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Abstract:

Increasing evidence shows that ICT investment improves firm performance. Among the many explanations on why ICT contributed to labor productivity surge since 1990, this is the most promising one. It is thus necessary to take the firm as an information processing organization, putting it in stochastic environment. As perfect information is no longer the assumption, that firms exogenously exist in the economy would no longer be assumed here. With these in mind, the paper provides a model that involves the division of labor and specialization, the production and consumption under demand uncertainty, and the value of information. It shows that under certain business conditions, a firm with certain type of information processing ability comes into being endogenously. A surplus, which could reasonably be argued as information rent, is generated with firm production. The size of this information rent depends on a few key parameters, including the level of uncertainty, the degree of market competition, and the cost of information processing. To test the model, case studies on the financial industry and the wholesale and retail industry are conducted, which corroborate the theoretical predictions of the model.

Keywords: demand uncertainty, information processing, firm, information rent

JEL classification: D2; D4; D8; L1; L2

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1. Introduction

Recently, the relation between firm and information needs to be clarified urgently for both practical reasons and theoretical reasons. On the practical side, many questions have been raised regarding the impact of Information and Communication Technology (ICT) on economic growth. Gradually the focus of interest has moved from nation level to firm level. Jorgenson and Stiroh (2000), Oliner and Sichel (2000), and Jorgenson (2001) generally confirm that ICT contributed around 1/3 of the growth in the U.S., through capital-deepening effect and TFP acceleration. Industrial level studies by Stiroh (2002), van Ark et al. (2002), Oulton and Srinivasan (2005) show that the service industries benefited most from investment in ICT, and that other OECD countries lagged behind the U.S. in exploiting the advantages brought by ICT. An EU commission report by Barrios and Burgelman (2007) indicates a "first-mover advantage" of the U.S. in applying ICT. This is hardly surprising as Apte and Nath (2004) reported that by 1997, 63% of the U.S. GNP is consisted of the so-called "information economy", which is information-related economic activities; and the service industries generally saw a growth in information-related activities.

Furthermore, Bryjolfsson and Hitt (2000) provide firm-level evidence that ICT contributes to firm productivity and that organizational investment as a complementary investment to ICT investment is important. Matteucci et al. (2005) find firm level evidence that, in the second half of 1990s, European OECD countries benefited from their ICT investment, with manufacturing sector benefited more than service sector, yet generally are lagged behind as compared to the U.S. performance.

According to the above, it has come to the stage that we ask what firms do with information, and how information technology affects firms' performance.

On the theoretical side, information economics has shown us that information plays essential role in explaining issues in contract design at individual level and firm level (Macho-Stadler et al. 2001), such as insurance policy, signaling, screening, share-cropping, and corporate governance. Beyond that, information is also important in explaining equilibriums of the overall economy, for example, the role of information in wage policy (labor market equilibrium), in equity market (allocation of financial resources), in diversification of prices, and in money market stability (Stiglitz, 2002).

Moreover, other economic theories of information have been developed over time. Marschak (1954) and Arrow (1971, 1985) discuss the economic value of information. The Arrow (1971, 1985) papers manage to link economic value of information to the Shannon measure of information. Weitzman (1974) discuss the efficiency of two different institutions when uncertainty exists in a system, which assumes imperfect information. Radner and Stiglitz (1984) show that there is nonconcavity in the value of information: Having little information is worse than having no information at all.

Given the importance of information in economic analysis, it also enters the theories of firm. Marschak (1954) introduces firm's structure with corresponding information processing procedure to analyze the value of information. Aoki (1986) distinguishes two alternative organizational structures of a firm: horizontal vs. vertical. And he found the conditions under which one is more efficient than the other when production uncertainty is embedded in the system. With organization costs under different firm structures considered, Carter (1995) discusses the effectiveness of seven different firm structures in processing information to reduce uncertainty, and thus to improve firm performance. Arrow (1975) points out that in an industry with upstream firms and downstream firms, downstream firms tend to vertically integrate to acquire input information to reduce uncertainty in input supply. And the industrial market tends to evolve from being competitive to imperfect competition as vertical integration provides market power. DeCanio and Watkins (1998) interpret and model the firm as an information processing network. Within this framework, the effect of different organizational structure on efficiency of the firm is discussed. Marschak (2004) provided a discussion on how IT investment, which is supposed to lower down information gathering cost, help a firm shift to a decentralized organizational form.

The above mentioned literature implies to us that there must be some connection among information processing, organizational structure, IT investment, and firm performance. Yet the picture is not really clear or comprehensive.

While efforts have been made to provide explanations linking information processing, organizational structure, ICT investment and firm's performance in one way or another, no comprehensive model has yet been developed to link them together. Therefore, in an attempt to accomplish this specifc aim, we see the firm as a structure for information processing, which emerges endogenously from industrial markets with demand uncertainties. Information processing ability is seen as the only thing that distinguishes firm production from non-firm production; and the ability varies from firm to firm. ICT investment, in this model, is used to reduce the cost of information processing. We show that the unique informational advantage brings firm a surplus which is reasonably argued as information rent, conditional on a few key parameters, including the level of uncertainty, the degree of market competition, and the cost of information processing[1].

[1] If one carries this point of view further, with matured financial market, the return to any productive factor, say labor skill, management, capital goods, can be capitalized in its market price. Thus any productive factor is readily available from market. Yet after compensating all factors employed, modern firms still stand to acquire

We also apply the framework of our theory to the data of the wholesale and retail industry and the financial intermediation industry from 10 OECD countries. We investigate the mechanism and the extent that the aggregate firm performance – measured as multi-factor productivity – of the industry is decided by ICT investment, intensity of market competition, as well as average firm size. It is found that the two industries actually have different market structures, from which we infer different patterns of impact from the above factors. Interestingly, we don't observe any "first-mover advantage". 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 structure of the paper is organized as follows. Section 2 provides the very theoretical backgrounds which lays out the building blocks for our model. Section 3 gives detailed descriptions of the model. Section 4 discusses the main results and properties of the model. Section 5 discusses implications derived from the model. To corroborate our theory, section 6 is devoted to case studies into the financial industry and the retail industry. section 7 concludes.

2. Theoretical Issues

We have mentioned some literature in the introduction which provide essential understandings and ideas for us to start with, but not really the specific techniques that are needed in this paper. In order to model this hypothesis, this study relies on the following building blocks.

Endogenous firm and information: Malmgren (1961) was among the first to ask why multi-person, multi-process firms exist in a competitive economy. In his view, a firm functions as an allocating mechanism of inputs and outputs.

The reason that the allocation is not done by markets, which is supposed to be efficient within traditional settings, is because that real economy is fraught with uncertainty and incomplete

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economic surplus – expected sustainable profit. In this sense, all unique advantages that a firm holds to generate this profit, be it technological or organizational, can be replicated by obtaining equivalent inputs such as manpower, human capital, or licenses from competitive markets of factors. The only thing that hinders one firm from replicating another is its information processing ability, namely the ability to acquire the best inputs and to process the information of the inputs in order to put them into the right positions.

Additionally, as information processing is a costly activity, efforts devoted to reduce such cost which include IT investment and its complementary organizational investment are supposed to positively affect performance of the firm.

information[2]. Even if we talk about expectational equilibrium[3], static equilibrium in this case is difficult to be reached, due to the formidable amount of information to coordinate individual producers. Firms arise firstly to reduce the requirement on information by integrating production procedures, vertically and horizontally, making the convergence of expectations possible; secondly, firms arise to process internal and external information, which in return gives firms higher expected profit.

Malmgren (1961) also discussed the two types of information processed by a firm: internal information regarding the production related variables; external information regarding the environment[4] – mainly intermediate input market and product market. Casson (1997) further developed the idea as firms' internal structure would routinize the processing of external information to be the processing of internal information, leaving the remaining external information area to the entrepreneurs of firms. For the purpose of this paper, we will focus on the routine information processing conducted by established firm structure.

Convex production technology: Next, we review literature that gives us ideas how to model firms with the features described above. Yang and Ng (1995) provided a general equilibrium framework in which firms are endogenously derived out of economic incentive. For their purpose, convex production technology was assumed, as well as multi-stage production. There the central argument was that firms substitute market in coordinating production procedure where transaction cost is too high.

This paper provides us with the idea to endogenously derive firms. However, as it operates in an environment with certainty, the problems of information and coordination are not included.

Information and coordination: As mentioned earlier, Arrow (1964) and Debreu (1959) had introduced uncertainty analysis into general equilibrium, but the problems of information and coordination were virtually assumed away.

Demand uncertainty and availability: Carlton (1978) introduced a simple one product economy with both demand uncertainty and supply uncertainty. Firms' existence is given. The product is featured

[2] 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.
[3] Individual agents in the economy can still maximize their expected utility or profit. Arrow (1964) and Debreu (1959) have shown that when agents are coordinated by a Walrasian auctioneer, market is cleared with a certain set of prices. In this way, equilibrium can be achieved. However, in Malmgren's case, by assuming away the Walrasian auctioneer, the economy can't automatically find and converge to an expectational equilibrium.
[4] Malmgren (1961) refers to external information as dependent on the so-called "structure of market".

in the market for both its price and availability (possibility of obtaining the product from a supplier given a certain price). In this economy, it is possible that each firm make a different decision on its production and pricing. It is shown that, however, 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. When demand uncertainty decreases, the economy moves closer to equilibrium under certainty, which means a uniform price equal to marginal cost and one hundred percent availability.

Intermediate input and vertical integration: As an extension of this framework, Carlton (1979) took the firms' existence as given, but assumed that initially the firms distribute in the upper stream as well as lower stream of a multi-stage production procedure. Rather than assuming existence of transaction cost, which is a vague concept that contains many things, uncertainty in demand and input supply was assumed. It was shown that firms could have better performance by vertically integrate the lower stream production and higher stream production. And vertical integration is virtually seen as the move of the integrating firm to acquire information at the stage of production been integrated.

