"STRATEGIC CHOICE OF FLEXIBLE PRODUCTION TECHNOLOGIES AND WELFARE IMPLICATIONS"

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Strategic Choice of Flexible Production Technologies and Welfare Implications

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Abstract

This paper examines the market conditions under which firms would choose a more flexible production technology with respect to product design. We use a two-stage game in which firms choose between flexible and less flexible production technologies in the first stage and subsequently choose output. We find conditions under which firms choose the flexible production option purely for strategic reasons, foresaking profits. In other words, the production technology game can be a Prisoner's Dilemma. Consumers, on the other hand, always benefit from the introduction of flexible production technologies. We derive the conditions under which the resulting equilibria are efficient.

1 Introduction

Hundreds of large manufacturing firms have faced the decision of whether or not to invest into what is known as flexible manufacturing systems (FMS). Examples of implementations of these new systems abound in the automobile, machine tool, aerospace, heavy machinery, electronics and military equipment industries. The decision process of whether to adopt an FMS has widespread implications for industry structure (see Mills and Schumann, 1985), international competitiveness, and labour markets. The highly competitive Japanese have the largest number of FMS implementations (see Economic Commission for Europe, 1986).

We focus on the choice between two types of production technologies, an FMS, and a less flexible technology referred to as dedicated equipment (DE). Because the new flexible systems are capable of being reprogrammed quickly, the potential scope of products manufactured by these systems is much greater than that of the dedicated machines (see Jaikumar, 1986). The cost of the equipment including the computer that controls an FMS, however, is often greater than that of dedicated systems.

Most of the current literature examines flexibility with respect to changes in scale. Stigler (1939) described flexibility as the attribute of cost curves that determines how responsive output decisions are to price fluctuations. In other words, flexibility is obtained by the ability to transfer the input factors from the fixed to the variable category. Marschak and Nelson (1962) argue that Stigler's concept of flexibility is one that varies inversely with the slope of the marginal cost curve. Mills (1984), makes use of this concept and proves that with an increase in the variance in demand firms will choose to increase the level of flexibility. Vives (1986) shows that in equilibrium, when firms switch from an inflexible to a flexible technology, the price ranges from the Cournot price to the Bertrand price. The choice between flexible or inflexible technologies has also been analyzed by Kulatilaka and Marks (1988). They define production flexibility as the ability to shift between labor-intensive and capital-intensive technologies. The type of flexibility considered here, however, is the ability to shift between different products, i.e. flexibility with respect to scope.

This paper analyzes the strategic implications of production technology choice in a game theoretic setting. We model this choice by having two firms simultaneously commit to a production technology in the first phase of the game. There are two differentiated products, each characterized by a linear demand function, with a positive cross-price effect. If a firm chooses to invest in the FMS technology, it can produce both products, whereas a DE technology limits the production possibility to only one of the two products. Given a set of technologies chosen by the firms in the first phase, a second phase of Cournot quantity competition in each of the product markets completes the model. We seek a subgame-perfect equilibrium in such a game.

The main goal of our analysis is to gain insight into which basic market forces drive certain industries into adopting FMS technologies. In other words, we are interested in the determinants of the technology choice. In particular, we analyze the impact of market fundamentals such as consumer perceptions, fixed costs of production, and market profitability on the resulting equilibrium outcome. We find that when consumers perceive the markets for different products being more related, the industry is driven to adopt FMS. Furthermore, as the markets become more profitable and as the distinction between the fixed costs of the two technologies diminishes, there is increased incentive to adopt FMS.

The second contribution of the paper concerns the welfare implications of our model. In general, we find that the same market forces that would push firms towards adoption of FMS will tend to ensure that total welfare is maximized as well. Under certain circumstances producers find themselves in a Prisoner's Dilemma, i.e. they would all invest into FMS purely for strategic reasons, resulting in a reduction in profits. Under these conditions the introduction of new flexible technologies for strategic purposes yields a transfer of welfare from producers to consumers.

The paper is organized as follows. In §2 we discuss the specifications of the general model and the assumptions incorporated therein. Section 3 presents the solutions of the game and interpretes the results. The welfare implications of the game are then analyzed in §4. In §5 we summarize the results of the study.

2 Specification of the Model

We model the the technology-quantity choice as a two-stage sequential duopoly game of complete information. In the first stage, firms simultaneously choose between a flexible production technology (denoted FMS) and a more inflexible product dedicated technology (denoted DE). In the second stage a Cournot game in quantities is played. Two markets exist, one for product A, and one for product B. The flexible manufacturing technology allows a firm to participate in both markets (i.e. the equipment is capable of producing both product A and product B) whereas the inflexible technology limits the firm to producing either product A or B.

