Is the Firm-Level Relationship between Uncertainty and Irreversible Investment Non- Linear?

by

Yigal Menashe*

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http://www.boi.gov.il Bank of Israel, Research Department.

מחלקת המחקר, בנק ישראל ת״ד 780, ירושלים 91007
Research Department, Bank of Israel, POB 780, Jerusalem 91007, Israel

ABSTRACT

Abel and Eberly (1994, 1999) suggest that the relationship between uncertainty and investment is non-linear and can be represented by an inverted U- curve: at low levels of uncertainty, investment and uncertainty show a positive relationship whereas at high levels of uncertainty the relationship is a negative one. We empirically test this hypothesis using panel data on 459 US manufacturing industries (4-digit level) for the period 1958 to 1996 for different sources of uncertainty: (i) output price, (ii) productivity, and (iii) factor costs. Our results tend to support Abel and Eberly's hypothesis and are robust with respect to different specifications of the investment model. Furthermore, this non-monotonic (inverted "U shaped") relationship was significant for almost all the various sources of uncertainty that were tested and for varying degrees of irreversibility. We further distinguish between the components of uncertainty: industry-wide and firm-specific. This distinction demonstrates that the investment-uncertainty relationship remains nonlinear and significant only in certain cases: when uncertainty is firm specific and arises from output prices or productivity, or when uncertainty is aggregate and arises from factor costs.

Key words: irreversible investment, aggregate and specific uncertainty.

JEL Classification: C23, E22, D80, D82,L60.

1. Introduction

The relationship between uncertainty and investment has been investigated quite extensively during the last three decades. While many economist would argue that an increase in uncertainty reduces capital accumulation and is an important factor in explaining episodes of investment contraction, others claim that a different set of assumptions concerning production technology, the level of competition in product markets and the nature of adjustment costs can even create a positive relation between uncertainty and investment. Empirical studies provide a more sharper conclusion and most of the studies found that uncertainty has a negative effect on investment. However, the empirical models have assumed a linear investment-uncertainty relationship. There are several theoretical studies, Such as Abel and Eberly (1994,1999) which suggest that the relationship between investment and uncertainty may be non-linear. In particular, it may be not monotonic and better represented by an inverted U-curve: at low levels of uncertainty, investment increases with uncertainty, whereas at high levels of uncertainty it decreases. Section 3 will discuss this models in detail.

We use "The NBER Manufacturing Productivity Database" which contains annual information on 459 US manufacturing industries (4-digit level)[1] for the period 1958 to 1996 in order to empirically investigate the possibly non-linear relationship (in particular, the inverted "U- curve"), between uncertainty and investment at the firm level under various degrees of irreversibility. The inverted "U-curve" relationship is analyzed for various sources of uncertainty: output price, productivity and the cost of raw materials and energy prices. Furthermore, we decompose our measures of uncertainty into two components (industry-wide and firm-specific) in order to test how investment responds

[1] We treat the 4-digit level which contains very detailed data as proxy for the firm level data.

to each type. We also attempt to determine whether the relationship between investment and uncertainty is symmetric in recessionary and non-recessionary periods.

The results of the fixed-effect panel regression support the theory of inverted "U-shaped relationship between uncertainty and investment at the firm level. The results appear to be robust with respect to various specifications of the investment model. Furthermore, the inverted "U-shaped" relationship is significant for almost all the sources of uncertainty that were tested and for various degrees of irreversibility. Regarding the latter, we assume that the degree of irreversibility for equipment is greater than, that for structures. This assumption is supported by Ramey and Shapiro (1998)'s empirical study on the sectoral mobility of capital based on the purchase of equipment at industry auctions (mainly in the aerospace industry). Their findings suggest that equipment is highly specialized by sector and that reallocating equipment across sectors entails real costs. They showed that equipment sold for only one-third of its estimated replacement cost across sectors. Furthermore in our panel data less than one percent of the observations for investment in equipment are negative, while for investment in structures, more than 20 percent of the observations are negative. Note that on the whole equipment is depreciated faster than structures, so it appears that equipment capital is more reversible than structures. However, unused structures can be resold even after a number of years while this option is much more limited for equipment, since equipment is more likely to embody new and specific technology.

As predicted by the theory, we found that the net effect of uncertainty from a particular source (at its mean level) on investment in equipment is negative and larger (in his absolute value) than the net effect of uncertainty from the same source (at its mean level) on investment in structures. The relationship between uncertainty by type (industry-wide or firm-specific) and investment remains nonlinear and significant but only for firm-specific uncertainty when the source is output price and productivity and aggregate uncertainty when the source is factor costs. This result is the outcome of the dominance in our data of only one type of uncertainty for each source of uncertainty, in the overall uncertainty at the 4-digit level.

The chapter proceeds as follows. Section 2 reviews the theoretical and empirical literature that has attempted to explain the effect of uncertainty on investment. Section 3 provides the theoretical arguments for assuming that, in general, the relationship between uncertainty and investment under irreversibility at the firm level is non-linear and in particular has an inverted "U-shape". The data are discussed briefly in Section 4. Sections 5 and 6 describe the results of the panel fixed-effect regressions based on two alternative theoretical models for different sources of uncertainty and for different degrees of irreversibility. Section 7 contains concluding remarks.

2. Uncertainty-Investment Relationship-A Brief Literature Review

Economic theory has much to say about the relationship between uncertainty and investment. A major role in this literature was attributed by Avinash Dixit and Robert Pindyck influential work which is reconstructed in their book *Investment under Uncertainty* (1994). Their study examines how "option" pricing theory can provide an understanding of investment behavior when future prices and returns are uncertain and investors' decisions are irreversible. Their key insight is that there exists an option value to delaying an investment decision in order to wait to the arrival of new information about market conditions.

Dixit and Pindyck argue that, at a given point in time, the firm invests only if the net present value of the investment is sufficiently larger than zero to cover the value to the decision maker of delaying the decision and keeping the investment option alive. This leads to a focus on the importance of the timing of investment decisions and on the role of uncertainty in influencing that timing and hence on the investment activity. Furthermore, it also points to the possibility of threshold effect, that is, rates of return below which investment will not be undertaken. An earlier study by Hartman (1972) and Abel (1983) reached the opposite conclusion, whereby greater uncertainty may increase investment as result of its positive effect on the value of a marginal unit of capital. This result requires that the marginal product of capital (of a risk-neutral competitive firm) be convex in price so that a mean-preserving increase in the variance of prices raises the expected return on a marginal unit of capital and therefore increases investment[2].

