"GAINS FROM STANDARDIZATION: THE CASE OF NUMERICAL CONTROLS"

by

Michael KENDE

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* Assistant Professor at INSEAD, Boulevard de Constance, Fontainebleau 77305 Cedex, France.

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Michael Kende *

Department of Economics

Massachusetts Institute of Technology

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Abstract

This paper tests the effects on consumer surplus and profits of standardizing a product from which consumers derive network externalities. Theory suggests that standardization would increase sales of the standardized product by enlarging the network of compatible products. If a country were to encourage standardization of its firms' products, domestic profits could increase even in foreign markets, making standardization a strategic trade policy. If domestic and foreign products are imperfect substitutes for one another, standardization of a domestic good, by increasing the price of the standardized good, increases sales and profits of the foreign incompatible goods. Consumer surplus increases regardless of the source of standardization because consumers benefit from the larger network. This paper studies the effects of the standardization of Japanese numerical controls on the U.S. market for machining centers. The results show that Japanese and U.S. profits are higher than they would have been had Japan not standardized, and U.S. and Japanese profits would have been higher if U.S. firms had also standardized. U.S. consumer surplus was greater due to Japanese standardization, and would have been greater yet if the U.S. had also standardized.

1 Introduction

If the utility derived from consuming a good increases with the number of other users of a compatible good, then it could be a strategic trade policy for a government to encourage domestic firms to standardize this product in order to increase sales.[1] In this paper the benefits of standardizing a product for which there are network externalities, and the costs of not standardizing, are empirically estimated. The specific example studied is the standardization of numerical controls for machine tools.[2] In the case of numerically controlled machine tools, while the Japanese government was actively encouraging standardization, the antitrust laws of the U.S. implicitly discouraged standardization. This paper measures the effects of these policies in the U.S. market for numerically controlled machine tools in terms of domestic consumer surplus and profits of the relevant Japanese and U.S. firms.[3] Both Japanese and U.S. profits are shown to be greater than they would have been had Japan not standardized numerical controls, and similarly both countries' profits would have been even greater had the U.S. also standardized numerical controls. U.S. consumer surplus increases with standardization, regardless of the source. Standardization is a policy which increases the total welfare of not only the standardizing country, but all countries

[1]The benefits derived from the number of other users of a compatible good are known as network externalities.

[2]Machine tools are power-driven machines used to cut or form metal. The various machining functions include drilling holes, chipping metal from a surface (milling), and finishing the surface (grinding). The importance of this industry is understated by its relatively small size because almost all manufactured products are directly or indirectly built by machine tools. Numerical controls (NC) and computer numerical controls (CNC) automate the movements of the machine tool. Numerical controls use a preprogrammed tape to guide the tools while computer numerical controls use a built-in microprocessor which can be controlled through a terminal. A more complete discussion of the industry can be found in The MIT Commission on Industrial Productivity, *Working Papers, The U.S. Machine Tool Industry and its Foreign Competitors* (Cambridge, MA: MIT Press, 1989), vol. 2.

[3]This paper only measures the effects of the standardization policies on the machine tool builders' profits, not on the downstream firms in the U.S. which use machine tools. This understates the true effects of machine tool policies on U.S. welfare because the quality of machine tools available to a country's industries can have a profound effect on the competitiveness of the country's goods in the world market.

which consume the standardized good.

In Kende (1991) I show the theoretical effects of the use of standardization as a strategic trade policy. The model shows the results of a country encouraging the domestic standardization of a homogeneous good with network externalities which is produced at home and abroad. Standardization increases the size of the network of compatible products at home and abroad, because all of the standardizing country's goods would now be compatible. The increased utility from consuming the standardized product with the larger network would translate into higher sales and profits for the firms whose products are standardized. Because the goods are homogeneous, sales and profits of the non-standardizing country's firms would fall. Thus, standardization can be used as a strategic trade policy to increase sales in a foreign country at the expense of the foreign country's firms. Consumer surplus in both countries would increase because consumers would derive higher network externalities from the larger network. While this type of strategic trade policy is a beggar-thy-neighbor policy with respect to the foreign firms, the decrease in the foreign firms' profits is offset by the increase in foreign consumer surplus.

The effects of standardization are estimated in the market for machine tools in the United States. A model of the U.S. market is developed in which all Japanese machine tools sold in the U.S. are compatible with one another and the outputs of each U.S. machine tool builder are incompatible with one another. Unlike in the theoretical model above, the machine tools of the U.S. and Japan are assumed to be imperfect substitutes for one another. Using empirically estimated demand parameters, this model is calibrated to determine the costs and profits of all of the relevant firms. Finally, two counterfactual cases are simulated to estimate the effects of both

Japanese standardization and the U.S. failure to standardize on both countries' profits and U.S. consumer surplus.

The first counterfactual case concerns the effects of Japanese standardization on the evolution of the market for machine tools in the United States. The theoretical prediction is that had the Japanese firms not standardized, their profits in the U.S. would have been lower because their machine tools would have been less attractive with a smaller network. The smaller network would have also led to lower prices for Japanese machine tools, which would have decreased demand for U.S. machine tools. Finally, U.S. consumer surplus would have been smaller without the utility derived from the large Japanese network. The effects of no Japanese standardization are measured by running a simulation in which each Japanese firm manufactures its own incompatible numerical control unit. The counterfactual is simulated using the estimated demand parameters and costs to determine the level of sales and prices which would have existed without a Japanese standard. The difference in profits and consumer surplus between this hypothetical situation and the actual situation represents the benefits of Japanese standardization, given no U.S. standard.

The second question concerns the costs of the U.S. not having standardized around a single numerical control. U.S. standardization would have increased U.S. profits because of the positive effect of the larger U.S. network. The larger U.S. network would have led to higher U.S. prices, increasing the demand for Japanese machine tools. The increased sales of both countries' goods would have increased U.S. consumer surplus. The effects of hypothetical U.S. standardization are explored via a simulation in which there is a sole numerical control supplier in the U.S., as in Japan. The difference in profits and consumer surplus between this counterfactual and the actual case represents the costs of the U.S. having failed to standardize, given Japanese standardization.

Section 2 discusses the relevant literature. Section 3 contains the history of numerically controlled machine tools as it relates to standardization. A model of the competition between U.S. and Japanese machining center builders in the U.S. market is developed in Section 4. Parameters of the U.S. demand for U.S. and Japanese machining centers are estimated empirically in Section 5. A calibration exercise in Section 6 estimates machining center costs using the model of the actual industry developed in Section 4 and the demand parameters estimated in Section 5. Finally, the two counterfactuals concerning the effects of standardization on the market for machining centers are tested in Section 7.

2 Literature Review

The network externalities literature provides a framework in which to analyze the effects on both users and producers of a government choosing a standard. On the user side, Farrell and Saloner (1985,1986) show how the coordination problem that users face in choosing between different technologies can lead to excess inertia. If the government chooses a standard, the coordination problem is eliminated and excess inertia is no longer possible. On the producer side, Katz and Shapiro (1985,1986a,b) show the incentives for firms to produce compatible products. In a static framework, their 1985 paper shows the effects on profits and consumer surplus of increased compatibility. In a dynamic framework, if firms can commit to low future prices for their technology, they show how it may become the dominant technology (Katz and Shapiro, 1986a,b).

The literature described above is the starting point for analyzing the effects of using standardization as a strategic trade policy. Krishna (1987) extends the strategic trade policy analysis of Brander and Spencer (1985) to show how credible subsidies can influence consumers' expectations of network size and in turn improve sales and profits of the home firm. Yanagawa (1990) introduces trade into the Katz and Shapiro (1985) model. He shows that high tariffs on foreign imports would eliminate possible equilibria where the foreign firm is the only seller in the domestic market. Finally, Kende (1991) shows that licensing for standardization is a strategic trade policy. Licensing is a credible commitment to lower future prices, which would make the licensed technology the dominant technology as predicted in Katz and Shapiro (1986a,b).

There has been much theoretical study of the issues of network externalities, and some study of government intervention in a market characterized by network externalities. However, there is little empirical work documenting the effects of network externalities and the effectiveness of government intervention. This paper shows how Japanese standardization of numerical controls affected the U.S. machine tool market. There are several empirical studies which deal with trade issues between the U.S. and Japan. Dixit (1988) uses a calibrated model to show the hypothetical effects of an optimal tariff and/or subsidy on the U.S. auto industry. Baldwin and Krugman (1988) study the effects of Japanese market closure on the 16K random access memory industry. The techniques used here are similar to these papers.[4] Due to the presence of network externalities in

[4]The general technique of these calibration papers is to first develop a model of the industry being studied. Using known estimates of certain parameters such as the number of firms or the elasticity of demand, missing parameters such as costs are estimated which make the model reproduce the actual prices and quantities. The effects of policy changes can be simulated by altering the industry structure according to the new policy and using both the known and the calibrated parameters to determine the new level of prices and quantities consistent with the policy change.

the numerically controlled machine tool industry, this paper uses a dynamic simulation to show the cumulative effect on network size of hypothetical policies.

3 Numerically Controlled Machine Tool Industry

Numerical controls, which automate the movements of machine tools such as lathes, were developed by MIT in the 1950s for the U.S. Air Force. The subsequent evolution in the usage and technology of numerical controls in the U.S. and Japan serves as a vivid example of the different approach of the two countries' governments and firms towards the development of new technology. The difference in the approach each government took towards the development of numerically controlled machine tools was very wide. While the Japanese government actively guided and supported the Japanese numerically controlled machine tool industry, the U.S. government limited its involvement in numerical control development to addressing the machining needs of the defense industry. The difference in the approach taken by each of the two countries' firms towards numerical control development can be characterized by the choice of the market that they developed products for, and the type of product developed to serve the chosen market. The Japanese machine tool industry developed general purpose machine tools for small shops to support the growing Japanese consumer goods industry, while the U.S. developed complex, customized machine tools for large firms in industries such as aerospace.

The different approach of the two countries towards the machine tool industry which is most relevant to this paper concerns the standardization of numerical controls. The introduction of numerical controls to machine tools made the size of the network of compatible machine tools an important factor for potential buyers. Numerical controls increased both training needs because of the requirement for programming as well as the complexity of servicing machine tools due to the electronics skills necessary. A larger existing user base ensures that more skilled programmers and better service are available, making the machines compatible with this user base more attractive to firms.[5]

Government action towards the standardization of numerical controls was diametrically opposed in Japan and the United States. In Japan, MITI encouraged one firm, Fanuc (formerly Fujitsu Fanuc), to develop simple controls for all Japanese producers to incorporate into their machine tools. Not only did this provide users with network externalities benefits, but additional benefits included economies of scale, learning, and reduced development costs resulting from having one firm manufacture all Japanese controls. The costs of choosing one firm to supply the numerical controls include the monopoly rents accruing to Fanuc and the risk of having chosen the wrong technology. The result was that by the 1970s Fanuc controlled 80-90% of the Japanese market for numerical controls and 40-50% of the world market by the early 1980s.[6] Meanwhile, in the United States firms felt constrained by the threat of antitrust action from setting a numerical control standard.[7] The result was a proliferation of incompatible numerical controls developed

[5]At the same time, employees have more incentive to invest in programming and servicing skills on a dominant technology because it makes them more marketable. This combination of employer and employee interest in using a dominant technology explains why the QWERTY keyboard has not been replaced by a more efficient alternative. See Paul A. David "Clio and the Economics of QWERTY," *American Economic Review; Papers and Proceedings* 75:2 (1985): pp. 332-337.

[6]The MIT Commission on Industrial Productivity, *Working Papers* (1989), vol. 2, p. 36.

[7]Ibid., p. 32. The antitrust threat for joint research and standard-setting was removed by Congress in 1984 with the passage of the National Cooperative Research Act.

both by machine tool builders themselves and outside suppliers with electronics expertise such as General Electric. By 1985 no U.S. numerical control supplier had more than a seven percent share of the U.S. market.[8]

Many other factors also influenced the relative performances of the U.S. and Japanese machine tool industries in the numerical control era. The governments of both countries had a major influence besides the role they played in standard-setting. In addition to the direction that MITI gave the machine tool industry, the Japanese government also provided the industry with large R&D subsidies.[9] U.S. governmental support of the domestic machine tool industry was mainly indirect, through Department of Defense contracts, beginning with the development of numerical controls in the 1950s. This aid naturally only addressed the machine tool industry as it related to the defense needs of the United States, and did not provide a commercial vision for the industry. In fact, with hindsight there is evidence that Department of Defense contracts actually led the U.S. machine tool industry down the wrong path.

The United States machine tool industry began the numerical control era by building machines to carry out precision tasks for the aerospace industry, at the bidding of the U.S. Air Force. When they turned their attention to the commercial market, for the most part they simply continued to build complex, customized machines. This approach led to a low volume of sales and few economies of scale. Meanwhile, Japanese firms concentrated on high-volume general purpose machine tools

[8]Frost & Sullivan, Inc. *Controls for Metalworking, Metalforming, and Robotic Machines - Standalone and Integrated Systems* (New York: Frost & Sullivan, Inc., 1986), p. 97.

