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Abstract

This paper contributes to the existing literature by showing that uncertainty produces a non-uniform impact to the extent that different types of capital goods exhibit heterogeneous irreversibility, which we define as asset-specific irreversibility. Hence, asset-specific irreversibility is responsible for asymmetries in responses across types of capital goods to uncertainty. We also show that for a given type of capital good, uncertainty produces a variety of responses across sectors, which we define sector-specific irreversibility. In other words, sectoral differences in terms of the ability to substitute a given type of capital with labour, introduce a second-order effect of uncertainty on investment.

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1. Introduction

Economic theory suggests that uncertainty exerts a negative impact on investment when such decisions are characterized by irreversibility (McDonald and Siegel, 1986; Pindyck, 1988; Dixit and Pindyck, 1994; Abel *et al*, 1996; Caballero and Pindyck, 1996). The literature treats irreversibility of investment decisions as being generated either from a technological constraint that restricts the ability to substitute labour for capital (Lee and Shin, 2000) or, to transaction costs that drive a wedge between the purchase and the selling prices of the installed undepreciated capital (Abel and Eberly, 1994, 1999; Bohm *et al*, 1999; Chirinko and Schaler, 2002; Cooper and Haltiwanger, 2005).

The main body of investment literature rarely considers the issue of capital heterogeneity, although it is an undisputed fact that firms own a variety of capital goods with different purposes and different characteristics (Goolsbee and Gross, 2000). Notable exceptions are Chirinko (1982, 1993), Wildasin (1984) and Eberly (1997) who discuss the repercussions for Q-theory and adjustment costs in the presence of many capital goods.

In contrast, the empirical literature on investment and uncertainty has recently acknowledged this fact and attempted to investigate the sign of the relationship by type of capital good (Guiso and Parigi, 1999; Goel and Ram, 1999, 2001; Butzen *et al.*, 2002; Bulan, 2003; Driver *et al.*, 2003; Wilson, 2004; Drakos, 2005a,b).

We conjecture that the effect of uncertainty on investment decisions will vary across types of capital goods reflecting variations in irreversibility, which we call **asset specific irreversibility**. Hence, uncertainty may lead a given decision maker to adopt different actions over different types of capital provided that they are associated with dissimilar degrees of irreversibility. In addition, different structural characteristics of decisions makers may produce a differential impact of uncertainty even when an identical capital good is considered. Thus, we also postulate that for a given type of capital good, uncertainty will produce a variety of responses across sectors, which we call **sector-specific irreversibility**.

In order to empirically investigate these conjectures, we resort to investment expenditures on various types of new and used capital (second-hand) for various manufacturing sectors. Initially, we compare the intensity of second-hand markets *between* types of capital goods as an indicator of asset-specific irreversibility. Then, *within a type of capital good*, we employ the variation of intensity of second-hand market across sectors as an indicator of sector-specific irreversibility.

The remainder of the paper is as follows. Section 2 offers a review of the theoretical and empirical literature. Section 3 describes the dataset employed in the econometric analysis. Section 4 refers to our measures of irreversibility. Section 5 offers *prima facie* evidence for the differential effect of irreversibility. Section 6 discusses the adopted econometric methodology, while Section 7 presents the empirical results. Finally, major findings are discussed in Section 8.

2. Irreversible Investment and Uncertainty

2.1 Review of the Theoretical Literature

The multidimensional impact of uncertainty on business fixed investment has been a 'hot' issue for quite sometime. Due to the complexity of this issue, economic theory suggests that the outcome regarding the linkage between investment and uncertainty crucially depends on the underlying assumptions with respect to the environment within which investment decisions are made.

Initially, Oi (1961), Hartman (1972, 1976), and Abel (1983) advocated that uncertainty amplifies the incentive to invest. In this setup, which is considered as a point of departure, it is assumed that the environment within which investment decisions are made is characterised by perfect competition, constant returns-to-scale, fully reversible capital, symmetric convex adjustment costs, and risk-neutral behaviour by the firm. This produces a convexity of the Marginal Revenue Product of Capital (*MRPK*, hereafter) with respect to the uncertain variable leading to a positive investment-uncertainty relationship. Applying Jensen's inequality, a mean-preserving increase in the variance of the stochastic variable increases the optimal level of capital stock, and subsequently increases investment. This literature assumes that investment decisions are determined by the Net Present Value (*NPV*, hereafter) rule. Essentially, an investment project is undertaken, if and only if, the expected discounted sum of all future marginal short-run profits of an extra unit of investment exceeds the cost generated by purchasing this extra unit of investment and any adjustment costs incurred in the future *i.e* . $NPV > 0$.