In contrast, most studies, including Bernanke (1983), McDonald and Siegel (1986) and Bertola (1988), argue that irreversibility leads to the postponement of investment. In other words, if investment is irreversible there is an opportunity cost to investing in the current period since this precludes the option of investing in the future when more is known. The opportunity cost increases with uncertainty, thus lowering current investment.

Other studies, such as Caballero (1991) tried to show how the sign of the investment-uncertainty relationship changes under different assumptions: Caballero shows that under constant returns to scale, there is a tradeoff between the asymmetry in adjustment costs (i.e. the degree of irreversibility) and imperfect competition whice shapes the relation: thus, under imperfect competition, the investment-uncertainty relationship is more likely to be negative as the degree of irreversibility increases, while given symmetric costs of adjustment the relationship between investment and uncertainty becomes more negative as the firm becomes less competitive. Pindyck (1993) shows how industry-wide uncertainty can have a negative effect on aggregate irreversible investment

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[2] With constant returns to scale in production, the marginal product of capital is a convex function of the uncertain price faced by the firm so that, by the Jensen inequality, greater uncertainty will increase investment.

(at the industry level) even when firms are perfectly competitive and have constant returns to scale.

Empirical studies of the uncertainty-investment relationship face many difficulties in testing the theoretical models. First, most models of investment under uncertainty do not deliver a closed-form solution. Second, micro-level data rich enough to test some of the theoretical predictions are often not available. Third, the nature of the relationship depends on such factors as the degree of irreversibility and f returns to scale which cannot be easily measured. Finally, uncertainty itself is not observable and indirect indicators often obtain measurement problems or troubled by issues of identification. Nonetheless, we can gain important insights into the investment–uncertainty relationship from the empirical studies implemented during the early 90's.

Caballero and Pindyck (1993) and Pindyck and Solimano (1993) use industry-level and cross-country data to test the empirical relevance of models of irreversible investment. They found a positive correlation between different measures of the threshold and variance of the marginal return on capital which was used as a proxy for uncertainty (i.e. there is a negative relation between investment and uncertainty). However, they observe that the correlation could be due to the way the threshold was measured rather than the effect of uncertainty.

Ferderer (1993a) relies on the proportionality between the risk premium and the variance of returns to derive a measure of uncertainty from data on the term structure of interest rates. He found that this measure has a negative effect on producers' expenditure durable equipment. In another paper, Ferderer (1993b) reaches a similar conclusion using data on macroeconomic forecasts made by financial institutions and non-financial firms that participated in a monthly survey (the Blue Chip survey). This result remained significant even after controlling for user cost and Tobin's-q[3]. Ferderer used the standard deviation of survey's point expectations to measure uncertainty. This measure of uncertainty has the advantage of being forward –looking.

A negative relation between investment and macroeconomic shocks has been found in studies such as Aizemman & Marion (1993,1995) which focus on cross-section data for major developing countries. An additional method of empirically testing the investment-uncertainty relationship is to use firm-level rather than aggregate data. This method has a number of potential advantages: First, it enables the measures of uncertainty to capture not only aggregate shocks but also idiosyncratic factors that affect an individual firm. A second advantage is the ability to control for e possible simultaneity between investment and uncertainty in the case that panel data are available. Third, the theory of investment under uncertainty has different implications for different types of firms, and empirical analysis of these features can be undertaken only with micro data, preferably at the firm level. Thus, ignoring firm heterogeneity can bias our assessment of the effect of uncertainty on investment.

An important study by Leahy and Whited (1996) investigated the investment-uncertainty relationship at the firm level. They used panel data for 600 US manufacturing firms over the period 1981-1987 and created ex-ante volatility measures based on GARCH models and forecasts of variance from a vector auto regression technique, as well as ex-post actual volatility measures. Uncertainty was found to have a negative effect on a firm's investment, for all of these measures while no evidence was found for the presence of a CAPM effect of risk. Guiso and Parigi (1996) used unique survey data on the subjective probability distribution of producers' expectations of future demand for

[3] Leahy (1993) obtained a similar result though in many other studies such as Leahy and Whited (1995) uncertainty effects investment only through Tobin's q.

their products. They found that uncertainty slows down capital accumulation and that this effect is stronger for firms that cannot easily reverse investment decisions and those with substantial market power.

3. The Non-Linear Relationship between Uncertainty and Investment - Literature Review

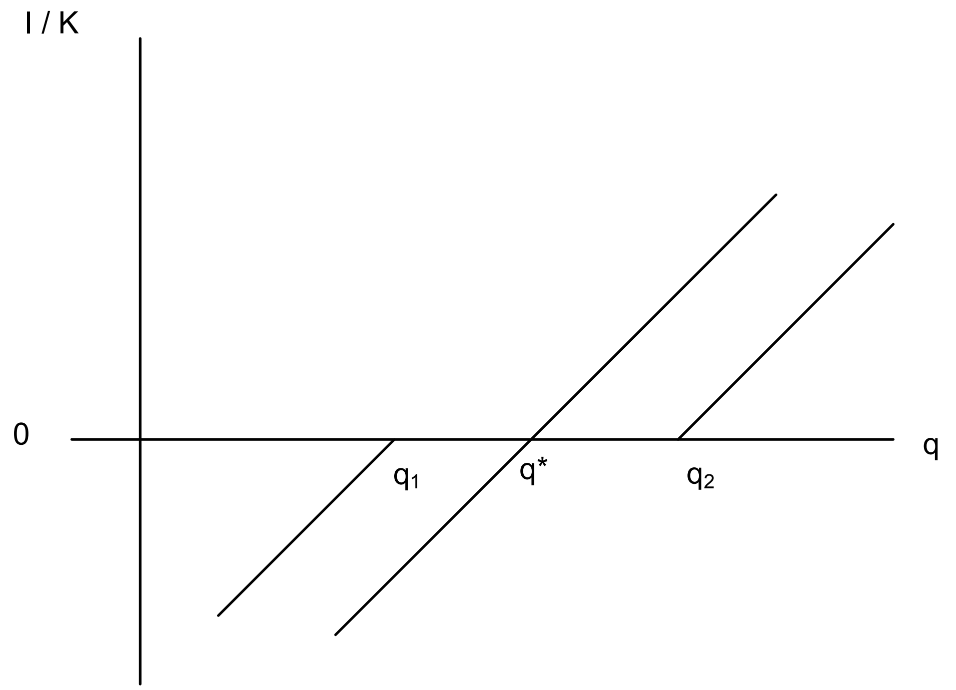
As mentioned earlier most studies have found that uncertainty (from various sources) has a negative effect on current investment. The basic intuition behind this is that when investment decisions are irreversible and returns to capital are uncertain, the firm faces a higher user cost of capital than if its were reversible. The higher user cost tends to reduce the firm's capital stock since the optimal investment policy is to purchase capital only as needed to prevent the value of the marginal product of capital from rising above an optimality–derived trigger, which is higher than the Jorgensonian user cost.