Based on the above three blocks of knowledge quoted, namely information economics, firm theory, and general equilibrium under uncertainty, we are ready to merge these ideas together to derive endogenous firms from a market under uncertainty. And the firm, because it's ability of information processing, would be rewarded the information rent.

3. The Model

Model Settings

In this certain industry, it is assumed that there are only one intermediate input M and one final product X. Each individual agent engaged in the industry is endowed with L labor time which we normalize it to one, and is capable of producing either of them with the following technologies:

$$\begin{aligned} m &= l_M{}^a \\ x &= m^\alpha \cdot l_X{}^{a(1-\alpha)} \end{aligned}, \quad a > 1,\ 0 < \alpha < 1.$$

l_X and l_M denote the portions of L devoted into production of X and M, respectively. The production technology does not allow two individuals to work together additively or multiplicatively in one production procedure, which means for each individual $l_X \leq 1$, $l_M \leq 1$, and $l_X + l_M = 1$.

Given that markets for both M and X exist, since the production technologies are convex with respect to individual's labor, individuals as producers prefer specialization in producing one product only and trading it in the market for what they need, provided that the product is with positive price in the market.

Production in the overall industry could then be coordinated via intermediate input market for M. Namely, a portion of the population R_M in the industry specializes in producing M, while the other portion of the population R_X in the industry specializes in producing X. The latter purchases M from the former in order to produce X, and sell their products in the final product market. Each of them runs his own shop to sell their products. We name the system as a '*market-organized production*' with full specialization.

However, due to imperfect information[5] with both buyers and producers, for both markets, no buyer knows how many others would go to the same shop as he does; and no producer knows how many buyers would drop by. Such would generate availability problem when there are suddenly too many buyers and the shop runs out of stock.

Now, what the buyer knows is the price and availability (a kind of quality) that a shop offers; and what the producers know is that they face random demand, which in this model we assume it to be subject to uniform distribution with parameter λ (mean as $\lambda / 2$, variance as $\lambda^2 / 12$). That the availability of the final product is decided by the output level of the shop[6] is common knowledge to both the buyers and the producers. So we have assumed complete information for buyers here, mainly for simplicity. This imperfect information setting allows individual shops to ask for arbitrary price given his availability, as perfect competition is no longer the case – demand is given exogenously.

However, complete information for buyers means competition still exists among shops, regarding policies of price and availability combinations. And such applies to both the intermediate input

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

[6] 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.

market and the final product market. It is shown that there exists a unique equilibrium, in which prices of the products convey information on intensity of market competition.

As consumers, individuals consume X . With availability considered, the utility of consuming x units of X is,

$U = x \cdot Q_A^X(P_X)$.

$Q_A^X(\cdot)$ is the availability of the commodity, which is measured as the probability of obtaining X [7]. The availability of the commodity can be taken as a kind of quality of it. P_X is the price of X . It is intuitive that $\frac{\partial Q_A^X}{\partial P_X} > 0$ [8].

Consumer Behavior

A typical consumer's decision problem is,

$\begin{array}{l} \max . U = x \cdot Q_A^X(P_X) \\ s.t. P_X \cdot x = I \end{array}$, where I is the exogenous income[9].

To maximize utility, consumers would require the combination of price and availability offered by a shop to satisfy the first order condition[10]:

(2.1) $Q_A^X = \beta_0 \cdot P_X$.

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[7] And it will be illustrated in the subsection for the X -producers' behavior.

[8] 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.

[9] 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.

[10] Put Lagrange function as $\psi = x \cdot Q_A^X(P_X) + \nu \cdot (I - P_X \cdot x)$. F.O.C. gives $\frac{\partial \psi}{\partial x} = Q_A^X(P_X) - \nu \cdot P_X = 0$ and $\frac{\partial \psi}{\partial P_X} = x \cdot Q_A^X{}'(P_X) - \nu \cdot x = 0$. Thus $Q_A^X(P_X) = Q_A^X{}'(P_X) \cdot P_X$. Then $Q_A^X(P_X)$ is solved as equation (2.1), where the constant term is intuitively set to be zero, and $\beta_0 = \nu$.

β_0 is a parameter that could be interpreted as the reverse of the shadow price of obtaining one unit of X with certainty (not the one unit of demand realized with availability smaller than 1). It is decided by product market competition at the equilibrium, as will be seen later.

Since $x = \frac{I}{P_X} = \frac{I \cdot \beta_0}{Q_A^X}$, it can be shown that $\frac{\partial x}{\partial Q_A^X} < 0$, as well as that $\frac{\partial^2 x}{\partial (Q_A^X)^2} > 0$.

Actually, when pricing condition β_0 has been decided, maximum utility is fixed at $U^* = I \cdot \beta_0$.[11]

Thus we have the following diagram:

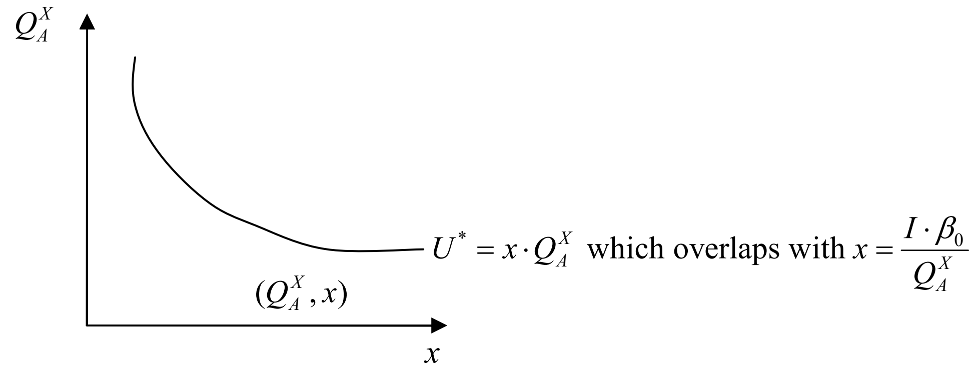

Figure 1: Indifference curve of utility function and the budget constraint of consumer

It can be observed that the indifference curve of maximum utility overlaps with the budget constraint curve. And the position of the (Q_A^x, x) curve depends on β_0. The optimal combination of Q_A^x and x for the consumers could be any point along the U^* curve.

The Individual X-Producers' Decision

On the demand side, an individual X-producer faces random demand with uniform distribution, which could be described by parameter λ_1. Thus probability density of the uniform distribution for

[11] Note that although this result shows that consumers choice on price and quality combination has no effect on utility gained, the optimization is necessary and important in the sense that it imposes constraint on producer's pricing behaviour, as will be shown later.

the X-producer is $\phi_{\lambda_1}(k)=\frac{1}{\lambda_1}, k\in[0,\lambda_1]$, where k denotes the realization of per shop random demand. It can be inferred that the larger the parameter λ_1, the greater the volatility in the market.

On the production side, the X-producer buys m_X units of the intermediate input. And then with full specialization, his output level is $m_X^{\alpha}\cdot L^{a\cdot(1-\alpha)}$. As we have normalized L to be one, the output level of each x-producer simply is $m_X^{\alpha}\cdot 1^{a\cdot(1-\alpha)}=m_X^{\alpha}$. Next, the X-producer needs to decide how many units of m to purchase from the market by maximizing his expected revenue.

Charging at a price P_{iX}, the revenue function of the ith X-producer is,

$$\pi=\begin{cases} P_{iX}k, \text{ if } k\le m^{\alpha} \\ m^{\alpha}P_{iX}, \text{ if } k>m^{\alpha} \end{cases}.$$

To maximize his expected revenue, the ith X-producer would decide the optimal output level and optimal price level according to

$$\max.E(\pi_X)=\left[\int_0^{m_X{}^{\alpha}} P_{iX}k\phi_{\lambda_1}(k)dk+\int_{m_X{}^{\alpha}}^{\infty} m_X{}^{\alpha}P_{iX}\phi_{\lambda_1}(k)dk-P_M m_X\right]Q_A^M(P_M)$$
$$\text{S.T. } U_{P_{iX}}=\frac{I}{P_{iX}}Q_A^X(P_{iX})\ge U^*,$$

where $Q_A^M(P_M)$ is the availability of intermediate input M from the intermediate input market. The constraint condition means that the X-producer needs to offer a combination of price and availability that delivers a utility at least as high as the average level in the market.

The constraint condition is equivalent to consumers' optimization condition (2.1). U^* is the average level of utility which a typical consumer can obtain from the market, by consuming with a certain combination of P_X and $Q_A^X(P_X)$. A seller thus has to provide a combination of price and availability which makes consumers at least as well off as this one.

Given his output level, this constraint condition actually decides the price that the X-producer can charge: Since $Q_A^X=F_{\lambda_1}(k<m_X{}^{\alpha})\times Q_A^M(P_M)$ is the availability ($F_{\lambda_1}(k<m_X{}^{\alpha})=\int_0^{m_X{}^{\alpha}}\phi_{\lambda_1}(k)dk$, the

cumulative density function), the i th X -producer can charge a price $P_{iX} = \frac{F_{\lambda_1}(k < m_X{}^{\alpha}) \times Q_A^M(P_M)}{\beta_0}$, according to equation (2.1).

Now the X-producer is to make two decisions with P_{iX} considered exogenous: the quantity of m_X to purchase; and the price of intermediate input M. Note that similar with the final product X, the availability of M is a function of the price that the buyer – X-producer – is willing to accept.

It's not difficult to show according to F.O.C. of the X-producer's maximization that[12]

(2.2) $Q_A^M = \beta_1 P_M$.

β_1 is subject to equilibrium of the competitive market of intermediate input M .

And the demand for M is decided by the F.O.C.,

(2.3) $2\alpha m_X{}^{\alpha-1} \int_{m_X{}^{\alpha}}^{\infty} \phi_{\lambda_1}(k)dk + \frac{\alpha}{m_X} \int_0^{m_X{}^{\alpha}} k\phi_{\lambda_1}(k)dk = \frac{P_M}{P_{iX}}$.