Following the Hartman-Abel environment, the next strand of literature relaxes the assumption of fully reversible capital, in an attempt to offer a more realistic representation of actual conditions faced by decision makers. In reality, irreversibility and the ability to delay an investment project is not an uncommon feature (Dixit and Pindyck, 1994). The introduction of irreversibility or non-convex adjustment costs leads to returns on investment that are asymmetric (Abel and Eberly, 1994, 1999; Dixit and Pindyck, 1994; Eberly, 1997). Due to this asymmetry, the marginal returns of capital are a concave function of the uncertainty variable. Indeed, in the presence of fixed or sunk costs, firms may be more reluctant to invest because of the possibility that they may wish to sell their installed capital in the future but will be able to reclaim little, if any, of the undepreciated value (Chirinko and Schaller, 2002). Irreversibility can be intuitively expressed in terms of the relationship between the buying; p^{+}, and resale price; p^{-}, of capital. Partial irreversibility requires that $p^{+} > p^{-} > 0$, while full irreversibility implies that $p^{+} > p^{-} = 0$, and finally when $p^{+} = p^{-} > 0$, investment is fully reversible.

Distinguishing among possible sources of irreversibility, one could claim that investment expenditures are sunk when (i) they are firm or industry-specific (McDonald and Siegel, 1986; Pindyck, 1988; Dixit and Pindyck, 1994; Barnett and Sakellaris, 1998; Chirinko and Schaller, 2002), (ii) there are limited ('thin') resale or second-hand markets, and (iii) government regulations or institutional arrangements restrict investors from selling assets and reallocating their funds (Dixit and Pindyck, 1994). Undoubtedly, the more user-specific or more costly to relocate a capital good is, the more difficult is to resell since the probability of finding a user with identical needs can be substantially low. Additionally, in the absence of resale or second-hand markets it is more possible that capital will be disposed at a heavy discount that widens with the thinness of the market.

Abel and Eberly (1994) postulate that under irreversibility the investment function can be expressed in three mutually exclusive regimes where (i) disinvestment is optimal when the $MRPK$ falls short of an appropriate lower threshold, (ii) positive investment is optimal when the $MRPK$ exceeds an upper threshold, and (iii) optimal investment is zero, producing an 'inaction' range, when the $MRPK$ lies between the lower and upper thresholds. The existence of irreversibility or non-convex adjustment costs alters the standard *NPV* rule main conclusions in two important ways. First, the *NPV* rule has to be modified, since an investment project qualifies as profitable when its *NPV* is greater, not just from zero, but from the cost of irreversibility. Second, and perhaps more important, irreversibility induces a negative impact of uncertainty on investment by extending this region of inactivity.

The most recent strand of literature advocates that investment opportunities can be represented in terms of the Real Options Theory (ROT). On the one hand, any investment decision can be viewed as a 'call' option where the firm has the right, but not the obligation, to implement the investment project in the future[i]. In the presence of higher uncertainty, the firm may find it more prudent to postpone current investment until part of the uncertainty resolves and more is known about future conditions. In other words, as the 'option' value of waiting increases, the opportunity cost of investment increases too, creating a negative effect of uncertainty on investment (McDonald and Siegel, 1986; Pindyck, 1988; Dixit and Pindyck, 1994; Abel *et al*, 1996; Caballero and Pindyck, 1996). On the other hand, any investment decision also embodies a 'put' option. The firm has the right to sell the already installed capital, at a price lower than the purchase price given that investment is (partially) irreversible. The value of the 'put' option decreases, as the degree of irreversibility increases.

Thus, irreversibility increases the hurdle that triggers investment and as a result the *NPV* rule must be amended, qualifying an investment project as profitable when its *NPV* exceeds the option value of the undertaken investment $(NPV > OV)$. What is more important, like in any option contract, the value of waiting is an increasing function of uncertainty, thereby raising the trigger threshold which leads to a negative relationship between investment and uncertainty.