In this chapter we investigate less researched question: is the relationship between uncertainty and investment under irreversibility at the firm level non-linear? One way to investigate this question is to define the capital stock ratio as the ratio of capital stock under irreversibility relative to that under reversibility. In particular, we are then empirically able to test Abel and Eberly (1999)'s argument that the relationship between uncertainty and the capital stock ratio is not linear and may be represented by an inverted U-curve. In other words, at low levels of uncertainty there is a positive relationship between this capital stock ratio and uncertainty whereas at high levels of uncertainty the relationship is negative. Another way to investigate the question is examine the relationship between investment rate and uncertainty for different types of capital with differing degrees of irreversibility.

Abel and Eberly show that there are two opposing effects at work in this relationship. On the one hand, if disinvestment is difficult during periods of adverse shocks due to irreversibility, then firms will have a larger capital stock than the optimal one (where the optimal level is derived from the standard neoclassical model in which investment is costlessly reversible). Abel and Eberly call this positive effect the "hangover effect". They argue that it reflects the dependence of the current capital stock on past behavior, in particular behavior that the firm would like to reverse. On the other hand, as mentioned above, uncertainty increases the user cost of capital, thus reducing investment. Abel and Eberly refer to this negative effect as the "user cost effect" which is the result of the firms' fear of being stuck with excessive capital in bad times. In the presence of uncertainty, the user cost of capital has a premium added into it (the irreversibility premium). In other words, the increase in the user cost due to increased uncertainty tends to further reduce the optimal capital stock under irreversibility. Abel and Eberly calibrate the parameters of their model and found an inverted U-curve relationship between uncertainty and the capital stock ratio. Other theoretical studies have also suggested that the investment-uncertainty relationship is best represented by an inverted U curve. French and Sichel (1993) suggest that firms treat negative and positive shocks asymmetrically. Since negative shocks are often associated with high levels of uncertainty, the negative effect of uncertainty dominates if uncertainty is high whereas a positive effect may appear at low levels of uncertainty. Sarkar (2000) provides an alternative explanation for the inverted U- curve through two effects that uncertainty has on investment. On the one hand, in line with the standard option price approach, uncertainty increases the investment threshold and therefore reduces investment. On the other hand, uncertainty increases the probability that the investment threshold will be exceeded. This positive effect is shown by Sarkar to dominate the negative threshold effect for low levels of uncertainty.

Another attempt to explain the non-linearity between investment and uncertainty in the presence of irreversibility was presented in an earlier study by Abel and Eberly (1994). In this study, the authors integrate irreversibility in investment with adjustment costs in a generalized model of investment under uncertainty. In contrast to traditional models with quadratic adjustment costs which generate a linear relationship between investment and marginal q (see figure 1), they show that in the presence of general adjustment costs and irreversibility, the relationship between investment and q will be non-linear[4].Under adjustment costs that are fixed, linear or convex, they establish that the relationship between q and the rate of investment will follow a non-linear pattern as shown in figure 3.1

Figure 3.1: The Relationship between Rate of Investment (I/K) and q under Non-Quadratic Adjustment Costs



in this model, there are potentially three regimes for investment ; $q < q_1$ where gross investment is negative (ruled out if we assume complete irreversibility);

[4] Note that marginal q is not the standard "Tobin's q" ratio , but rather is an marginal value to the firm of an additional unit of installed capital (i.e. the shadow price of installed capital) which we compare to the purchase cost of the marginal unit of capacity (including adjustment costs).

$q_1 < q < q_2$ where investment is zero and $q > q_2$ where investment is positive and increasing in q . Note that in the regions where investment does respond to q, the relationship need not necessarily be linear. Thus, in the presence of some degree of irreversibility and uncertainty there are two different thresholds :1) q_2, the upper threshold which reflects the classical user cost (q*) plus the extra irreversibility premium. If the level of uncertainty increases then the upper threshold increases as well and more investment is delayed. Alternatively, if the degree of irreversibility increases we obtain the same result. 2) q_1 the lower threshold is also influenced by the irreversibility constraint, but in this case through the potential decrease in the price that the capital can be sold relative to its purchase price. In other words if the firm were to sell the capital (disinvest) it would get a lower return than it would in the classical case (the linear function), and therefore there will be a greater tending to wait and do nothing rather than disinvest. Therefore, we obtain positive effect between uncertainty and investment. Once again, greater uncertainty or irreversibility will increase the possible range of this effect. Note that if we have a full irreversibility (i.e. no possibility to disinvest) we are left only with the upper threshold[5].

Abel and Eberly (1997, 2002) use the US COMPUSTAT data and a company–level international comparative dataset to compare the performance of the non-linear investment function to that of the linear one. Their results indicate that higher moments of q improve significantly the performance of the aggregate investment function. Only a few empirical studies, have tried to test whether there is an uncertainty –investment "Laffer curve". One is Bo and Lensink (2002) who investigated a panel of Dutch manufacturing firms and found a non linear relationship between the uncertainty of firms

[5] It is also possible that there exists asymmetry between the upper and lower thresholds since the price of capital can not be negative. Thus, as uncertainty reaches a certain level, the negative effect may come to dominate.

stock market price and its investment to capital stock ratio. Another is Hatakeda (2003) who examined the relationship between firm investment and uncertainty (the variance of marginal q), using panel data for Japanese firms during the period 1983-1993. The results did not support the existence of a non- linear effect between uncertainty and investment, but rather only a negative one.

In this chapter we investigate the possibly non-linear relationship (in particular the inverted "U- shape") between uncertainty and investment (or between uncertainty and the capital ratio) at the firm level under varying degrees of irreversibility. The analysis is performed for several sources of uncertainty: output price, productivity and the cost of raw materials and energy. Furthermore, we decompose our uncertainty measures into two components: industry-wide and firm-specific in order to ascertain how investment or capital stock ratio responds to each type of uncertainty.

