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Outsourcing as an Evolutionary Game

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Abstract: This paper applies an evolutionary game approach to analyze firms' "make or buy" decision in a dynamic framework. This evolutionary game model provides a theoretical framework to sort out the interdependencies in the organizational decisions of individual firms. The results show that outsourcing is more likely to be pervasive in the long run when (1) the pecuniary diseconomy of an outsourcing firm is small, (2) the cost advantage of an outsourcing firm is large, (3) the quality risk of outsourcing is small, or (4) the product substitutability of the two goods is low.

Keywords: outsourcing, evolutionary game, vertical integration
JEL Classification: C73, C92, D23, F23, L22

1. Introduction

One significant feature of globalization is the prevalence of outsourcing. Rather than concentrating production in one single country, more and more firms are outsourcing a wide range of their production processes across borders. There are several examples illustrating this phenomenon. For example, Sun MicroSystem purchases between 75 to 80 percent of its components from other companies (see Domberger, 1999), the American aircraft manufacturer Boeing currently outsources over 34,000 of the components that are assembled to create its 747 passenger aircraft (see Shy and Stenbacka, 2005), and 39 percent of Hewkett-Packard's notebook computers is attributed to contracted manufacturers (see Lo, 2011).

Coase's (1937) pioneering study on outsourcing explains firms' boundaries from the aspect of transaction costs and imperfect information. Following Coase (1937), Williamson (1975, 1985), Grossman and Hart (1986) and Hart and Moore (1990) discuss the factors that determine the boundaries of firms in the context of contractual incompleteness and asset specificity. Holmstrom and Roberts (1998) provide a detailed survey of research on the boundaries of the firms and focus on the importance of "hold-up" problems between transaction parties. Based on the literature indicated above, Grossman and Helpman (2002) develop a general equilibrium model to study the determinants of firms' equilibrium production modes (i.e., vertical integration vs.

outsourcing). Firms' "make or buy" decision is taken as a tradeoff between the additional governance costs associated with vertical integration and the transaction costs created due to searching and incomplete contracts associated with outsourcing. Grossman and Helpman (2005) use a similar framework to study the determinants of the location of subcontracted activity.

Rather than focusing on cost-saving motives, the literature of "strategic outsourcing" focuses on the role of strategic competition in firms' decision to choose a particular production mode. Shy and Stenbacka (2003) analyze how the market structure of the input-producing industry affects production efficiency in a differentiated final goods markets. Chen *et al.* (2004) identify the strategic incentive for international outsourcing and demonstrate that the trade liberalization in intermediate goods can lead to higher prices for both intermediate and final goods. Shy and Stenbacka (2005) discuss firms' outsourcing decisions when taking the monitoring costs and market structure into account. Arya *et al.* (2008) show that the vertically integrated producer may set a higher input price under Bertrand competition than under Cournot competition when the production of inputs is outsourced to retail rivals.

More recently, Antràs and Helpman (2004) incorporate inter-firm heterogeneity into firms' globalization decision and show that the high-productivity firms prefer FDI and the low-productivity firms prefer outsourcing. Grossman *et al.* (2005) focus on firms' foreign and domestic outsourcing decisions. Tomiura (2007) uses firm-level data to investigate how productivity varies with globalization modes in Japan. Ito *et al.* (2011) use the original survey data of Japanese firms to examine the relation between offshore outsourcing and productivity growth. Lo (2011) incorporates firms' R&D investment into Antràs and Helpman (2004) model and explains why Apple chooses outsourcing for the iPod instead of FDI. Harrison (2011) examined the empirical effects of offshoring on employment and wages of the home country. Lo (2014) uses a three-country model to investigate the wage gap and welfare effects of international outsourcing.

Regardless of whether firms' outsourcing decisions are based on cost-saving motives or strategic motives as discussed above, firms' decisions on whether to outsource also depend on the relative profitability of the organizational modes. The relative profitability depends not only on the economic environment but also on the relative prevalence of each mode, which adjusts over time as firms attempt to increase profits by switching modes. However, the literature still lacks a coherent framework for sorting out the interdependencies in the organizational decisions of individual firms.[1] Our paper applies an evolutionary game approach to provide such a framework in a dynamic setting.[2]

This paper focuses on firms' "make or buy" decisions and assumes that each final goods producer chooses between two organizational modes: vertical integration and outsourcing. We ignore some other potential organizational forms such as the Japanese *keiretsu* system (Fung 2002, Lin 2005, and Fung *et al.* 2013) in this study. The production of each final goods requires a specialized intermediate input. Vertically integrated firms are able to produce intermediate goods in ways that fit their needs more closely. However, such firms might have high production costs due to the lack of complete specialization. Outsourcing firms acquire the intermediate inputs they need from foreign input producers. Although outsourcing firms can acquire the intermediate inputs at lower costs, they have to face higher risk on quality. We assume that the defect rate of outsourcing firms' output is higher than the vertically integrated firms.

