Discussion Paper No. 719

WHY ARE CONCAVITY CONDITIONS NOT SATISFIED IN THE COST FUNCTION? THE CASE OF JAPANESE MANUFACTURING FIRMS DURING THE BUBBLE PERIOD

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September 2008

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Why Are Concavity Conditions Not Satisfied in the Cost Function?: The Case of Japanese Manufacturing Firms during the Bubble Period*

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* This paper is a complete revision of one previously circulated under the title “How Important Is Land as a Production Factor for Japanese Manufacturing Industries?” An earlier version of this paper was presented at the informal seminar in honor of Professor Saito held at Kobe University. The author is grateful to the participants at the seminar for their helpful comments and suggestions. This research was partially supported by a Grant-in-Aid for Scientific Research (19330044) from the Ministry of Education and the Japan Economic Research Foundation. All remaining errors are, of course, my own.

Abstract

This paper examines empirically some of the reasons why Japanese manufacturing firms frequently fail to satisfy concavity conditions of the cost function. We focus on the "bubble period" in the 1980s when land was in great demand for reasons related to both production and speculation, and land prices soared. By estimating the translog cost function with land as one of production inputs for manufacturing firms, we find that violation of concavity resulted from borrowing constraints and large adjustments of employment. We also demonstrate that elasticities of substitution between land and other inputs and input demand with respect to land rental prices are both estimated with large biases if the firms violating concavity are not excluded from the analysis.

JEL Classification Number: D24, R14
Keywords: Land, Translog cost function, Concavity

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1. Introduction

One of the anomalies of empirical economics is the failure of concavity conditions in estimating cost functions. From a theoretical perspective, concavity of the cost function is a basic tenet because concavity ensures a firm's rational behavior for cost minimization. Therefore, many attempts have been made to incorporate concavity into estimating cost functions. Jorgenson and Fraumeni (1981) and Diewert and Wales (1987) proposed methods for imposing concavity conditions globally in the context of cost function estimation, while Terrell (1996) and Ryan and Wales (2000) devised methods for incorporating local concavity conditions into the cost function, maintaining flexibility of the functional forms. Imposing concavity either globally or locally is desirable to obtain the parameter estimates used for inferring the production structure of the firm and evaluating the effects of various policy measures on the firm's behavior.[1]

However, it is important to recognize that such an approach is based on the implicit assumption that all of the firms in the sample are indeed minimizing production costs. If some of the firms are incapable of minimizing production costs due to extraneous circumstances, then imposing concavity conditions on the cost function misspecifies the model and therefore yields inconsistent estimates of the cost function parameters.

The purpose of this study was to empirically investigate firms violating concavity conditions of the cost function and identify economic factors responsible for violating concavity conditions. This research is based on Japanese manufacturing firm data from the period during the 1980s known as the "bubble period" when land and stock prices soared as exemplified by the average rate increases of 25.3% and 26.2% for the land prices in six large metropolitan areas and the stock price index of the Tokyo Stock Exchange (TOPIX), respectively, during this period.

The bubble period is ideal for our analysis because its sharp rise in land prices encouraged firms to retain and/or increase their land holdings for speculative purposes unrelated to production. Additionally, land played a collateral role in loan contracts

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[1] For empirical studies that estimate the parameter estimates of the cost function by imposing concavity conditions on the cost function, see Kumbhakar (1990, 1992) and Chua et al. (2005).

such that large firms, which had relied heavily on bank loans to finance investment prior to the bubble period, began to raise funds directly from capital markets owing to overall liberalization of financial market. This forced banks to search for new customers, and they eventually lent money to smaller and/or nonmanufacturing firms, establishing new ties that were nonexistent prior to the bubble period. Land assets held by the borrowers played vital collateral roles in mitigating the informational asymmetry between creditors and debtors during this period.[2] When the purchase of land is driven primarily by such speculative motivations, land acquisition does not necessarily contribute to production and it is highly unlikely that cost minimization is attained under these circumstances. Also, when factor prices change, the optimal combination of inputs for a firm will change accordingly and the firm may not be able to choose the optimal level of inputs due to borrowing constraints, resulting in unattained cost minimization for some firms. The above discussions suggest that a goal of identifying factors responsible for the violation of concavity conditions is best achieved by examining the behavior of Japanese manufacturing firms during the bubble period.