We characterize the demand in the two markets in the following symmetric way:

$$P^A = \alpha - \beta Q^A + \lambda Q^B$$

and

$$P^B = \alpha - \beta Q^B + \lambda Q^A$$

where

P^A, P^B = the prices for products A, and B, respectively
Q^A, Q^B = the total quantities for products A, and B, respectively
λ = a measure of cross price effect of demand.

We assume that markets are symmetric in order to avoid any fortuitous differences in demand conditions and also to simplify the solution. We interpret the above parameter λ as a measure of consumer perceptions - to what degree they distinguish between the product characteristics of A and B other than price. We assume that the two products are gross substitutes and that the own price effect dominates the cross price effect, i.e. that $\beta \geq \lambda$ and $\lambda \geq 0$.

The second stage payoff functions are then:

$$\pi_{i,j} = P^A Q^A_{i,j} + P^B Q^B_{i,j} - F_k - C(Q^A_{i,j} + Q^B_{i,j})$$

where
- i denotes the firm (i=1 or 2)

- j denotes the state of the industry in terms of production technologies. j=1 when both firms invest in FMS referred to as (FMS, FMS), j=2 when firm 1 invests in FMS and firm 2 in DE denoted, (FMS,DE), j=3 when firm 1 invests in DE and firm 2 in FMS, (DE, FMS), and j=4 when both firms invest in DE, (DE, DE)).

- $\pi_{i,j}$ is the payoff to firm i in the second stage Cournot game in the two markets, given that the firms are in state j.

- $Q^A_{i,j}, Q^B_{i,j}$ are the quantities chosen by firm i in state j for markets A, and B, respectively. In order to capture the idea that the choice of DE limits the firm to one of two markets, we set without loss of generality, $Q^B_{1,2} = 0$ and $Q^B_{2,3} = 0$ (i.e. firms with DE technology can serve only market A). [1] If both firms choose DE (j=4) then one firm will enter market A and the other will enter market B (we set $Q^B_{1,4} = Q^A_{2,4} = 0$). This simplifies the game without loss of generality because entering the same market in state 4 cannot be a Nash equilibrium.

- F_k = the fixed costs of the firm associated with the chosen technology k (either FMS or DE). We let $F_{FMS} \geq F_{DE}$ to keep the analysis nontrivial and realistic[2]

- C = the marginal costs of the firm.

We have assumed in the above expression that the fixed costs and marginal costs of firms using the same technology are equal. Hence we have dispensed with any firm subscripts for F and C. We also assume that marginal costs are equal for both technologies. [3] In order to focus the anal-

[1] Alternatively $Q^A_{1,2}$ or $Q^A_{2,3} = 0$ could have been set to zero and the following results will still hold due to symmetry in the markets.

[2] The development costs of FMS are higher than that of DE (see, Jaikumar, 1986).

[3] This assumption is motivated by empirical observation see, for example, the cases referred to in, Boothroyd, (1982) and the Economic Commission for Europe (1986). In

ysis in terms of the three market characteristics defined below, we make the following simplifying assumptions without loss of generality:

$$\beta = 1, \qquad F_{DE} = 1,$$

As a result, $\pi_{1,1} = \pi_{2,1}$, $\pi_{1,4} = \pi_{2,4}$, $\pi_{1,3} = \pi_{2,2}$, and $\pi_{1,2} = \pi_{2,3}$.

Since we wish to investigate which market forces influence the adoption of FMS technologies and how they exert their influence we focus on three market fundamentals. In addition to λ, we define a measure of market profitability by $\alpha = C + t$ where t (≥ 0) is our measure of industry profitability. The third determinant of market outcome is a measure of the difference in fixed costs between an FMS and a DE technology. We set $F_{FMS} = 1 + s$, where s ($\geq$ 0) is the difference in fixed costs between the two technologies. As a result, our solutions are in terms of industry profitability (t), the differences in fixed costs (s), and the consumer perception parameter (λ).

In the first stage of the game the firms simultaneously choose the production technology. This stage of the game is illustrated in Figure 1.

general the marginal cost differences are small when the production lot sizes and the product variety for the production system are in the middle to high range.