[9]This included secret subsidies from the profits of bicycle and motorcycle gambling in Japan. An interesting discussion is found in Marvin J. Wolf, *The Japanese Conspiracy: The Plot to Dominate Industry Worldwide - and how to deal with it.* (New York: Empire Books, 1983), chapter 3, pp. 61-78.

for small suppliers of growing Japanese industries such as the automobile industry. This emphasis led to economies of scale and learning which, meshed with standardized numerical controls, put the Japanese firms in an excellent position to begin their successful export drive in the mid-1970s.

In the United States, the market which is studied in this paper, there is evidence that the machine tools of Japan served a different market segment than those built in the United States, partly because of the types of machines built. The complex machine tools of the United States tended to be bought by large firms, while the simpler Japanese machines with Fanuc controls were bought by smaller firms. A Frost & Sullivan, Inc. (1986) report on the machine tool industry states that Fanuc "decided that since the major U.S. Computer Numerical Control users refused to purchase CNC machine tools produced in Japan, the best way to penetrate the U.S. market was to target those potential users neglected by the U.S. CNC suppliers and machine tool builders, i.e. the small-to-medium shops."[10]

The Frost & Sullivan, Inc. report claims that this market segmentation shows up in the usage patterns of the two sectors purchasing the most numerically controlled machine tools, the transportation equipment industry (SIC 37) and the machinery industry (SIC 35).[11] The transportation industry, much of which is defense-related, tends to buy mostly U.S. machine tools. Part of the reason is that they require the more complex machines that the U.S. builders are selling, and part of it is because U.S. defense contractors are required to use machines with numerical controls approved by the Department of Defense. Fanuc was not one of the approved numeri-

[10] Frost & Sullivan, Inc. (1986), p. 64.

[11] In 1988 over 75 percent of numerically controlled machine tools were being used by firms in these two industries, according to the 14th *American Machinist* Inventory of Metalworking Equipment.

cal control suppliers.[12] On the other hand, the machinery industry is a large consumer of the simpler Japanese machine tools. Many of the firms in this industry, especially the small discrete parts manufacturers, resemble those firms in Japan for whom the Japanese machine tools were developed. Unfortunately, the aggregate data available for sales in the U.S. market do not show the complexity of machine sold or the industry of the buyer. In the empirical section below this market segmentation is somewhat identified and controlled for.

While this paper argues that differences in standardization had a major effect on the relative performance of the Japanese and U.S. machine tool industries, there are other important factors which had an influence. While one explanation of the success of Fanuc controls is certainly its status as the *de facto* standard for Japanese machines, Fanuc also benefitted from a key technological decision. Fanuc introduced microprocessors to numerical controls, creating the computer numerical control (CNC), in 1976, a full four years before its major U.S. competitors introduced comparable controls.[13] This improved the controls and reduced costs, giving machine tools with Fanuc controls yet another edge in the market.

The outcome in the U.S. market for machine tools is typical of the relative industrial performances of the two countries. Total imports of machine tools into the U.S. increased from approximately ten percent of consumption in 1969 to over fifty percent in 1988.[14] Japanese imports of machine tools into the U.S. increased from one percent of consumption in 1969 to almost

[12] One reason why Fanuc formed a joint venture with General Electric in 1986 may have been to be able to begin selling to defense contractors.

[13] E. Sciberras and B.D. Payne, *Machine Tool Industry; Technical Change and International Competitiveness.* (Great Britain: Longman Group Limited, 1985), p. 40.

[14] NMBTA - The Association of Manufacturing Technology, *The Economic Handbook of the Machine Tool Industry Handbook* 1989-1990, p.126.

thirty percent in 1988.[15] In a category of machine tools which is exclusively numerically controlled, namely machining centers, the results are even more pronounced. Total imports increased from approximately five percent of consumption in 1969 to over sixty percent by 1988. Japanese imports increased from none in 1969 to forty-five percent of U.S. consumption by 1988.[16] By 1986, the increase in imports led U.S. machine tool producers to petition the government successfully for relief from international competition in the form of a voluntary export restriction, agreed to by the major machine tool importers including Japan.

This paper focuses on the U.S. market for machining centers. Machining centers combine several traditional machining operations such as turning, drilling, boring, and milling into one tool. This multifunction capability was made possible by two innovations. The first is an automatic tool changer which holds the tools that are required for the various functions. The second innovation is numerical controls, which allow the machine to perform the different complex tasks automatically. It is this reliance on numerical controls which made machining centers the focus of this study. Because all machining centers have numerical controls, there is no manual substitute which needs to be controlled for in demand. On a more practical level, machining center sales are the only data for numerically controlled machine tools which were kept before numerical controls were recognized as a subdivision of traditional machine tools in the late 1970s by the U.S. Department of Commerce. The U.S. market is studied mainly because of data availability.

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[15] Ibid., p. 134.

[16] U.S. Department of Commerce, MQ-35W, *Current Industrial Report, Metalworking Machinery* and FT 246, *U.S. Imports for Consumption and General Imports - TSUSA Commodity by Country of Origin*, 1969-1988.

4 Model

The U.S. market for Japanese and U.S. machining centers is modelled here. All Japanese machining center builders exporting to the U.S. are assumed to install compatible Fanuc numerical controls in their machines. The Japanese machining centers are assumed to be homogeneous. Each machining center builder in the U.S. is assumed to develop its own numerical control for its machining centers. The U.S. machines are assumed to be incompatible with one another, but otherwise perfect substitutes in demand. The Japanese and U.S. machining centers are imperfect substitutes for one another.

4.1 Demand

The inverse demand curves for the machining centers of the U.S. and Japan respectively, are;

$$P_t = P(Q_t, Q_t^*, y_t, \sum_t q_{it}, q_{it}^e) \tag{1}$$

and

$$P_t^* = P^*(Q_t, Q_t^*, y_t, \sum_t Q_t^*, Q_t^{*e}) \tag{2}$$

where the variables for year t are:

- P_t = Price of U.S. machining centers in the United States.
- P_t^* = Price of Japanese machining centers in the United States.
- q_{it} = Quantity of U.S. machining centers sold in the U.S. by firm i, where $i = 1, \ldots, n$.

- $Q_t = \sum_{i=1}^{n} q_{it}$, total quantity of U.S. machining centers sold in the U.S.
- q^*_{jt} = Quantity of Japanese machining centers sold in the U.S. by firm j, where $j = 1, \ldots, n^*$.
- $Q^*_t = \sum_{j=1}^{n^*} q^*_{jt}$, total quantity of Japanese machining centers sold in the United States.
- y_t = Macro variable(s) affecting machine tool demand.
- $\sum_t q_{it}$ = Existing network of compatible U.S. machining centers including current year.
- $\sum_t Q^*_t$ = Existing network of compatible Japanese machining centers including current year.
- q^e_{it} = Expected future cumulative sales of U.S. machining centers by firm i.
- Q^{*e}_t = Expected future cumulative sales of Japanese machining centers.

The demand for any machining center sold in the U.S. is a function of the network externalities derived from the existing stock of compatible machining centers. Because most of the network externalities are assumed to arise from personnel-related benefits such as training, there is no spillover of the network externalities from one country to another. In the case of U.S. machining centers, where each vendor's stock is incompatible with that of the other U.S. firms, network externalities arise only from the stock of machining centers sold by the respective firm in the United States ($\sum_t q_{it}$). Because all Japanese machining centers are sold with compatible numerical controls, consumers receive network benefits from all Japanese machining centers existing in the United States ($\sum_t Q^*_t$).

The demand for machining centers is also an increasing function of expected future sales of compatible machining centers. This introduces a dynamic aspect to the model, because consumers must form expectations of future sales. A model of this dynamic game would require the use of multiple periods. For simplicity, I collapse the model into the current period using a result from

Kende (1991). That paper uses a two-period model to show the effects of standardization. The results show that future sales are a positive function of current sales;[17]

$$q_{it}^{e} = q^{e}(q_{it}) \tag{3}$$

$$Q_t^{*e} = Q^{*e}(Q_t^{*}). \tag{4}$$

Substituting these functions into (1) and (2) allows demand to depend on the output of a single period.

4.2 Profits

For U.S. firms I make the simplification that each producer of machining centers creates their own numerical control rather than buying it from an outside supplier. This is not much of a

[17]Michael Kende "Strategic Standardization in Trade with Network Externalities," MIT mimeo, 1991. This paper uses a two-period, two-country model with one firm in each country to show the theoretical results of standardization as a strategic trade policy. Demand in the second period can be shown to be a positive function of sales in the first period (i.e. the existing network). Let home demand for the home firm's output in period two equal

$$p_2 = 1 - q_2 - q_2^* + nq_1 + nq_2$$

and home demand for the foreign firm's output equals

$$p_2^* = 1 - q_2^* - q_2 + nq_1^* + nq_2^*$$

where n represents the level of network externalities, p_t and q_t represent price and sales of the home firm in period t, and p_t^* and q_t^* represent foreign price and sales in period t, where $t = 1, 2$. If the two firms play Cournot in the second period and marginal cost equals c, then the home reaction function is

$$q_2(q_2^*) = \frac{1 + nq_1 - q_2^* - c}{2(1-n)}.$$

Because of the network effect, n, the second-period reaction curve shifts out with increases in first-period sales, and thus second-period output is a positive function of first-period output. Because the goods are homogeneous here, the second-period output of the foreign firm decreases as the home firm's first-period output increases.

simplification since at least ten machine tool companies developed their own numerical controls.[18] There are n symmetric U.S. machining center builders. The profit function for a representative American machining center producer is:

$$\pi_{it} = q_{it}(P(Q_t, Q_t^*, \cdot) - c_{mc,t} - c_{nc,t}). \tag{5}$$

The total cost of a U.S. built machining center equals $(c_{mc,t} + c_{nc,t})$, where $c_{mc,t}$ equals the cost of producing the machining center hardware, and $c_{nc,t}$ equals the cost of producing the numerical control unit.

In Japan all of the machining center builders are assumed to install the numerical control units of Fanuc into their machining centers. This assumption is realistic because in 1985 close to 90 percent of the numerically controlled machine tools imported from Japan used Fanuc's controller.[19] There are n^* symmetric Japanese machining center manufacturers. The respective profit functions of Fanuc and the builders are:

$$\pi_{Ft}^* = Q_t^*(p_{nc,t}^* - c_{nc,t}^*) \tag{6}$$

and

$$\pi_{jt}^* = q_{jt}^*(P^*(Q_t, Q_t^*, \cdot) - c_{mc,t}^* - p_{nc,t}^*). \tag{7}$$

In this model Fanuc builds the numerical control units at cost $c_{nc,t}^*$ and sells them to the builders at price $p_{nc,t}^*$. The builders incorporate them into their machining centers, which cost $c_{mc,t}^*$ to

[18] David J. Collis "The Machine Tool Industry and Industrial Policy, 1955-1982," in *International Competitiveness*, Heather Hazard and A. Michael Spence, eds. (Cambridge, MA: Ballinger Publishing Co., 1988), pp. 92.
[19] Frost & Sullivan, Inc. (1986), p. 89.

build, and sell the whole system to consumers for $P^*(Q_t, Q_t^*, \cdot)$. The variables are:

- π_{it} = Profit of the U.S. machining center builder.
- π^*_{jt} = Profit of the Japanese machining center builder.
- π^*_{Ft} = Profit of Japanese numerical control manufacturer (Fanuc).
- $c_{mc,t}$ = Cost of U.S. machining center (hardware).
- $c_{nc,t}$ = Cost of U.S. numerical control (software).
- $c^*_{mc,t}$ = Cost of Japanese machining center (hardware).
- $c^*_{nc,t}$ = Cost of Japanese numerical control (software).
- $p^*_{nc,t}$ = Price of Japanese numerical control.
- n = Number of U.S. machining center manufacturers.
- n^* = Number of Japanese machining center manufacturers.

Because of the dynamic nature of network externalities firms must internalize the effect of the current level of output on future profits. If firms decide to exploit their existing stock of machining centers and set high prices today, then the future network would be smaller, leading to lower future sales and profits. Conversely, firms can set low prices today to increase their network size and hence future profits. These considerations will be integrated into the model in the calibration section.

4.3 Competition

The model has two stages. In the first stage Fanuc determines the price of the numerical controls it sells to the Japanese builders. In the second stage the competing U.S. and Japanese builders of machining centers are assumed to **engage in** Cournot competition. As in Kende (1991) the consumers observe the current level of production before purchasing. Therefore, firms take into account the effect of current production on consumers' expectations of the size of the network. As usual, the stages are solved in the reverse order. It is assumed that U.S. machining center builders do not buy numerical control units from Fanuc. This assumption is not very restrictive because of the evidence cited in Frost & Sullivan, Inc. (1986) that the larger U.S. firms buying U.S. machine tools did not want to use Fanuc controllers.