We estimate the translog cost function of value-added type using the factor inputs of labor, capital, and land based on manufacturing firm data for five industries: chemicals, iron and steel, machinery, electrical machinery, and transport equipment. After identifying the firms that fail to satisfy concavity conditions, we determine the factors that cause violation of concavity conditions. Furthermore, we compare the elasticities of substitution and the input demand elasticities with respect to the land rental price between the unconstrained case including the firms that violate concavity conditions and the case excluding the firms that violate concavity conditions.

The proportion of firms violating concavity conditions is approximately 50% of the total firms regardless of the industry. The probit analysis reveals that a large rate of change in labor and less dependence on bank loans increase the probability of violating

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[2] For empirical evidence to support the collateral role of land in Japan, see Ogawa et al. (1996) and Ogawa and Suzuki (1998, 2000).

concavity conditions. We also find that the degree of substitution between land and other input factors as well as input elasticities with respect to land rental price are both estimated with large biases unless the firms violating concavity are carefully excluded from the analysis.

The paper is organized into five sections. Section 1 consists of this introductory discussion. In Section 2, we specify the translog cost function together with the cost-share equations to be estimated. Then we explain the procedure for identifying the firms that violate concavity conditions. Section 3 deals with econometric issues and an explanation of the panel data set. Section 4 presents the estimation results and identifies factors responsible for the violation of concavity conditions. We also gauge the extent to which the violation of concavity conditions affects the estimates of the elasticities of substitution as well as the input demand elasticities with respect to the land rental price. Finally, our conclusions are summarized in Section 5.

2. Theoretical Framework: Characterization of Cost Function and Concavity Conditions

The real value of a manufacturing firm is primarily the result of some combination of capital, land stock, and labor factors. I represent a firm's production technology using the translog cost function so that the flexibility of production structure can be incorporated into the model. Any degree of substitutability or complementarity of production factors can be attained under the translog cost function.[3]

The translog cost function is specified as follows:

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[3] For an exposition of translog cost function, see Christensen, Jorgenson, and Lau (1971, 1973). Jorgenson (1986) gives a comprehensive survey of modeling producer behavior.

$$\ln C(p,y) = \alpha_0 + \sum_{i=1}^{3} \alpha_i \ln p_i + \alpha_y \ln y + \frac{1}{2} \sum_{i=1}^{3} \sum_{j=1}^{3} \alpha_{ij} \ln p_i \ln p_j + \sum_{i=1}^{3} \alpha_{iy} \ln p_i \ln y$$
$$+ \frac{1}{2} \alpha_{yy} (\ln y)^2 + \sum_{f=1}^{N} \gamma_f DF_f + \sum_{t=1}^{T} \lambda_t DT_t + \varepsilon \tag{1}$$

where $C(p,y)$: nominal value-added or total cost

p_i : factor price of i-th input

y : real value-added

DF_f :dummy variable for the f-th firm

DT_i :dummy variable for year

ε : disturbance term

$i = 1,2,3$ for capital stock, labor and land stock, respectively

The cost function of Eq. (1) incorporates nonconstant returns to scale and time-varying technical progress, represented by time dummies. The factor demand function is derived by employing Shephard's Lemma. We obtain the following cost-share equations:

$$s_i \equiv \frac{p_i X_i}{C} = \alpha_i + \sum_{j=1}^{3} \alpha_{ij} \ln p_j + \alpha_{iy} \ln y \tag{2}$$
$$(i = 1,2,3)$$

We estimate the cost-share equations jointly with the cost function. In so doing, we impose the following integrability conditions of the cost function on the system.

1) symmetry $\alpha_{ij} = \alpha_{ji}$

2) cost exhaustion $\sum_{i=1}^{3} \alpha_i = 1$, $\sum_{i=1}^{3} \alpha_{iy} = 0$ and $\sum_{i=1}^{3} \alpha_{ij} = 0 \quad (j = 1,2,3)$

3) linear homogeneity in factor prices $\sum_{j=1}^{3} \alpha_{ij} = 0 \quad (i = 1,2,3)$

Note that one of the components in Eq. (2) is linearly redundant.

