ECONOMICS BULLETIN

The Structure of Adjustment Costs in Information Technology Investment

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Abstract

We examine the pattern of information technology (IT) capital adjustment using data from U.S. industries. Using the gap between actual and desired IT capital stocks, we estimate the shape of the adjustment cost function in IT investment. Both ordinary least squares and nonparametric regression estimates support irreversibility in IT investment.

We would like to thank M. Ishaq Nadiri and Shinkyu Yang for their helpful suggestions, and Steve Rosenthal for providing the data used in this paper.
Citation: Chun, Hyunbae and Sung−Bae Mun, (2005) "The Structure of Adjustment Costs in Information Technology Investment." *Economics Bulletin,* Vol. 5, No. 4 pp. 1−9
Submitted: April 27, 2005. **Accepted:** July 14, 2005.
URL: http://www.economicsbulletin.com/2005/volume5/EB−05E20001A.pdf

1. Introduction

Investment in information technology (IT) such as computer hardware and software has expanded tremendously since the 1970s. In the U.S., IT (including communication and other information processing equipment) investment accounts for about 50 percent in total nominal equipment and software investment in 2003. This increase can be attributed to IT prices falling more than 20 percent annually in this period. In addition, IT investment also depends on adjustment costs associated with the implementation of new IT capital, such as the costs of training workers and reorganizing the structure of firms. However, there have been few empirical studies on adjustment costs of IT capital.

In this paper, we estimate the shape of the adjustment cost function in IT investment. In particular, we focus on the irreversibility in IT investment. Investment in ordinary capital such as non-IT equipment and structures could be irreversible because conversion of capital is difficult and the sale of used capital faces a thin market and heavy discount. In contrast, IT capital is relatively standardized equipment and has well-developed used markets, which tends to make IT investment reversible. However, Hall (2000) argues that IT investment can be strongly irreversible because IT investment induces a large investment in intangibles which are firm- or industry-specific, and are difficult to sell in the market. Irreversibility in IT investment cannot be settled down in theoretical studies. Therefore, it must be resolved in empirical studies.

We employ the gap approach proposed by Caballero, Engel, and Haltiwanger (1995), henceforth referred to as CEH.[1] Without specifying the functional form of adjustment costs a priori, this approach uses the gap between the actual and desired capital stocks to estimate the shape of the adjustment cost function (e.g., convex or non-convex) or investment irreversibility.[2] We use two-digit industry-level data on IT investment in computer hardware and software from 1987 to 1999. Estimation results suggest convex adjustment technologies for a high mandated investment as well as irreversibility for a low mandated investment.

The paper is organized as follows: Section 2 formulates the empirical specification to estimate the shape of the IT capital adjustment, Section 3 describes the data used in this study, and Section 4 presents empirical results.

2. Empirical Specification

Desired capital is the stock of capital that the firm would hold if adjustment costs were momentarily removed, whereas frictionless capital is the stock of capital that the firm would hold if it never faced adjustment costs. The desired capital stock is not observable, so that (following CEH) we assume that the desired stock of IT capital (K^d) is proportional to the frictionless stock of IT capital (K^f):

$$K_t^d = \theta K_t^f . \tag{1}$$

We assume that the production function has a constant elasticity of substitution:

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[1] This approach is also used to examine the employment adjustment technology in the study of Caballero, Engel, and Haltiwanger (1997).

[2] The size of adjustment cost for IT capital is important to the effect of IT on productivity growth (Kiley, 2001). This unsettled issue on productivity effect of IT investment is known as the 'Solow productivity paradox,' but this is beyond the scope of this paper.

$$Y_{it} = [(a_K K_{it})^{\rho} + (a_N N_{it})^{\rho} + (a_L L_{it})^{\rho}]^{\frac{1}{\rho}} \tag{2}$$

where Y_{it} is the output for industry i at time t, K , N, and L are IT and non-IT capital stocks and labor input, respectively, and the elasticity of substitution between IT and other inputs is $\sigma = 1/(1-\rho)$. The static profit maximization with respect to IT capital gives the frictionless stock for IT capital as:

$$K_{it}^{f} = a_K Y_{it} \left(\frac{W_{Kit}}{P_{it}} \right)^{-\sigma} \tag{3}$$

where W_K is the user cost of IT capital and P is output price.