In the second stage, machining center producers engage in Cournot competition. The first-order conditions, derived from profit functions (5) and (7) are:

$$q_{it}P'(Q_t, Q_t^*, \cdot) + P(Q_t, Q_t^*, \cdot) - c_{mc,t} - c_{nc,t} = 0 \tag{8}$$

$$q_{jt}^* P^{*'}(Q_t, Q_t^*, \cdot) + P^*(Q_t, Q_t^*, \cdot) - c_{mc,t}^* - p_{nc,t}^* = 0. \tag{9}$$

The two first order conditions are solved simultaneously to determine $q_{it} = q_{it}(p_{nc,t}^*, c_{mc,t}^*, c_{nc,t}, c_{mc,t})$ and $q_{jt}^* = q_{jt}^*(p_{nc,t}^*, c_{nc,t}^*, c_{nc,t}, c_{mc,t})$.

In the first stage Fanuc sets the price of the numerical control, $p_{nc,t}^*$. Fanuc is assumed to maximize profits in the price charged for the numerical control units to the builders,

$$\max_{p_{nc,t}^*} \; Q_t^*(p_{nc,t}^*, \cdot) \cdot (p_{nc,t}^* - c_{nc,t}^*) \tag{10}$$

where by symmetry $Q_t^* = n^* \cdot q_{jt}^*(p_{nc,t}^*, \cdot)$. Solving (10) determines $p_{nc,t}^*(c_{nc,t}^*)$. Substituting $p_{nc,t}^*(c_{nc,t}^*)$ into the results from the second stage leads to the equilibrium quantities of machining centers produced, $Q_t^*(c^*_{nc,t}, c^*_{mc,t}, c_{nc,t}, c_{mc,t})$ and $Q_t(c^*_{nc,t}, c^*_{mc,t}, c_{nc,t}, c_{mc,t})$.

5 Empirical Results

In this section demand parameters for consumption of U.S. and Japanese machining centers in the United States are estimated. Aggregate data were gathered on machining center sales from 1970-1990. These data are described in detail in the Appendix. The parameters estimated in this section are used in Section 6 to calibrate the model developed above and for the simulation exercises in Section 7.

This section follows the procedure developed by Baker and Bresnahan (1984, 1985) for estimating residual demand curves. In their papers they analyze the market power of a subset of firms in an industry and show that without any information on the demand for the omitted firms' products, demand estimates can be interpreted as those of residual demand curves. I apply this procedure here to studying the demand for Japanese and U.S. machining centers in the United States. The major difference in estimating the demand for products of a subset of countries rather than firms is the difficulty of finding common variables. In this case it is easy to find common demand-side variables because the products are being sold in the same market. However, it is difficult to find common cost variables because the goods are produced in different countries.

In deriving the demand curves for estimation, I follow Baker and Bresnahan (1985) which shows how to estimate the residual demand curves for two brewing firms which are planning to merge. The demand system for all machining centers sold in the U.S. is given below:

$$Q_t = Q(P_t, P_t^*, \tilde{P}_t, y_t, z_t) \quad (11)$$

$$Q_t^* = Q^*(P_t, P_t^*, \tilde{P}_t, y_t, z_t^*) \quad (12)$$

$$\tilde{Q}_t = \tilde{Q}(P_t, P_t^*, \tilde{P}_t, y_t, \tilde{z}_t). \quad (13)$$

The first two equations show the demand for the U.S. and Japanese goods respectively. The last equation is a vector of demands for the machining centers of the remaining $(\eta - 2)$ countries which sell machining centers in the United States. $\tilde{P}_t$ is a vector of U.S. prices for the machining centers of the rest of the world. Common U.S. demand variables are represented by y_t, and demand-side variables specific to the goods of the U.S., Japan, and the rest of the world are referred to by z_t, z_t^*, and $\tilde{z}_t$, respectively.

The vector of machining center supply relations for the $(\eta - 2)$ countries in the rest of the world is:

$$\tilde{MC}(\tilde{Q}_t, \tilde{W}_t, W_t) = P\tilde{M}R(P_t, P_t^*, \tilde{P}_t, y_t, \tilde{z}_t) \quad (14)$$

where $P\tilde{M}R$ is perceived marginal revenue, $\tilde{W}_t$ is a vector of country-specific factor prices, and W_t are factor prices common to all producers. The next step is to substitute (13) into (14) to solve for $\tilde{P}_t = \tilde{P}(P_t, P_t^*, y_t, \tilde{z}_t, \tilde{W}_t, W_t)$. Substituting $\tilde{P}_t$ into equations (11) and (12) gives the residual demand curves:

$$Q_t = R(P_t, P_t^*, y_t, z_t, \tilde{z}_t, W_t, \tilde{W}_t) \quad (15)$$

$$Q_t^* \quad = \quad R^*(P_t, P_t^*, y_t, z_t^*, \tilde{z}_t, W_t, \tilde{W}_t). \tag{16}$$

As in Baker and Bresnahan the equations are estimated in log-linear form:

$$\ln Q_t \quad = \quad \alpha_0 + \alpha_1 \ln P_t + \alpha_2 \ln P_t^* + \alpha_3 \ln z_t + \alpha_4 \ln y_t + \epsilon \tag{17}$$

$$\ln Q_t^* \quad = \quad \beta_0 + \beta_1 \ln P_t^* + \beta_2 \ln P_t + \beta_3 \ln z_t^* + \beta_4 \ln y_t + \epsilon^* \tag{18}$$

where the elasticities are now interpreted as residual demand elasticities. The aggregate reaction of the $(\eta - 2)$ other exporters to a price change by the U.S. and/or Japan is incorporated into the elasticities. Because the demand curves are log-linear, the coefficients are the elasticities. The ϵ and ϵ^* terms are residuals.

Prices are assumed to be endogenous in demand equations (17) and (18). Following Baker and Bresnahan, country-specific cost variables are used as instruments to identify the residual demand curve for the respective country's product. There are two general instruments available for identifying demand for either country's machining centers. Costs for either of the countries' machining centers would be expected to shift down in the year that the country's major numerical control producers began using microprocessors. Therefore, one potential instrument is a dummy variable signalling the year that the country's machining centers began using computer numerical controls. In addition, the introduction of microprocessors to numerical controls allowed for the gradual cost reductions from learning which are typical of electronics industries. A time trend is used as a potential instrument to proxy for these cost reductions.

In addition, there are potential instruments available which are unique to the demand for each country's machining centers. There are two more instruments available for identifying demand for Japanese machining centers. The first is the yen/dollar exchange rate, which is appropriate due to the large shifts in the relative value of the currencies over the last twenty years. An additional instrument is made available by the presence of the voluntary export restriction (VER) governing exports to the U.S. of most categories of machine tools from the major machine tool producing countries, including Japan. The voluntary export restriction went into effect in 1987. Therefore, a dummy variable is used as an instrument to proxy for the effect of the VER on the Japanese supply of machining centers. The wage paid in the U.S. machine tool industry is used as an instrument for U.S. price in the demand curve for American machining centers.

The common demand-side variable y_t is represented by BFI_t, which is a series of the business fixed investments of manufacturing firms in the United States. The country-specific demand-side variables z_t and z_t^* are represented by the relevant stock of existing compatible machining centers. This is included in order to show the effect of network externalities on purchases of machining centers. An additional country-specific demand-side variable is made available by the presence of the voluntary export restraint. A dummy variable is included in the demand curve for U.S. machining centers to control for the effect of the VER. A time trend is also included in the demand curve for U.S. machining centers to control for unobservable variables shifting demand towards imported machining centers. Finally, variables are used to control for the different markets which the U.S. and Japanese machining centers served. Industrial production indexes are included in the demand curves to control for the derived demand of sectors which bought either primarily U.S.

machining centers (transportation equipment) or primarily Japanese ones (machinery).

No specific demand-side variables $\tilde{z}_t$, such as the stock of compatible machining centers, were available for the $(\eta - 2)$ excluded producing countries. In addition, no suitable factor prices, representing costs in all η countries (W_t) or any of the $(\eta - 2)$ countries specifically ($\tilde{W}_t$), were found. No attempt is made to correct for demand arising from depreciation because machining centers are a new type of machine tool and within the time period of the data not many of the machining centers could be expected to have depreciated. I do not attempt to model the diffusion of this new technology because the aggregate data do not allow a breakdown of the adoption pattern at the firm level.

The results are given in Table 1. The first group of results in Table 1 show the results of ordinary least squares regressions of the demand equations, and the second group of results in Table 1 shows the results of two-stage least squares regressions. In both cases the standard errors are robust, and the t-statistics are reported in parentheses. The estimates all have the the expected signs. For both Japanese and U.S. machining center demand the own-price elasticity is negative and the cross-price elasticity is positive. The elasticity of demand with respect to the stock of existing compatible machining centers is positive for both countries' machining centers. This implies that the network externalities derived from the existing stock of machining centers positively affect the sales of machining centers. In all results the elasticity of demand with respect to business fixed investment is also positive, as expected.

The final instruments used in the two-stage least squares estimation of demand for Japanese machining centers were the time trend and the value of the yen. The dummy for the voluntary

Table 1: Regression results

	Dependent Variable			
	OLS		2SLS	
	$\ln Q_t^*$	$\ln Q_t$	$\ln Q_t^*$	$\ln Q_t$
Constant	-26.11	-1.40	-33.55	-5.22
	(-5.61)**	(-.29)	(-2.23)**	(-.41)
$\ln P_t$	1.59	-1.17	2.24	-.80
	(4.05)**	(-3.50)**	(3.96)**	(-.67)
$\ln P_t^*$	-.60	.19	-2.79	.15
	(-5.02)**	(2.51)**	(-2.50)**	(1.16)
$\ln \sum_t q_{it}$	-	1.32	-	1.10
		(1.37)		(.84)
$\ln \sum_t Q_t^*$	.80	-	.70	-
	(12.55)**		(4.54)**	
$\ln BFI_t$	2.85	2.43	8.04	2.51
	(2.25)**	(3.19)**	(3.04)**	(3.16)**
$\ln Transport_t$	-	.39	-	.55
		(1.07)		(.81)
$time$	-	-.18	-	-.16
		(-2.35)**		(-1.33)
R^2	.98	.67	.91	.65

(t-statistic)** Significant at the .95 level.
(t-statistic)* Significant at the .90 level.

export restraint was insignificant, probably because the restraint was not binding due to the high value of the yen relative to the dollar in the years that the VER was in effect. The dummy for the effect of the adoption of microprocessors was not used because this effect was picked up by the time trend instrument.

The final instrument used for U.S. demand estimation was the wage paid in the U.S. machine tool industry. The time trend and the year microprocessors were adopted were not good instruments, probably because the fragmentation of the machining center and numerical control industry in the U.S. led to less learning and economies of scale than were present in Japan.

Instead of being used as an instrument, the time trend is used as a right-hand side variable in the U.S. demand equation to proxy for the trend towards foreign machining centers. The coefficient estimate is negative. A dummy for the VER was insignificant in the U.S. demand curve, giving further credence to the evidence that the VER was not binding. A production index for the transportation equipment sector ($Transport_t$) was included in the demand for U.S. machining centers. This index controls for the derived demand of this sector for U.S. machining centers. It is the only sectoral index which had any impact on the results, probably because a large part of the sector is barred from using machining centers with Fanuc's numerical controls by the Department of Defense. The coefficient estimates were positive, as expected.

The results show a strong difference in the characteristics of demand for U.S. and Japanese machining centers. The demand for Japanese machining centers is much more sensitive to the prices of both countries' machining centers than the demand for U.S. machining centers is. This could reflect the fact that the buyers of U.S. machining centers tended to be larger firms who generally had more inelastic demand for major investments than did smaller firms, which tended to buy Japanese if they bought at all. It could also reflect the differences in the types of machines being sold by the two countries. There is also a big difference in the elasticity of demand with respect to the business fixed investment for the different machining centers which is difficult to explain. Finally, demand for U.S. machining centers is more sensitive to the size of the network than demand for Japanese machining centers is. The two-stage least squares estimates are used as the demand parameters for the calibration exercise below.

6 Calibration

In this section, using the model of competition derived in Section 4 and the two-stage least squares demand parameters from Table 1, the machining center costs for the years 1970-1990 are estimated using the technique of calibration. The implied costs are those that are consistent with the actual output and prices of the two countries' machining centers given the assumed model of competition. Using these costs the profits of the firms can be calculated. Finally, a measure of consumer surplus is proposed so that welfare can be determined.

6.1 Demand

For simplicity, linear forms of the estimated log-linear demand equations (17) and (18) are needed in order to calibrate the model. Linear demand equations are derived by using a first-order Taylor approximation. Then the two linear approximations are inverted to get the inverse demand curves $P(Q_t, Q_t^*, \cdot)$ and $P^*(Q_t, Q_t^*, \cdot)$ for U.S. and Japanese machining centers:

$$P(Q_t, Q_t^*, \cdot) = \gamma_0 + \gamma_1 Q_t + \gamma_2 Q_t^* + \gamma_3 \sum_t q_{it} + \gamma_4 BFI_t + \gamma_5 t + \gamma_6 TE_t + \tilde{\epsilon} \tag{19}$$

$$P^*(Q_t, Q_t^*, \cdot) = \delta_0 + \delta_1 Q_t^* + \delta_2 Q_t + \delta_3 \sum_t Q_t^* + \delta_4 BFI_t + \tilde{\epsilon}^* \tag{20}$$

where residuals $\tilde{\epsilon}$ and $\tilde{\epsilon}^*$ were added so that the equations result in the actual values of P_t and P_t^* given the estimated coefficients, and TE_t is the production index of the transportation equipment sector.