Concavity of the cost function is data-dependent and we examine whether they are satisfied for each observation based on the parameter estimates. Note that we are examining local but not global concavity evaluated at each observation. Specifically, the concavity of the translog cost function in the input prices implies that the following matrix must be negative semidefinite.[4]

$$\Phi = \mathrm{A} + ss' - \Omega \qquad (3)$$

where $A \equiv \lfloor \hat{\alpha}_{ij} \rfloor$ $\hat{\alpha}_{ij}$:parameter estimates of the translog cost function $(i, j = 1,2,3)$

$s' \equiv [s_1, s_2, s_3]$ s_i : cost share of the i-th input

$$\Omega \equiv \begin{bmatrix} s_1 & 0 & 0 \\ 0 & s_2 & 0 \\ 0 & 0 & s_3 \end{bmatrix}$$

Therefore we calculate the eigenvalues of the Φ matrix for each observation and identify the firms satisfying concavity conditions if none of the eigenvalues take positive values.

3. Econometric Issues and Data Description

Since we employ a panel data set of firms in estimation, the firm-specific effects are taken into consideration explicitly as firm dummies in the translog function. Note that firm-specific effects do not appear in the cost-share equation. A random disturbance term is also added to each cost-share equation and we assume that the resulting disturbance vector together with the one in the translog cost function is multivariate normally distributed with a mean vector zero and constant variance–covariance matrix. Then we apply the maximum likelihood estimation to the system.

Equations (1) and (2) are estimated on the basis of panel data of the Japanese

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[4] For an example, see p. 1887 in Jorgenson (1986).

manufacturing firms listed on the Tokyo Stock Exchange. The panel data set employed for estimation is constructed from the database of the Japan Development Bank. Our total sample consists of 342 firms, each chosen using the criterion that neither a change in the term of account settlements nor any large mergers or acquisitions occurred during the sample period from 1979 to 1993. The cost function and cost-share equations are estimated separately for each of the five industrial categories: chemicals (80), iron and steel (38), machinery (91), electrical machinery (71), and transport equipment (62), with the total number of firms for each category indicated in parentheses. The firms for the cost analysis are categorized because firms in the same industries are more likely to share common production technologies; thus, the parameters characterizing their production technologies are expected to be estimated with greater precision. A more detailed explanation of the data construction procedure is provided in the Data Appendix.

Table 1 shows the sample average of the investment rate, defined as gross investment divided by the beginning-of-period capital stock, rate of change in real land stock, and the rate of change in employment or number of employees for the five industries. The average is calculated separately for the “pre-bubble period” (1979–1985) and the “bubble period” (1986–1993) with the standard deviations indicated in parentheses. Among these industries, the average rate of change in land stock is higher during the bubble period for chemicals, iron and steel, and machinery, and the corresponding fourfold and threefold higher standard deviations for iron and steel and machinery, respectively, imply that land purchasing behavior varied considerably across firms during the bubble period.

4. Estimation of Results and Implications

To what extent are concavity conditions violated?

Table 2 shows the proportion of the firms that violated the concavity condition of the translog cost function for the entire period from 1979 to 1993.[5] On average,

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[5] The parameter estimates of the translog cost function are given in the Appendix.

approximately 50% of the observations do not satisfy concavity conditions. However, wide variations across time and industry are apparent. The average proportion of firms violating concavity conditions is less than 50% for the chemicals and iron and steel industries but more than 50% for the machinery, electrical machinery, and transport equipment industries. These proportions range from 32.5% (chemicals in 1980) to 69.2% (machinery in 1993) and there seems to be no discernible trend or regularity in the proportion of firms violating concavity conditions.

What factors are responsible for violation of concavity conditions?

Once we identify observations that violate the concavity conditions of the cost function, we can empirically identify the factors that cause violations of concavity conditions. Concavity conditions are violated owing primarily to two basic processes.

First, large changes in quasi-fixed inputs over a short time period require a firm to readjust its organizational structure, which may be accompanied by the relocation of employees and/or machinery. This process will result in additional expenses and allocations and prevent minimization of production costs.[6] Furthermore, large volume transactions of land stock might be motivated for speculative gains in which case the change in land stock is unrelated to the change in manufacturing output. Therefore, cost minimization is not attained.

The second process relates to optimization in that even if factor prices change, a firm does not necessarily choose the optimal combination of inputs under the newly changed circumstances due to borrowing constraints. In this case, the firm will be forced to choose an input combination that is suboptimal, and therefore, production costs will not be effectively minimized. This scenario seems quite likely for the case of purchasing indivisible capital stock. When a firm has a close relationship with a bank, it is less likely that borrowing constraints will exist for that firm. We measure bank–firm

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[6] This inference is along the same line as the adjustment cost story of demand for quasi-fixed inputs. A more rigorous approach incorporating the adjustment cost needs formulation of cost minimization is obtained from dynamic aspects.

relationships using the ratio of bank loans to total assets denoted by $BANK$.