Another question we investigate is whether the relationship between investment or the capital stock ratio and uncertainty is symmetric in recessionary and non-recessionary periods. As mentioned earlier, we assume that the degree of irreversibility for equipment is higher than that for structures. Hence, we can use the ratio between the stock of equipment to the stock of structures as a proxy to the ratio of irreversible to reversible capital that was used in Abel and Eberly (1999).

4. The Data

The panel data used in our study is based on the research project of Bartelsman and Gray (1996) who constructed the unique "NBER Manufacturing Productivity Database" which contains annual data on 459 US manufacturing industries (4 digit level) for the period 1958 to 1996. The main variables included in the database (for each year and industry) are the number of production workers, the number of production worker hours, total wages of production workers, value of shipments, value added, total payroll, end of year inventories, new capital investment, capital stock (equipment and structures) and expenditure on raw materials and energy. All the data are in millions of (nominal) dollars, except for the data on labor input variables. Using price deflators we computed the data in fixed 1987 prices[6].

The data on capital stock is based on gross book value. In order to divide total investment between equipment and structures, we computed investment in structures using the data on the capital stock of structures and the rate of depreciation for structures. The rate of depreciation for structures is assumed to have been 4 percent for all years and in all industries. Note that we now can compute the investment in equipment as the difference between total investment and investment in structures. The computed shares of equipment in the total investment are presented in the following Table:

Table 4.1 Share of Equipment in Total Investment
(Annual Average for 1958-1996 in percent)

Industry-2 dig level	Equipment Share
Food products	79.9
Tobacco manufactures	80.5
Textile mill products	85.9
Appeal and textiles	78.0
Lumber products	84.0
Furniture and fixtures	69.2
Paper and allied products	87.0
Printing and publishing	81.9
Chemicals and allied products	75.9
Petroleum and coal products	85.4
Leather and leather products	77.2
Stone, clay and glass products	88.3
Primary metal industries	88.5
Fabricated metal products	85.0
Machinery, except electrical	85.0
Electrical & electronic equip	86.3
Transportation equip	81.2
miscellaneous	82.4
Total manufacturing	**83.4**

[6] For more details on the average annual growth of production, capital stock, investment in equipment and TFP for the US manufacturing sector during the period sample (1958-1996), see Table A-1.

Note the share of equipment is relatively high with an average of about 80 percent for all industries.

This finding is consistent with the evidence reported in Bartelsman and Gray (1996).

Furthermore, as mentioned earlier, less than one percent of the observations of the investment in equipment are negative, while more than 20 percent of the observations for investment in structures are negative. This evidence supports our assumption that the degree of irreversibility for equipment is higher than that for structures. The dataset also includes estimates of TFP (Total Factor Productivity) growth, computed as Sollow residuals from standard production functions for each industry.

5. Regression Results for Non-Linear Relationship between Uncertainty and Investment

We empirically test for the possibly non-linear relationship (the inverted "U shape") between uncertainty and investment in two ways: 1) Estimation of the non- linear effect of uncertainty on the capital ratio, under varying degrees of irreversibility (measured by the ratio of the stock of equipment divided to that of structures) and 2) Estimation of the non-linear effect of uncertainty on investment rate (the ratio of investment in equipment or structures to total capital stock).

The basic regression for the first way is:

(1) $ke\_ks_{it} = \alpha_1 + \alpha_2 dTFP_{it-1} + \alpha_3 dp^k_{it-1} + \alpha_4 rec_t + \alpha_5 uncert_{it} + \varepsilon_{it}$

where:

ke_ks_{it} - the ratio of the stock of equipment to that of structures in industry *i* at the beginning of year *t*.

$dTFP_{it-1}$ - the change in TFP in industry *i* in year *t-1*.

dp^{k}_{it-1} - the change in the price of capital for industry *i* in year *t-1*.[7]

rec_t - a dummy variable for recessions (based on the NBER US business cycle data). Which takes the value 1 for periods of recession and 0 otherwise.

$uncert_{it}$ - A measure of uncertainty in industry *i* in year *t*. The measure is based on the variance of output price growth (and that of the growth in the other variables: productivity, energy prices and raw material prices). Following Pindyck and Solimano (1993) and Honda and Suzuki (2000), we compute the variance of output price growth using the conventional variance definition based information for the past five years[8]:

$$uncert_{it} = 1/5 * \sum_{j=t-5}^{t-1} (dp_{ij} - meandp_{it})^2$$

where:

dp_{ij} - the output price growth of firm *i* in year *j*.

$meandp_{it}$ - the mean of dp_{ij} during the five year period prior to year *t*.

In order to test whether the relationship between our capital stock ratio and uncertainty has an inverted U-shape, we add the squared measure of uncertainty to the regression in addition to y measure itself. All regressions use fixed effects estimation. Regressions estimated by TSLS method yielded very similar results (see Table A-5 in the appendix)[9].

[7] A more suitable variable is the ratio of the price of equipment to that of structures but since we did not possess the appropriate data we used the change in the total price of capital instead.
[8] We obtain similar results if we use the variance based on past three or four years.
[9] We also obtain similar results if we add time specific dummy variables to the regressions as explanatory variables.

Table 5.1: Panel Data Regression Results (Fixed Effect)
Dependent variable: ratio of the stock equipment to that of structures

	(1)	(2)	(3)	(4)	(5)
Source of uncertainty	Output price	Productivity	Price of Raw Material	Price of Energy	Price of Energy
Uncert	0.028 (2.23)	0.011 (1.95)	0.021 (1.71)	0.065 (0.82)	-0.366 (-1.77)
Uncert_sqr	-0.924 (-2.35)	-0.592 (-1.87)	-0.532 (-1.95)	-0.528 (-2.18)	
Change in TFP *(with one lag)*	0.054 (2.40)	0.056 (2.61)	0.053 (2.39)	0.053 (2.39)	0.053 (2.39)
Change in price of capital *(with one lag)*	-0.011 (-0.60)	-0.028 (-0.15)	-0.008 (-0.46)	-0.011 (-0.59)	-0.029 (-0.15)
Recession (dummy)	-0.032 (-2.92)	-0.032 (-2.84)	-0.032 (-3.00)	-0.032 (-2.92)	-0.032 (-2.87)
Constant	-1.601 (-0.96)	-2.293 (-0.85)	-1.605 (-0.96)	-1.611 (-0.95)	-1.628 (-0.94)
Adjusted R^2 Observations	0.62 14,229	0.64 14,688	0.60 14,229	0.63 14,229	0.63 14,229

t-statistic in parentheses. Standard deviation corrected for hetroscedasticity.