		Firm 2	
		FMS	DE
Firm 1	FMS	π_{11}, π_{21}	π_{12}, π_{22}
	DE	π_{13}, π_{23}	π_{14}, π_{24}

Figure 1 The Production Technology Game

In Figure 1 π_{ij} is the payoff to firm i from the second stage Cournot game in the two markets, given that the firms are in state j. If a firm is indifferent between technologies then it will choose FMS (a tiebreaking rule).

We choose not to analyze issues involving entry deterrence in this paper. We do so not because this is an unimportant or irrelevant issue, but because entry deterrence with FMS is a complex phenomenon, separate from the analysis of this paper. We therefore assume that it is always profitable to enter. In the language of Bain (1956), we assume "easy entry".

3 Characterization of the Equilibria

The equilibrium concept we use for the game in Figure 1 is subgame perfection (see Selten, 1975), denoted SPE. In our analysis we will concentrate on three possible equilibria. First, (FMS, FMS) in which both firms choose flexible production technologies and enter both markets. Second (DE, DE) where both firms choose not to invest in flexible technologies and consequently enter seperate markets. Third, the "mixed" case, where one firm chooses a flexible technology and the other firm does not. For each equilibrium we first solve the second stage Cournot quantity game for the two markets A and B. The solutions to this second-stage are then substituted into the payoff functions to give us our π^*_{ij}'s for all possible states (j) of the first stage production technology game.

3.1 The (FMS, FMS) Equilibrium

From Figure 1 we see that (FMS, FMS) is an equilibrium when

(1) $$\pi^*_{21} - \pi^*_{22} \geq 0 \quad \text{and} \quad \pi^*_{11} - \pi^*_{13} \geq 0.$$

For the model outlined in the previous section we can write (1) as:

(2) $$\frac{1}{9}\Big(\frac{t^2+\lambda t^2-9s+9\lambda s}{1-\lambda}\Big) \geq 0.$$

From the above condition one can see that strategic incentives move the market to adopt FMS when λ and t are high and when s is low. One can interpret a high λ as the situation in which the two products are perceived by consumers as being close substitutes. When this is the case any firm choosing DE automatically locks themselves out of almost half of the market, hence the natural tendency to invest in a FMS. A high t reflects a high industry profitability, encouraging more active participation in both markets. A high s is indicative of the fixed costs of the FMS being much greater than the fixed costs of the DE ($F_{FMS} \gg F_{DE}$). This would lead to the result that firms are discouraged from investing in FMS.

3.2 The (DE, DE) Equilibrium

Similarly, the conditions for (DE, DE) to be an equilibrium for the game in Figure 1 are:

(3) $\pi^*_{23} - \pi^*_{24} < 0$, and $\pi^*_{14} - \pi^*_{12} > 0$.

These conditions imply that

(4) $$\frac{1}{36}\left(\frac{16t^2+5t^2\lambda^3-7\lambda^2t^2+4t^2\lambda-180\lambda^2s+288\lambda s+36\lambda^3s-144s}{(1-\lambda)(\lambda-2)^2}\right) < 0.$$

As one would expect, these conditions yield market λ's, t's, and s's that lie at opposite ends of their respective ranges from the conditions for (FMS, FMS). Consequently, for low λ's, low t's, and high s's (DE, DE) will be the resulting SPE.

3.3 Mixed Equilibria (FMS, DE) or, (DE, FMS)

Finally, (FMS, DE) is an equilibrium when

(5) $\pi^*_{21} - \pi^*_{22} < 0$, and $\pi^*_{12} - \pi^*_{14} \geq 0$,

and (DE, FMS) is an equilibrium when

(6) $\pi^*_{13} - \pi^*_{11} < 0$, and $\pi^*_{23} - \pi^*_{24} \geq 0$.

Both the condition sets (5) and (6) imply that

$$\frac{1}{9}\left(\frac{t^2 + \lambda t^2 - 9s + 9\lambda s}{1-\lambda}\right) < 0$$

and

$$\frac{1}{36}\left(\frac{16t^2 + 5t^2\lambda^3 - 7\lambda^2 t^2 + 4t^2\lambda - 180\lambda^2 s + 288\lambda s + 36\lambda^3 s - 144s}{(1-\lambda)(\lambda-2)^2}\right) \geq 0.$$

These equilibria would result from our market fundamentals being in a region between conditions (2) and (4). This gives us the intuitive result that asymmetric equilibria are likely to occur when the relative values of λ and t are high enough and s relatively low enough to support only one firm switching to FMS.

The three regions in λ, t parameter space, where the above conditions for equilibria hold, are shown in Figure 2 for a value of s = 100.