In addition to each organizational mode's strengths and weaknesses, there exists pecuniary diseconomy in outsourcing. The diseconomy arises when an increasing number of firms compete for foreign intermediate inputs whose supply is not perfectly elastic. Therefore, outsourcing firms' costs increase as their prevalence increases.

To put our analysis in a dynamic framework, we describe firms' choices as an evolutionary decision and define the relative prevalence of each mode as the state at a certain time. The state changes over time as firms switch between vertical integration and outsourcing. An individual firm switches if it can increase its profit, which depends not only on each mode's strength and weakness, but on how prevalent it is. We look for the evolutionary equilibrium in which no firm can increase its short run profits by unilaterally switching modes.

Our model allows us to examine in detail several determinants of firms' organizational choices. Our simulation results show that, when (1) the pecuniary diseconomy of outsourcing firm is small, (2) the cost advantage of an outsourcing firm is large, (3) the quality risk of outsourcing is small, or (4) the product substitutability of the two goods is low, outsourcing is more likely to be pervasive in the long run.

This paper is organized as follows. Section 2 lays out the basic model. Section 3 describes the evolutionary dynamics. In Section 4, we first examine what affects firms' choices between the two organizational modes. Then we look for the conditions under which one mode dominates the other and the conditions under which neither dominates.

The final section includes the concluding remarks.

2. The Model

Consider an industry with $N \geqslant 2$ final good producers. The production of final good requires a specialized intermediate input which can be either produced in house or purchase from outside. We define firms undertaking the production process in house as the vertically integrated firms and firms purchasing intermediate input from outside as outsourcing firms. For the sake of simplicity, we denote vertically integrated firms as mode V firms and outsourcing firms as mode U firms hereafter. We describe the final good producers' "make or buy" choice as a strategic interaction over time and define the relative prevalence of each mode as the state at a certain time. Suppose for the moment that sN of the firms are mode U firms and $(1-s)N$ of the firms are mode V firms, where $s \in [0,1]$.

The output quantity chosen by a mode V firm is x_V, and the output quantity chosen by a mode U firm is x_U. The goods produced by a mode V firm and a mode U firm are imperfect substitutes.

The market demand functions for good V and good U are given by:

$$\begin{aligned} P_V &= \alpha_V - \beta X_V - \gamma X_U \\ P_U &= \alpha_U - \beta X_U - \gamma X_V \end{aligned} \tag{1}$$

where $X_V = \sum x_{Vj}$ and $X_U = \sum x_{Uj}$ represent the total industry outputs for goods produced by mode V firms and mode U firms, respectively. α_V, α_U, β, and γ are positive parameters. β represents the own-price effect and γ represents the cross-price effect. We assume that $\beta \geq \gamma$.

The total fixed costs for both firms are assumed to be zero. The constant marginal cost for a mode V firm is c_V. The marginal cost for a mode U firm is $c_U + gs$, where $c_V \geq c_U$ reflects the diseconomies of scope due to the lack of specialization in the production process. The relative prevalence of the two modes affects the efficiency in the form of pecuniary diseconomy. The diseconomy arises when more and more firms compete for the foreign intermediate inputs whose supply is not perfectly elastic. Therefore, mode U firms' costs increase as their prevalence increases. The parameter g captures this pecuniary diseconomy in a simple linear fashion: mode U firms' costs increase at rate g as their prevalence s increases.

Quality is also a major concern if a firm is deciding whether to outsource. We suppose that quality and other particulars of specialized intermediate goods are difficult to describe or verify. Eddie Maxie, vice president of acquisitions for Digital Equipment Corp.'s PC Business Unit, says that "outsourcing looks attractive, but are outside manufacturers cutting corners on quality?'' Mel Friedman, the vice president of corporate supplier management for Sun Micro systems, says the risk of an OEM outsources is that its "quality reputation can end up in the hands of a third party because the product may not come to the OEM's factory floor but be shipped directly to the customer.'' We simply use a defect rate, d, to capture the risk in quality that outsourcing firms face, where $0 < d < 1$.