The results in Table 5.1 indicate that the relationship between the capital stock ratio and each source of uncertainty is nonlinear and significant (usually at the 5% level and in some cases at the 10% level). This relationship can be represented by an inverted U-curve since the coefficients of the squared measure of uncertainty are negative while those of the uncertainty measure itself are positive[10].

Table 5.1a: The Net Effect of Mean Uncertainty Measures on the Ratio of the stock of Equipment to that of Structures

Source of uncertainty	Coefficient of *Uncert*: β_1	Coefficient of Uncert_sqr: β_2	The net effect of mean uncertainty on capital ratio: $\beta_1 + 2\beta_2 * mean(Uncert)$
Variance of output price growth	0.028	-0.924	-0.021
Variance of productivity growth	0.011	-0.592	-0.023
Variance of raw material price growth	0.021	-0.532	-0.012

[10] Note that the mean variance of the rate of growth in productivity, raw material prices and output prices is about 3 percent (see Table A-2 in the appendix), so that although , the net effect of uncertainty on the capital ratio is negative , in some industries it is positive.

In Table 5.1a we use the estimated coefficients of uncertainty and squared uncertainty (from Table 5.1) in order to calculate the net (overall) effect of uncertainty from the various sources (at their mean level) on the dependent variable. We can see that the net effect of uncertainty on the dependent variable is negative and significant for all sources except energy price uncertainty, for which only the negative linear effect between uncertainty and investment was significant. The fact that, for energy uncertainty there was no positive effect on the capital stock ratio, in contrast to the other sources of uncertainty, can be explained by the higher mean value of energy price uncertainty (25-45 percent) as compared to the other sources of uncertainty (see Table A-2 in the appendix). Putting together all the uncertainty measures for all the different sources yields similar results, although the coefficients of the output price and energy price uncertainty become insignificant. The coefficients of the other variables are of the expected sign and mostly significant – thus confirming the theoretical model and the results of other empirical studies.

The effect of the recession dummy variable on the ratio between the stock of equipment and structures is negative and significant, while the effect of the increase in total factor productivity which may be capturing technological progress is positive and significant. These results are reasonable since equipment is likely to be more sensitive to technological change than structures. The coefficient of the change in the price of the total capital stock is negative but not significant. In addition, we separated our uncertainty measures into recessionary and non-recessionary periods, using a variable for the interaction between uncertainty and the recession dummy. We found no significant effect on the capital stock ratio. Note that we would have expected a stronger negative effect of uncertainty on these capital ratio when the relationship is linear and a stronger positive and negative effect when the relationship is nonlinear since in a recession the irreversibility constraint is more restrictive (both the user cost and hangover effects are more pronounced) than in non-recessionary periods. Alternatively, we obtained a similar, through less significant, U-shaped relationship between uncertainty and investment in our regressions when the ratio of the stock of equipment (or structures) was used as the dependent variable.

Another way to test the non-linear effect of uncertainty on investment is to examine the effect of each source of uncertainty on the rate of investment in equipment (the ratio of investment in equipment to total capital stock) and on the rate of investment in structures.

The basic regression is[11]:

(2) $$ie\_k_{it} = \alpha_1 + \alpha_2 dryk_{it} + \alpha_3 cu_{it-1} + \alpha_4 dp^k_{it-1} + \alpha_5 rec_t + \alpha_6 uncert_{it} + \varepsilon_{it}$$

where:

ie_k_{it} - the ratio of investment in equipment to total capital stock for industry *i* in year *t*.

$dryk_{it}$ - the change in production divided by total capital stock (the "accelerator" effect)

cu_{it-1} - capital utilization[12] for industry *i* in year *t-1*. .

dp^k_{it-1} - the change in the price of capital for industry *i* in year *t-1*.

rec_t - a dummy variable for recessions (based on the NBER US business cycle data). It takes the value one for periods of recession and zero otherwise.

$uncert_{it}$ - A measure of uncertainty for industry *i* in year *t*.

[11] To ensure that all variables are stationary, we run a panel unit root test (the Im, Pesaran and Shin test) which rejects the null assumption of an individual unit root.

[12] Capital utilization is measured as the difference between the level of TFP to its HP trend.

Table 5.2: Panel Data Regression Results (Fixed Effect)
Dependent variable: ratio of investment in equipment to total capital stock

	(1)	(2)	(3)	(4)	(5)
Source of uncertainty	Output price	Productivity	Price of Raw Material	Price of Energy	Price of Energy
Uncert	0.018 (1.75)	0.014 (1.75)	0.016 (2.15)	0.073 (1.24)	0.037 (0.63)
Uncert_sqr	-0.649 (-1.84)	-0.389 (-1.87)	-0.378 (-1.96)	-0.120 (-0.61)	0.187 (1.13)
Rec*Uncert					0.054 (1.52)
Rec*Uncert_sqr					-0.828 (-3.65)
Change in production *(divided by total capital stock)*	0.124 (12.3)	0.124 (12.9)	0.125 (12.5)	0.124 (12.3)	0.124 (12.3)
Change in capital utilization *(with one lag)*	0.041 (12.0)	0.041 (12.4)	0.040 (11.8)	0.040 (11.9)	0.039 (11.8)
Change in price of capital *(with one lag)*	-0.015 (-1.13)	-0.016 (-1.11)	-0.016 (-1.23)	-0.016 (-1.12)	-0.015 (-1.09)
Recession (dummy)	-0.042 (-4.73)	-0.043 (-4.87)	-0.041 (-4.70)	-0.042 (-4.75)	-0.044 (-4.48)
Constant	0.062 (39.4)	0.063 (39.0)	0.062 (39.5)	0.062 (39.8)	0.062 (39.8)
Adjusted R^2 Observations	0.77 14,026	0.76 14,464	0.77 14,026	0.77 14,026	0.77 14,026

t-statistic in parentheses. Standard deviation corrected for hetroscedasticity.

The results in Table 5.2 indicate that the relationship between each of the various sources of uncertainty and the rate of investment is nonlinear and significant (mostly at the 5% level and in some cases at the 10% level). This relationship can be represented by an inverted U-curve since the coefficients of the squared measure of uncertainty are negative while those of the uncertainty measure itself are positive f[13]. In the case of energy price uncertainty, the non-linear relation between uncertainty and investment was significant only during the recession years (as captured by the interaction variable between uncertainty and the recession dummy). For other sources of uncertainty the coefficient of this interaction variable was not significant. Regarding the other explanatory variables, the panel results yield coefficients of the expected signs and mostly significant. Adding the ratio of investment in structures to total capital stock with a one year lag (the positive but not significant effect on equipment investment rate), will

[13] Alternatively we obtain a similar U-shaped relationship if the dependent variable is the ratio of investment in equipment to the stock of equipment for industry *i* in year *t*.

not change our main results (see Table A-4 in the appendix). Table 5.3 presents the results of the same regressions we run for equation 2, except that the dependent variable is now the ratio of investment in structures to total capital stock.