6.2 Profits

The machining center builders' profits (5) and (7) are adjusted to account for the fact that although this is a one period model, current sales affect future profits. Depending on the time frame of the firm, there are conflicting effects of any level of output. With a short-run outlook, given the market power bestowed by their existing networks, firms would tend to restrict output to increase current profits. With a long-run time frame, however, firms would increase current output to increase the future network size and thus future market power. The following terms were added to the variable for the existing stock of U.S. and Japanese machining centers to indicate how firms internalize the effect of a given output level on the long-run network size: $a_t \cdot (q_{it} - \bar{q}_{it})$ and $a_t^* \cdot (Q_t^* - \bar{Q}_t^*)$. The new profit functions of the machining center builders are:

$$\pi_{it} = q_{it} \cdot (P(Q_t, Q_t^*, \sum_t q_{it} + a_t \cdot (q_{it} - \bar{q}_{it}), \cdot) - c_{mc,t} - c_{nc,t}) \tag{21}$$

$$\pi_{jt}^* = q_{jt}^* \cdot (P^*(Q_t, Q_t^*, \sum_t Q_t^* + a_t^* \cdot (Q_t^* - \bar{Q}_t^*), \cdot) - c_{mc,t}^* - p_{nc,t}^*). \tag{22}$$

The variables a_t and a_t^* are the multipliers showing the implicit effect of increasing current quantity on future profits, and $\bar{q}_{it}$ and $\bar{Q}_t^*$ represent the realized level of sales. Because $q_{it} = \bar{q}_{it}$ and $Q_t = \bar{Q}_t$ in equilibrium, the added terms do not directly affect the current level of profits or demand. However, the current level of output is a positive function of the respective firm's multiplier. The greater the multiplier, the greater current production will be, increasing the future network and profits at the expense of current profits.[20] The added expressions differ in

[20]When the multiplier (a_t or a_t^*) is greater than zero, the output level is greater than the profit-maximizing

the quantity variables used because U.S. firms must only internalize the effect of their quantity decision on their own future network, while each Japanese firm must take into account the effect of an increase in its own output on the entire network of Japanese machining centers.

6.3 Welfare

The measure of consumer surplus used is similar to that of Dixit (1988). Let the demand curves (19) and (20) be written as:

$$P(Q_t, Q_t^*) = \bar{\gamma}_0 + \gamma_1 Q_t + \gamma_2 Q_t^* \tag{23}$$

$$P^*(Q_t, Q_t^*) = \bar{\delta}_0 + \delta_1 Q_t^* + \delta_2 Q_t \tag{24}$$

where $\bar{\gamma}_0$ and $\bar{\delta}_0$ are the sums of the remaining variables. These demand curves can be thought of as arising from the following utility function:

$$U(Q_t, Q_t^*) = \bar{\gamma}_0 Q_t + \bar{\delta}_0 Q_t^* + \frac{1}{2}(\gamma_1 Q_t^2 + \delta_1 Q_t^{*^2} + 2\kappa Q_t \cdot Q_t^*). \tag{25}$$

I set $\kappa = \frac{\gamma_2+\delta_2}{2}$ in order to avoid having to force the restriction $\gamma_2 = \delta_2 = \kappa$ to hold for the

output level would be if the firm were not forward-looking (i.e. when the multiplier equals zero), so the effect of the multiplier is to lower current profits.

regressions.[21] Consumer surplus equals:

$$CS(Q_t, Q_t^*) = U(Q_t, Q_t^*) - P_t \cdot Q_t - P_t^* \cdot Q_t^*. \tag{26}$$

U.S. welfare equals consumer surplus plus domestic profits.

6.4 Costs

The model of Section 4 is calibrated on the actual sales and prices in order to estimate the implicit costs, which are used later as the basis for the simulations. The calibration is based on the following assumptions about the model. The U.S. and Japanese machining center builders are assumed to compete in quantities. The Japanese producer of numerical controls is assumed to profit-maximize in price. In addition, the actual average pre-tax profit of Fanuc on its sales of numerical controls is known.[22] These assumptions lead to the following four equations:

$$q_{it}P'(Q_t, Q_t^*, \cdot) + P(Q_t, Q_t^*, \cdot) - c_{mc,t} - c_{nc,t} = 0 \tag{27}$$

$$q_{jt}^* P^{*'}(Q_t, Q_t^*, \cdot) + P^*(Q_t, Q_t^*, \cdot) - c_{mc,t}^* - p_{nc,t}^* = 0 \tag{28}$$

$$q_{jt}^{*'}(p_{nc,t}^*) \cdot (p_{nc,t}^* - c_{nc,t}^*) + q_{jt}^*(p_{nc,t}^*) = 0 \tag{29}$$

$$\pi_{Ft} = \frac{(p_{nc,t}^* - c_{nc,t}^*)}{p_{nc,t}^*} = .35 \tag{30}$$

[21] This would have required restricting regressions of the log-linear demand curves (17) and (18) so that after inverting the Taylor first-order approximations, $\gamma_2 = \delta_2 = \kappa$ in equations (19) and (20).

[22] It is estimated from the yearly *Japan Company Handbook* to be 0.35 % of pre-tax revenues.

where equations (27) and (28) are the Japanese and U.S. firms' first-order conditions from equations (8) and (9) and equation (29) is the first order condition for Fanuc from equation (10). Finally, equation (30) represents the actual pre-tax profit of Fanuc.

The unknown parameters besides costs are all estimates because there are not enough degrees of freedom to calibrate them. The U.S. dynamic multiplier, a_t, is assumed to be 0.1.The results to follow are robust to this assumption. The number of U.S. firms, n, is set equal to ten, and the number of Japanese firms, n^* is set equal to eight.[23] Finally, it is estimated that the cost of the numerical controls is one-third of the total cost of the machining center, i.e. $c_{nc,t} = \frac{c_{mc,t}}{2}$ and $p^*_{nc,t} = \frac{c^*_{mc,t}}{2}$.[24] Substituting these estimates, the two-stage least squares demand parameters, and the actual prices and quantities P_t, P^*_t, Q_t, and Q^*_t into the model found in equations (27) to (30) gives the implicit values of the remaining unknowns, $a^*_t, c^*_{nc,t}, c^*_{mc,t}$, and $c_{mc,t}$.

Figures 1 and 2 show the actual sales of Japanese and U.S. machining centers in the U.S. and the respective prices of the machining centers. Figure 3 shows the calibrated costs of Japanese machining centers and Figure 4 shows the calibrated costs of U.S. machining centers. Note that the Japanese costs are significantly below those of the American firms. Part of the reason for the lower costs is the value of the yen, but it is also due to economies of scale and learning resulting from both Fanuc's status as sole producer of numerical controls as well as the machine tool builders focus on machines for high-volume markets. Japanese and U.S. machining center producers' profits are given in Figure 5. After 1980 the Japanese firms' profits are significantly higher than the U.S. firms' profits are, but the profits converge towards 1990 as the yen appreciated. Finally, the profits

[23]See the Appendix for a discussion of these estimates.
[24]This is an estimate from Frost & Sullivan, Inc., p. 97.

of Fanuc, the Japanese numerical control producer, are given in Figure 6.

Figure 1: Sales of Machining Centers in the U.S.

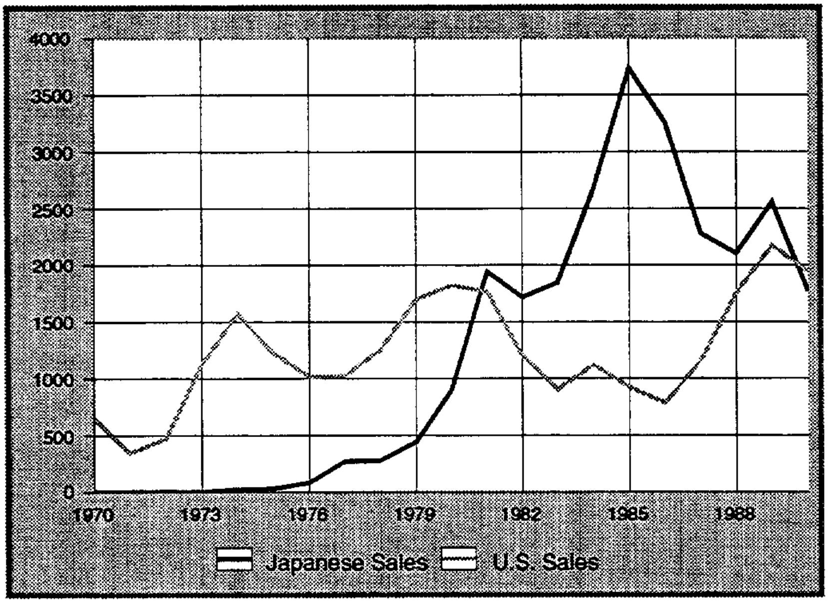


Figure 2: Prices of Machining Centers in the U.S.

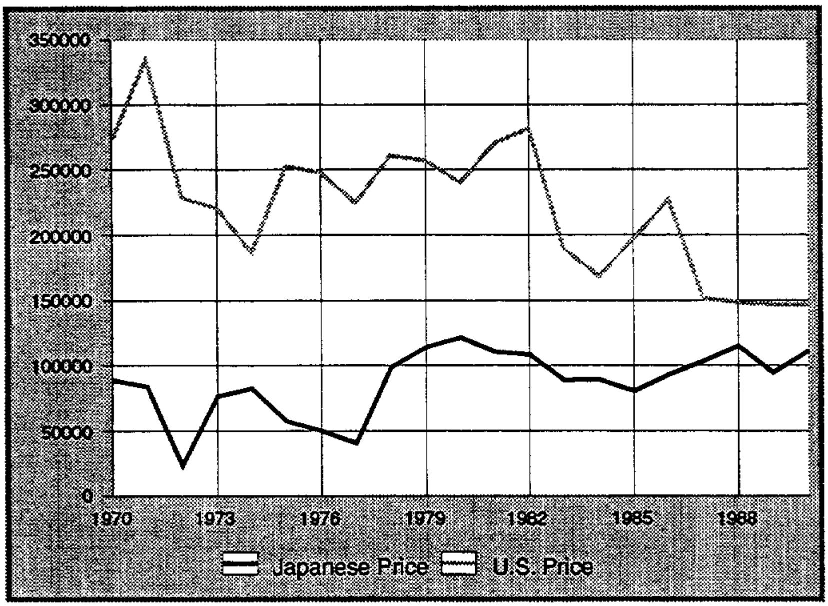


Figure 3: Calibrated Japanese Machining Center Costs.

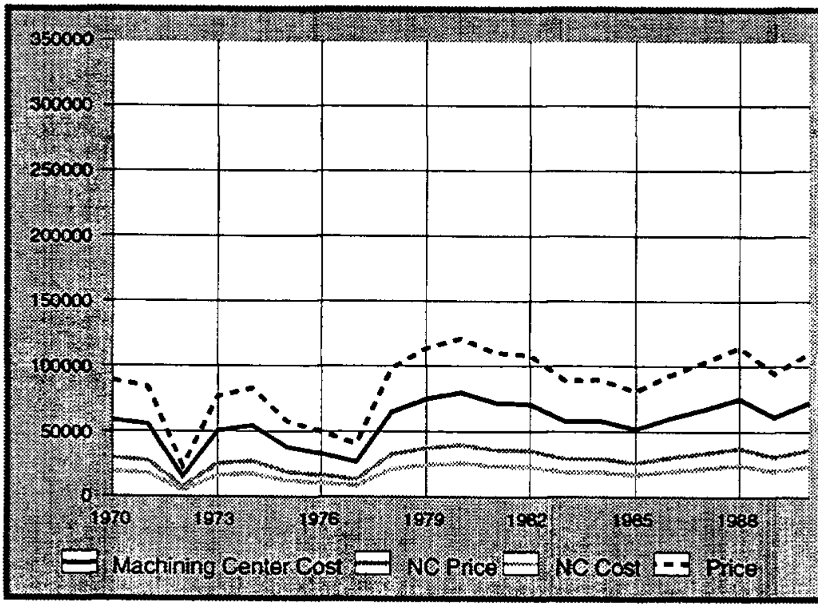


Figure 4: Calibrated U.S. Machining Center Costs.