Figure 2 here

The line seperating the (FMS, FMS) equilibria from the mixed equilibria is given by (2). Since (2) is increasing in λ and t, it follows that all parameter configurations to the right and above (2) represent (FMS, FMS) equilibria. Similarly, the regions for (DE, DE) and mixed equilibria are seperated by (4). Since the function (4) is decreasing in λ and t it follows that (DE, DE) is the equilibrium for all parameter configurations below and to the left. Consequently, all mixed equilibria are between (2) and (4).

4 Welfare Implications

Due to the linear demand functions, the consumer surplus in both markets for a given technology state j is given by:

$$CS_j = \frac{1}{2}((Q_j^{A*})^2 + (Q_j^{B*})^2)$$

where
Q_j^{A*}, Q_j^{B*} = the total equilibrium quantities supplied of products A and B, respectively.

Table 1 gives the expressions in λ, t, s for consumer surplus in each of the equilibrium states.

Equilibrium	$CS_j(\lambda, t, s)$
(FMS, FMS)	$\frac{4t^2}{9(\lambda-1)^2}$
MIXED (j=2 or 3)	$\frac{25t^2+\lambda^2t^2-8\lambda t^2}{72(\lambda-1)^2}$
(DE, DE)	$\frac{t}{(\lambda-2)^2}$

Table 1 Consumers Surplus

Proposition 1 *Consumer surplus is highest in an (FMS, FMS) equilibrium and lowest in an (DE, DE) equilibrium.*

Proof:

All the consumer surplus expressions given in Table 1 are increasing in λ and t. For CS_1 and CS_4 the derivatives are trivial. The derivative with respect to λ for the consumers surplus in the mixed equilibria is:

$$\frac{\partial CS_{MIXED}}{\partial \lambda} = \frac{t^2(\lambda - 7)}{12(\lambda - 1)^3}$$

which is also positive. Since (FMS,FMS) is an equilibrium for high λ's and t's we need only to show that CS_1 is highest when (2) is an equality (the lower bounds of λ and t obtaining an (FMS, FMS)). To obtain a complete ranking we show that CS_4 is less than CS_{MIXED} when (4) is an equality.

From Table 1 we can derive:

$$CS_1 - CS_{MIXED} = \frac{t^2(7 - \lambda^2 + 8\lambda)}{72(\lambda - 1)^2},$$

$$CS_1 - CS_4 = \frac{t^2(\lambda + 1)(7 - 5\lambda)}{9(\lambda - 1)^2(\lambda - 2)^2}$$

and

$$CS_{MIXED} - CS_4 = \frac{t^2(-11\lambda^2 + 12\lambda + 28 + \lambda^4 - 12\lambda^3)}{72(\lambda - 1)^2(\lambda - 2)^2}$$

All of the above expressions are ≥ 0 for all λ, t and s. Thus, CS_1 is highest when (2) is an equality and CS_4 is lowest when (4) is an equality.

Q.E.D.

The above proposition shows that consumers benefit if λ, t, and s are changed such that FMS technologies are adopted. For example, if the government subsidized FMS technologies, thereby reducing s, consumer welfare increases if the subsidy leads to new introductions of FMS. The above proof is based on a comparison of consumer surplus over different equilibria. However, one could also make the comparison over just second stage equilibria. In other words, what technology choice would consumers prefer for a given λ, t, and s.

Corollary 1 *Given any state of the market consumer surplus is highest when firms utilize FMS and lowest when firms use DE.*

Proof:

As we have shown in the proof of Proposition 1 $CS_1 \geq CS_{MIXED}$, $CS_1 \geq CS_4$, and $CS_{MIXED} \geq CS_4$ for all λ, t, and s.

Q.E.D.

This corollary shows that consumers benefit from FMS introductions even if (DE, DE) is the equilibrium. For example, by simply eliminating the DE option from the first stage of the game consumer welfare increases.

Next we analyze strategic incentives by examining the firms' payoffs for each equilibrium. Table 2 provides the expressions for producer surplus for λ, t, s (i.e. the sum of the second stage equilibrium payoffs).