Table 5.3: Panel Data Regression Results (Fixed Effect)
Dependent variable: ratio of investment in structures to total capital stock

	(1)	(2)	(3)	(4)	(5)
Source of uncertainty	Output price	Productivity	Price of Raw Material	Price of Energy	Price of Energy
Uncert	0.010 (1.89)	0.004 (1.79)	0.004 (1.68)	0.007 (0.99)	0.005 (0.69)
Uncert_sqr	-0.395 (-1.84)	-0.179 (-1.72)	-0.082 (-1.77)	-0.183 (-0.94)	-0.169 (-0.77)
Rec*Uncert					0.011 (0.93)
Rec*Uncert_sqr					-0.203 (-0.69)
Change in production *(divided by total capital stock)*	0.056 (4.82)	0.055 (5.05)	0.056 (5.05)	0.054 (4.73)	0.053 (4.74)
Change in capital utilization *(with one lag)*	0.018 (5.09)	0.018 (5.68)	0.018 (4.99)	0.017 (5.22)	0.017 (5.22)
Change in price of capital *(with one lag)*	-0.013 (-0.57)	-0.012 (-0.54)	-0.008 (-0.35)	-0.008 (-0.35)	-0.008 (-0.33)
Recession (dummy)	-0.047 (-2.23)	-0.047 (-2.18)	-0.046 (-2.21)	-0.046 (-2.11)	-0.049 (-2.12)
Constant	0.013 (7.55)	0.014 (7.81)	0.014 (7.59)	0.014 (7.45)	0.014 (7.35)
Adjusted R^2 Observations	0.41 14,026	0.40 14,404	0.41 14,026	0.40 14,026	0.41 14,026

t-statistic in parentheses. Standard deviation corrected for hetroscedasticity.

The results in Table 5.3 show that on the whole, we found again (as it was in Table 5.2) that the relationship between the uncertainty of output price, productivity growth and material prices and the rate of investment in structures investment rate is nonlinear and significant. However, the coefficients are smaller when the dependent variable is the rate of investment in structures than when (Table 5.3) it is the rate of investment in equipment (Table 5.2). Furthermore, the net (overall) effect of uncertainty from the various sources (at their mean level) on the investment in equipment is negative and larger (in absolute value) than the negative net effect of uncertainty on the investment in structures. This result is in line with the theory, which predicts that for higher degrees of irreversibility, the effects on investment (both positive and negative) are more stronger. The effect of the uncertainty of energy prices on the investment in structures is insignificant in all versions of the regression. The rest of the coefficients have, in almost all cases, the same signs as in Table 5.2. We ran all the regressions using alternative methods of estimation such as TSLS in order to overcome potential problems of endogeneity, but the main results remained the same. Running the same regressions with rate of the total gross investment (divided by total capital stock) as the dependent variable leaves the results almost unchanged (see Table A-3 in the appendix).

6. Regression Results for Non-Linear Relationship Between Aggregate and Firm Specific Uncertainty and Investment

Shocks to demand or supply can be characterized as either aggregate or firm-specific. Examples of firm-specific (in our terms at the 4 digit level) shocks include a change in the firm's quality of management or a shift of fashion to differentiated products. Examples of aggregate or industry–wide shocks include an increase in oil prices or a technological innovation shared by all firms in an industry. Note that the degree of irreversibility may depend on type of uncertainty: in the case of a negative idiosyncratic(firm-specific), demand shock, a firm can sell its capital more easily to another firm in the same industry while in the case of a negative industry-wide demand shock, firms may find it difficult to sell their capital to other firms.. In order to quantify the response of the capital stock ratio to different types of uncertainty, we decomposed the uncertainty measures into two parts: aggregate uncertainty (2-digit level or "between-industry uncertainty") and the remainder which is the firm-specific uncertainty ("within-industry uncertainty"). The former can be calculated once we have computed our uncertainty measure for the aggregate (2-digit level) variables in the same way that we computed the 4-digit level uncertainty measures. Once we have all the measures of uncertainty at the aggregate level i.e. the variances of output price growth, productivity growth, energy price growth and raw material price growth, we regressed each source of uncertainty at the 2-digit level on the corresponding uncertainty at the 4-digit level and obtained the residuals that ought to represent firm-specific uncertainty (denoted in our study as *spec_uncert*). The aggregate uncertainty from the various sources is denoted in table 2 as *agg_uncert*.

Table 6.1: Panel Data Regression Results (Fixed Effect)
Dependent variable: ratio of the stock equipment to that of structures

	(1)	(2)	(3)	(4)	(5)
Source of uncertainty	Output price	Productivity	Price of Raw Material	Price of Energy	Price of Energy
Agg_Uncert	0.017 (0.96)	0.044 (1.02)	0.021 (1.64)	0.019 (1.37)	-0.168 (-0.31)
Agg_Uncert_sqr	-0.005 (-1.05)	-0.004 (-1.19)	-0.525 (-3.11)	-0.317 (-0.99)	-0.126 (-0.92)
spec_Uncert	0.027 (2.20)	0.014 (2.53)	0.011 (-0.34)	-0.038 (-1.84)	-0.038 (-1.79)
spec_Uncert_sqr	-0.913 (-2.31)	-0.783 (-2.39)	-0.14 (-0.81)	-0.029 (-0.53)	-0.021 (-0.38)
Rec*Agg_Uncert					0.046 (3.71)
Rec*Agg_Uncert_sqr					-0.908 (-2.85)
Change in TFP *(with one lag)*	0.054 (2.39)	0.053 (2.37)	0.053 (2.49)	0.053 (2.38)	0.053 (2.39)
Change in price of capital *(with one lag)*	-0.013 (-0.74)	-0.021 (-0.12)	-0.032 (-0.62)	-0.007 (-0.39)	-0.014 (-0.64)
Recession (dummy)	-0.032 (-2.93)	-0.032 (-2.89)	-0.032 (-3.26)	-0.032 (-3.02)	-0.023 (-2.36)
Constant	-1.599 (-0.96)	-1.628 (-0.95)	-1.633 (-0.95)	-1.608 (-0.95)	-1.617 (-0.96)
Adjusted R^2 Observations	0.62 14,229	0.61 14,688	0.56 14,229	0.63 14,229	0.63 14,229

t-statistic in parentheses. Standard deviation corrected for hetroscedasticity.