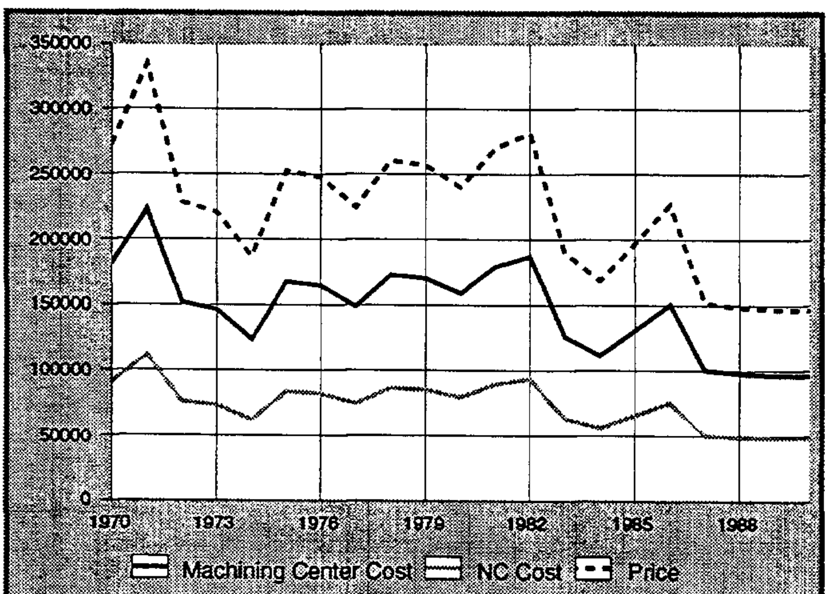


Figure 5: Calibrated Machining Center Producers' Profits.

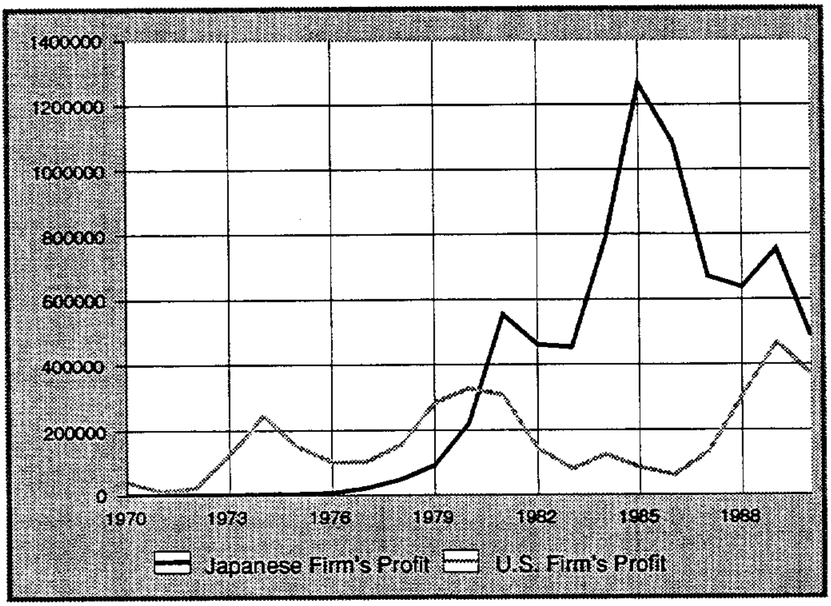
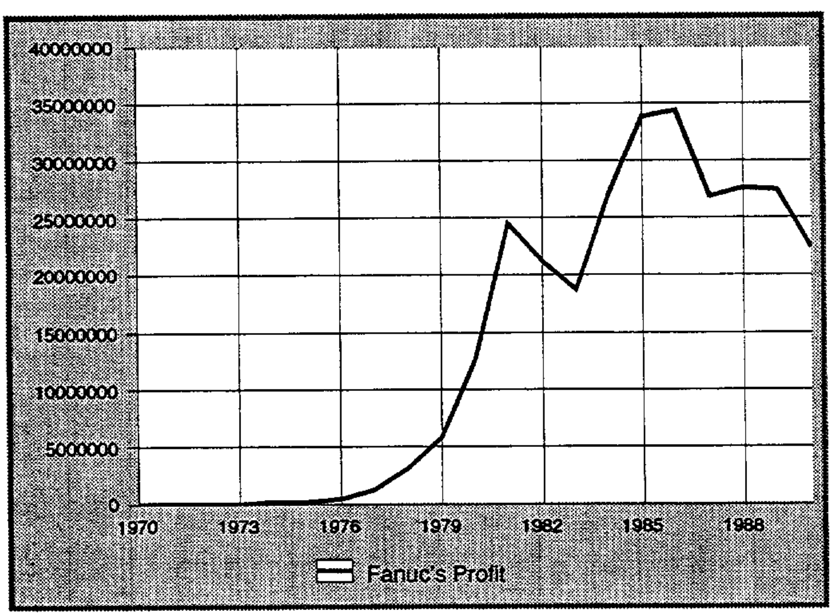


Figure 6: Calibrated Profits of Fanuc.



7 Simulations

In this section the two counterfactual cases of interest are simulated dynamically. In each case the calibrated costs and the estimated demand parameters are used to determine the prices and outputs consistent with the conditions of the counterfactual. The first counterfactual is the case where neither Japan nor the U.S. had adopted standardized numerical controls. The second counterfactual is where both the U.S. and Japan had adopted standardized numerical controls. In both of these cases the standardization regime of one of the countries is the same as the base case for which the demand parameters and costs were estimated. A third possible counterfactual, in which the U.S. had standardized and Japan hadn't, was not attempted because in this case the standardization regime in both countries would not resemble the one for which the demand parameters and costs were estimated. Instead, the two proposed simulations show the effects of Japanese standardization and U.S. lack of standardization separately.

The hypothetical cases are simulated dynamically. A dynamic simulation is used because the proposed changes would affect the level of sales, which would change the size of the network and thus the level of future sales. A static simulation is not able to show the full long-term effects of a policy change.

7.1 The case without standards.

The first hypothetical case is the one in which there was no standardization of numerical controls by Japanese firms. I assume that in 1977, instead of using the new computer numerical controls developed by Fanuc in 1976, each of the existing Japanese machining center builders would have begun using their own CNC. In this case the Japanese industry structure would be similar to the actual one found in the United States. The only relevant firms would be the n American and the n^* Japanese machining center/numerical control builders. The relevant profit functions would be:

$$\pi_{it} = q_{it}(P(Q_t, Q_t^*, \cdot) - c_{mc,t} - c_{nc,t}) \tag{31}$$

$$\pi_{jt}^* = q_{jt}^*(P^*(Q_t, Q_t^*, \cdot) - c_{mc,t}^* - c_{nc,t}^*). \tag{32}$$

where the cost of the numerical control units for the Japanese builders would now be $c_{nc,t}^*$.

For the counterfactual simulation all parameters including the number of firms are assumed to be the same as in the base case of Japanese standardization. The counterfactual is simulated using the following four equations:

$$P(Q_t, Q_t^*, \cdot) = P_t \tag{33}$$

$$P^*(Q_t, Q_t^*, \cdot) = P_t^* \tag{34}$$

$$q_{it}P'(Q_t, Q_t^*, \cdot) + P(Q_t, Q_t^*, \cdot) - c_{mc,t} - c_{nc,t} = 0 \tag{35}$$

$$q_{jt}^*P^{*'}(Q_t, Q_t^*, \cdot) + P^*(Q_t, Q_t^*, \cdot) - c_{mc,t}^* - c_{nc,t}^* = 0. \tag{36}$$

The first two equations are the estimated demand curves for U.S. and Japanese machining centers, and the second two are the first-order conditions of the U.S. and Japanese builders engaged in Cournot competition, derived from profit functions (31) and (32). The hypothetical prices and quantities for the years 1977-1990 are calculated using these four equations plus the costs estimated in Section 6. For this counterfactual, each Japanese firm is assumed to start without an existing network of compatible machine tools in 1977. In other words, the new computer numerical controls which each firm would have developed in 1977 would not have been backward-compatible with the Fanuc controllers that the Japanese builders supplied with their machines before 1977.

The dynamic simulation is executed year-by-year. In 1977, the network of each Japanese firm's existing machining centers would have been zero by assumption, and for each U.S. firm i it would have been the historical figure, $\sum^{1976} q_{it}$. Using these network sizes and the calibrated 1977 cost estimates, hypothetical 1977 prices and sales (P_{1977}, P^*_{1977}, Q_{1977}, and Q^*_{1977}) are determined using the four equations above. The new network facing the Japanese firm in 1978 is simply its level of 1977 sales, $\frac{Q^*_{1977}}{n^*}$, and that facing the U.S. firm is its old network plus its 1977 sales, $(\sum^{1976} q_{it} + \frac{Q_{1977}}{n})$. This procedure is repeated until 1990. A dynamic simulation is used because the effects of standardization are cumulative due to the network externalities.

The results of not having a Japanese standard are given in the figures below. This hypothetical change in the Japanese industry would have led to a smaller compatible network facing each Japanese firm, which would have shifted the U.S. demand curve for Japanese machining centers inwards because demand is a positive function of the size of the network. The inward shift of the demand curve would have led to the lower prices seen in Figure 7. Figure 8 shows that until roughly 1982 the lower prices would have led to higher Japanese sales. Eventually the absence of a large network would have overcome the lower prices, and Japanese sales would have fallen until they reached zero by 1990. This result suggests that network size was a big factor in the decision of many buyers of Japanese machining centers in the United States.

The effect on the market for U.S. machining centers of not having a Japanese standard is in the next set of figures. Figures 9 and 10 show the effects on U.S. prices and output. The lack of a Japanese standard and the resulting smaller network would have made Japanese machining centers less expensive than they would have been otherwise. The lower price of the Japanese machines would have caused the demand curve for U.S. machining centers to shift inwards because the products are substitutes in demand. The inward shift of the demand curve for U.S. machining centers would have been small because the elasticity of demand for U.S. machining centers with respect to the price of the Japanese machining centers was very small, as seen in Table 1. The result would have been slightly lower sales of the U.S. machines, at approximately the same prices as in the presence of a Japanese standard.

The effect on Japanese and U.S. machining center sales and prices of the counterfactual of not having a Japanese standard is consistent with the hypothesis that each country was selling differentiated products to different market segments. Japanese sales would have decreased to zero in the absence of the network externalities benefits of standardization. Because U.S. sales would not have increased correspondingly as Japanese sales decreased, it appears that many buyers would not have bought a machine had they not bought a Japanese machine. This is consistent with the hypothesis that many small firms bought a Japanese machine partly because of the advantages of being in a large network. The larger firms bought the U.S. machines regardless of the standardization of Japanese machines. In fact, the only effect of Japanese standardization was to *increase* U.S. sales slightly due to the higher Japanese prices.

The effect on Japanese profits of not having a Japanese standard is given in the following two figures. Profits for the Japanese builders would have been higher until roughly 1982, during the period that sales would have been higher, but after 1982 as sales would have fallen, profits would have fallen as well. The profits are shown in Figure 11. Total Japanese profits would have been much lower than the actual case where Fanuc was supplying all of the numerical controls, because in this hypothetical case Fanuc's profits are zero by assumption. This can be seen in Figure 12. Therefore, Japanese standardization increased Japanese profits earned in the United States.

U.S. welfare would have been lower without Japanese standardization. U.S. firms' profits would have been slightly lower than in the presence of a Japanese standard because of the projected decrease in sales, as seen in Figure 13. Figure 14 shows the effects on U.S. consumer surplus of the lack of a Japanese standard. Until 1982, as Japanese sales are greater than they would have been otherwise, consumer surplus would have been slightly greater than the actual consumer surplus. However, after 1982 as Japanese sales would have fallen, U.S. consumer surplus would have been lower. Therefore, Japan's strategy of standardizing numerical controls led to higher U.S. consumer surplus as well as higher U.S. profits. The increase in U.S. profits stems from the fact that the products of the U.S. and Japan are imperfect substitutes. By increasing Japanese prices, standardization of Japanese numerical controls increased U.S. sales.

Using the costs calibrated for the base model understates the costs of the Japanese numerical controls had there been no standard because Fanuc had greater economies of scale than any individual builder could have had. Adjusted for higher costs, the Japanese prices would not have been as low as they would have been here without the standard, and sales would have been even lower. Finally, the assumption that the compatible stock for each Japanese firm would have been zero in 1977 in this hypothetical situation may not be realistic. Even if each firm's new controls would have been backward-compatible with the whole existing stock of Fanuc controls, as long as their new sales would not be compatible with each other their sales would still have gone to zero by 1990.

Figure 7: Japanese Prices with and without a Japanese Standard.

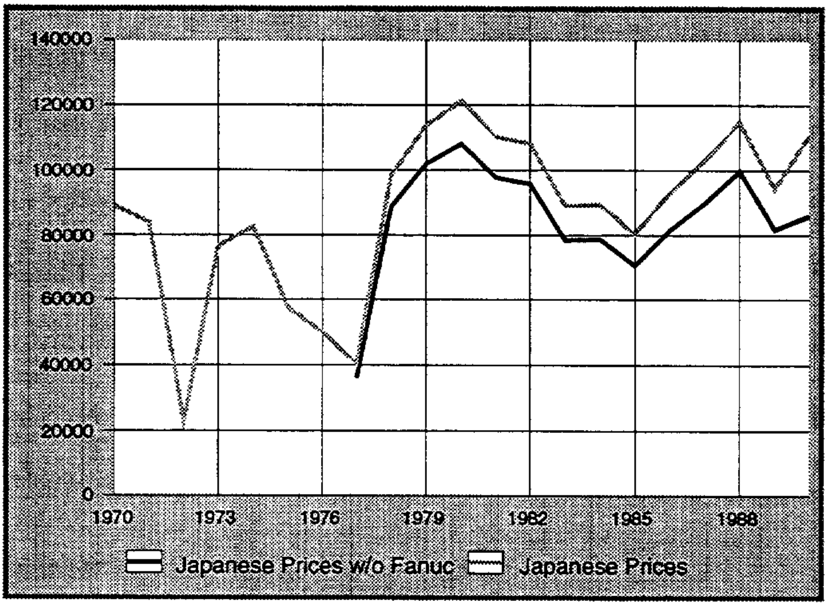


Figure 8: Japanese Sales with and without a Japanese Standard.