Equilibrium	$PS_j(\lambda, t, s)$
(FMS, FMS)	$\frac{2(-2t^2-9\lambda s+9s-9\lambda+9)}{9(\lambda-1)}$
MIXED (j=2 or 3)	$\frac{-\lambda t^2-17t^2-36\lambda s+36s-72\lambda+72}{36(\lambda-1)}$
(DE, DE)	$\frac{2(t+\lambda-2)(t-\lambda+2)}{(\lambda-2)^2}$

Table 2 Producers Surplus

Proposition 2 *There exists λ, t, and s's such that both firms invest in FMS for strategic reasons although it is suboptimal for them to do so. In this situation the production technology game is a Prisoner's Dilemma.*

Proof:

From the expressions in Table 2 we obtain:

$$(7) \qquad PS_4 - PS_1 = \frac{2(\lambda t^2 - t^2 + 2\lambda^2 t^2 + 9\lambda^3 s - 45\lambda^2 s + 72\lambda s - 36s)}{9(\lambda-2)^2(\lambda-1)}$$

When (7) > 0, and Condition (2) holds the production technology is a Prisoners' Dilemma. Condition (2) holds when,

$$\lambda = \lambda^* \geq \frac{9s - t^2}{t^2 + 9s}$$

Substituting the lower bound λ^* for λ into (7) we obtain,

$$PS_4 - PS_1 = \frac{8t^2 s(t^2 + 6s)}{3(t^2 + 3s)^2}$$

which is > 0 for all t, s. Consequently, there always exists an area in the parameter space where the production technology game is a Prisoners' Dilemma.

Q.E.D.

Proposition 2 is illustrated in Figure 3 for a given t and s. Figure 3 shows the average of the firms payoffs as a function of λ for each of the equilibria. λ^* is the lower bound of λ which makes (FMS, FMS) the equilibrium (i.e. where (2) $= 0$). λ^{**} is the point at which the equilibrium changes from (DE, DE) to mixed (i.e. where (4) $= 0$). When λ is between λ^* and λ' then (FMS, FMS) is the equilibrium but (DE, DE) would give the firms a higher payoff. If market parameters are in this region the firms are in a Prisoners' Dilemma.

The questions then arise as to whether and how firms can break the Prisoner's Dilemma. Firms may be able to change λ through advertising, thereby differentiating their products and segmenting the market. If λ is reduced the payoff structure could be altered such that (DE, DE) becomes the equilibrium, and the Prisoner's Dilemma is then broken. Alternatively, there is an incentive to increase λ since this would increase the payoffs to the firms within the (FMS, FMS) equilibrium.

Whether or not it is optimal for firms to reduce λ is not clear. If the costs of changing λ were zero, firms would maximize their profits by choosing FMS and making $\lambda \to 1$.[4] If the costs of changing λ were positive then a firm engaged in a market where λ was less than λ'' (as depicted in Figure 3) would either reduce λ to the point where the equilibrium would change or would increase λ to increase profits within the same equilibrium.

[4] it can be shown that $\frac{\partial PS_j}{\partial \lambda} \geq 0$ for all j

Figure 3 here

We next turn to analyzing the production technology effects on the total surplus. The total surplus in both markets for a given technology state j is given by:

$$TS_j = \alpha(Q_j^{A*} + Q_j^{B*}) - \frac{1}{2}((Q_j^{A*})^2 + (Q_j^{B*})^2) + 2\lambda Q_j^{A*} Q_j^{B*}$$

Table 3 gives the expressions in λ, t, s for total surplus in each of the equilibrium states.

Equilibrium	$TS_j(\lambda, t, s)$
(FMS, FMS)	$\frac{2(4t^2-2\lambda t^2-9\lambda^2 s+18\lambda s-9\lambda^2+18\lambda-9s-9)}{9(\lambda-1)^2}$
Mixed	$\frac{(59t^2-\lambda^2 t^2-40\lambda t^2-72\lambda^2 s+144\lambda s-144\lambda^2+288\lambda-72s-144)}{72(\lambda-1)^2}$
(DE, DE)	$\frac{(3t^2-2\lambda^2+8\lambda-8)}{(\lambda-2)^2}$

Table 3 Total Surplus

Proposition 3 *(FMS, FMS) is the efficient market outcome when λ, and t, are high and s is low.*

Proof:

For (FMS, FMS) to be efficient we must show that TS_1 is greater than either TS_{MIXED} or TS_4. From Table 3 we can obtain:

$$(8) \qquad TS_1 - TS_{MIXED} = \frac{5t^2+8\lambda t^2-72\lambda^2 s+144\lambda s-72s+\lambda^2 t^2}{72(\lambda-1)^2}$$

and

$$(9) \quad TS_1 - TS_4 =$$
$$\frac{-3\lambda^2 t^2 + 6\lambda t^2 + 5t^2 + 4t^2\lambda^3 - 18\lambda^4 s + 108\lambda^3 s - 234\lambda^2 + 216\lambda s - 72s}{9(\lambda-1)^2(\lambda-2)^2}$$

both of which are ≥ 0 when λ and t are high and s is low. The same conditions will make (2) ≥ 0. Consequently, under these conditions, (FMS, FMS) is the efficient equilibrium.