Table 6.1 above presents the regression results for equation (1) except that instead of using the combined uncertainty at the 4-digit level as before, we distinguish between its two components: aggregate uncertainty and firm-specific uncertainty.

The results in Table 6.1 show that on the whole, we found again (as in Table 5.1) that the relationship between the uncertainty of output prices, productivity growth and raw material prices and the capital stock ratio is nonlinear and significant though only for one type of uncertainty. Thus, in the case of output prices and productivity, firm- specific uncertainty had a significant effect on the capital stock ratio (negative and positive in the sense of Abel and Eberly) while aggregate uncertainty did not. Meanwhile, in the case of raw material price only aggregate uncertainty had a significant effect[14]. This result can be explained by the fact that almost 85 percent of the uncertainty at the 4-digit level in the case of output price and productivity uncertainty is explained by firm-specific uncertainty. A similar argument applies to the raw material price uncertainty since almost 83 percent of the uncertainty at the 4-digit level can be attributed to aggregate uncertainty. The dominance of only one type of uncertainty makes it difficult to determine whether the degree of irreversibility is higher in the aggregate case or in the specific one. In the case of energy price uncertainty, we found that only firm-specific uncertainty has a negative and significant effect on capital ratio. However, if we add a variable for interaction between aggregate and specific uncertainty and the recession dummy the results reveal again another a significant and non-linear relationship (negative and positive in the sense of Abel and Eberly) between aggregate energy price uncertainty and the capital stock ratio. Note that the coefficients are higher in the case of aggregate energy price uncertainty case than in the case of specific uncertainty. This result is in line with the theory, that in a bad times the degree of irreversibility in the case of aggregate uncertainty is higher than in the case of specific uncertainty and therefore its effect on investment is stronger. The rest of the coefficients have the same signs as in Table 5.1 in almost all the cases. We tested all the regressions using other methods of estimation such as TSLS in order to overcome potential problems of endogeneity, but the main results remained largely unchanged. Once again, we obtain a similar U- shaped relationship between uncertainty and investment which becomes less significant if the

[14] This results remained ,unchanged even when we used only one type of uncertainty either: aggregate or firm-specific in the regressions.

ratio of the stock of equipment (or structures) to production is used as the dependent variable.

Table 6.2: Panel Data Regression Results (Fixed Effect)
Dependent variable: ratio of equipment investment to total capital stock

	(1)	(2)	(3)	(4)	(5)
Source of uncertainty	Output price	Productivity	Price of Raw Material	Price of Energy	Price of Energy
Agg_Uncert	0.007 (1.56)	0.013 (1.49)	0.023 (3.60)	0.022 (0.85)	0.014 (0.30)
Agg_Uncert_sqr	-0.087 (-1.31)	-0.001 (-1.17)	-0.516 (-3.51)	-0.637 (-0.88)	-0.346 (-0.25)
spec_Uncert	0.016 (1.71)	0.011 (1.73)	0.062 (1.34)	0.065 (1.38)	0.043 (0.72)
spec_Uncert_sqr	-0.750 (-1.79)	-0.761 (-1.84)	-0.051 (-1.37)	-0.101 (-0.65)	-0.066 (-0.32)
Rec*Agg_Uncert					0.049 (3.71)
Rec*Agg_Uncert_sqr					-0.928 (-2.85)
Change in production *(divided by total capital stock)*	0.125 (12.2)	0.183 (11.9)	0.124 (12.2)	0.124 (12.2)	0.180 (11.9)
Change in capital utilization *(with one lag)*	0.041 (11.8)	0.062 (9.84)	0.040 (11.7)	0.040 (11.7)	0.062 (9.96)
Change in price of capital *(with one lag)*	-0.015 (-1.12)	-0.031 (-1.13)	-0.015 (-1.10)	-0.018 (-1.12)	-0.029 (-1.05)
Recession (dummy)	-0.042 (-4.64)	-0.042 (-2.06)	-0.042 (-4.71)	-0.041 (-4.61)	-0.043 (-2.33)
Constant	0.062 (39.8)	0.076 (25.8)	0.062 (39.7)	0.062 (39.4)	0.076 (24.8)
Adjusted R^2 Observations	0.77 14,026	0.71 14,464	0.76 14,026	0.76 14,026	0.71 14,026

t-statistic in parentheses. Standard deviation corrected for hetroscedasticity.

Using investment in equipment (divided by total capital stock) as the dependent variable provides another way of testing the hypothesis. The results are presented above in Table 6.2. The results on the whole, indicate again (as those in Table 5.2 did as well) that the relationship between the uncertainty of output price, productivity growth and raw materials price and the rate of investment in equipment is nonlinear and significant but only for one type of uncertainty. Adding an interaction variable between aggregate and specific uncertainty and the recession dummy to the regression yields a significant and non- linear relationship (negative and positive in the sense of Abel and Eberly) between aggregate energy price uncertainty and the rate of investment in equipment. Running the same regressions with the rate of investment in structures (divided by total capital stock) as the dependent variable yields very similar results (U-shaped relationship between uncertainty and investment), though only for the uncertainties of output price and raw material price the effect is significant.

7. Concluding remarks

Abel and Eberly present two theoretical studies (1994, 1999) which describe non-linear relationship between uncertainty and investment. In fact the relationship is non-monotonic and may be represented by an inverted U-curve i.e. at low levels of uncertainty there is a positive relationship between uncertainty and investment whereas at high levels of uncertainty the relationship is negative. In this chapter we have investigated this relationship using data on uncertainty deriving from changes in output price, productivity and factor costs, and investment (or alternatively the capital stock ratio) for a panel data of 459 US manufacturing industries (4-digit level) for the period 1958 to 1996 for different types of capital (equipment and structures) that have different degrees of irreversibility.