We can econometrically formulate the ideas described above by the following probit model. The dichotomous dependent variable, denoted by Z_i, takes the value 1 if the i$^{\text{th}}$ observation satisfies concavity conditions of the cost function; otherwise, it takes the value 0. The explanatory variables are the absolute value of the rate of change in capital stock, labor, and land stock for the i$^{\text{th}}$ observation, represented by g_{ij} $(j = 1,2,3)$, and the bank–firm relationship $(BANK)$. Then our probit model is written as

$$Z_i = \beta_0 + \sum_{j=1}^{3} \beta_j \left| g_{ij} \right| + \theta BANK_i + \sum_{j=1}^{T} \eta_j DT_j + \nu_i \qquad (4)$$

where ν_i : disturbance term

Time dummies (DT_j) are added in Eq. (4) to account for macroeconomic shocks. The coefficients of β_j are expected to be negative and that of θ to be positive. Equation (4) is estimated for each of the five industries (Table 3). The coefficient estimate of the absolute value of the rate of change in employees is significantly negative for machinery and electrical machinery, implying that a large rate of change in employees is likely to cause violation of concavity conditions. It hints that the firms incur extra costs in adjusting a large volume of labor input factors. Unexpectedly, the coefficient estimates of the absolute value of the rate of change in capital stock and land stock are statistically insignificant, irrespective of industry. Closer bank–firm relationships significantly increase the probability that concavity conditions are satisfied for chemicals, machinery, and electrical machinery. This implies that borrowing constraints do prevent some firms from attaining cost minimization. To summarize, failure of concavity conditions arises mainly from a large change in employees and borrowing constraints but not from massive trading of land for speculative purposes.

Consequence of ignoring concavity conditions

Characteristics of the production technology are often expressed in terms of elasticity of substitution between inputs and input elasticities with respect to input prices. They provide useful information in quantitatively evaluating the effects of policy change on demand for factor inputs. However, if the estimates of elasticity of substitution and input elasticities with respect to input prices are calculated using the sample that includes the firms violating concavity conditions of the cost function, then any inferences based on such estimates are highly suspect.

In this subsection, we quantitatively evaluate the severity of this problem by comparing the estimates of elasticity of substitution among inputs and input elasticities with respect to land rental price between the case in which the whole sample including the firms that violate concavity is used and the case excluding those violating concavity.

As for the measure of elasticity of substitution, we calculate the Allen partial elasticities of substitution. The Allen partial elasticity of substitution between the i^th^ input and the j^th^ input, denoted by σ_{ij}, is defined as

$$\sigma_{ij} = 1 + \frac{\alpha_{ij}}{s_i s_j} \qquad (5)$$

Two inputs are a substitute if σ_{ij} is positive, while they are a complement if σ_{ij} is negative. Based on the coefficient estimates of the translog cost function, the elasticities of substitution are computed for two different samples. One sample consists of all the firms in the sample, regardless of whether concavity conditions are satisfied. The other sample consists of only the firms that satisfy concavity conditions. In both cases, the elasticities of substitution are computed for each observation of the sample and then averaged out. The elasticities of substitution thus calculated are given in Table 4. There is no discernible difference in the estimates of the elasticity of substitution between capital and labor, irrespective of industry. However, the elasticity of substitution between land and other inputs are estimated with large biases. When the firms violating concavity conditions are included in calculation, complementarity between capital and land is overestimated for chemicals, iron and steel, and machinery, while substitutability between capital and land is overestimated for electrical machinery and transport equipment. Complementarity between land and labor is also overestimated for transport equipment and substitutability between land and labor is underestimated for machinery and electrical machinery.