Accordingly, expected revenue of the X - producer is

$$E(\pi_X) = \left[\frac{F_{\lambda_1}(k < m_X{}^{\alpha}) \times Q_A^M(P_M)}{\beta_0} \left[\int_0^{m_X{}^{\alpha}} k\phi_{\lambda_1}(k)dk + m_X{}^{\alpha} \int_{m_X{}^{\alpha}}^{\infty} \phi_{\lambda_1}(k)dk \right] - \frac{Q_A^M(P_M)}{\beta_1} m_X \right] \cdot Q_A^M(P_M).$$

The M - Producers' Decision

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[12] P_{iX} is exogenous to the X-producer's optimization problem at this moment for two reasons: on the one hand the producer can decide arbitrarily to charge any price he wants and it is only when the market converges to the equilibrium that he is bounded by the constraint condition; on the other hand the price is to be determined by β_0 in the equilibrium, which is an exogenous variable to individual producers.

Thus we have $\frac{\partial E(\pi)}{\partial P_M} = Q_A^M{}' \cdot \left[P_{iX} \cdot \left(\int_0^{m^{\alpha}} kP_{\lambda_1}(k)dk + \int_{m^{\alpha}}^{\infty} m^{\alpha} P_{\lambda_1}(k)dk \right) - P_M \cdot m \right] - Q_A^M \cdot m = 0$, and $\frac{\partial E(\pi)}{\partial Q_A^M} = \left[\int_0^{m^{\alpha}} P_{iX} kP_{\lambda_1}(k)dk + \int_{m^{\alpha}}^{\infty} m^{\alpha} P_{iX} P_{\lambda_1}(k)dk - P_M(Q_A^M)m \right] - Q_A^M \cdot P_M{}'(Q_A^M) \cdot m = 0$. Combining the two we have $\frac{1}{Q_A^M{}'} = P_M{}'$, which gives us equation (2.2).

Again 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_2 , such that $\phi_{\lambda_2}(k)=\frac{1}{\lambda_2}$ is the probability density function, $k\in[0,\lambda_2]$. Parameter λ_2 describes the volatility in the intermediate input market, and is itself partially decided by the professional distribution of population: $\frac{R_x}{R_m}$ [13]. However, there is a precondition for the M - producer to fully specialize in the production of m: $\lambda_2\geq 1$. Otherwise, given that an M - producer knows that the maximum of demand coming to him is less than one, there is no reason to fully specialize in the production of M : $1^a=1$.

The revenue function for the i th M - producer is,

$$\pi=\begin{cases} P_{iM}k, \text{ if } k\leq 1 \\ P_{iM}, \text{ if } k>1 \end{cases}.$$

The M producer's faces a decision problem that

$$\max .E(\pi)=\int_0^1 P_{iM}k\phi_{\lambda_2}(k)dk+\int_1^\infty P_{iM}\phi_{\lambda_2}(k)dk$$
$$\text{S.T. } E(\pi_X\mid P_{iM})\geq E(\pi_X)^*$$.

The constraint condition is equivalent to the X-producers' optimization condition (2.2). It means that the combination of price and availability of M offered by one M - producer in the market should provide the buyer – X-producers – with an expected revenue at least as high as the average level. Given that the M - producer's output level is fixed at 1 (if $\lambda_2\geq 1$), the constraint condition already decides the price that can be charged for m at the equilibrium: $P_{iM}=\frac{F_{\lambda_2}(k<1)}{\beta_1}$, since $Q_A^M(P_{iM})=F_{\lambda_2}(k<1)=\int_0^1\phi_{\lambda_2}(k)dk$.

[13] Intuitively, λ_2 (as well as λ_1) describes the largest possible demand that one shop-runner might face. It must be jointly decided by factors like the size of the population of buyers and purchasing power of the buyers.

Accordingly, expected revenue of the M -producer is[14]

$$E(\pi_m)=\frac{F_{\lambda_2}(k<1)}{\beta_1}\left(\int_0^1 k\phi_{\lambda_2}(k)dk+\int_1^\infty \phi_{\lambda_2}(k)dk\right).$$

Virtually the only decision for the M-producer at the equilibrium is whether he wants to stay in the industry. When his expected revenue deteriorates, he might wish to leave. With the exit of some M - producers, parameter λ_2 would adjust to push up the expected revenue of the rest of the M - producers.

The Equilibrium of Market-Organized Production

That individually specialized X and M producers implement the two-stage production procedure via market transactions of intermediate input M is referred to as *market-organized production*. Now we try to look for the equilibrium of the markets of an industry organized as this.

Since we have identical consumers and identical producers in this economy, it is intuitive that the equilibrium of this economy is a certain combination of price and availability for each of the two products, to which all producers and buyers would converge.

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

Take the X -producer as an example. Given such equilibrium is arrived at, suppose that firm i disobeys the equilibrium $(\overline{P_X},\overline{Q_A^X})$ and raises its price, resulting in no purchase from the consumers because of its higher price with the same availability as before. However, it is possible that he uses the higher price to pay high production cost to increase availability of his product. To do this, note that the availability of intermediate input is virtually fixed because the M -producer can't increase its production anymore, so the x-producer can't get higher availability of M , by paying a higher price. The only way to increase output, and thus availability, is to increase its purchase of M . Nevertheless this is not a revenue maximizing method, as the marginal product of M would decrease,

[14] With uniform distribution, $E(\pi_M)=\frac{\frac{1}{\lambda_2}}{\beta_1}\cdot(1-\frac{1}{2\cdot\lambda_2})$. Thus $E(\pi_M)$ increases as λ_2 decreases.

which means cost is to be incurred to increase production is going to be higher than the possible increase in price of X.

Alternatively, if one deviates by quoting a price lower than $\overline{P_x}$, he loses expected profit if he produces at equilibrium output level. However, if he chooses to cut down his output level, note that the marginal product of M is higher than the price of M in the market. And that implies he should increase his production.

Thus we find that the equilibrium is stable at least in its neighbourhood. The proof of this point can be found in the appendix A.

The other important property of the equilibrium is

(2.4) $E(\pi_X) = E(\pi_M)$.

The property helps us determine pricing parameters β_0 and β_1. Without loss of generality, normalize the price of M as $P_M = 1$. Then we have

$$\beta_1 = \frac{F_{\lambda_2}(k<1)}{P_M} = F_{\lambda_2}(k<1) = \frac{1}{2\lambda_2}.$$

Using equation (2.4), we have β_0 in terms of m - the optimal quantity of M that X - producers would like to purchase.

$$\beta_0 = \frac{F_{\lambda_2}{}^2(k<1)\cdot F_{\lambda_1}(k<m_X{}^{\alpha})\left[\int_0^{m_X{}^{\alpha}} k\phi_{\lambda_1}(k)dk + m_X{}^{\alpha}\int_{m_x{}^{\alpha}}^{\infty}\phi_{\lambda_1}(k)dk\right]}{\int_0^1 k\phi_{\lambda_2}(k)dk + \int_1^{\infty}\phi_{\lambda_2}(k)dk + m_X\cdot\phi_{\lambda_2}(k<1)}$$

Applying the above results to equation (2.3), when $\alpha = \frac{1}{2}$, m_X can be solved in terms of λ_1 and λ_2. Thus the output level of the X - producer simply is $q = m_X{}^{\frac{1}{2}}$, which has different value according to the specific value of λ_1 and λ_2 (Figure 2)[15].

[15] For certain combinations of (λ_1, λ_2), m_X turns negative, simply because specializing in producing X is no longer optimal, due to volatile uncertainty in the markets. Mathematically, we could add non-negative

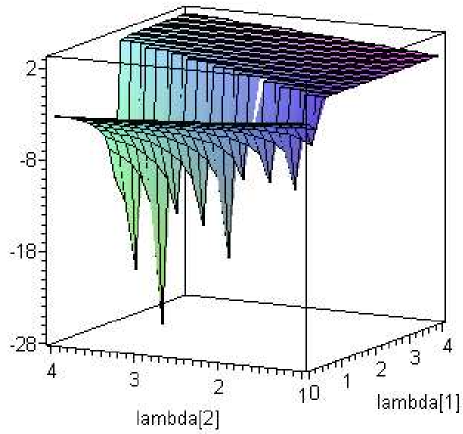

Figure 2: Output level q of x-producers with specific values of λ_1 and λ_2.

Since β_0 can be written in terms of m_X, β_0 is also decided by λ_1 and λ_2 (Figure 3).

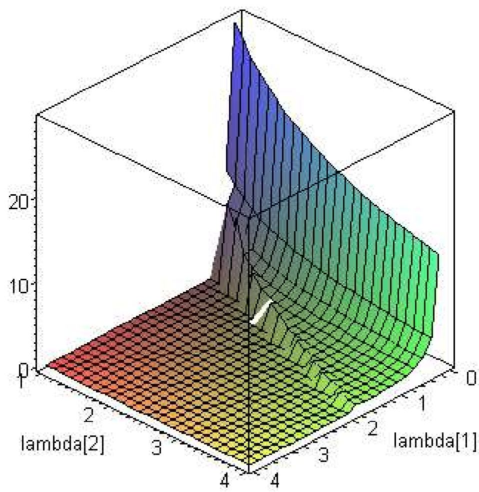

Figure 3: Pricing parameter β_0 with specific values of λ_1 and λ_2.

constraint to the X - producer's maximization problem, which gives us corner solutions and eliminate the negative part. However, doing this would not influence any of our major conclusions.

It is not difficult to observe that both output level and pricing parameter assume values with economic sense within certain range of the values of λ_1 and λ_2 (Figure 4 and 5).

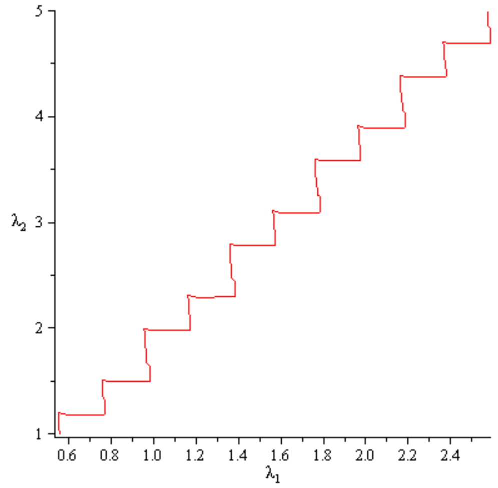

Figure 4: Contour plot of q. q is positive in the area below the contour curve.