From the situation illustrated above, we can write the respective objective functions for a mode V and a mode U firms as

$$\max_{x_V} \pi_V = P_V x_V - c_V x_V$$

$$\max_{x_U} \pi_U = P_U (1-d) x_U - (c_U + gs) x_U \tag{2}$$

Substituting the market demand for good V and good U into the equations above, the objective functions can be rewritten as:

$$\max_{x_V} \pi_V = [\alpha_V - \beta(\hat{X}_V + x_V) - \gamma X_U] x_V - c_V x_V$$

$$\max_{x_U} \pi_U = [\alpha_U - \beta(\hat{X}_U + x_U) - \gamma X_V](1-d) x_U - (c_U + gs)\mathrm{x_U} \tag{3}$$

where $X_V = X_V - x_V$ and $\hat{X}_U = X_U - x_U$.

The first-order conditions of the profit maximization are the following:

$$[\alpha_V - \beta(\hat{X}_V + x_V) - \gamma X_U] - \beta x_V - c_V = 0$$

$$[\alpha_U - \beta(\hat{X}_U + x_U) - \gamma X_V](1-d) - \beta(1-d) x_U - (c_U + gs) = 0 \tag{4}$$

In equilibrium, the symmetric Cournot-Nash outputs are given by:

$$x_V = \frac{(1+sN)(1-d)\beta(\alpha_V - c_V) - \gamma sN\{[(1-d)\alpha_U - c_U] - gs\}}{D}$$

$$x_U = \frac{[1+(1-s)N]\beta[(1-d)\alpha_U - c_U - gs] - \gamma(1-s)(1-d)N(\alpha_V - c_V)}{D} \tag{5}$$

where $D = (1-d)\{(1+sN)[(1-s)N+1]\beta^2 - sN(1-s)N\gamma^2\}$. Eq. (4) can be written as

$$P_V - c_V = \beta x_V \tag{6}$$

$$P_U(1-d) - (c_U + gs) = \beta(1-d)x_U \tag{7}$$

Multiplying both sides of Eq. (6) and Eq. (7) by x_V and x_U respectively, we can express the respective short-run equilibrium profits for the mode V firm and the mode U firm as

$$\pi_V = \beta(x_V)^2 \tag{8}$$

$$\pi_U = \beta(1-d)(x_U)^2 \tag{9}$$

3. Evolutionary Dynamics

Firms' "make or buy" decisions are described as an evolutionary game, and the relative prevalence of each mode is defined as the state at a certain time. In this Cournot-Nash parametric model, a feasible environment (with a fixed number N of firms) is a six-component vector in the set $Z = \{(\alpha, \beta, \gamma, c, g, d) \in R^6 : \alpha > c \geq 0, \beta \geq \gamma > 0, 1 > d > 0, g \geq 0\}$. For specified values of the environment $z \in Z$, the short run profits can be expressed as a function of the fraction s of mode U firms.

A state s is a Nash equilibrium (NE) if no firms can gain by switching modes at s. The condition can be written as $\pi_D(s;z) = 0$ for $s \in (0,1)$, and as $\pi_D(s;z) \leq 0$ for $s = 0$ or $\pi_D(s;z) \geq 0$ for $s = 1$ where $\pi_D(s;z) = \pi_U(s;z) - \pi_V(s;z)$. A state s is a steady state if there is no tendency to change over time. However, the steady state is not necessarily stable. When the state is not stable, it will evolve to the evolutionary equilibrium (EE) in the long run if there is even a tiny amount of noise (or shock) in the system. For example, at state $s = s_1$ in Figure 1, mode V and mode U are equally profitable, so there is no reason for firms to switch modes. Thus, s_1 is a steady state. However, mode V is more profitable at states s even slightly above s_1, and mode U is more profitable at states s even slightly below s_1. Therefore, s_1 is unstable, and we are unlikely to observe it after the state has a chance to evolve. The EEs in Figure 1 are $s = 0$ and $s = 1$. In this case, all firms in the country will adopt the same mode eventually, either all V or all U depending on the initial conditions.