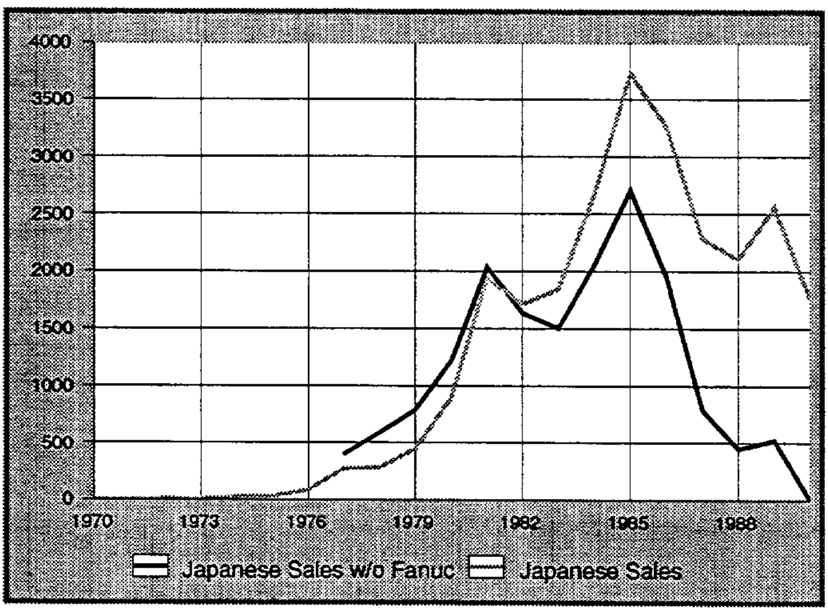


Figure 9: U.S. Prices with and without a Japanese Standard.

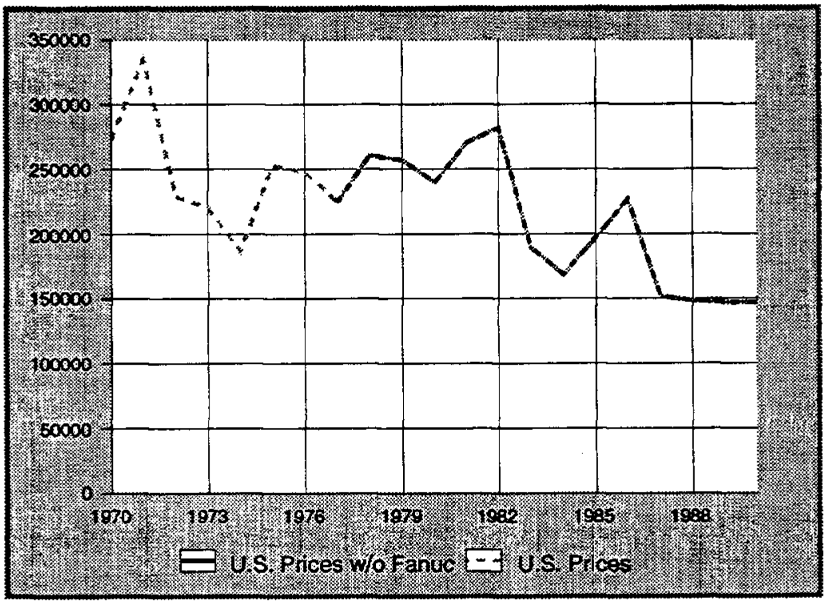


Figure 10: U.S. Sales with and without a Japanese Standard.

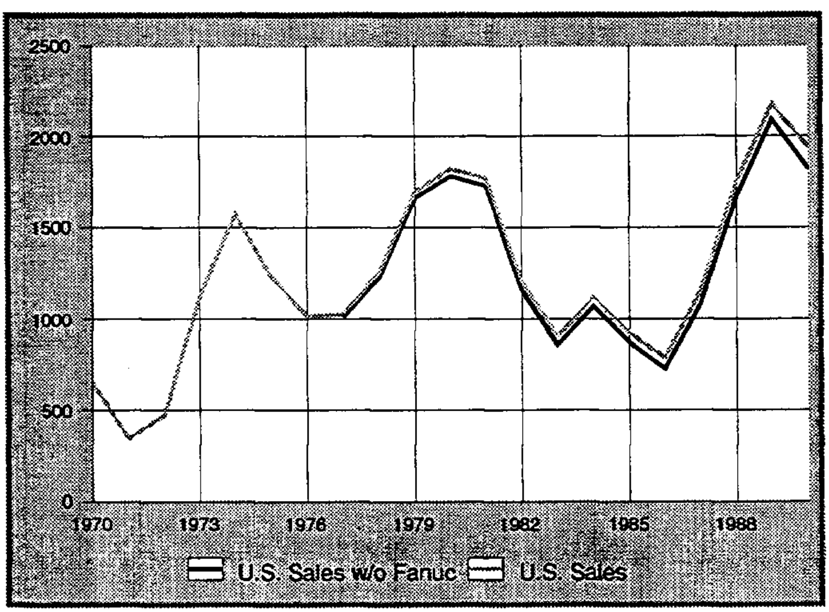


Figure 11: Japanese Profits with and without a Japanese Standard.

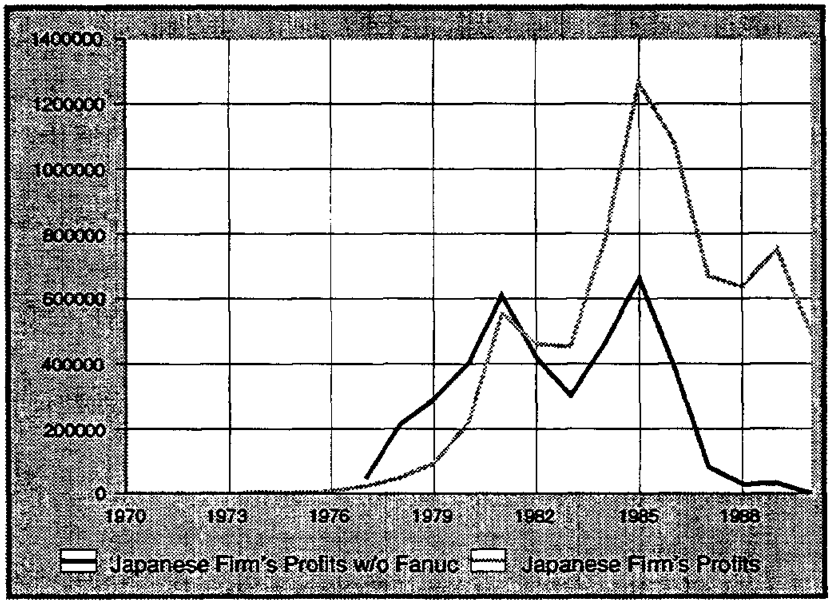


Figure 12: Total Japanese Profits with and without a Japanese Standard.

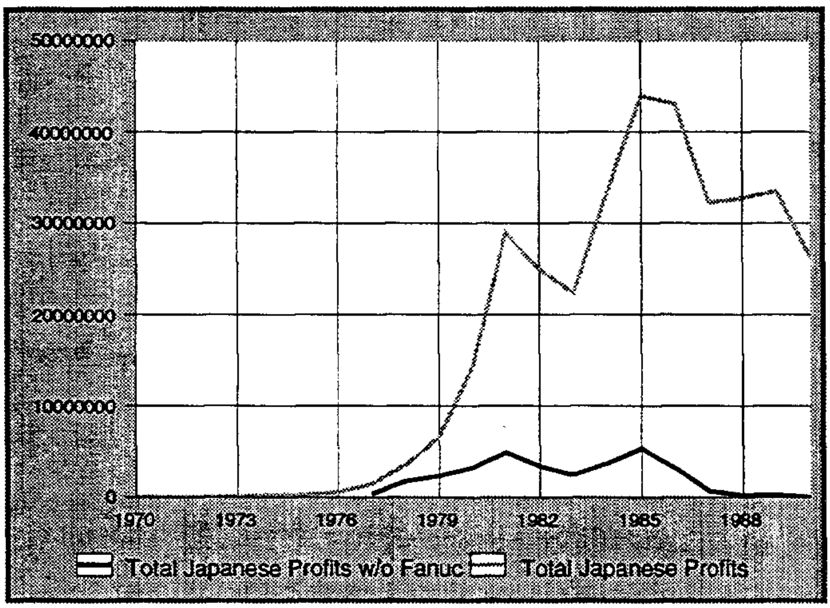


Figure 13: U.S. Profits with and without a Japanese Standard.

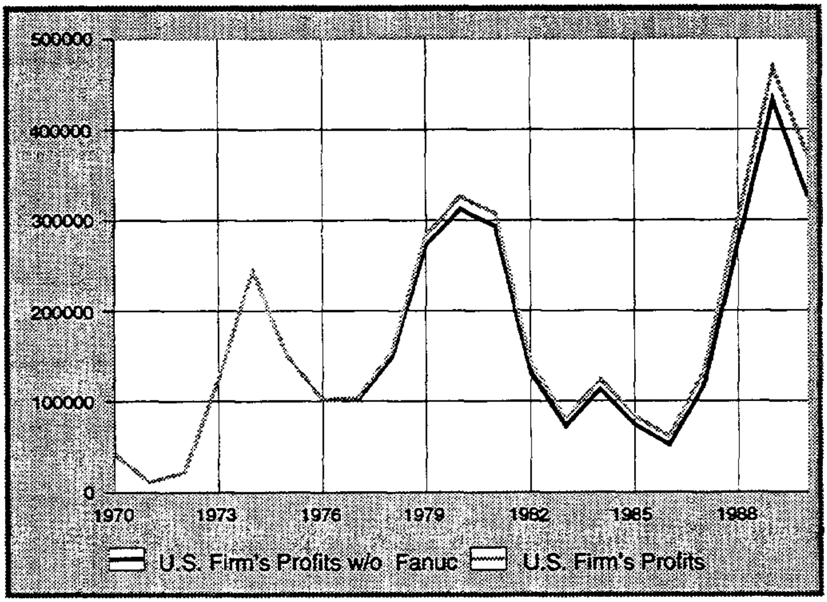
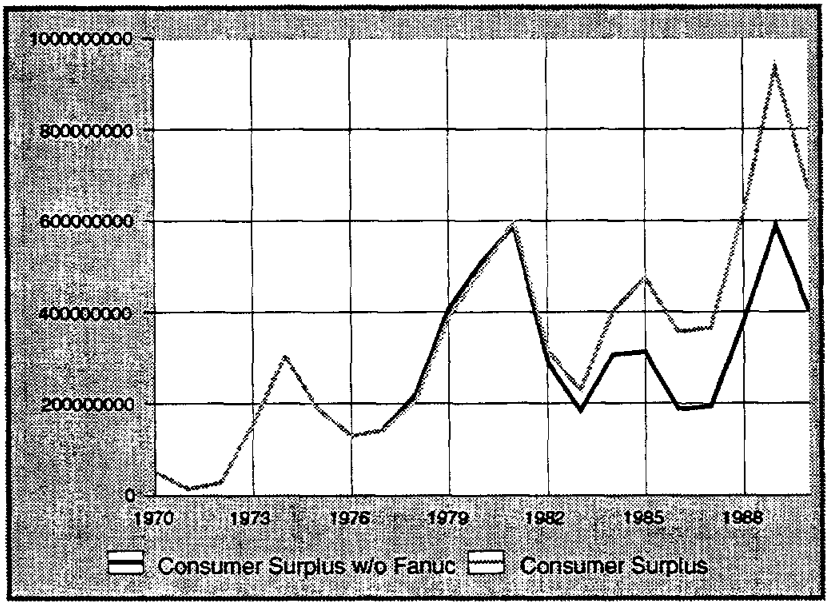


Figure 14: Consumer Surplus with and without a Japanese Standard.



7.2 The case with two standards

In this section I explore the hypothetical case in which the U.S. had also standardized numerical controls. The results of this simulation show the opportunity costs of the U.S. failure to standardize. The year that the hypothetical standardization takes place is assumed to be 1980, the year that the the major U.S. numerical control manufacturers converted to computer numerical control. The U.S. firm structure in this case would be analogous to the actual structure existing in Japan, namely one firm (such as GE) would produce all of the numerical control units for the U.S. machining center builders. The profit functions for the machining center producers would be:

$$\pi_{it} = q_{it}(P(Q_t, Q_t^*, \cdot) - c_{mc,t} - p_{nc,t}) \tag{37}$$

$$\pi_{jt}^* = q_{jt}^*(P^*(Q_t, Q_t^*, \cdot) - c_{mc,t}^* - p_{nc,t}^*) \tag{38}$$

where $p_{nc,t}$ is the price that the U.S. machine tool builder would pay for the standardized U.S. computer numerical controls. Solving the first-order conditions of Cournot competition gives $q_{it} = q_{it}(p_{nc,t}, p_{nc,t}^*)$ and $q_{jt}^* = q_{jt}^*(p_{nc,t}, p_{nc,t}^*)$.