I now discuss the extent to which the elasticities of factor inputs with respect to land rental price are biased without paying proper attention to the firms violating concavity conditions. The elasticity of the ith input with respect to land rental price $\left(\varepsilon_{iL}\right)$ is calculated as

$$\varepsilon_{iL} = \sigma_{iL} s_L \qquad (6)$$

where σ_{iL} : elasticity of substitution between land and i-th input

The computed values are shown in Table 5. Note that own price elasticities are estimated with large biases except for iron and steel. Own price elasticities are all negative and stable around –0.68 (transportation equipment) to –0.43 (machinery) when the firms violating concavity conditions are excluded in the calculation. However, own price elasticities are underestimated in the absolute value for chemicals, electrical machinery, and transport equipment when the firms violating concavity conditions are included in the calculation. For machinery, own price elasticity is estimated to be positive and the evidence can be interpreted as follows. An increase in land rental price induces the firms satisfying concavity conditions to reduce the land inputs as production factors, so that own price elasticity takes a positive value. In contrast, the firms violating concavity conditions might demand land not for production purposes, but for speculative purposes. If this is the case, then an increase in the land price might generate the expectation that the land price will rise further in the future, which might prompt the firms to increase land purchases in pursuit of speculative gains. Thus, a negative response of the land purchase to a land price hike by the firms satisfying concavity conditions is offset by a positive response by the firms violating concavity conditions. This situation was quite likely during the bubble period in Japan.

To sum up, unless proper attention is paid to the firms violating concavity conditions of the cost function, we end up obtaining biased estimates of the elasticity of substitution among inputs and input elasticities with respect to factor prices and we are misled into making erroneous inferences regarding policy evaluations.

5. Concluding Remarks

In this paper, we examined empirically why some manufacturing firms failed to satisfy concavity conditions of the cost function. We focused on the bubble period during the 1980s in Japan when land prices soared and land was in great demand not only for production purposes but also for speculation. By estimating the translog cost function with land as one of the production factors, violation of concavity was found to result primarily from borrowing constraints and large adjustments in employment. Furthermore, elasticities of substitution between land and other inputs and input elasticities with respect to land rental prices were found to be estimated with large biases if the firms violating concavity conditions were not excluded from the analysis.

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Data Appendix

We give brief explanations how the data series are constructed with special emphasis on stock variables such as capital stock and land stock.

Construction of Capital Stock

Our basic strategy to construct a series of the physical depreciable capital stock is to follow the perpetual inventory method, as discussed in Hayashi and Inoue(1991) . Our benchmark capital stock is that in the fiscal year of 1970. It is assumed that the book-valued benchmark is equal to the capital stock in terms of replacement cost basis. The physical depreciation rates (δ) are based on those reported in Hayashi and Inoue(1991). Given the benchmark value of the depreciable stock, real investment series, and depreciation rate, we obtain the series of capital stock from the following formula. For detailed explanations see Hayashi and Inoue(1991).

$$K_t = (1-\delta)K_{t-1} + I_t \qquad \text{(A-1)}$$

where K_t : capital stock at the end of t-th period

I_t : investment

Construction of Land Stock

We also follow the perpetual inventory method in calculating the series of land stock, along the lines suggested by Hoshi and Kashyap(1990) and Hayashi and Inoue(1991). We choose the fiscal year of 1970 as our benchmark period. The benchmark stock of land at the market price is obtained by multiplying the book value of land stock in the balance sheet by the market-book ratio, 5.27, which is borrowed from Ogawa et al.(1994). The net investment in land at the market price $(NILAND)$ is calculated as the increment of land, which is evaluated at current price, minus the decrement of land at current price. The decrement of land in the balance sheet is originally book-valued, so that it is converted into market-value under the LIFO-type assumption that the land sold in period t was purchased in the most recent period, period t-1. Then the land stock at the market price is constructed by the following formula.

$$LANDY_t = LANDY_{t-1}\frac{p_t^L}{p_{t-1}^L} + NILAND_t \qquad \text{(A-2)}$$

where $LANDY_t \left(= p_t^L L_t\right)$: stock of land at market price

p_t^L :land price

Finally the real land stock series is obtained by dividing the land stock at market price by land price index.

Labor Input

Number of employees at the beginning of period

Rental Price of Capital Stock

The rental price of capital stock is computed as follows:

$$p_t^I\left(R_t + \delta\right) \qquad \text{(A-3)}$$

where: p_t^I investment goods deflator

R_t : borrowing interest rate of the firm which is computed as the sum of interest and discount paid and bond interest expenses divided by the sum of short-term and long-term loans payable, bonds payable and notes receivable discounted.

δ : depreciation rate, which is assumed to be constant (0.08 per annum)

Rental Price of Land Stock

The rental price of land stock is computed as follows:

$$p_t^L R_t \qquad \text{(A-4)}$$

Wage Rate

The wage rate is computed as the average monthly wages times 12 to convert into annual basis.