Firm Production

We are now ready to derive firms with features identified by Malmgren (1961): a multi-person, multi-process mechanism of allocating inputs and outputs. For the purpose of examine our hypothesis, the firm derived in this model will be assumed with no advantages in terms of production technology and retail channels (Figure 6).

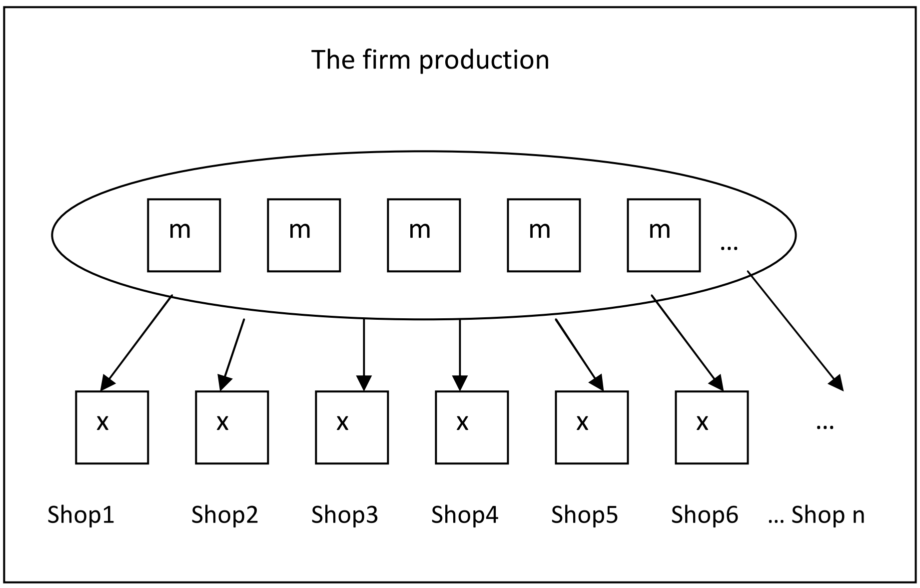

Figure 5: The structure of a firm

As described by Figure 5, a firm hires individuals from the labor market, making them specialize either in producing M or producing X. The production and supply of M is pooled together with its products distributed to individual X–shops according to Figure 6. The production and supply of X is still done at individual shops. We assume that the shops are relatively independent and do not communicate with each other. Thus the only difference between the firm production and the market-organized production is that a labor market replaces the intermediate input market. By doing this, a firm processes the information of supply and demand of intermediate input within the firm.

At each X-shop, the expected revenue is,

$$P_X\left[\int_0^{m_f{}^{\alpha}} k\phi_{\lambda_1}(k)dk + m_f{}^{\alpha}\int_{m_f{}^{\alpha}}^{\infty}\phi_{\lambda_1}(k)dk\right].$$

Decision problem for the firm to maximize its expected profit is, when there are i shops,

$$\max.E(\pi_f)=\sum_i P_X\left[\int_0^{m_f{}^{\alpha}} k_i\phi_{\lambda_1}(k_i)dk_i + m_f{}^{\alpha}\int_{m_f{}^{\alpha}}^{\infty}\phi_{\lambda_1}(k_i)dk_i\right]-w\times i\times(m_f+1)-C(i\cdot(m_f+1))$$

$$s.t.\frac{I}{P_X}\cdot F_{\lambda_1}(k<m_f^{\alpha})\geq U^*.$$

$C(\cdot)$ is the informational cost incurred by running such an organization, with $C'>0$, $C''>0$. For simplicity, let's assume that C takes the function form of $C(z)=\theta\cdot z^2$, while θ reflects the level of information processing ability, which mainly depends on factors like the entrepreneur's ability, communication infrastructure, and organizational structure. And w is the wage that firm pays to its employees.

Due to the existence of informational cost, the number of firms that qualifies in terms of information processing ability is limited – only those that make non-negative expected profit could survive. Moreover, due to that such cost is monotonically increasing, the size of a firm is limited with informational cost considered. Thus it is reasonable to assume such a scenario that the *market-organized production* with individual producers involved is still dominating the economy. Or alternatively, we say that information processing ability is scarce resource. Thus the firm production, either in terms of firm's size or in terms of number of firms, could not affect the pricing parameter β_0 given by the equilibrium of markets dominated by *market-organized production*.

Therefore, under the firm production arrangement, availability of the product is $Q_A^X = F_{\lambda_1}(k < m_f{}^{\alpha})$; and with pricing parameter β_0 from the equilibrium of *market-organized production*, the price that the firm can charge is:

$$P_X = \frac{F_{\lambda_1}(k < m_f{}^{\alpha})}{\beta_0}.$$

As the expected labor income level in the industry in equilibrium is not affected by the entry of firms in the current scenario, the wage w that the firm needs to offer in order to make individual agents indifferent between taking a job and running his individual shop is $w = E(\pi_X) = E(\pi_M)$. Proof can be found in appendix B.

Rewrite the maximization problem of a firm as

$$\begin{aligned}\max . E(\pi_f) &= i \times P_X \left[\int_0^{m_f{}^{\alpha}} k\phi_{\lambda_1}(k)dk + m_f{}^{\alpha} \int_{m_f{}^{\alpha}}^{\infty} \phi_{\lambda_1}(k)dk \right] \\ &- \frac{F_{\lambda_2}(k<1)}{\beta_1}\left(\int_0^1 k\phi_{\lambda_2}(k)dk + \int_1^{\infty} \phi_{\lambda_2}(k)dk \right) \times i \times (m_f + 1) - C(i \cdot (m_f + 1))\end{aligned}.$$

The firm needs to decide its optimal supply of intermediate input M to each shop, as well as its optimal size – how many shops to run.

According to the first order conditions (when $\alpha = \frac{1}{2}$),

$$(2.5)\quad i^* = \frac{P_X \left[\int_0^{m_f{}^{\alpha}} k\phi_{\lambda_1}(k)dk + m_f{}^{\alpha} \int_{m_f{}^{\alpha}}^{\infty} \phi_{\lambda_1}(k)dk \right] - (m_f + 1)\left(\int_0^1 k\phi_{\lambda_2}(k)dk + \int_1^{\infty} \phi_{\lambda_2}(k)dk \right)}{2\theta(m_f + 1)^2},$$

and

$$(2.6)\quad m_f{}^* = \frac{\left(\left(2\lambda_1 + \sqrt{1 + 4\lambda_1^2} \right)^{2/3} - 1 \right)^2}{\left(2\lambda_1 + \sqrt{1 + 4\lambda_1^2} \right)^{2/3}}.$$

m_f is now in terms of λ_1 only (Recall that m_X was solved in terms of both λ_1 and λ_2). Firm size i is in terms of λ_1 and λ_2.

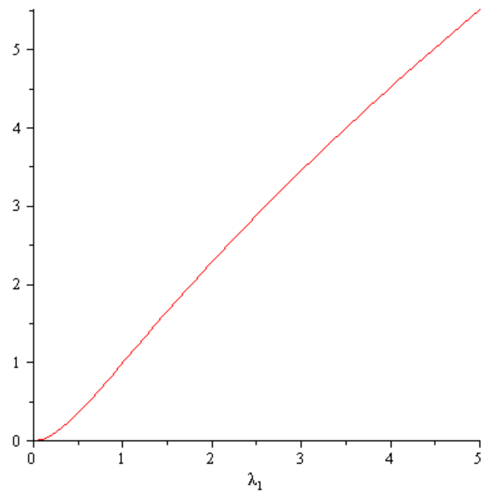

Figure 6: Plotting m_f *. Horizontal axis is λ_1, and vertical axis is m_f.

Output level at each shop is $q = m_f^{\frac{1}{2}}$.

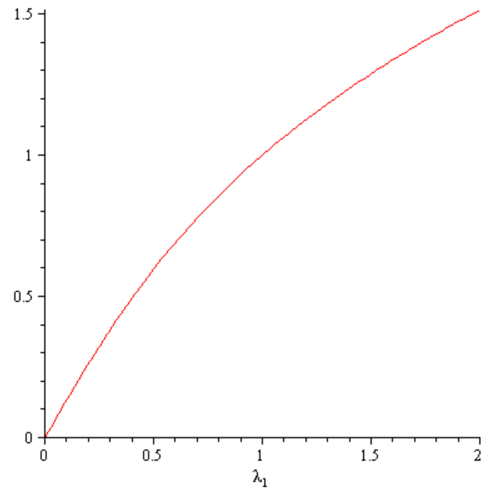

Figure 7: Plotting $q = m_f^{\frac{1}{2}}$. Horizontal axis is λ_1, and vertical axis is q.

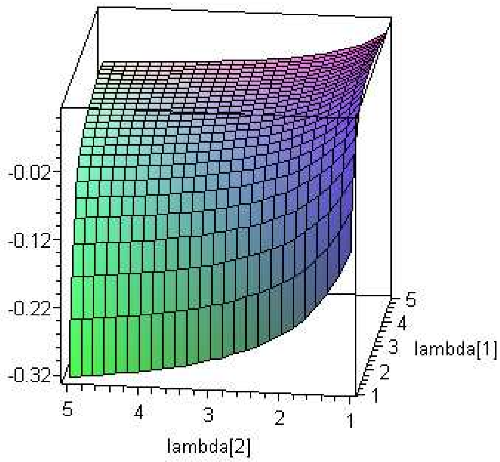

Figure 8: Plotting $i \cdot \beta_0 \cdot \theta$, which implies the size of the firm when β_0 and θ are given.

Total employment of the firm is $i \cdot (m+1)$, which can also be written in terms of λ_1 and λ_2.