Substituting the frictionless capital stock with the desired stock using equation (1) yields the first-stage regression equation for estimating the desired IT capital stock as:

$$\ln(\frac{K_{it}^{d}}{Y_{it}}) = \mu_i + \eta_t + \beta \ln \left(\frac{W_{Kit}}{P_{it}} \right) + \varepsilon_{it} \tag{4}$$

where $\ln(\theta) = \mu_i + \eta_t + \varepsilon_{it}$, μ_i is the industry dummy, η_t is the year dummy, and ε_{it} is an error term. The coefficient of the user cost of IT capital (β) is equal to $-\sigma$. In contrast to CEH and Gelos and Isgut (2001), who included only the industry-varying θ when estimating the plant-level desired capital stock, we include both industry- and time-varying θ. As Jorgenson (1972) pointed out, the desired stock of capital should be interpreted as a moving target rather than as the long-run equilibrium level of capital. This target can change according to both industry-specific factors (e.g., different growth rates of industry outputs and different rates of IT adoption across industries) and time-specific factors (e.g., IT-specific technological changes and the introduction of new IT products).

In the first stage, we estimate equation (4) using ordinary least squares (OLS). The predicted value from equation (4) yields the desired stock of IT capital. In the second stage, we estimate the relationship between investment-to-capital ratio and mandated investment (x_{it}), which is defined as the difference between the log of desired stock and the log of the actual stock:

$$\frac{I_{it}}{K_{i,t-1}} = f(x_{it}) + u_{it} \tag{5}$$

where I is the gross investment in IT. Following Goolsbee and Gross (1997) and Gelos and Isgut (2001), we use nonparametric regression to estimate the capital adjustment function of the mandated investment, $f(x_{it})$.[3] Irreversibility can occur when firms do not disinvest even though the mandated investment is low, which suggests a flat slope for $f(x_{it})$.

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[3] See Härdle (1990) and Yatchew (1998) for nonparametric regression methods and their application in economics.

3. Data

We obtained data of IT investment in two-digit industries from the *Fixed Reproducible Tangible Wealth* (FRTW) published by the Bureau of Economic Analysis (BEA). We construct capital stock using the perpetual inventory method with a geometric depreciation rate which is 0.315. Using the Törnqvist index, total IT capital is aggregated from eight IT assets (mainframe computers, personal computers, computer storage devices, computer printers, computer terminals, prepackaged software, custom software, and own-account software).[4]

The user cost of IT capital is defined as

$$W_{Kit} = \frac{1 - itc_{Kt} - u_t z_{Kt}}{1 - u_t}(r_t + \delta_K - \pi_{Kt}) q_{Kit} + \psi_{it} q_{Kit} \qquad (6)$$

where W_K is the user cost of IT capital, *itc* is the investment tax credit, u is the corporate income tax rate, z is the present value of the capital consumption allowance, r is the nominal interest rate, δ is the depreciation rate, π is the capital gain, q is the investment deflator, and ψ is the property tax rate. We obtained tax-related variables from the Bureau of Labor Statistics. Note that the user cost of IT capital varies across industries because their different compositions of IT investment result in different investment deflators of the total amount of IT. Real output is obtained from the *Gross Product Originating* published by the BEA, and the capacity utilization index is obtained from the Federal Reserve Board.

The sample used for estimation consists of 44 U.S. private industries, comprising 20 manufacturing and 24 non-manufacturing industries.[5] Investment-to-capital ratios before the mid-1980s were very high and volatile because the stock of IT capital was extremely small during this period, which can cause measurement errors. Therefore, we restrict the sample to the period 1987–1999. After omitting observations that have missing information, the sample size in estimation is 570.