Q.E.D.

That (FMS, FMS) is efficient under the conditions specified, is illustrated in Figure 4. Figure 4 is analagous to Figure 3 except that we plot total surplus along the vertical axis. Also $\hat{\lambda}$ is the lower bound λ that satisfies both (8) ≥ 0 and (9) ≥ 0 that is, for all $\lambda \geq \hat{\lambda}$ (FMS, FMS) is efficient. Since $\hat{\lambda} < \lambda^*$ for the case illustrated in Figure 4 we have efficient equilibria of the (FMS, FMS) type. It can be shown (since (2) does not imply (8)≥ 0 and (9)≥ 0 for all λ, t, s) that equilibria resulting in firms adopting flexible technologies are not necessarily efficient.

Figure 4 Here

5 Conclusions

We have gained three main insights through the analysis of the model. The first is that we have determined conditions under which each of the states would constitute a subgame perfect equilibrium. We found the intuitive result that with a lower difference in fixed costs between the flexible and the inflexible technologies, FMS investments are encouraged. We also found that firms are encouraged to become more flexible with a higher industry profitability and a higher consumer perception of the products being substitutes.

Our second finding was that consumers are always better off with the introduction of the new flexible production technologies. It was shown that consumer surplus was higher in the (FMS, FMS) equilibrium than in the mixed equilibrium and higher in the mixed equilibirum than in the (DE, DE) equilibrium. Furthermore, it was shown that consumer surplus increases under all market configurations when the DE option is eliminated.

Thirdly, we found that there exist market conditions in which firms are in a Prisoner's Dilemma game. That is firms may be investing in FMS for purely strategic reasons, foresaking some profit.

In conclusion, we specify three conditions under which a society would benefit as a whole from the introduction of new flexible production technologies (i.e. when (FMS, FMS) is the efficient equilibrium). These are when:

1. industry profitability is high,

2. differences between the fixed costs of the two technologies is low, and

3. consumers perceive the products in related markets as highly substitutable.

Consequently, government bodies should consider following the lead of Japan, Sweden, and West Germany in subsidizing research and development of flexible manufacturing systems in markets which satisfy the above description.