2.2 Review of Empirical Studies

Despite the fact that there is no consensus in the theoretical literature regarding the impact of uncertainty on investment, the majority of empirical studies conclude that the sign of the investment-uncertainty relationship is negative (Federer, 1993; Huizinga, 1993; Pindyck and Solimano, 1993; Episcopos, 1995; Price, 1995, 1996; Caballero and Pindyck, 1996; Ghosal and Loungani, 1996, 2000; Bell and Campa, 1997; Aizenman and Marion, 1999).

In particular, this relationship becomes more negative with the degree of irreversibility. In the absence of active second-hand markets, firms may not be able to reclaim the full value of their undepreciated capital stock if they decide to sell it. Capital gets more irreversible, and therefore more uncertainty about future conditions implies less investment. Indeed, a burgeoning empirical literature attempts to identify the investment-uncertainty link focusing on the role of irreversibility in the investment decisions. All these studies investigate two testable implications; (i) the negative response of investment to uncertainty, and (ii) the monotonic increase of uncertainty's adverse impact with the degree of irreversibility.

Leahy and Whited (1996) using a panel of US corporations showed that conditional uncertainty exerts a strong negative influence on investment which is mainly driven by the degree of irreversibility.

Pattillo (1998) utilizing data on Ghanaian manufacturing firms concluded that higher uncertainty raises the hurdle that triggers investment, and uncertainty has a negative effect on investment which is greater for firms with more irreversible investment.

Guiso and Parigi (1999) using cross-sectional data for Italian firms investigate the individual effects of market structure and irreversibility by splitting their sample, first between firms with high and low market power, and then by high and low irreversibility. Their findings indicate that the effect of uncertainty on investment differs when firms are grouped according to the reversibility of investment decisions or to market power. For instance, the negative impact of uncertainty is substantially stronger when firms cannot easily dispose their excess capital stock in second-hand markets (high irreversibility).

Goel and Ram (1999) employing aggregate data for 12 OECD countries considered how uncertainty affects investment in the following assets with different degrees of reversibility: (a) producer durables, (b) residential structures, and (c) non-residential structures. The authors perform their analysis based on the conjecture that investment in producer durables is more irreversible, followed by investment in non-residential structures. They conclude that when investments with different degrees of irreversibility are aggregated, the effect of uncertainty may be obscured.

In a later study Goel and Ram (2001) using a similar dataset to their earlier work, exploit differential reversibility by distinguishing between R&D and non-R&D investment, where the former is assumed to be more irreversible. According to their findings for the case of investment outlays on R&D, which are likely to be more irreversible, uncertainty has a strongly significant negative sign, however when non-R&D outlays are used, it has the wrong sign.

Butzen *et al*. (2002) investigated how demand and output price uncertainty affect the investment behaviour of a panel of Belgian manufacturing firms. By segmenting the sample, they found that the negative impact of uncertainty is weaker when investing in buildings (more reversible), which are multi-purpose, than machinery (less reversible). In other words, they concluded that irreversibility amplifies the negative effect of uncertainty on investment.

Bulan (2003) investigates the impact of uncertainty after dividing the sample in terms of market power, irreversibility and size. He quantifies irreversibility as it is derived from asset-specificity at the industry level. In agreement with the Real Options theory, he reports that under the existence of more irreversible capital increased uncertainty depresses firm investment.

Focusing on the UK case, Driver *et al*. (2003) compared investment in machinery versus new buildings, conducting their analysis assuming that machinery is characterised by higher specificity and thus higher irreversibility. In general, they conclude that irreversibility amplifies the negative influence of uncertainty on fixed investment.

Le Khuong *et al*. (2004) measured irreversibility based on survey data for 210 rice-milling firms in the Mekong River Delta in Vietnam, and found that uncertainty exerts a more negative influence on investment as irreversibility increases.

Drakos (2005a) utilising aggregate investment spending for the E.U. countries across different types of capital goods, exploits the diversity of these goods in terms of their degree of irreversibility. He establishes a monotonically increasing impact of uncertainty on investment across the irreversibility spectrum, which implies that changes in perceived uncertainty are bound to alter capital formation in a non-homogeneous way depending on the underlying irreversibility of each capital good.