Nominal Value-added

Nominal value-added is defined as the sum of payment to capital stock, land stock and labor.

Land Price

In the first place the rate of change in land price is calculated as a weighted average of the rate of change in land price of six large city areas and that of other areas. The weight is the proportion of land at market price held by the corporations in six large city areas. Then a time series of land price is constructed using the rate of change in land price calculated above so that the land price in 1990 can be unity.

Appendix

Estimation Results of the Translog Cost Function

Chemicals

Parameter	Coefficient estimates
α_0	2.0340(5.54)***
α_1	0.2964(4.97)***
α_2	0.4147(6.00)***
α_3	0.2889(6.67)***
α_{11}	0.0648(6.27)***
α_{12}	-0.0233(-2.82)***
α_{13}	-0.0415(-8.61)***
α_{22}	0.0235(2.84)***
α_{23}	-0.0002(-0.04)
α_{33}	0.0417(7.64)***
α_y	0.6389(15.86)***
α_{yy}	0.0121(3.21)***
α_{1y}	0.0154(6.54)***
α_{2y}	-0.0051(-2.26)**
α_{3y}	-0.0102(-6.07)***
$DT1980$	-0.1331(-15.38)***
$DT1981$	-0.2034(-20.53)***
$DT1982$	-0.2610(-23.47)***
$DT1983$	-0.2790(-23.01)***
$DT1984$	-0.3136(-24.12)***
$DT1985$	-0.3724(-24.93)***
$DT1986$	-0.3711(-23.66)***
$DT1987$	-0.3677(-23.16)***
$DT1988$	-0.4161(-24.17)***
$DT1989$	-0.4426(-24.45)***
$DT1990$	-0.4847(-23.89)***
$DT1991$	-0.5029(-24.21)***
$DT1992$	-0.5417(-25.77)***
$DT1993$	-0.5595(-25.71)***
Log of likelihood	4073.29
Number of observations	1183

Iron and Steel

Parameter	Coefficient estimates
α_0	1.6175(2.09)**
α_1	0.2118(1.87)*
α_2	0.7927(7.04)***
α_3	-0.0044(-0.06)
α_{11}	0.0668(3.33)***
α_{12}	-0.0213(-1.31)
α_{13}	-0.0455(-5.30)***
α_{22}	0.0094(0.61)
α_{23}	0.0119(1.37)
α_{33}	0.0336(3.50)***
α_y	0.5174(5.58)***
α_{yy}	0.0494(5.04)***
α_{1y}	0.0264(8.37)***
α_{2y}	-0.0358(-9.71)***
α_{3y}	0.0094(3.89)***
$DT1980$	-0.1456(-11.97)***
$DT1981$	-0.1229(-10.38)***
$DT1982$	-0.1543(-11.45)***
$DT1983$	-0.2338(-16.01)***
$DT1984$	-0.2056(-13.89)***
$DT1985$	-0.1936(-12.69)***
$DT1986$	-0.1739(-10.12)***
$DT1987$	-0.1521(-9.45)***
$DT1988$	-0.1163(-7.93)***
$DT1989$	-0.0984(-6.18)***
$DT1990$	-0.1203(-5.67)***
$DT1991$	-0.1235(-5.94)***
$DT1992$	-0.1290(-8.22)***
$DT1993$	-0.1725(-11.81)***
Log of likelihood	2018.81
Number of observations	542

Machinery

Parameter	Coefficient estimates
α_0	2.1019(6.23)***
α_1	0.0812(2.21)**
α_2	0.4472(10.27)***
α_3	0.4716(14.45)***
α_{11}	0.0251(3.81)***
α_{12}	-0.0035(-0.74)
α_{13}	-0.0216(-6.64)***
α_{22}	0.0247(5.75)***
α_{23}	-0.0211(-6.48)***
α_{33}	0.0427(18.81)***
α_y	0.4572(8.05)***
α_{yy}	0.0331(5.37)***
α_{1y}	0.0150(7.67)***
α_{2y}	0.0025(1.10)
α_{3y}	-0.0175(-11.56)***
$DT1980$	-0.1064(-11.24)***
$DT1981$	-0.0994(-9.47)***
$DT1982$	-0.1028(-8.69)***
$DT1983$	-0.1151(-8.93)***
$DT1984$	-0.1351(-10.94)***
$DT1985$	-0.1627(-11.36)***
$DT1986$	-0.1643(-12.59)***
$DT1987$	-0.1653(-12.98)***
$DT1988$	-0.2343(-15.74)***
$DT1989$	-0.2520(-19.99)***
$DT1990$	-0.2452(-19.08)***
$DT1991$	-0.2454(-19.34)***
$DT1992$	-0.2081(-16.84)***
$DT1993$	-0.1851(-15.65)***
Log of likelihood	4394.85
Number of observations	1356