The essence of biological evolution is the "survival of the fittest" requirement. The economic analogue is that fitter strategies increase relative to less fit strategies. Friedman (1991) calls this principle "compatibility", which implies a relationship between fitness (or payoff) function f and the corresponding dynamics $\dot{s} = F(s)$. According to Friedman and Fung (1996), there are four ways to specify the compatibility for the rates of change $\dot{s}$. From the strongest to weakest, the specifications of $\dot{s}$ are (1) proportional to relative fitness, (2) have the same rank-order as relative fitness, (3) have the same signs as relative fitness, or (4) are positively correlated with relative fitness. In our model, the "survival of the fittest" requirements imply that the more profitable mode becomes more prevalent over time. The evolutionary path $\dot{s}$ satisfies the ordinary differential equation $\dot{s} = F(s; z)$, where $\operatorname{sgn} F(s;z) = \operatorname{sgn} \pi_D(s;z)$.[5]

A state $s \in S$ is an evolutionary equilibria if $sgn(s-r) = sgnF(r;z)$ for all $r \in [0,1]$ that are sufficiently close to s. The EE can be seen as the refinement of the Nash equilibrium since they are a subset of the steady states. Moreover, by definition, each evolutionary path starting at a point r near an EE s will converge to s. The basin of attraction of an EE s is the set containing all points that eventually evolve to s.[6]

4. The Results

4.1 The Pecuniary Diseconomy

As discussed in the simple model, the interdependency of efficiency and the relative prevalence is directly captured by the pecuniary diseconomy, g. This diseconomy arises when more and more firms compete for the foreign intermediate inputs whose supply is not perfectly elastic.

The strength of g is highly correlated with the thickness of the input market. When there are few input producers (the supply elasticity of the specialized input is small), the greater prevalence of mode U firms leads to tighter competition in the input market, and the mode U firms' costs increase at a higher rate, *g*. On the other hand, when there are many input producers (the supply of the specialized input approaches perfect elasticity), the cost externality may be small (or negligible), and the value of *g* is small.

Figure 2 shows the relative profitability of the two types of firms under the different values of *g*. When g small (say, *g=1*), mode U firms are more profitable in all $s \in [0,1]$. The only EE is $s = 1$, i.e., eventually all firms adopt the U mode. However, when g increases to 5, the unique EE is the interior equal profit point $\hat{s}_{g=5}$. In other words, there is a stable mixture of $100\hat{s}_{g=5}\%$ mode U firms and $100(1-\hat{s}_{g=5})\%$ mode V firms in this case. When g increases further to 15, the unique EE is the interior equal profit point $s\%_{g=15}$, where $1 > \hat{s}_{g=5} > \hat{s}_{g=15} > 0$. Figure 3 is 3D plot of *s*, *g*, and π. The intersection of surface π_V and π_U shows the path of evolutionary equilibrium when *d* is from *1* to *20*. The simulation results suggest that a *ceteris paribus* increase in *g* decreases the relative prevalence of mode *U* firms in the evolutionary equilibrium.

4.2 The Production Cost

Without the pecuniary diseconomy, the production cost for a mode *V* firm is higher due to the lack of a complete specialization. Figure 4 and Figure 5 examine the case when the cost advantage for a mode *U* firm is decreasing. From Figure 4, we can see that, when the cost advantage of a mode *U* firm is large enough, a mode *U* firm is more profitable than a mode *V* firm at all states. The unique EE in this case is *s=1*, even in the presence of the pecuniary externality and the higher defect rate. When the cost advantage for mode *U* firms falls, mode *U* firms are more profitable at the states of $s \in (0.5,1]$, and the interior equal profit point $s = 0.5$ is the unique EE. The coexistence of mode *V* firms and mode *U* firms are observed in the long run. When the cost advantage is small, the impacts of the pecuniary diseconomy dominate the cost advantage of mode *U* firms. In this case, mode *V* firms are more profitable than mode *U* firms at all states, so the unique EE is $s = 0$. The path of evolutionary equilibrium is demonstrated in Figure 5. The results suggest that a *ceteris paribus* increase in c_U decreases the profitability of mode *U* firms and decreases their relative prevalence in the evolutionary equilibrium.