4. Information Rent

The firm decisions made above deliver an expected profit

$$(3.1)\ \ E(\pi_f) = \frac{i^*}{\beta_0} \cdot \left(\frac{m_f^{\ 2\alpha}}{\lambda_1} - \frac{m_f^{\ 3\alpha}}{2\lambda^2_{\ 1}}\right) - \left(1 - \frac{1}{2\lambda_2}\right) \cdot i^* \cdot (m_f + 1) - \theta \cdot i^{*2} \cdot (m_f + 1)^2 .$$

Inserting equation (2.5) and (2.6) into (3.1), the expected profit can be written in terms of λ_1 and λ_2. Figure 9 gives expected profit of the firm under different combinations of λ_1 and λ_2, when pricing parameter β_0 and parameter of informational cost θ are given[16].

[16] Pricing parameter β_0 is decided by λ_1 and λ_2 in the equilibrium of *market-organized production*. However, setting β_0 as irrelevant to λ_1 and λ_2 is a generalized case that the firm does not necessarily always stay in an environment dominated by *market-organized production* – intuitively β_0 increases as number of firms increases because of competition. Should this be the case, β_0 exogenously assumes different value.

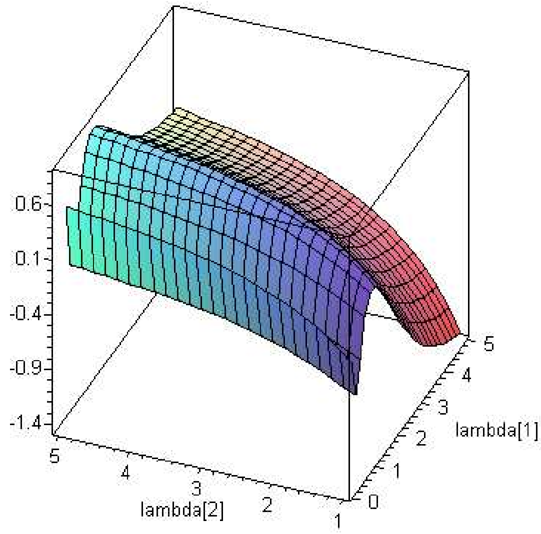

Figure 9: Plotting $E(\pi_f)$ when $\beta_0 = 0.8$, $\theta = 0.1$.

Given low enough informational cost of the firm (in this case, $\theta = 0.1$), the result comes that the firm production conditionally makes positive expected profit. It shows the motivation of starting up a firm, as well as the sustainability of firm production.

Note firstly that this positive expected profit of the firm is a surplus, since all visible productive factors – intermediate input and labor input – have been decently paid at market rates. And secondly, since the basic difference between firm production and *market-organized production* is that the firm has had the information regarding production and demand of intermediate input processed, the surplus can only be ascribed to the information that the firm has obtained. Thirdly, previously we have assumed that the information processing ability is unique to a firm, which is equivalent to that parameter θ is unique to a firm. Thus the supply of such ability is completely inelastic.

In order to get this information processing ability into work, with its best effort and with the true information, the right to claim this surplus (residual return) should be assigned to the provider of this ability. The argument is similar as the one in Alchian and Demsetz (1972) about team production.

Furthermore, not all firms earn positive expected profit. It will be shown later that with informational cost increasing (value of θ growing), surplus vanishes. Firms at the margin make it break-even – whatever they get from controlled information would be paid to cover informational cost. Thus according to the theory of economic rent, the surplus claimed by the provider of information processing ability – the firm, is considered economic rent, both in the sense of Ricardian rent and in the sense of Paretian rent (Wessel, 1967; Lackman, 1976). Since the source of this surplus is information, we name it "information rent".

Next, we analyze some properties of this information rent to the firm.

Proposition 2: Ceteris paribus, the firm's information rent depends on both volatility in the intermediate input market and volatility in the final product market. The more volatile the markets are, the greater the economic rent would be.

It can be shown that the firm's information processing ability is only profitable within a certain range of value of parameters, which describe the market environment that they face (Figure 10).

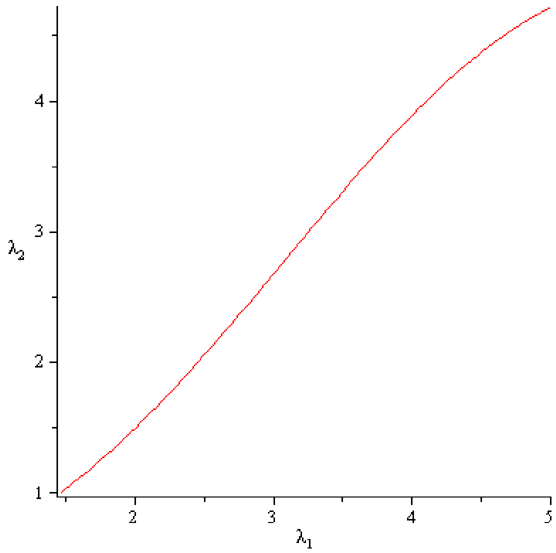

Figure 10: Contour plot of $E(\pi_f)=0$. ($\beta_0=0.8,\ \theta=0.1$)

According to the plot, for certain ranges of λ_1 and λ_2, the information rent to firm's information processing ability is positive. Combining this with what we see in Figure 9, the implication is that given volatility of demand in the final product market (λ_1), the greater the volatility of demand in the intermediate input market (λ_2), the higher the information rent is. But growing volatility of demand in the final product market (λ_1) has a threshold effect on information rent – it drives information rent up in a certain range, but then makes the information rent vanishing.

On the other hand, given λ_1 and λ_2, values of β_0 and θ would decide the sign and scale of the information rent.

Proposition 3: By entering the firm decision on firm size (i), pricing parameter β_0, which is decided by outside market environment, and informational cost parameter θ would also decide economic rent to entrepreneur's information processing ability. The changes of the two parameters both have *threshold effects* on the sign and scale of economic rent, via their effects on firm size i. They also have further influence on the position of the threshold.

Proof:

Taking derivative of $E(\pi_f)$ w.r.t. i,

$$\frac{\partial(E(\pi_f))}{\partial i} = \frac{1}{\beta_0}\left(\frac{m_f}{\lambda_1} - \frac{m_f^{1.5}}{2\lambda^2_1}\right) - \left(1 - \frac{1}{2\lambda_2}\right)(m_f) - 2\theta i(m_f + 1)^2 .$$

When $i > \dfrac{\frac{1}{\beta_0}\left(\frac{m_f}{\lambda_1} - \frac{m_f^{1.5}}{2\lambda^2_1}\right) - \left(1 - \frac{1}{2\lambda_2}\right)(m_f)}{2\theta(m_f + 1)^2}$ (the threshold),

we have $\dfrac{\partial(E(\pi_f)}{\partial i} < 0$.

From equation (2.5) it can be observed that a smaller β_0 gives a larger i. When i is smaller than the threshold, economic rent to information processing ability could be higher than before. But once i has passed the threshold, a smaller β_0 reduces the economic rent.

The effect of a decreasing θ or β_0 brings more potential to increase economic rent to the firm. This is because on the one hand it increases the value of i; On the other hand it also increases the value of threshold, leaving more room for the firm to grow. However, when θ is increasing, the negative effect on economic rent could be stronger as well. ▯

5. Implications

The current model does not close as what usually happens in a general equilibrium setting, by setting the income of consumers of product X as endogenously decided by pricing parameter β_0 [17]. Rather, it is better that we consider it as an equilibrium analysis for a certain industry existing in a broader economy – there are other industries in the economy. Consumers of product X come from all industries including the one under discussion. Then the idea that consumers have exogenously determined income would make sense.

However, it does require certain extent of imagination to accept that, the pre-determined population engaged in this certain industry reflects an equilibrium of the overall economy which is beyond the analysis of this model, so that the demand and supply of X could be balanced. As with the problem of optimal division of labor inside the industry, given the business environment – demand uncertainty, the current model deals with it.

Recall the essential assumptions we have made in the model:

1. There is convex production technology openly available for all producers – individual and firm. It provides incentive for specialization.
2. There is imperfect but complete information for both buyers and sellers. The buyers randomly visit seller's shops. As a result, sellers find themselves facing demand uncertainty, which in this model is subject to uniform distribution. For the same reason, the availability of the product from one shop is smaller than one hundred percent. This applies to both intermediate input market and final product market.
3. A firm is featured as an organization with multi-person and multi-stage 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 shops are independent from each other.
4. The only difference between firm production and *market-organized production* is that, a firm has the production process organized by processing the information of demand and supply of the intermediate input. In the latter, no one knows more than anyone else.
5. Information processing is a costly process.

With these settings, any superior performance of a firm must be due to its informational advantage. And we come up with the following implications derived from such a model:

[17] Pricing parameter β_1, which works for the intermediate input market, is virtually given by normalizing P_M to be one, and by assuming m -producers would fully specialize. Thus we have $\beta_1 = \dfrac{F_{\lambda_2}(k<1)}{1}$.

1. Under certain conditions, firm production generates a positive surplus, after all factors and costs been well-paid. The advantage is not due to better technology or better organizational form, but unique information processing ability only. For this reason, the surplus is named "information rent".
2. A firm's performance depends on a set of parameters, among which λ_1 and λ_2 describe extent of demand uncertainty in the two markets, β_0 describes pricing condition given by the competitive market, and θ describes level of informational cost.
3. The competitive market environment – described by β_0 – affects the size of information rent in a few ways. One is that it decides the expected income level of individual producers - $E(\pi_X) = E(\pi_M)$, which is equivalent to labor cost w of the firm when the *market-organized production* dominates. Secondly, as indicated by proposition 3, it has certain impact on firm size, which has a *threshold effect* on information rent.
4. For a firm, pricing parameter β_0 deteriorate in two ways. When the market is dominated by *market-organized production*, overly volatile demand uncertainties in the two markets lead to too small a β_0, which drives out information rent. When the market is dominated by firm production, with the number of capable competitor firms increasing, β_0 turns larger[18]. This also eventually drives information rent to become zero. The latter case might be due to spill-over of information processing ability, as people gradually learn to mimic entrepreneur's practice. This could be called the dissipation of rent.