Electrical Machinery

Parameter	Coefficient estimates
α_0	1.7576(6.16)***
α_1	0.6758(12.72)***
α_2	-0.0389(-0.65)
α_3	0.3631(11.49)***
α_{11}	0.0722(7.40)***
α_{12}	-0.0822(-10.21)***
α_{13}	0.0099(2.51)**
α_{22}	0.1171(14.75)***
α_{23}	-0.0350(-9.05)***
α_{33}	0.0250(7.60)***
α_y	0.9278(35.75)***
α_{yy}	0.0131(6.01)***
α_{1y}	0.0232(11.43)***
α_{2y}	-0.0233(-11.19)**
α_{3y}	0.0001(0.08)
$DT1980$	-0.2420(-24.51)***
$DT1981$	-0.2486(-23.99)***
$DT1982$	-0.3192(-27.35)***
$DT1983$	-0.3919(-29.76)***
$DT1984$	-0.4297(-29.15)***
$DT1985$	-0.5803(-34.82)***
$DT1986$	-0.6207(-34.79)***
$DT1987$	-0.6932(-35.61)***
$DT1988$	-0.8277(-40.42)***
$DT1989$	-0.9161(-42.63)***
$DT1990$	-1.0002(-44.05)***
$DT1991$	-1.1022(-46.10)***
$DT1992$	-1.1234(-46.35)***
$DT1993$	-1.1526(-47.09)***
Log of likelihood	4634.25
Number of observations	1065

Transport Equipment

Parameter	Coefficient estimates
α_0	4.9098(11.85)***
α_1	0.5828(8.48)***
α_2	-0.1491(-1.88)*
α_3	0.5663(15.71)***
α_{11}	0.0188(1.81)*
α_{12}	-0.0536(-6.02)***
α_{13}	0.0348(7.00)***
α_{22}	0.1029(10.31)***
α_{23}	-0.0493(-11.07)***
α_{33}	0.0145(4.44)***
α_y	0.5211(8.75)***
α_{yy}	0.0300(4.69)***
α_{1y}	0.0210(8.49)***
α_{2y}	-0.0103(-4.58)***
α_{3y}	-0.0107(-7.34)***
$DT1980$	-0.1656(-16.45)***
$DT1981$	-0.1360(-12.23)***
$DT1982$	-0.0958(-8.22)***
$DT1983$	-0.1013(-8.82)***
$DT1984$	-0.1109(-8.94)***
$DT1985$	-0.1229(-10.22)***
$DT1986$	-0.1359(-10.45)***
$DT1987$	-0.1187(-8.89)***
$DT1988$	-0.1590(-11.50)***
$DT1989$	-0.1738(-11.98)***
$DT1990$	-0.1862(-11.66)***
$DT1991$	-0.2035(-12.56)***
$DT1992$	-0.1704(-11.03)***
$DT1993$	-0.1709(-11.90)***
Log of likelihood	3564.45
Number of observations	913

Note: The number in parenthesis is t-value. The coefficient estimates of firm dummies are suppressed.

Table 1

Descriptive Statistics of the Rate of Change in Quasi-fixed Inputs

(%)

	Investment rate		Rate of change in real land stock		Rate of change in employment	
	1979-85	1986-93	1979-85	1986-93	1979-85	1986-93
Chemicals	13.8	14.9	1.0	1.3	-0.8	1.1
	(10.9)	(11.5)	(3.5)	(4.3)	(5.8)	(4.7)
Iron and steel	12.0	15.1	0.6	2.6	-2.4	-1.1
	(13.5)	(27.8)	(5.0)	(19.9)	(9.0)	(6.2)
Machinery	15.2	14.4	1.8	2.6	-0.4	0.0
	(16.4)	(21.4)	(9.8)	(30.8)	(8.5)	(6.8)
Electrical machinery	20.9	16.2	2.2	1.9	1.5	1.7
	(12.4)	(28.4)	(9.4)	(6.9)	(7.9)	(8.5)
Transport equipment	17.4	15.6	2.5	1.4	0.7	0.8
	(5.6)	(8.9)	(10.7)	(4.1)	(6.2)	(5.2)

Note: Number in parenthesis is standard deviation.