4.3 The Defect Rate

We now return to the setting in which quality and other particulars of the specialized intermediate goods are only partially verifiable. We use defect rate *d* to capture the risk in quality that outsourcing firms face. Figure 6 provides the simulation of how change in *d* affects the relative profitability and *EE* in the long run. Figure 7 is 3D plot of *s*, *d*, and π. We find that, when *d* is small, the cost advantage of the outsourcing firms makes mode *U* firms more profitable at all states $s \in [0,1]$. The unique *EE* is $s = 1$, *i.e.*, all firms adopt *U* mode in the long run. While *d* increases, the *EE* comes to an interior equal profit point $\hat{s}$, i.e., both mode *V* firms and mode *U* firms coexist in the system. When *d* increases further, the profit for a mode *V* firm is higher at all states $s \in [0,1]$. The only EE in this case is $s = 0$, *i.e.*, eventually all firms adopt the *V* mode. The results suggest that a *ceteris paribus* increase in *d* decreases the profitability of mode *U* firms and decreases their relative prevalence in the evolutionary equilibrium.

4.4 The Product Substitutability

Figure 8 and Figure 9 examine the case when the two goods move from low substitutability to high substitutability. Starting from low substitutability, $\gamma = 0.8$, the only EE is $\hat{s}_{\gamma=0.8}$, *i.e.*, there is a mixture in the system. With $\gamma = 0.9$ (fairly substitutable goods), the only EE is still an interior equal profit point which implies that fewer firms will adopt *U* mode in the long run. With $\gamma = 0.98$ (highly substitutable goods), the only EE is the left corner, $s = 0$.[7] All firms adopt the *V* mode in the long run. The results suggest that a *ceteris paribus* increase in the product substitutability reduces the profitability of mode *U* firms and decreases their relative prevalence in the evolutionary equilibrium.

5. Concluding Remarks

The existing literature has examined the prevalence of outsourcing. The causes and the consequences of outsourcing have also been discussed. However, the literature still lacks a coherent framework for sorting out the interdependencies in the organizational decisions of individual firms. This paper applies an evolutionary game approach to provide such a framework in a dynamic setting.

Our model allows us to examine in detail several determinants of firms' organizational choices. Our simulation results show that, when (1) the pecuniary diseconomy of outsourcing firm is small, (2) the cost advantage of an outsourcing firm is large, (3) the quality risk of outsourcing is small, or (4) the product substitutability of the two goods is low, outsourcing is more likely to be pervasive in the long run.

This paper applies a dynamic evolutionary approach to an issue that has been analyzed in various static models. The results not only extend some standard conclusions in the literature but also offer a contribution to the literature on evolutionary games and adjustment dynamics.

Endnotes

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1. Mol and Kotabe (2011) use statistical evidence to analyze the slow occurrence of outsourcing process in the face of environment change. Chen *et al.* (2015) use a three-stage dynamic game framework to model the outsourcing firms' quality investment. But the focuses of their papers are very different from ours.
2. Friedman and Fung (1996) apply an evolutionary game approach to analyze firms' organizational choice between American mode and Japanese mode. Lin (2005) uses this framework to analyze how changes in the economic environments and firms' interdependencies affect firms' choices of internal organizational modes.
3. See Williamson (1985), McAfee and McMillan (1995), and Grossman and Helpman (2002).
4. Grossman and Helpman (2005) emphasize the effects of the thickness of markets on the search cost.
5. For example, $F(s;z) = \upsilon\pi_D$.
6. See Friedman (1991) and Friedman and Fung (1996) for detailed discussions on EE.
7. For simplicity, we assume $\beta = 1$ here.

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Figure 1. An Example of the Basin of Attraction