Now we are ready to examine whether information rent exists as a sustainable source of firm profit in real economy. We are interested in the service industries which are close to our assumptions in many ways. Specifically, in the current study, we take the *wholesale & retail industry* and the *financial intermediation industry* as examples.

Firstly, production technology of these industries is plain and open to anyone. No one can claim a patent on the design or organization of a store; nor could one claim patent on an investment tool tailored for customers. Actually, there exist many individually run retail shops, as well as many self-employed financial agents. Secondly, demand in the markets do appear random to certain extent. Thirdly, both the labor market and final product market are relatively competitive in the two industries, which means market power can hardly be the source of sustainable profit. However, neither are they perfectly competitive with homogeneity embedded. We do observe that with the

[18] There could be less volatility in the intermediate input market, which means a smaller λ_2. According to Figure 3, this would deliver a larger β_0.

same commodity sold in the shop, or with the same banking service from a financial institution, different prices are charged by different suppliers. Thus the reality is close to our assumption in model. Fourthly, according to empirical studies (van Ark, 2002), these two industries do benefited 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 examples.

6. Case studies

To echo the proposition that U.S. stands a "First-mover advantage" (Barrios and Burgelman, 2007), a cross-country industry-level panel data analysis will be conducted. The wholesale and retail industry and the financial intermediation industry are the subjects of this empirical analysis. Our sample includes data of the two industries from the United States, the United Kingdom, Japan, Germany, Italy, Australia, South Korea, Denmark, Finland, and Austria. The range of time period is from 1980 to 2005. Data is collected respectively from the EU-KLEMS database, the OECD.stats database, and statistics bureaus of the respective countries.

Combining the theoretical frameworks of growth accounting approach in literature and our model, the following econometric model is established.

Real output of industry i is, $Y_i = A_i \times F_i(K_i, N_i) = A_i \times K_i^{\rho} \times N_i^{1-\rho}$.

where K is capital stock, N is employment, and A is multi-factor productivity.

With P_i denoting the price of the product, nominal output then is, $P_i \times Y_i = P_i \times A_i \times K_i^{\rho} \times N_i^{1-\rho}$.

It follows that $g_{P_i \times Y_i} = g_{P_i} + g_{A_i} + \rho g_{K_i} + (1-\rho) g_{N_i}$

Next, for two reasons we want to look at the growth of nominal value-added per labor hour rather than real value-added per labor hour: Firstly, it's 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 inflation[19]. A measure of real value-added could thus be a biased measure. 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.

[19] Interested readers can refer to SNA93 for detailed information.

Thus we have,

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

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

If we name the nominal value-added per labor hour as 'nominal labor productivity', it's growth rate ($glph_i$) is decided as,

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

where k_i is capital per labor hour, and glq_i is the measure of growth of labor quality as defined by Jorgenson and Stiroh (2000). g_{A_i} is the growth rate of industrial multi-factor productivity, which is the key variable that we use to measure the aggregate firm performance in the industry.

INF is the general inflation rate of the economy, which is used to proxy for g_{P_i} with $g_{P_i} = \alpha \cdot INF$. This treatment is necessary since it's difficult to accurately estimate the price for a single unit of service, and the overall inflation data is readily available.

It is important to bear in mind that the subjects under study are service industries, which means the g_{A_i} term, as the aggregate firm performance of the industry, hardly contain technological improvement in the production of the service provided by the industry. Additionally, technological improvement in capital goods is counted for in the growth of capital stock per capita; and labor skill improvement is counted for in the glq_i term. Therefore, according to our model, the g_{A_i} term should only be explained by cost of information (described by parameter θ), market competition (described by parameter β_0), and size of firms.

To examine this hypothesis, we further run the regression of g_{A_i} over the following explanatory variables, as implied by our theoretical model:

- Growth of ICT capital stock of the industry, measured as g_{IT_i} , to control for cost of information;
- Growth of level of labor compensation in the very industry, measured as g_{ILCPH_i} ;
- Average firm size of the industry, measured as FZ_i ;

The regressions are designed to find evidence that θ, β_0, and firm size impact economic performance of firms in the way that our model predicts; and secondly, to examine if the expected profit which is sustainably generated from information processing ability of firms, is the reason that U.S. industries have had outstanding performances.

Therefore, after g_{A_i} is estimated from equation (5.1), we have,

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

where u_{ij} is fixed country effect of country j, and g_{ILCPH_i} is the growth rate of industrial per hour labor compensation, which is used as a proxy for β_0.

As TFP (Multi-factor productivity) data for each industry in each country is readily available from EU-KLEMS database using growth accounting method, we would also like to run regressions (5.3) against this data to check if the results from the above are reliable, as a robustness test.

(5.3) $g_{tfp_i} = \beta_1 g_{IT_i} + \beta_2 g_{ILCPH_i} + (\beta_3 FZ_i) + u_{ij} + \varepsilon_i$

Case I: The wholesale and retail industry

Figure 11 gives the mean and standard deviation of some key variables relevant to firm performance, according to our theoretical model. It can be observed that industries in different economies follow different patterns of growth, probably due to the fact that they are running at different stages of development. The U.S. wholesale and retail industry seems to be relying more on 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 seems to be relying more on significant labor quality improvement, while growth of labor compensation is among the lowest, hinting that firm performance benefited more from slack domestic competition; the industry of U.K. and Korea has low ICT growth, low labor quality growth, while industrial labor compensation grows relatively faster, supporting firm performance to surge high. Combining data of average firm size in the industry, it is observed that firms in the industries of the two countries experienced faster expansion.

While there is a variety in our individual observation, by pooling the countries together in panel regression, the pattern for this wholesale and retail industry is quite clear (table 1)

Table 1: Wholesale and retail industry regression results

Regression	(1)	(2)	(3)	(4)
Method of Estimation	OLS	OLS	OLS	OLS
Observations	104	104	104	104
Regressand:				
Resid_gtfp	Yes		Yes	
gtfp		Yes		Yes
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.

It can be read from table 1 that regressions results applying equation (5.2) and equation (5.3) are very close. The results generally reveal that ICT capital stock, which reduces the cost of information processing, has a positive impact on the performance of firms; growth in labor compensation and firm size both have positive impact on the performance of firm, which implies a lower θ has pushed the threshold of firm size higher so that given a certain β_0 value (intensity of competition), size of firms can be larger to improve firm performance, and number of firms can also be larger in the industry to improve the performance of the whole industry. In other words, ICT investment brings new opportunities to the industry, as well as room for expansion.

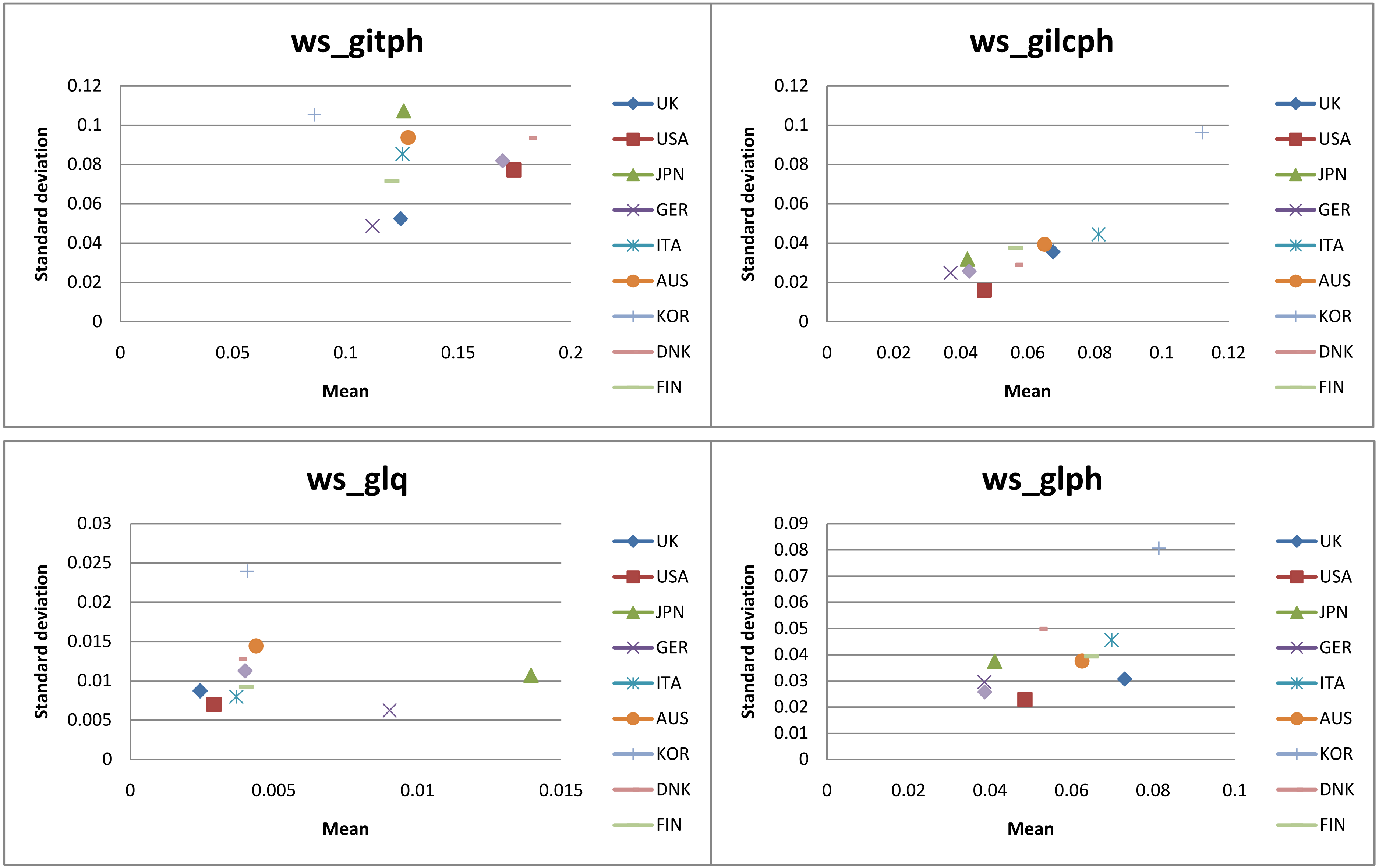

Figure 11: Key variables of the Wholesale and retail industry.