4. Estimation Results

The top panel in Table 1 reports the first-stage OLS estimation results for equation (4) for various specifications. In column (1), the estimate for the log of the user cost of IT capital indicates that the elasticity of substitution between IT capital and other inputs is 0.995.

The bottom panel in Table 1 reports the second-stage estimation results for the relationship between the investment-to-capital ratio and mandated investment, which is defined in equation (5). In column (1) of the bottom panel, the OLS estimate for mandated investment in the full sample is 0.402, and is statistically significant. However, the OLS estimate in the full sample cannot capture any nonlinearity in IT capital adjustments.

To examine possible nonlinearities in IT capital adjustments, we split the sample into two subsamples. If mandated investment is less than zero (i.e., the desired stock is smaller than the actual stock), firms need to disinvest to reduce IT capital. Since the desired stock is

[4] A recent comprehensive revision of the *National Income and Product Accounts* published by the BEA includes expenditure on software as a fixed investment.

[5] Although the BEA FRTW includes IT investment data for about 55 industries, we aggregated some industries in the agriculture, mining, and transportation sectors because IT investment in these sectors is extremely low.

greater than the actual stock in most observations, it is difficult to divide the sample using a criterion of a mandated investment equal to zero. Instead, we divide the sample into two subsamples of low and high mandated investments. The sample of high mandated investment includes observations that are greater than or equal to the average mandated investment in the full sample (i.e., 0.175).

The coefficient estimates for mandated investment in the two subsamples are significantly different from that in the full sample. The coefficient in the sample of high mandated investment is 0.661, which is greater than that in the full sample, while the coefficient in the sample of low mandated investment is very close to zero and is not statistically significant. In particular, this inactive investment response to changes in mandated investment in the sample of low mandated investment suggest a possible irreversibility in IT investment.

Figure 1A presents a nonparametric regression curve that shows the relationship between the investment-to-capital ratio and mandated investment in more detail.[6] In the region of low mandated investment – where mandated investment is lower than the average mandated investment – the curve is flat, which supports the presence of irreversibility in IT investment. The flat curve indicates that IT investment does not decrease as the mandated investment becomes smaller.

In the region of a high mandated investment, the curve is approximately linear with a positive slope.[7] If the adjustment costs are strictly convex, the curve should be linear. Therefore, the results indicate that convex adjustment costs for high mandated investment cannot be rejected.[8]

Ignoring year dummies in the first-stage estimation in column (2), the estimate of elasticity of substitution is 1.534, which is greater than that in column (1). But the second-stage estimates of mandated investment in the full sample and two subsamples are very close to those in column (1). In a similar vein, the nonparametric regression curve of Figure 1B is also similar to that of Figure 1A. Furthermore, the inclusion of the utilization rate in column (3) and the real output in column (4) do not change the results in column (1).

Some recent studies by Kiley (2001) and Cummins (2004) assume a convex (especially, quadratic) adjustment cost function for IT investment. Although we have used different data, our results cast doubt on their assumptions on the adjustment technologies for IT capital. Our results support the presence of irreversibility in IT investment for a low mandated investment but cannot be used to reject convex adjustment costs for a high mandated investment. The findings are consistent with intuitive assumptions made in the study of Hall (2000), in which the form of adjustment costs for e-capital (possibly correlated with IT capital) is convex for a positive adjustment (i.e., the net investment is greater than zero) and exhibits irreversibility for a negative adjustment.[9]

[6] The Gaussian density function is used for the kernel function, and the optimal bandwidth is chosen using least-squares cross-validation. Dotted curves represent 95 percent confidence bands and optimal bandwidths for all figures are between 0.06 and 0.07. For right- and left-hand tails, approximately 2 percent of the observations are not shown in all figures to avoid distorting the scale of the axes.

[7] The curve is nonlinear when the mandated investment is greater than 0.6, but such observations represent only 4 percent of the total sample.