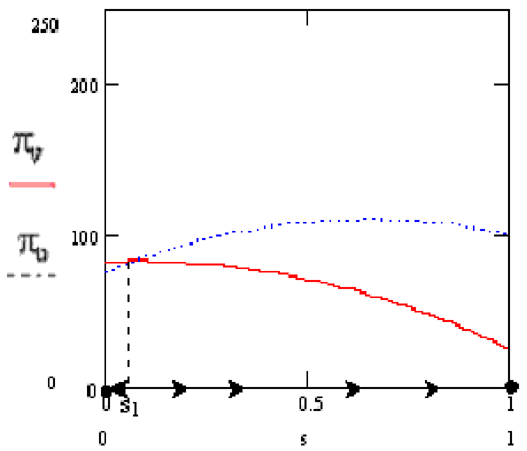


Figure 2. The Change of the Pecuniary Diseconomy

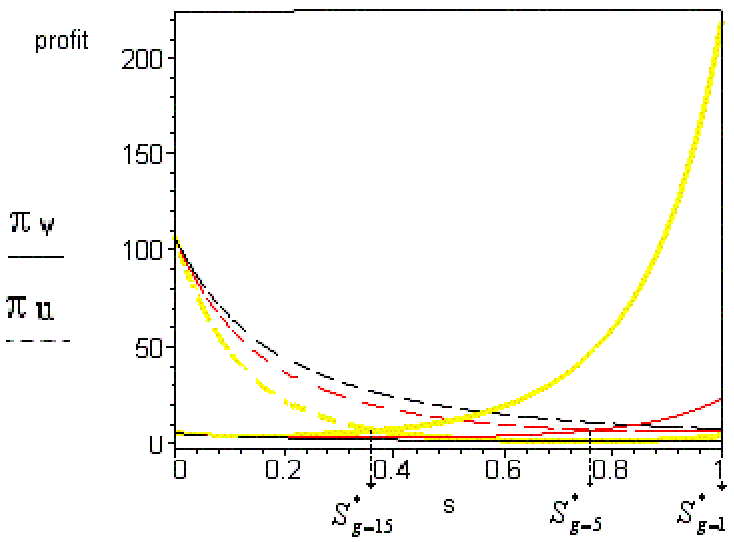


Figure 3. The 3-D Plot of the Pecuniary Diseconomy and the Relative Prevalence

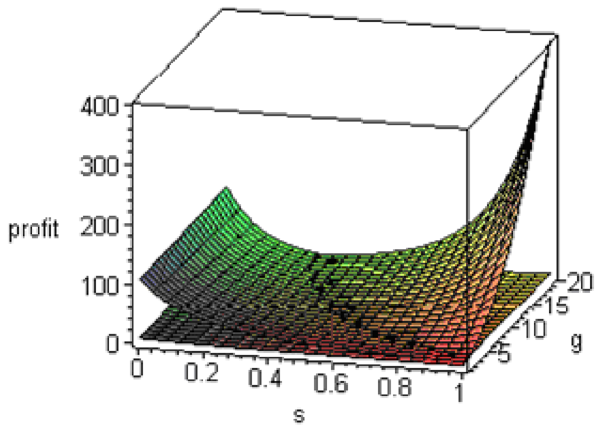


Figure 4. The Change of the Production Cost

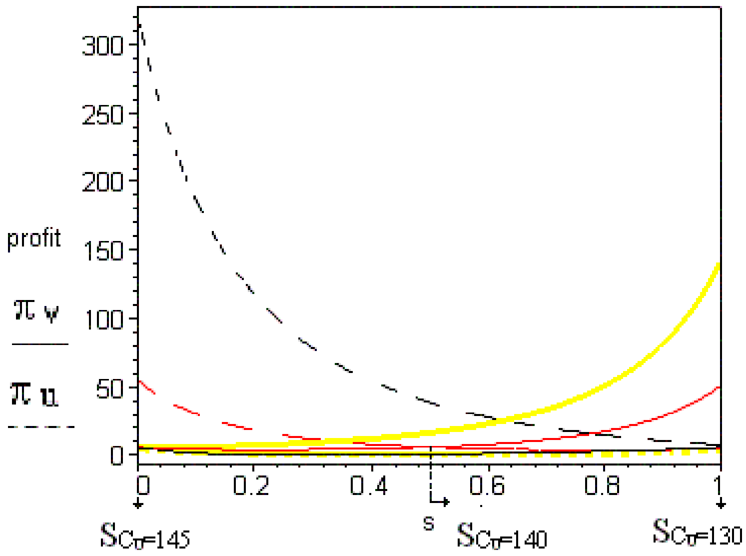


Figure 5. The 3-D Plot of the Production Cost and the Relative Prevalence

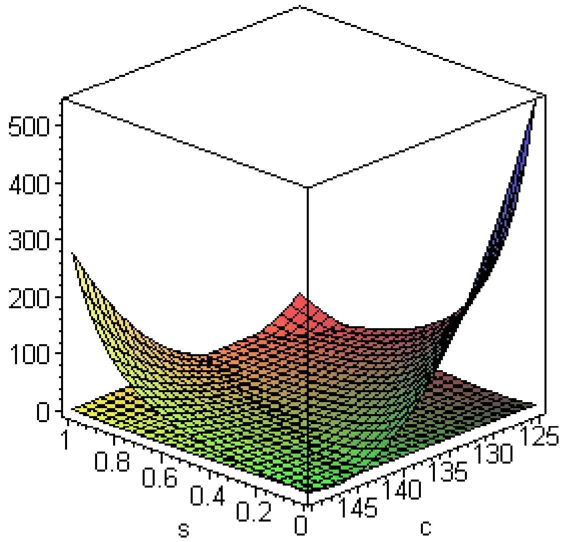
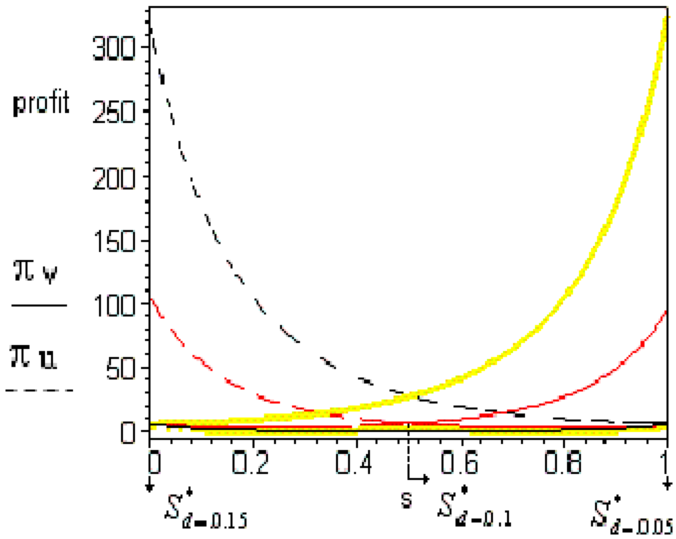