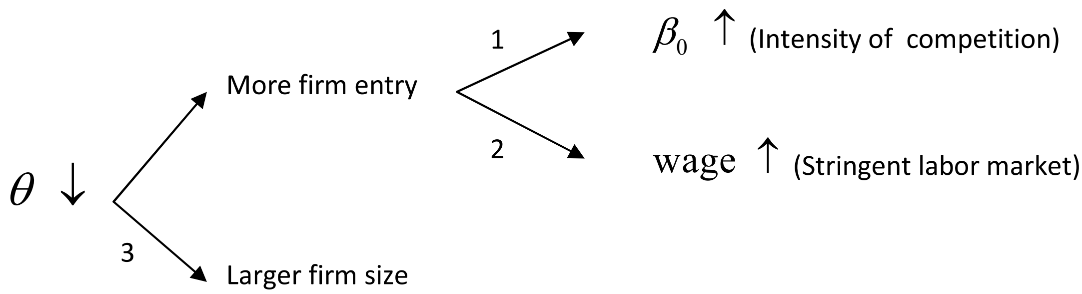

Figure 12: The effects of decreasing θ. Effects are numbered as 1, 2, and 3.

Figure 12 illustrates the three simultaneous effects numbered as 1, 2, and 3, of the decreasing cost of information processing:

(1) As more firms enter the industry, the intermediate input market turns less volatile, pushing β_0 higher[20], which is negative to the aggregate firm performance.

(2) As more firms enter the industry, labor market becomes stringent, the rising labor cost would squeeze information rent for each firm. Thus it's negative as well.

But for the industry as a whole, before number of firms coming to a certain level, aggregate firm performance could be improving as production switches from market-organized style to firm style. At this stage, that more firms come in with positive profit outweighs that each firm has less profit than before.

(3) θ has the effect of pushing up the threshold of firm size. Thus the optimal firm size would be larger– therefore it is a positive effect.

Accordingly, the generally positive effect of ICT investment over the wholesale and retail industry keeps happening as long as positive effects more than compensate the negative effect, which means when β_0 and w do not increase to too high.

Thus the story of the wholesale and retail industry can be well explained by our model.

Case II: The financial and insurance industry

[20] See footnote 8.

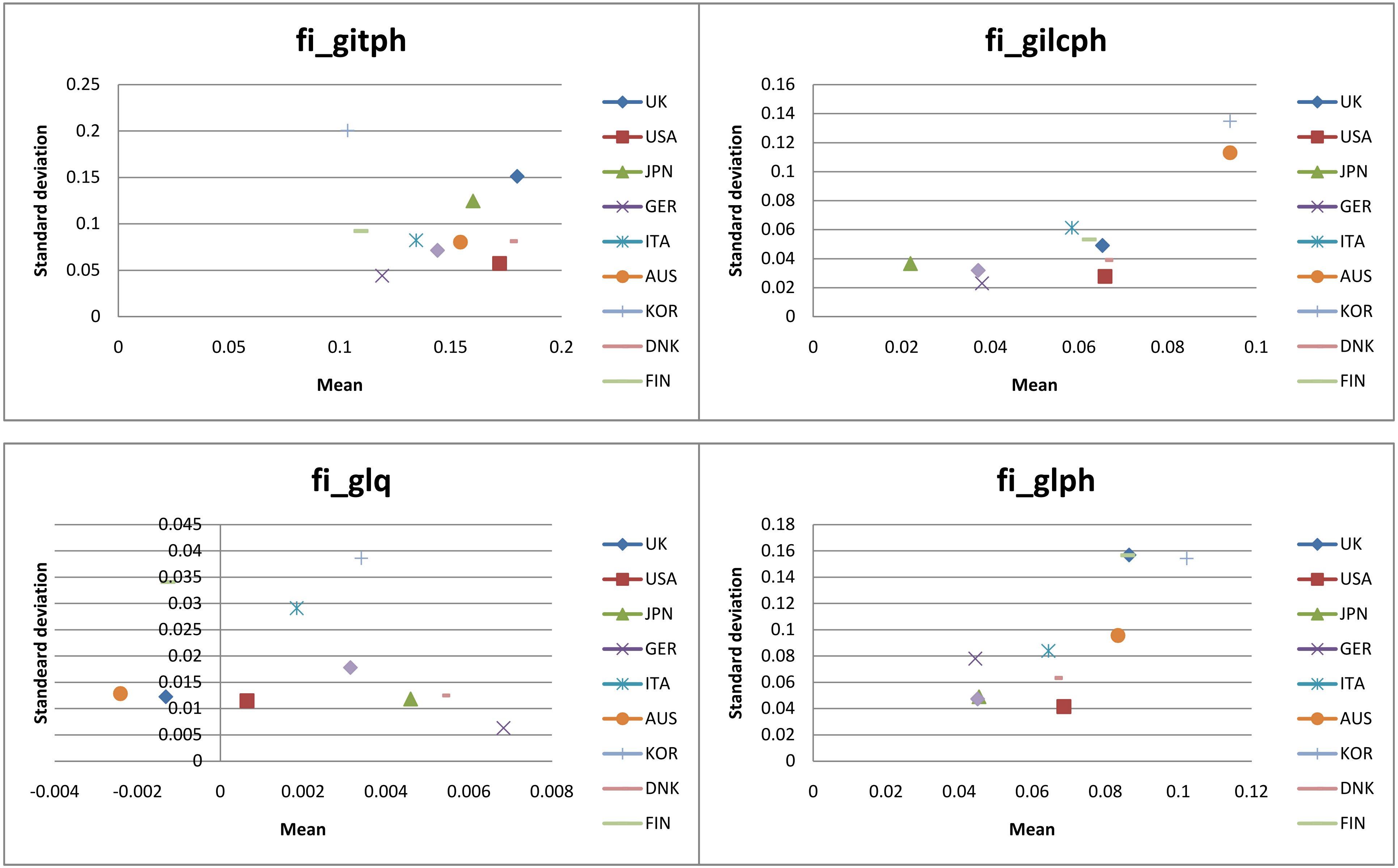

Figure 13: Key variables of the finance and insurance industry

Figure 13 displays the different growth patterns that the finance and insurance industry of each economy follows. For example, ICT growth of the U.S. finance and insurance industry 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. Combining data on its firm size in the industry, evidence is clear that increasing intensity of competition is the reason that keeps improvement of aggregate firm performance low, while labor compensation grows relatively high. The U.K. and Australia cases are different. They have relatively high IT accumulation, negative labor quality growth, but relatively high labor compensation growth. And these features deliver them significant improvement in aggregate firm performance. Possible explanation is that as the cost of information processing is cut down by ICT investment, while competition in the industry intensifies in the sense of both more number of firms and larger firm size (Australia firm size data does support this story), the positive effects outweighs the negative effects described by Figure 13. Thus we see a double high growth in firm performance and labor compensation.

Table 2: Finance and insurance industry regression results

Regression	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Method of Estimation	GLS	OLS	OLS	GLS	OLS	OLS	OLS	OLS
Observations	65	65	65	64	64	228	228	228
Regressand:								
Resid_gtfp	Yes			Yes	Yes			
gtfp		Yes	Yes			Yes	Yes	Yes
Regressors:								
gitph	0.14*	-0.03	-0.01	0.15*	0.07	-0.06*	-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**	-1.43	-0.29	-1.96	-0.34	-	-	-
C	0.10	0.08	0.02	0.09	0.01	0.01	0.02	0.01
Fixed country	Yes	Yes	None	Yes	None	Yes	None	Yes
Fixed period	None	None	Yes	None	Yes	None	Yes	Yes
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 formal econometric analysis of the finance and insurance industry data is ambiguous, however. Generally, the following observations are made: (1) when firm size is controlled, growth of IT capital stock has positive impact; when firm size is dropped, the impact of growth of IT capital stock turns significantly negative; (2) the growth of labor compensation in the industry has positive impact on the performance of firms; (3) period fixed effect is more suitable for this industry, rather than fixed country effect.

Recall Figure 13, the story implied for the finance and insurance industry is that accelerated investment in IT reduces cost of information processing. According to our model, it pushes up the threshold of optimal firm size, thus enabling the expansion of the size of each firm. On the other hand, lower information processing cost would continue to enable more entry of firms in to the industry, pushing up industrial labor compensation. This would push up the β_0 value, while turning the firm size effect to be negative. In the case of the finance and insurance industry, in contrast to the previous industry discussed, that firm size effect turns negative is due to that β_0 - intensity of competition - is already large enough.

Fixed country effect

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 with equation (5.2) and equation (5.3). Under equation (5.2), the U.S. has positive fixed effect, yet it is neither unique nor the most significant one. Under equation (5.3), 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.

Within the framework of this study, we are examining what contribute to the growth of the residual term of an industrial production function, as well as the magnitude that these factors contribute to it. After all productive factors have been well paid for its service (equation 5.1)[21], the residual term states the ability of the industry to generate surplus, which, according to our analysis, is basically due to the information processing ability of firms. Generally speaking, there is no unique country effect in the growth of this residual term for the U.S., which is not consistent with the hypothesis that there is a first-mover advantage attached to the U.S. Rather, the growth of this residual term can be explained by ICT investment (with its capital-deepening effect filtered), intensity of market competition, and the size of firms. And these factors impact on the aggregate performance of firms in the industry, in the way that our model can predict.

[21] Our residual term estimated is trivially different from the TFP data provided by the EU-KLEMS database, which is estimated using growth accounting approach.