[8] Inactive investment around the average mandated investment suggests a wedge between the purchase and sale price of capital. See Goolsbee and Gross (1997) for implied curves for various adjustment costs.

[9] Hall (2000) also assumes that the size of adjustment costs for e-capital is the same as that for physical capital.

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Table 1. Estimation Results on Adjustment Costs in IT Investment: 44 U.S. Industries, 1987-1999

	(1)	(2)	(3)	(4)
1st Stage				
Dependent variable: log of IT capital to output ratio				
Log of user cost of IT capital	-0.995***	-1.534***	-0.983***	-0.371**
	(0.108)	(0.038)	(0.108)	(0.159)
Utilization rate			0.013*	
			(0.007)	
Log of real output				0.308**
				(0.133)
Industry dummy	Yes	Yea	Yes	Yes
Year dummy	Yes	No	Yes	Yes
R^2	0.929	0.925	0.930	0.964
Sample size	570	570	570	570
2nd Stage				
Dependent variable: IT investment-to-capital ratio				
OLS estimation				
Full sample				
Mandated investment	0.402***	0.365***	0.401***	0.431***
	(0.039)	(0.039)	(0.039)	(0.040)
R^2	0.157	0.135	0.154	0.172
Sample size	570	570	570	570
Sample splits: High mandated investment				
Mandated investment	0.661***	0.659***	0.690***	0.677***
	(0.064)	(0.063)	(0.064)	(0.064)
R^2	0.290	0.279	0.302	0.303
Sample size	263	282	274	258
Sample splits: Low mandated investment				
Mandated investment	-0.073	-0.054	-0.055	-0.079
	(0.072)	(0.076)	(0.075)	(0.076)
R^2	0.003	0.002	0.002	0.003
Sample size	307	288	296	312
Nonparametric estimation	Figure 1A	Figure 1B	Figure 1C	Figure 1D

Notes: In all columns, the sample of a high mandated investment includes observations that are greater than or equal to the average mandated investment in the full sample. The average mandated investment for each column is very close to each other, which is about 0.175.The user cost of IT capital is normalized by the price of output. In the first-stage regression, the dependent variable in column (4) is the log of IT capital.
***: Significant at 1 percent level. **: Significant at 5 percent level. *: Significant at 10 percent level.