Figure 6. The Change of the Defect Rate



Fung and Lin, International Journal of Applied Economics, 13(2), September 2016, 1-18

Figure 7. The 3-D Plot of the Defect Rate and the Relative Prevalence

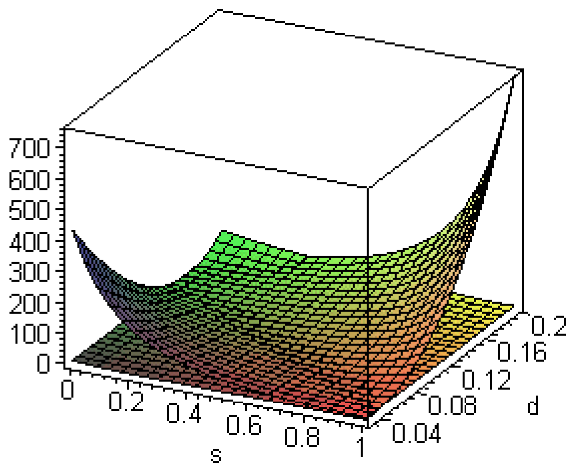
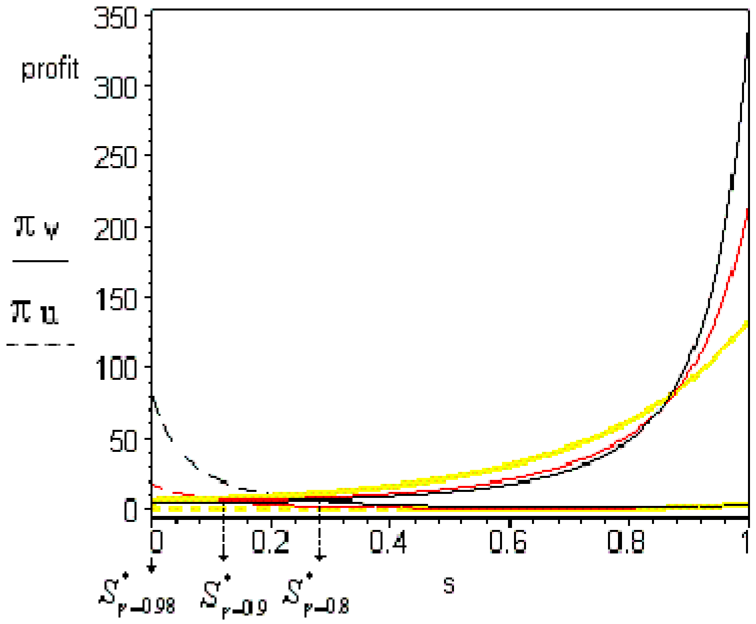


Figure 8. The Change of the Product Substitutability



Fung and Lin, International Journal of Applied Economics, 13(2), September 2016, 1-18

Figure 9. The 3-D Plot of the Product Substitutability and the Relative Prevalence