The policy implication is that any country can conduct an optimal ICT investment strategy, combined with industrial organization policy to improve the performances of the service industries, thus leading to a higher growth path.

7. Conclusion

We started with the enquiry that how the information and communication technology (ICT) improves firm performance, so as to improve the performance of the industry, as well as that of the economy, which is argued by empirical literature. Then a model of firm in a certain industry with demand uncertainty is developed.

Initially in the model, there are only individual producers specialized at two different stage of production, coordinated via an intermediate input market. However, facing demand uncertainty in both two markets, efficiency of resource allocation is lower than a full information scenario. Alternatively, if we count the availability property of the products in this model as the only type of quality, the model means that under demand uncertainty, product quality would be lower or a higher price is charged for the same quality as compared to full information scenario. A firm then is organized to eliminate uncertainty in the intermediate input market. The realization of a firm organization in this model is as described by Figure 6, where a firm hires workers and divide them into two groups: one producing $M$and one producing X. To assume away any special technological advantage of a firm, it is assumed that in the final product market, the firm is still loosely organized as several shops ran by individual x producers.

The firm, although without assuming special technological advantage, manages to provide final product with higher availability (or higher quality), charging a higher price in the market. This way the firm would gain an excessive surplus, which we refer to as information rent, after all production factors being well paid at market rate of compensation, provided that the cost of processing information in order to run this organization.

All these come by assumptions. However, it is via the model that we understand in what ways the cost of information processing, intensity of market competition, as well as size of the firm affect this information rent.

To test if these theoretical predictions apply to real economy, the paper conducted 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 directly; indirectly, it pushes up the threshold of optimal firm size and allows more firms to enter, making the aggregate effect positive to aggregate firm performance. In the finance and insurance industry, as intensity of competition is already high, lower information cost soon pushes firm size effect into negative – firm size exceeding optimal threshold; the positive sign of labor compensation term means that it is working in another way round, in which higher labor cost curbs firm entry, relieving information rent from the squeeze of labor cost.

Lastly, we learn from the fixed country effect coefficients that it is unlikely that there is a first-mover advantage attached to any single economy. 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. It depends on many other factors, especially intensity of market competition, that we should consider in policy-making.

To put an end to this stage of study, bear in mind that the current research is a partial equilibrium analysis, rather than general equilibrium analysis, of one industry. Also we have assumed away capital investment and human capital accumulation in the model. By adding those into consideration could generate the dynamic pattern of performance improvement related to information processing. Moreover, one might find the convex production technology too strong an assumption.

Thus future researches can be conducted in at least two ways: One is to establish general equilibrium analysis with multi-sector and multi-product; the other is to introduce dynamic analysis to see the evolution of performances of industries and the overall economy.

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Appendix A

Stability of equilibrium with market-coordinated production

§ Equilibrium as the intersection of demand and supply curves

To show that the equilibrium exists for the final product market, we can derive the consumer's demand curve and the X-producer's supply curve. Consumers demand is readily described by equation (2.1). Now we derive the producer's supply curve.

For the X-producer,

$$\max.E(\pi_X)=\left[\int_0^{m_X{}^{\alpha}} P_{iX}k\phi_{\lambda_1}(k)dk+\int_{m_X^{\alpha}}^{\infty} m_X^{\alpha}P_{iX}\phi_{\lambda_1}(k)dk-P_M m_X\right]Q_A^M(P_M)\,.$$

$$\text{S.T. } U_{P_{iX}}=\frac{I}{P_{iX}}Q_A^X\geq U^*$$

Q_A^X is a function of m_X only for the current analysis. P_{iX} is also separately decided.

$$L=\left[P_{iX}\cdot\left(\int_0^{m_X{}^{\alpha}} k\phi_{\lambda_1}(k)dk+m_X{}^{\alpha}\int_{m_X{}^{\alpha}}^{\infty}\phi_{\lambda_1}(k)dk\right)-P_M m_X\right]Q_A^M(P_M)+\varphi(\frac{I}{P_{iX}}Q_A^X-U^*)$$

$$\frac{\partial L}{\partial m_X}=\left[P_{iX}\cdot\alpha m_X{}^{\alpha-1}\cdot(1-\frac{m_X{}^{\alpha}}{\lambda_1})-P_M\right]Q_A^M(P_M)+\varphi\cdot\frac{I}{P_{iX}}\cdot\alpha\cdot m_X{}^{\alpha-1}\cdot\frac{1}{\lambda_1}\cdot Q_A^M(P_M)=0$$

$$\frac{\partial L}{\partial P_X}=\left(m_X{}^{\alpha}-\frac{m_X{}^{2\alpha}}{2\lambda_1}\right)\cdot Q_A^M(P_M)-\varphi\frac{I}{P_{iX}{}^2}Q_A^X=0$$

$$\Rightarrow \varphi=\frac{P_{iX}^2\left(m_X{}^{\alpha}-\frac{m_X{}^{2\alpha}}{2\lambda_1}\right)\cdot Q_A^M(P_M)}{I\cdot Q_A^X}$$

$$\Rightarrow \alpha\cdot m_X{}^{\alpha-1}\cdot\left[1-\frac{Q_A^X}{Q_A^M(P_M)}+\frac{P_{iX}}{I}(1-\frac{1}{2}\frac{Q_A^X}{Q_A^M(P_M)})\right]=\frac{P_M}{P_{iX}}$$

$\frac{P_{iX}}{I}$ is the reverse of demand from one consumer. As what the producer cares about is how much price to set for exactly one unit of demand, we can safely put $\frac{P_{iX}}{I}=1$.

Then we end up with

$$\alpha \cdot m_X^{\alpha-1} \cdot \left(2 - \frac{3}{2} \frac{Q_A^X}{Q_A^M(P_M)}\right) = \frac{P_M}{P_{iX}}$$

Since $Q_A^X = F_{\lambda_1}(k < m^\alpha) \cdot Q_A^M(P_M)$, the above equation is exactly equal to equation (2.3).

Thus this equation describes the producer's supply curve (consumer's requirement on combinations of price and availability is ignored here so as to derive producer's independent optimal behavior).

To find out the intersection of the consumer's demand curve and the producer's supply curve, simply substitute P_{iX} with equation (2.1).

Then we are lead back to equation (2.3).

§ Existence of Global Equilibrium

Suppose that an individual X-producer produces at $(m')^\alpha$, and m'>m*. Then he sets a price according to $P_{iX} = \dfrac{F_{\lambda_1}(k < (m')^\alpha) \cdot Q_A^M(P_M)}{\beta_0}$, assuming that β_0 is the reverse of a commonly accepted shadow price of one actual unit of demand in the x market.

This producer's profit is,

$$E(\pi'_{iX}) = \left[\frac{F_{\lambda_1}(k < (m')^\alpha) \cdot Q_A^M(P_M)}{\beta_0} \cdot \left[\int_0^{(m')^\alpha} k\phi_{\lambda_1}(k)dk + \int_{(m')^\alpha}^{\infty} (m')^\alpha \phi_{\lambda_1}(k)dk\right] - P_M m'\right] \cdot Q_A^M(P_M)$$

We already have

$\beta_0 = \dfrac{\alpha m_X^{2\alpha-1}}{\lambda_1 P_M}(2 - \dfrac{3m_X^{\alpha}}{2\lambda_1})$, which is given by market equilibrium.

$$E(\pi'_{iX}) = P_M \left[\left(\frac{m'}{m}\right)^{2\alpha} \frac{1}{(2\alpha - \frac{3\alpha m^\alpha}{2\lambda_1})} \cdot \left[1 - \frac{(m')^\alpha}{2\lambda_1}\right] m - m'\right] \cdot Q_A^M(P_M)$$

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

$$E(\pi'_{iX}) = P_M m' \frac{3\sqrt{m} - 2\sqrt{m'}}{4\lambda_1 - 3\sqrt{m}} \cdot Q_A^M(P_M).$$

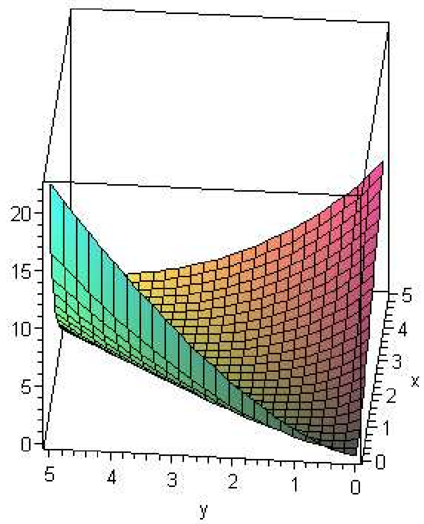
And without deviation, the expected profit is,

$$E(\pi_{iX}) = P_M m \frac{\sqrt{m}}{4\lambda_1 - 3\sqrt{m}} Q_A^M(P_M).$$

$$E(\pi_{iX}) - E(\pi'_{iX}) = P_M Q_A^M(P_M) \left(\frac{\sqrt{m}(m-m') + 2m'(\sqrt{m'} - \sqrt{m})}{4\lambda_1 - 3\sqrt{m}} \right)$$

When $\sqrt{m^*} < \frac{4}{3}\lambda_1$, which is always the case,

$E(\pi_{iX}) - E(\pi'_{iX}) > 0$. Thus any deviation is not an optimal choice.



Let $L = \sqrt{m}(m - m') + 2m'(\sqrt{m'} - \sqrt{m})$.

It can be shown that

$$\frac{\partial L}{\partial m'} = 3(\sqrt{m'} - \sqrt{m}),$$

which is positive when m'>m, and negative when m'<m. In the first case, it means m' should be decreased so as to reduce the positive gap between expected profit at m and expected profit at m'; in the latter case, it means m' should be increased so as to reduce the positive gap between expected profit at m and expected profit at m'. Thus there is incentive to converge to m.

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,

$$U(x) = \frac{\pi}{P_X} \times Q_A^X (P_m) = \pi \times \beta_0 = U(\pi)$$

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 $w = E(\pi_X) = E(\pi_M)$.