improved performance. Importantly, we realize that ICT does not promise improved performance for sure. Rather, it is conditioned on the relevant features of the markets, so that ICT finds a way to facilitate the creation of value in products and services.

The research on the roles of ICT in economic performance is still an on-going one, just like this technology itself. The forthcoming age of cloud computing could further change the nature of businesses and the organization of industries. Therefore, it is important and urgent for us to understand these roles as deeply and as comprehensively as possible. However, at many times, efforts are limited by the availability of data, at both macro and micro level. For example, the estimation of ICT investment at both economy level and industry level is missing for many countries, and the data of ICT investment at firm level is even rarer. This is the most important issue for future research to resolve. For theoretical research, more attention should be paid to modeling information processing in firm production under uncertainty. After all, ICT is a technology to deal with information, and information is used to reduce uncertainty. For example, one possible future research is to discuss how the organizational structure of the firm and its cost of communication channel (information structure) determine firm performance under uncertainty, as well as how ICT impacts the organizational structure by improving the communication channel. Additionally, these would affect the behaviour of firms in capital investment and product innovation. It would be interesting to investigate these issues, if technically possible, in general equilibrium models. Last but not least, as highlighted by Varian (2010), ICT also brings deep changes to the organization of transactions and consumer behavior. This is another direction for future research.

Appendix A

Stability of equilibrium with market-coordinated production

The purpose is to show that deviating from equilibrium is not an optimal decision. Suppose that an individual X -producer produces at $(m_X')^\alpha$, and $m_X' \neq m_X^*$. Clearly, if he tries to offer consumers higher utility, he receives less revenue; if he tries to offer consumers lower utility, consumers won't make any purchase when dropping by. Therefore, he has to make the consumers indifferent. With consumers' utility level given by equation

(5), he can charge a price at

$$P_X' = \frac{F_{\lambda_X}(k < (m_X')^\alpha) \cdot Q_M}{\beta_X^*}.$$

Then this producer's expected revenue is,

$$E(\pi'_{iX}) = \left[\frac{F_{\lambda_X}(k < (m_X')^\alpha) \cdot Q_M}{\beta_X^*} \cdot \left[\int_0^{(m_X')^\alpha} k \phi_{\lambda_X}(k) dk + \int_{(m_X')^\alpha}^{\infty} (m_X')^\alpha \phi_{\lambda_X}(k) dk \right] - P_M m_X' \right] \cdot Q_M$$

When $\alpha = \frac{1}{2}$, we have

$$E(\pi'_{iX}) = \frac{Q_M^2}{\lambda_X \beta_X^*} \left(m_X' - \frac{m_X'^{\frac{3}{2}}}{2\lambda_X} \right) - P_M m_X' Q_M.$$

And without deviation, the expected profit is,

$$E(\pi_X)^* = \frac{Q_M^2}{\lambda_X \beta_X^*} \left(m_X^* - \frac{m_X^{*\frac{3}{2}}}{2\lambda_X} \right) - P_M m_X^* Q_M = 1.$$

$$E(\pi_X)^* - E(\pi'_{iX}) = 1 - \frac{Q_M^2}{\lambda_X \beta_X^*} \left(m_X' - \frac{m_X'^{\frac{3}{2}}}{2\lambda_X} \right) - P_M m_X' Q_M$$

It can be shown numerically that $E(\pi_{ix})^* - E(\pi'_{ix}) \geq 0$, for any m_x' . Thus any deviation is not an optimal choice.

Appendix B

Wages in the labor market

Wages offered by the firm should be at least as high as the certainty equivalent income of the expected net revenue of the typical producers of m and x under market organized production and exchange.

Assume that an individual spends all his income in consuming the product X .

Step 1: from $U(x)$ to $U(\pi)$ - a transformation,

$$U(x) = \frac{\pi}{P_x} \times Q_A^X(P_m) = \pi \times \beta_x = U(\pi)$$

Step 2: finding certainty equivalent income.

As the utility of π is a linear function. It implies that the certainty equivalent income is $E(\pi)$ itself. Thus at equilibrium, wage is set at $w = E(\pi_x) = E(\pi_M)$.

Appendix C

Table 11: 1997 Industrial Clusters

Factor	Primary Industries*	Cluster Name	Group
1	3311, 3312, 3321, 3322, 3323, 3324, 3325, 3328, 3329, 3331, 3334, 3336, 3339, 3365, 3369, 3372	Iron and Steel Products	Manufacture
2	5310, 5411, 5416, 5417, 611A, 611B, 621A, 621B, 6220, 6230, 6244, 624A, 7120, 721A, 8121, 8129, 813A, 813B	Real estate, professional services, education, health care and other services	Service
3	3271, 3273, 3274	Non-metallic mineral products manufacturing	Manufacture
4	3341, 3342, 3344, 3345	Information and communication technology (ICT) products	High-tech
5	3222, 3231	Paper products, printing and publishing	Manufacture
6	3259, 3260	Other chemical products and preparation manufacturing; Plastics and rubber products	High-tech
7	3211, 3212, 3219	Wood product manufacturing	Manufacture
8	2301, 2302, 2303	Construction	Manufacture
9	3251, 3252, 3253, 3256	Chemicals, rubber and artificial fibre products	High-tech
10	3131, 3141, 3149, 3151	Textile and apparel manufacturing	Manufacture
11	3112	Grain processing	Manufacture
12	3113, 3119, 3121	Confectionery, sugar, syrup, and coffee products	Manufacture
13	3141, 3152	Other textile and apparel	Manufacture