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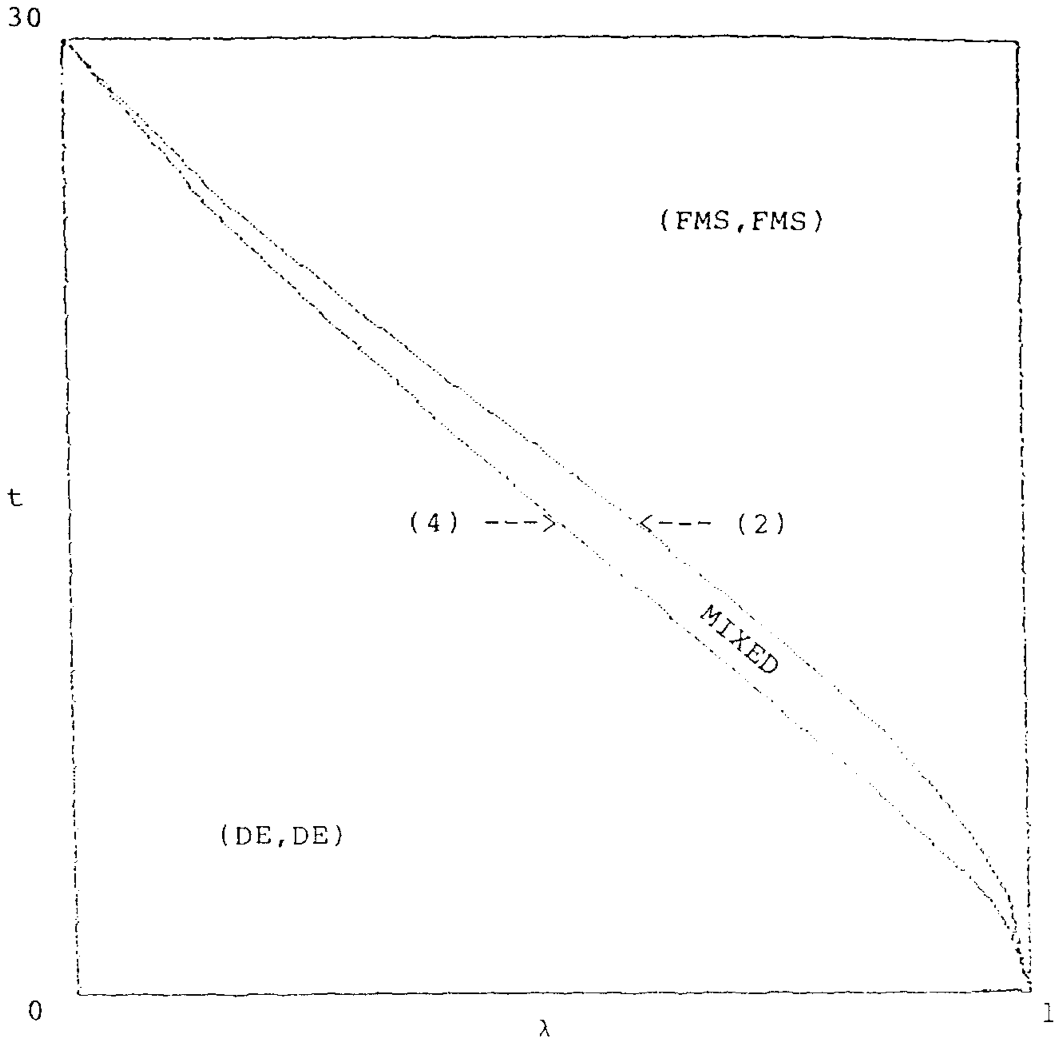
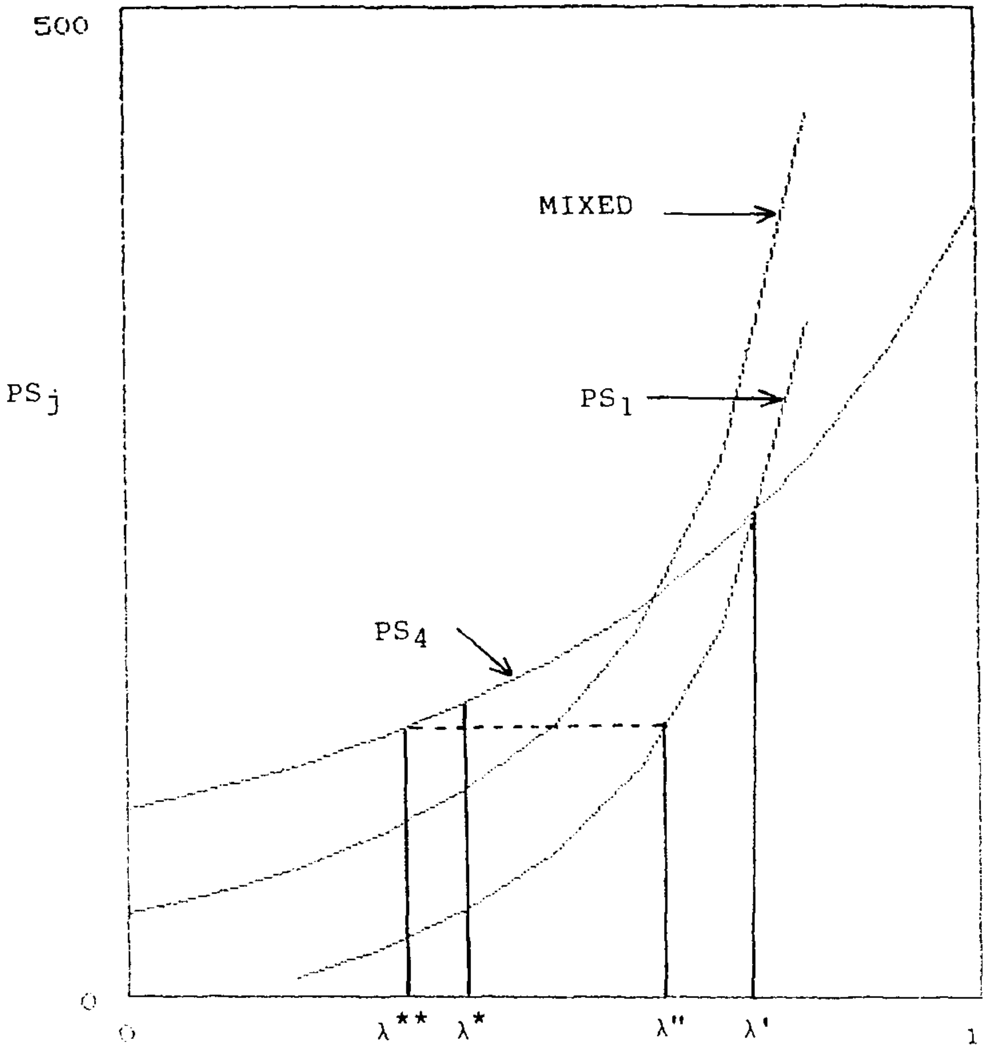
The Parameter Regions of the Equilibria (S=100)