The results of the fixed-effect panel regression support the existence of an inverted "U-shaped" relationship between uncertainty and investment at the firm level. The results appear to be robust with respect to various specifications of the investment model. Furthermore, The inverted "U-shaped" relationship is significant for almost all the sources of uncertainty that were tested and for varying degrees of irreversibility. Note that, in line with the theory, the net effect of uncertainty from the various sources (at their mean levels), on investment in equipment (which is assumed to have a higher degree of irreversibility than investment in structures) is negative and larger (in absolute value) than the negative net effect on investment in structures investment. We further distinguish between the components of uncertainty: industry-wide and firm-specific. This distinction demonstrates that the investment-uncertainty relationship remains nonlinear and significant only in certain cases: when uncertainty is firm specific and arises from output prices or productivity, or when uncertainty is aggregate and arises from factor costs. This outcome is the result of the dominance in our data (for each source of uncertainty) of only one type of uncertainty in overall uncertainty at the 4-digit level.

Appendix

Table A-1: The Production, Capital Stock, Investment in Equipment and TFP for the US Manufacturing Sector (1958-1996)

(annual average growth, in percentages)

	1958-1996	1958-1970	1971-1980	1981-1996
Capital stock growth	**2.9**	5.6	3.5	1.2
Production growth	**1.8**	1.3	1.4	2.2
growth of investment in equipment	**4.8**	3.1	7.2	3.9
TFP growth	**0.6**	0.6	0.6	0.7

Table A-2: Summary Statistics of the Constructed Uncertainty (Variances) Measures

Source of uncertainty	Mean	Median	Std. dev	Obs
Variance of output price growth	0.0266	0.0116	0.0102	15,147
Variance of productivity growth	0.0287	0.0154	0.0156	15,147
Variance of raw material price growth	0.0307	0.0234	0.0165	15,147
Variance of energy price growth	0.0385	0.0113	0.0116	15,147

Table A-3: Panel Data Regression Results (Fixed Effect)

Dependent variable: ratio of total gross investment to total capital stock

	(1)	(2)	(3)	(4)	(5)
Source of uncertainty	Output price	Productivity	Price of Raw Material	Price of Energy	Price of Energy
Uncert	0.016 (3.11)	0.010 (1.72)	0.015 (2.13)	0.011 (0.13)	0.010 (0.11)
Uncert_sqr	-0.597 (-3.45)	-0.367 (-1.77)	-0.347 (-1.84)	-0.756 (-0.26)	0.562 (1.10)
Rec*Uncert					0.013 (1.43)
Rec*Uncert_sqr					-0.154 (-0.73)
Change in production *(divided by total capital stock)*	0.183 (11.9)	0.184 (12.5)	0.184 (12.1)	0.183 (12.1)	0.183 (11.9)
Change in capital utilization *(with one lag)*	0.062 (10.1)	0.063 (10.5)	0.062 (10.0)	0.062 (10.1)	0.062 (9.92)
Change in price of capital *(with one lag)*	-0.037 (-1.28)	-0.034 (-1.26)	-0.037 (-0.98)	-0.031 (-1.12)	-0.030 (-1.09)
Recession (dummy)	-0.041 (-2.04)	-0.042 (-1.94)	-0.041 (-2.05)	-0.041 (-2.08)	-0.043 (-2.18)
Constant	0.075 (26.7)	0.076 (27.0)	0.076 (26.7)	0.076 (26.7)	0.076 (26.1)
Adjusted R^2 Observations	0.71 14,026	0.71 14,404	0.71 14,026	0.71 14,026	0.71 14,026

t-statistic in parentheses. Standard deviation corrected for hetroscedasticity.

Table A-4: Panel Data Regression Results (Fixed Effect)

Dependent variable: ratio of equipment investment to total capital stock

	(1)	(2)	(3)	(4)	(5)
Source of uncertainty	Output price	Productivity	Material price	Energy price	Energy price
Uncert	0.020 (1.84)	0.017 (1.69)	0.017 (2.26)	0.066 (1.19)	0.040 (0.68)
Uncert_sqr	-0.709 (-1.75)	-0.393 (-1.82)	-0.381 (-2.04)	-0.100 (-0.52)	0.184 (1.10)
Rec*Uncert					0.056 (1.62)
Rec*Uncert_sqr					-0.765 (-3.51)
Change in production *(divided by total capital stock)*	0.131 (12.9)	0.131 (13.6)	0.132 (13.0)	0.130 (13.0)	0.131 (13.0)
Change in capital utilization *(with one lag)*	0.043 (11.6)	0.043 (11.8)	0.042 (11.5)	0.042 (11.5)	0.042 (11.5)
Change in price of capital *(with one lag)*	-0.018 (-1.36)	-0.018 (-1.32)	-0.018 (-1.43)	-0.018 (-1.29)	-0.017 (-1.24)
Recession (dummy)	-0.037 (-4.67)	-0.038 (-4.78)	-0.036 (-4.62)	-0.037 (-4.70)	-0.038 (-4.31)
Ratio of structure investment to total capital stock *(with one lag)*	0.013 (0.82)	0.008 (0.38)	0.012 (0.81)	0.013 (0.81)	0.014 (0.90)
Constant	0.063 (32.3)	0.064 (38.5)	0.063 (39.2)	0.063 (39.4)	0.063 (39.3)
Adjusted R^2 Observations	0.77 14,026	0.77 14,464	0.77 14,026	0.77 14,026	0.77 14,026

t-statistic in parentheses. Standard deviation corrected for hetroscedasticity.

Table A-5: Panel Data Regression Results (Panel TSLS Fixed Effect)

Dependent variable: ratio of the stock equipment to that of structures

	(1)	(2)	(3)	(4)	(5)
Source of uncertainty	Output price	Productivity	Material price	Energy price	Energy price
Uncert	0.027 (2.23)	0.011 (1.95)	0.022 (1.71)	0.064 (0.83)	-0.367 (-1.78)
Uncert_sqr	-0.924 (-2.35)	-0.592 (-1.87)	-0.532 (-1.95)	-0.528 (-2.18)	
Change in TFP *(with one lag)*	0.053 (2.40)	0.055 (2.60)	0.053 (2.38)	0.053 (2.38)	0.053 (2.38)
Change in price of capital *(with one lag)*	-0.012 (-0.60)	-0.027 (-0.15)	-0.007 (-0.44)	-0.011 (-0.59)	-0.028 (-0.15)
Recession (dummy)	-0.032 (-2.92)	-0.032 (-2.84)	-0.032 (-3.00)	-0.032 (-2.93)	-0.031 (-2.87)
Constant	-1.602 (-0.96)	-2.294 (-0.86)	-1.604 (-0.97)	-1.612 (-0.94)	-1.627 (-0.95)
Adjusted R^2 Observations	0.65 14,229	0.65 14,688	0.62 14,229	0.64 14,229	0.64 14,229

t-statistic in parentheses. Standard deviation corrected for hetroscedasticity.

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