		manufacturing	
14	113A, 1142	Animal production, hunting and trapping	Agriculture
15	3241, 4810, 4860, 4920	Fuel products and transportation	High-tech
16	3115, 3116	Dairy products	Manufacture
17	3313	Non-ferrous metal products	Manufacture
18	3361, 8111	Motor vehicles and related repair and maintenance services	Manufacture
19	2211, 2212	Utilities	Manufacture
20	2121, 2122, 3251,	Mining and industrial gas	Manufacture
21	3118	Bakery	Manufacture
22	3311, 3314, 3359, 3391, 3399	Ferroalloy and non-ferrous metal products, and other related products manufacturing	Manufacture
23	3314	Copper products	Manufacture
24	3111, 3116	Meat by-products, dog and cat food	Manufacture
25	1133, 3212	Logging and wood processing	Manufacture
26	5121, 5131	Motion picture, sound recording, radio, and television broadcasting	Service
27	5133	Telecommunication	Service
28	3253	Agricultural chemical manufacturing	High-tech
29	3344, 3359	Semiconductors and fibre optic cables	High-tech
30	3116, 3161	Meat and leather processing	Manufacture
31	3112	Soybean processing	Manufacture
32	4830	Water transportation	Service

33	5250	Funds, trusts, and other financial vehicles	Service
34	3313	Aluminium production	Manufacture
35	3364	Aerospace product and parts manufacturing	High-tech
36	3121, 3122	Tobacco manufacturing	Manufacture
37	7115, 711A	Arts, sports, and other entertainment	Service
38	1123, 3116	Poultry production and processing	Manufacture
39	3222	Flexible packaging foil manufacturing	Manufacture
40	5111	Database, directory, and other publishers (Information service)	Service
41	5241	Insurance carriers	Service

* Four-digit level industries as defined in the 1997 U.S. Input-Output tables.

Table 12: 2002 Industrial Clusters

Factor	Primary Industries	Cluster Name	Group
1	3118, 3254, 3256, 3342, 3345, 3364,	Pharmaceutical and medicine; electronic instrument; and aerospace product and parts manufacturing	High-tech
2	4930, 5414, 5415, 5419, 621A, 6230, 624A, 8129	Professional and technical services; Health care; and other services	Service
3	3312, 3321, 3322, 3323, 3324, 3326, 3328, 3329, 3372	Iron and steel products	Manufacture
4	3212, 3219	Wood product manufacturing	Manufacture
5	3261	Plastic and rubber products	Manufacture

		manufacturing	
6	2122, 3273	Metal ore mining and processing	Manufacture
7	1141, 3241, 3251,	Fuel and basic chemical	High-tech
		manufacturing	
8	3361	Motor vehicle manufacturing	Manufacture
9	2302	Construction	Manufacture
10	1113, 113A	Tree products and forestry	Agriculture
		products	
11	3222	Converted paper product	Manufacture
		manufacturing	
12	3131, 3141	Textile and textile product mills	Manufacture
13	3112	Grain processing	Manufacture
14	3141	Other textile product mills	Manufacture
15	3251	Basic chemical manufacturing	High-tech
16	5250	Funds, trusts, and other financial	Service
		vehicles	
17	1121	Animal production	Agriculture
18	3115	Dairy products	Manufacture
19	3345	Other electronic instrument	High-tech
		manufacturing	
20	1133	Forestry and logging	Manufacture
21	3399	Other miscellaneous	Manufacture
		manufacturing	
22	2211, 2212	Utilities	Service
23	3314	Copper products	Manufacture
24	5151	Radio and television broadcasting	Service
25	3273	Non-metallic mineral product	Manufacture
		manufacturing	
26	3313	Aluminium products	Manufacture
27	5111	Newspaper, periodical, book, and	Service
		directory publisher (Information	
		service)	
28	3119	Food manufacturing	Manufacture

29	2213	Other utilities	Service
30	3113	Sugar and related product manufacturing	Manufacture
31	3161	Leather products manufacturing	Manufacture
32	3336	Engine, turbine, and power transmission equipment manufacturing	High-tech
33	3152	Apparel manufacturing	Manufacture
34	3112	Soybean processing	Manufacture
35	5241	Insurance carriers	Service

* Four-digit level industries as defined in the 2002 U.S. Input-Output tables.

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