Figure 1A. OLS and Nonparametric Regression Estimates:
44 Industries, 1987-1999

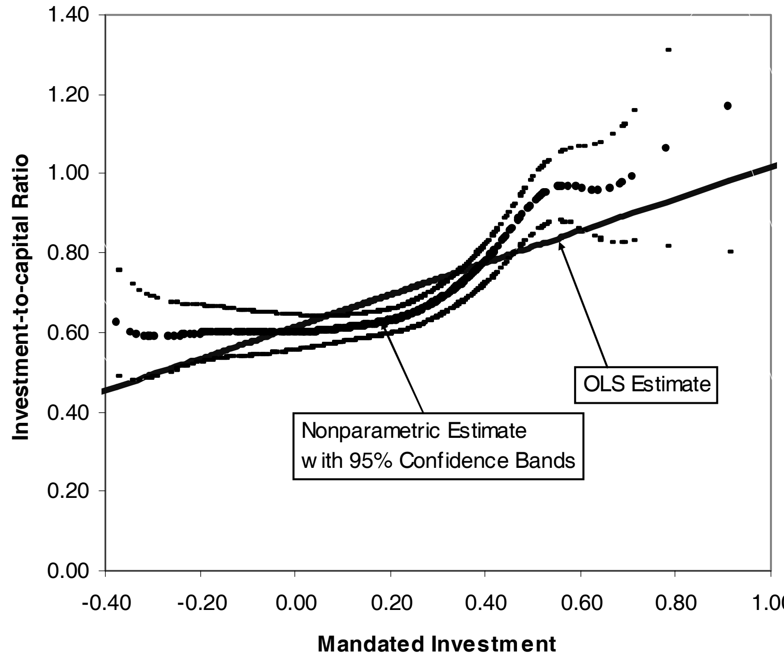

Figure 1B. OLS and Nonparametric Regression Estimates:
44 Industries, 1987-1999

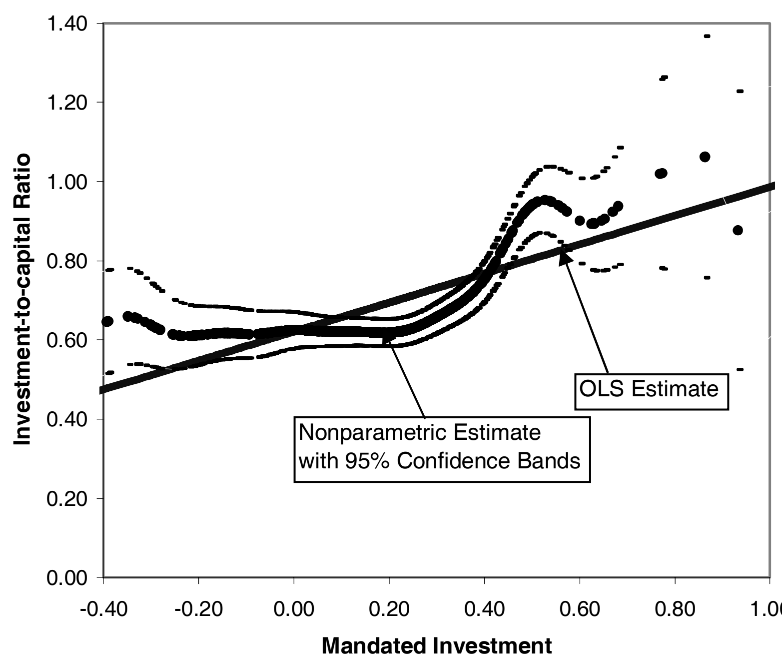

Figure 1C. OLS and Nonparametric Regression Estimates: 44 Industries, 1987-1999

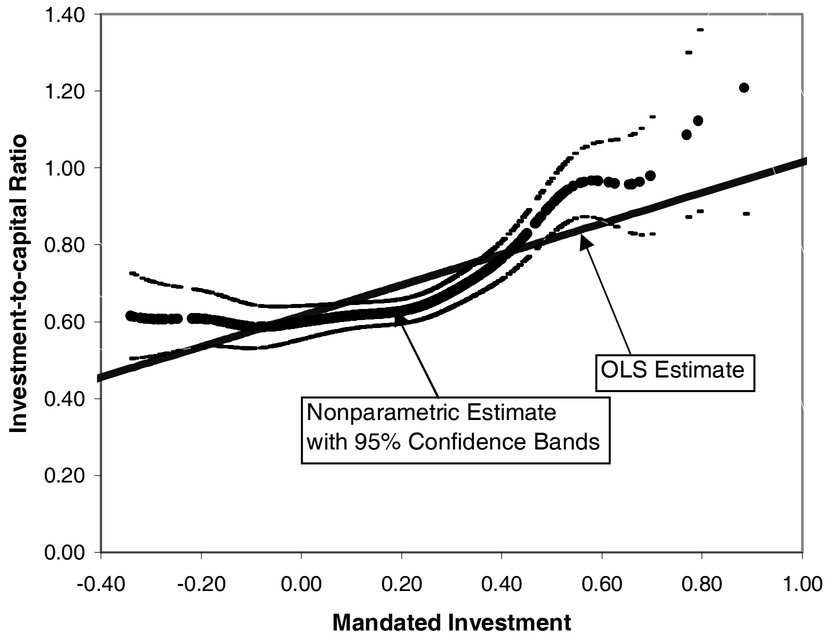

Figure 1D. OLS and Nonparametric Regression Estimates: 44 Industries, 1987-1999