The competing U.S. and Japanese numerical control suppliers would have, respectively, the following profit functions:

$$\pi_{Gt} = Q_t(p_{nc,t}, p_{nc,t}^*) \cdot (p_{nc,t} - c_{nc,t}) \tag{39}$$

$$\pi_{Ft}^* = Q_t^*(p_{nc,t}, p_{nc,t}^*) \cdot (p_{nc,t}^* - c_{nc,t}^*) \tag{40}$$

where π_{Gt} is the profit of the American computer numerical control supplier. The American computer numerical control supplier would build the computer numerical control unit at cost $c_{nc,t}$ and sell it for $p_{nc,t}$. The Japanese industry structure would remain as in the original model. The producers would be assumed to engage in Bertrand price-competition to determine $p_{nc,t}(c_{nc,t})$ and $p^*_{nc,t}(c^*_{nc,t})$. The U.S. and Japanese builders would then decide how much to produce based on the numerical control prices and known demand parameters.

The equations to simulate the results of no U.S. standard are:

$$P(Q_t, Q^*_t, \cdot) = P_t \tag{41}$$

$$P^*(Q_t, Q^*_t, \cdot) = P^*_t \tag{42}$$

$$q_{it}P'(Q_t, Q^*_t, \cdot) + P(Q_t, Q^*_t, \cdot) - c_{mc,t} - p_{nc,t} = 0 \tag{43}$$

$$q^*_{jt}P^{*'}(Q_t, Q^*_t, \cdot) + P^*(Q_t, Q^*_t, \cdot) - c^*_{mc,t} - p^*_{nc,t} = 0 \tag{44}$$

$$q'_{it}(p_{nc,t}, p^*_{nc,t}) \cdot (p_{nc,t} - c_{nc,t}) + q_{it}(p_{nc,t}, p^*_{nc,t}) = 0 \tag{45}$$

$$q^{*'}_{jt}(p_{nc,t}, p^*_{nc,t}) \cdot (p^*_{nc,t} - c^*_{nc,t}) + q^*_{jt}(p_{nc,t}, p^*_{nc,t}) = 0. \tag{46}$$

The first two equations are the demand functions for Japanese and U.S. machining centers, the second two are the first-order conditions for the machining center builders engaged in Cournot competition, derived from equations (37) and (38), and the last two are the first-order conditions for the computer numerical control manufacturers engaged in price-competition, derived from equations (39) and (40). The new network of compatible U.S. machines is assumed to not be backward-compatible with the pre-1980 stock of the U.S. builders. Once again all parameters and the number of firms in each country are assumed to be the same as in the base case with only Japanese standardization. The above equations are solved using the calibrated costs for $P_t, P_t^*, Q_t, Q_t^*, p_{nc,t}$, and $p_{nc,t}^*$.

The results are given in the figures below. The simulation is only run through 1982 because sales and profits from both countries would have been increasing exponentially. The differences in U.S. prices and sales are shown in Figures 15 and 16. The increase in network size due to the standardization of U.S. machining centers would have shifted the demand curve for U.S. machining centers outwards because demand is a positive function of the size of the network, so that both prices and sales would have increased dramatically. The shift in the demand curve would have been large because consumers of U.S. machining centers are very sensitive to the size of the network, as seen in Table 1. In addition, these consumers are not very price-sensitive, so sales would have increased despite the increases in prices. The price and quantity increases would have led to huge increases in U.S. builders' profits, as seen in Figure 17. In addition there would have been a U.S. CNC manufacturer, analogous to Fanuc, also earning large profits as seen in Figure 18.

The simulated results of U.S. standardization on Japanese prices and sales can be seen in Figures 19 and 20. The demand for Japanese machining centers would have shifted outwards because of the increase in U.S. prices. The shift would have been large because the buyers of Japanese machining centers are very sensitive to U.S. prices. Both the price and output of Japanese machining centers would have gone up had the U.S. standardized. The profits of Fanuc and the Japanese machining center producers would have both increased due to the increased sales and prices of Japanese machining centers. The effects of U.S. standardization on profits can be seen in Figures 21 and 22.

Finally, U.S. consumer surplus would have increased dramatically had there been a U.S. standard, as seen in Figure 23. Although the prices would have increased for both U.S. and Japanese machining centers, the accompanying increases in sales would have increased the network externalities accruing to purchasers sufficiently to have raised overall U.S. consumer surplus. Therefore, U.S. standardization would have increased U.S. welfare because of the greater consumer surplus and the larger profits. In addition, Japanese welfare would have increased because of the increase in Japanese profits. The total market for machining centers in the United States would have been increased substantially by U.S. standardization because the two countries were selling differentiated products.

These results understate the effects of U.S. standardization for three reasons. The first reason is that while the base costs are used for the simulation, in reality U.S. standardization would have lowered U.S. numerical control costs due to the economies of scale and learning of having one computer numerical control supplier. These lower costs would have further accelerated U.S. sales and welfare increases. In addition, assuming that the standardized U.S. computer numerical controls would have been incompatible with existing U.S. numerical controls reduces the network externalities effects of U.S. standardization. Had the new controls been backward-compatible, U.S. sales and welfare would have been even higher. Finally, assuming that the computer numerical control suppliers engage in Bertrand competition may understate the hypothetical profits with U.S. standardization because Bertrand competition is relatively competitive.

Figure 15: U.S. Prices with and without a U.S. Standard.

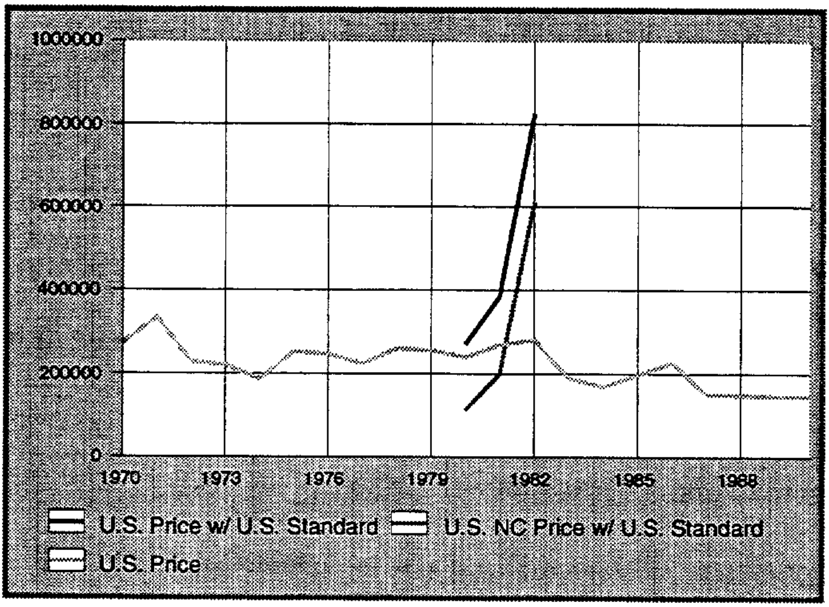


Figure 16: U.S. Sales with and without a U.S. Standard.

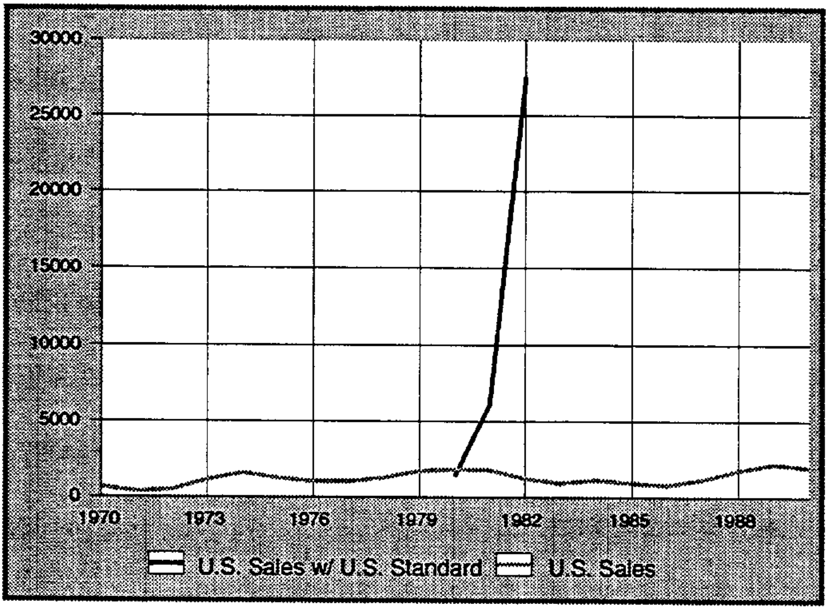


Figure 17: U.S. Firm's Profits with and without a U.S. Standard.

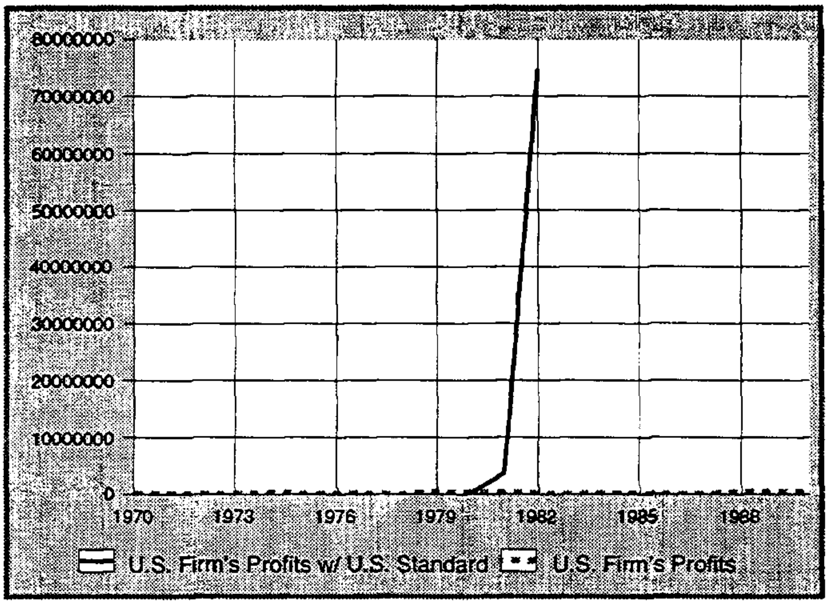


Figure 18: U.S. NC Profits with a U.S. Standard.

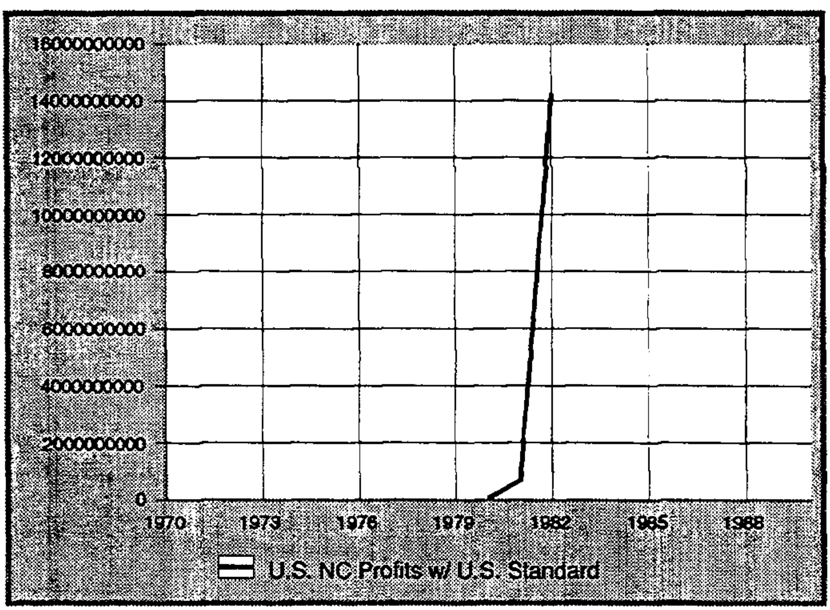


Figure 19: Japanese Prices with and without a U.S. Standard.