Table 2 Proportion of Firms That Do Not Satisfy Convavity Conditions of the Cost Function

(%)

Year	Chemicals	Iron and steel	Machinery	Electrical machinery	Transport equipment
1979	50.0	55.3	63.7	54.9	58.1
1980	32.5	44.7	59.3	60.6	56.5
1981	46.3	44.7	48.4	59.2	45.2
1982	51.2	57.9	64.8	59.2	48.4
1983	50.0	47.4	60.4	52.1	51.6
1984	43.8	42.1	59.3	53.5	41.9
1985	46.3	44.7	59.3	52.1	51.6
1986	45.0	55.3	58.2	62.0	41.9
1987	47.5	63.2	54.9	67.6	54.8
1988	52.5	42.1	49.5	59.2	45.2
1989	46.3	50.0	56.0	49.3	53.2
1990	38.7	42.1	50.5	46.5	51.6
1991	47.5	36.8	47.3	36.6	46.8
1992	52.5	47.4	57.1	64.8	51.6
1993	63.7	36.8	69.2	56.3	59.7
Mean	47.6	47.4	57.2	55.6	50.5

Table 3

Probit Analysis on the Determinants of Concavity Conditions of the Translog Cost Function

Industry	**Explanatory variables**						
	absolute value of investment rate	absolute value of rate of change in real land stock	absolute value of rate of change in employees	dependence on bank loans	log of likelihood	fraction of correct prediction	number of observations
Chemicals	-0.0415 (-0.12)	0.1420 (0.14)	0.2989 (0.36)	0.3690** (2.11)	-804.101	0.5714	1183
Iron and steel	0.1544 (0.38)	0.1342 (0.21)	-1.2519 (-1.32)	0.1768 (0.61)	-364.706	0.5923	542
Machinery	0.0372 (0.20)	-0.2604 (-0.85)	-1.3429** (-2.08)	0.6824*** (4.02)	-905.114	0.5841	1356
Electrical machinery	-0.2057 (-0.87)	0.1012 (0.21)	-1.0814* (-1.75)	0.8975*** (4.05)	-708.825	0.5991	1065
Transport equipment	0.2712 (0.52)	-0.7224 (-1.26)	0.1848 (0.19)	0.0697 (0.27)	-626.584	0.5487	913

Note: The coefficient estimates of time dummies are suppressed.

Table 4

Estimates of the Allen Partial Elasticities of Substitution

	Sample satisfying concavity conditions	Whole sample
Chemicals		
Capital and labor	0.8449	0.8471
Capital and land	-0.0410	-0.7024
Land and labor	0.9971	0.9955
Iron and steel		
Capital and labor	0.8692	0.8703
Capital and land	-0.2648	-0.7116
Land and labor	1.2409	1.2622
Machinery		
Capital and labor	0.9686	0.9637
Capital and land	-0.1239	-2.4377
Land and labor	0.6821	0.0447
Electrical machinery		
Capital and labor	0.4755	0.4581
Capital and land	1.7706	2.4511
Land and labor	0.0867	-0.4706
Transport equipment		
Capital and labor	0.6821	0.6847
Capital and land	2.7814	4.1721
Land and labor	-0.2866	-1.0174

Note: Whole sample includes the firms violating concavity conditions as well as those satisfying concavity conditions.

Table 5
Estimates of Input Demand Elasticities with Respect to Land Rental Price

	Sample satisfying concavity conditions	Whole sample
Chemicals		
land	-0.5136	-0.3204
capital stock	0.0310	0.0124
labor	0.1639	0.1485
Iron and steel		
land	-0.5418	-0.4973
capital stock	0.0080	-0.0037
labor	0.1659	0.1576
Machinery		
land	-0.4297	0.5199
capital stock	0.0273	0.0069
labor	0.1117	0.0842
Electrical machinery		
land	-0.4831	-0.1792
capital stock	0.1182	0.1098
labor	0.0213	0.0115
Transport equipment		
land	-0.6752	-0.5300
capital stock	0.2164	0.2105
labor	0.0094	0.0032

See the note in Table 4.