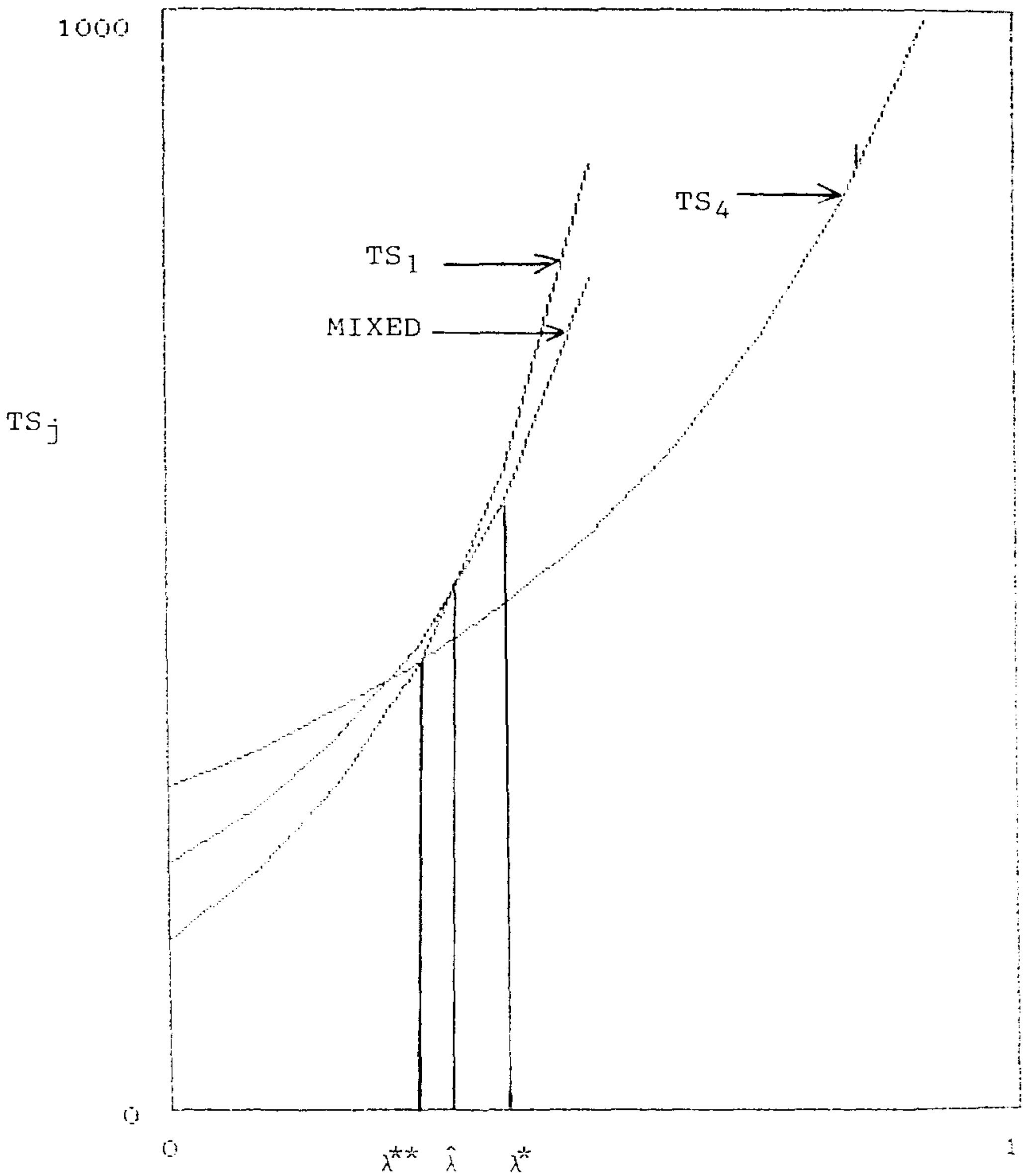
F I G U R E 2

Average Firms' Payoffs (S=100, t=20)



F I G U R E 3

Total Surplus (S=100, t=20)



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