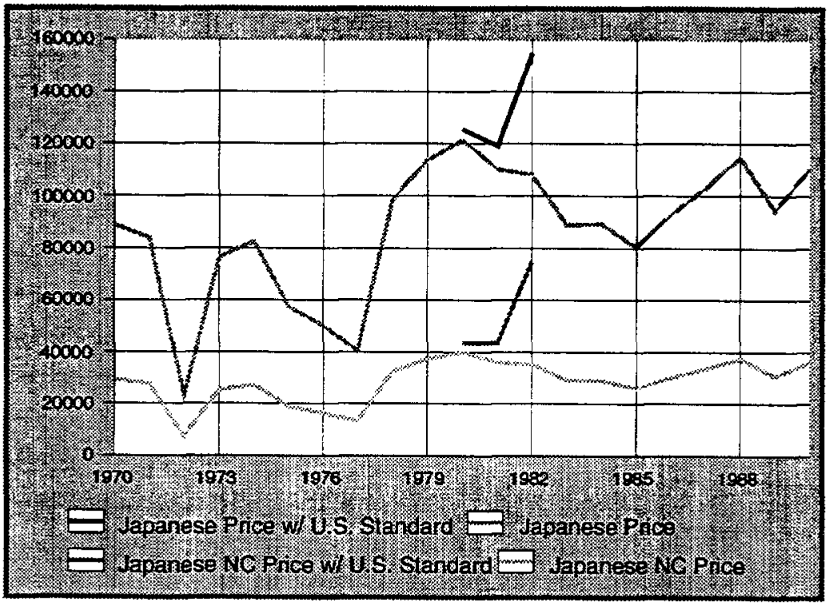


Figure 20: Japanese Sales with and without a U.S. Standard.

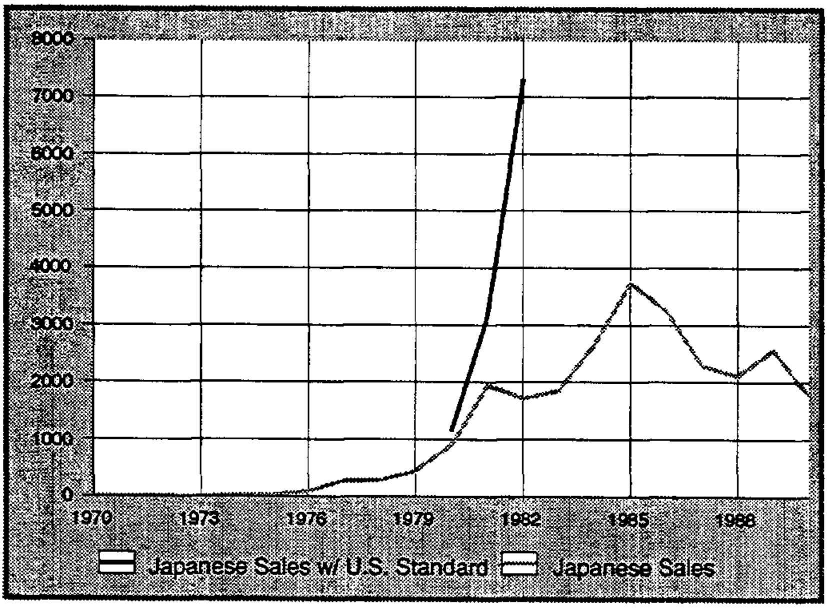


Figure 21: Japanese Firm's Profits with and without a U.S. standard.

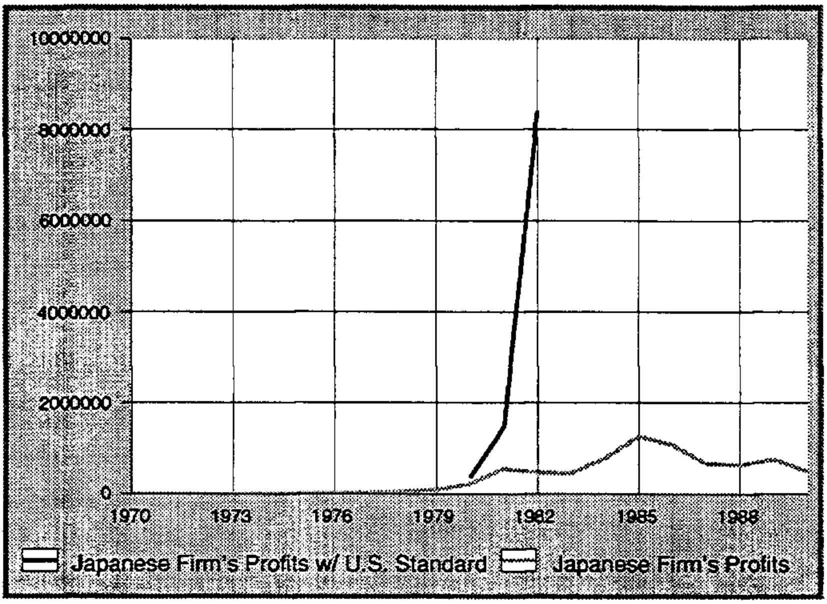


Figure 22: Fanuc's Profits with and without a U.S. standard.

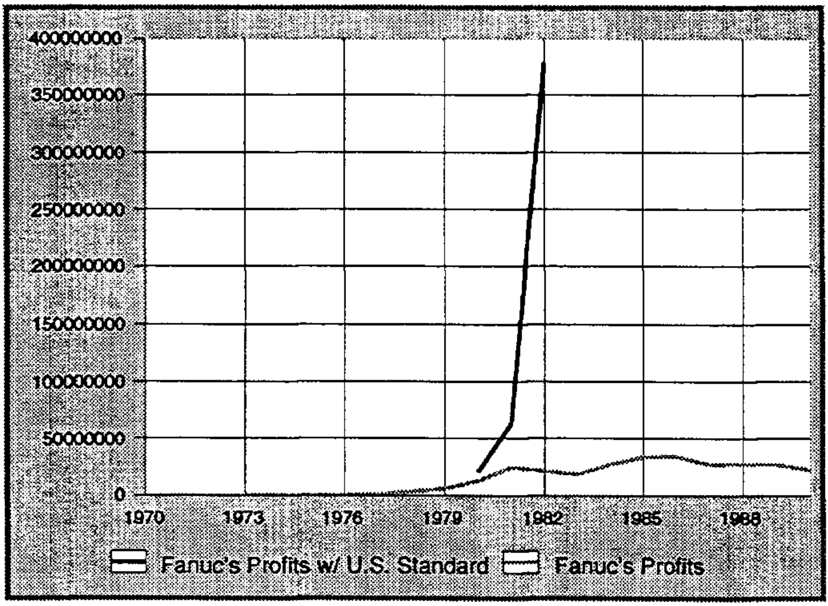
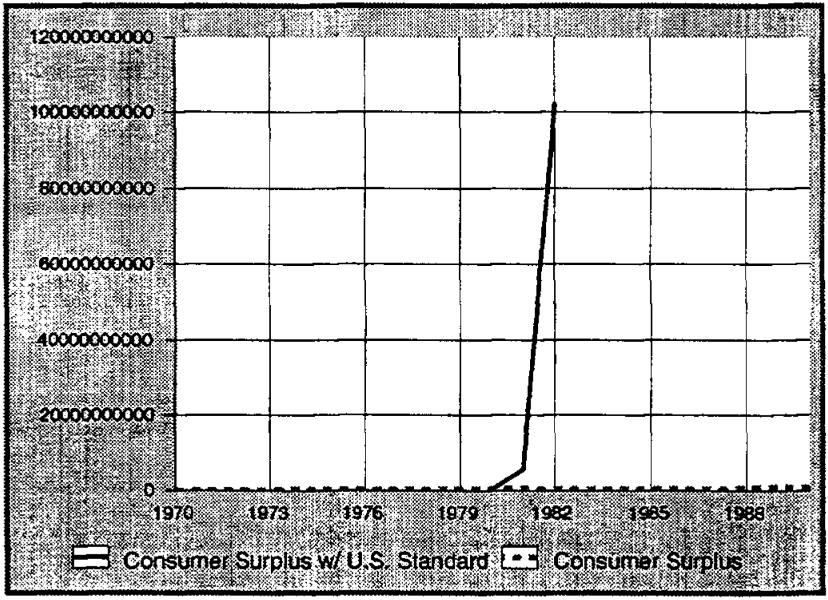


Figure 23: U.S. Consumer Surplus with and without a U.S. Standard.



8 Conclusion

The results of these simulations show the direction, if not the magnitude, of the effects of Japanese standardization of numerical controls, and the U.S. lack of standardization. The results show that standardization by either country increases (or would have increased) U.S. consumer surplus as well as the profits of both countries. The direction of the change in consumer surplus confirms the theoretical results of Kende (1991) that any standardization increases consumer surplus because of the increased network externalities effects. For the numerical control case, this paper shows that U.S. consumer surplus is greater than it would have been had Japan not standardized, and would have been greater yet had the U.S. also standardized.

The fact that standardization by the firms of one country increases the sales and profits of the other country's firms is a somewhat surprising result. Kende (1991) predicts that if the machining centers had been homogeneous goods, standardization of numerical controls would have been a beggar-thy-neighbor strategic trade policy. The fact that the U.S. and Japanese machining centers were differentiated and served different market segments affected the direction of the change in firms' profits resulting from a counterfactual change in standardization. U.S. firms' profits increased from Japanese standardization because the increased prices of Japanese machines due to the larger standardized network led some consumers to buy U.S. machines. U.S. profits would have been greater if the U.S. had also standardized. Japan's long-run machining center profits in the U.S. are shown here to be contingent on having standardized. Had Japan not standardized, even with the cost advantage Japanese machining centers had, Japanese sales in the U.S. would have decreased to zero. If the U.S. had also standardized, Japanese profits would have increased due to the U.S. price increases resulting from U.S. standardization.

These simulation exercises suffer from the usual problems, which make the magnitude of the effects described above somewhat suspect. The lack of degrees of freedom did not permit estimation of parameters of competition as in Dixit (1988). Thus, the true costs may not be those calibrated assuming Cournot competition, and the results of the simulations would further magnify the effect of misspecifying the form of competition. Furthermore, it is plausible that under the counterfactual standardization regimes there would have been different parameters of demand and/or competition. In particular, it is unlikely that U.S. demand for both countries' machining centers would have increased exponentially if the U.S. had also standardized numerical controls, suggesting that the demand parameters would have been different if both countries had standardized. Because the different regimes are hypothetical, it is impossible to determine the true nature of any changes in parameters.

However, this paper has several strengths. First of all, the availability of aggregate data allow demand to be estimated more thoroughly than has previously been done in calibration studies, hopefully lending more realism to the results. Second of all, dynamic elements have been taken into consideration. The effect of firms' current output decisions on the size of the network and future profits has been accounted for. In addition, the cumulative effects of a counterfactual standardization regime on the size of the network has been accounted for.

Any further results would require more detailed data and/or studying a different industry. Independent cost estimates for the industry would allow the parameters of competition to be calibrated. A breakdown of the aggregate data by supplier of numerical control, buyer, or complexity of machine would allow for a more accurate model of demand taking into account the market segmentation and product differentiation. Finally, studying an industry whose actual standardization regime is different than that of the numerical control industry would allow different scenarios to be tested, such as U.S. standardization with Japanese lack of standardization.

Within the limitations of the data and procedures used, the results of this paper make a strong case for the United States to evaluate its role in both domestic and international standardization. This does not necessarily imply taking an active role and choosing a standard as was done in Japan with numerical controls, but it supports both the relaxation of U.S. antitrust laws with respect to standardization and aid to industry-wide standardization bodies.

Appendix

The data sources used are as follows:

- U.S. Price and Quantity: 1970-1988, U.S. Department of Commerce Report MQ-35W, *Current Industrial Report, Metalworking Machinery.* 1989-1990, National Machine Tool Builders Association, mimeo.
- Japanese Price and Quantity: 1970-1988, U.S. Department of Commerce Report FT-246, *U.S. Imports for Consumption and General Imports - TSUSA Commodity by Country of Origin.* 1989-1990, National Machine Tool Builders Association, mimeo.
- BFI: *1990 Economic Report of the President*, total manufacturing business expenditures for new plant and equipment, p. 347.
- Transport: *1990 Economic Report of the President*, total transportation equipment industrial production index, p. 342.
- Yen: *1990 Economic Report of the President*, p. 410.
- CPI: *1990 Economic Report of the President*, p. 351.
- Fanuc Profit: *Japan Company Handbook.*
- Number of firms: Estimated from *American Machinist* reports on manufacturers' offerings at biannual International Machine Tool Show.
- Stock of compatible machining centers: The U.S. stock of machining centers in 1968 is taken from the 10th *American Machinist* Inventory of Metalworking Equipment. All of these machines are assumed to be built in the United States. From 1969-1990 the stock of Japanese and U.S. machining centers is built up by adding the yearly sales to the previous stock. This assumes no depreciation of the existing stock. The resulting stock estimates are lower than the corresponding numbers in the 11th-14th Inventories, so the assumption of no depreciation may not be very restrictive.
- U.S. wages: U.S. wages in the metal-cutting industry, from the *U.S. Bureau of Labor Statistics.*

The sales figures do not take into account other sources of machining centers with Fanuc controls, namely machines from third countries such as Taiwan which had Fanuc controls, or machines built in the U.S. with Fanuc controls, or machining centers built with controls manufactured by a Fanuc joint venture, General Numeric. This is offset by the fact that not all Japanese machines were shipped with Fanuc controls. It is very difficult to get an accurate breakdown of sales, partly due to firm's desire to keep proprietary sales information confidential, and partly due to the sensitivity of Japanese firms to U.S. trade concerns. Therefore, I had to assume that all Japanese sales in the U.S. had Fanuc controls, and all U.S. domestic sales were with incompatible U.S. controls.

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