Finally, Drakos (2005b) studied investment across a set of European manufacturing sectors, considering an asset type classification in terms of the degree of irreversibility. Essentially, apart from decomposing Tangible Fixed Assets into Plant & Machinery and Land & Buildings, he also decomposes Fixed Assets into Intangible Fixed Assets and Tangible Fixed Assets. His findings are consistent with the two predictions of the Real Options theory since higher uncertainty is negatively affecting investment, highlighting a deferral of decisions until part of the uncertainty resolves, and furthermore the negative impact of uncertainty is an increasing function of the degree of irreversibility.

3. Data Issues

Our sample employs data from the **Annual Survey of Manufacturing** for Greece, which were kindly provided by the **General Secretariat National Statistical Service of Greece**. Essentially, the dataset is an unbalanced panel where the time dimension spans a 9-year period; $t = 1993,...,2001$, while the cross-sectional dimension; $i = 1,...,22$, identifies the following sectors on a 2-digit level (NACE): *Food and Beverages* (15), *Tobacco* (16), *Textiles* (17), *Clothing* (18), *Leather and Footwear* (19), *Wood and Cork* (20), *Paper and Paper Products* (21), *Printing and Publishing* (22), *Petroleum and Coal Products* (23), *Chemicals* (24), *Rubber Articles and Plastics* (25), *Non-Metallic Minerals* (26), *Basic Metals* (27), *Manufacture Final Metallic Products* (28), *Machines and Equipment Articles* (29), *Office Accounting and Computing Machinery* (30), *Electrical Machines, Apparatus etc.* (31), *Radio, TV, Communications Appliances* (32), *Medical* *and Accuracy Instruments* (33), *Transport Equipment* (34), *Other Transport Equipment* (35), *Furniture and Other Industries* (36) . In particular, we obtained four components of Investment Expenditure of Tangible Fixed Assets:

- Investment Expenditure on new Buildings; $\left(I_{i,t}^{B}\right)$,
- Investment Expenditure on new Machinery; $\left(I_{i,t}^{M}\right)$,
- Investment Expenditure on new Vehicles; $\left(I_{i,t}^{V}\right)$,
- Investment Expenditure on new Furniture; $\left(I_{i,t}^{F}\right)$,

The sum of investment expenditures across these four types of capital goods is defined as Total New Investment Expenditure; $\left(I_{i,t}\right) \equiv \left(I_{i,t}^{B} + I_{i,t}^{M} + I_{i,t}^{V} + I_{i,t}^{F}\right)$.

We also collected data on Total Investment Expenditure on used capital goods; $\left(U_{i,t}\right)$, which is similarly decomposed; $\left(U_{i,t}\right) \equiv \left(U_{i,t}^{B} + U_{i,t}^{M} + U_{i,t}^{V} + U_{i,t}^{F}\right)$.

In addition, we sampled the following:

- Gross Value of Production, hereafter called output; $Q_{i,t}$
- Value of Sales; $S_{i,t}$

Note that all above defined variables are measured at current market prices expressed in Greek Drachmas, since the sample corresponds to the period before Greece's joining the Euro. Apart from the set of variables mentioned above, which are both time-varying as well as cross-sectionally varying, we also obtained two more variables that are only time-varying:

- Nominal Long-Term Interest Rate; $\left(NLR\right)_t$, which will be used as a proxy of the user-cost of capital.

- Marginal Efficiency of Capital; $(MEFF)_t$, which will capture the return on capital. This variable is defined as:

$$(MEFF)_t = \frac{GDP_t - GDP_{t-1}}{\frac{GFKF_{t-1} + GFKF_t}{2}} \quad \textbf{(1)}$$

Where GDP denotes gross domestic product at constant market prices, and $GFKF$ stands for gross fixed capital formation at constant prices, total economy. Data on $(NLR)_t$ and $(MEFF)_t$ variables come from the AMECO database, which is maintained by Eurostat.

Based on the data described above, we constructed the following variables that will later be used in our empirical model. Initially, all investment expenditures (for each type of capital good, new and used) were divided by output, and therefore produced the corresponding investment rates; $\left[\left(\frac{I}{Q}\right)_{i,t}^{j}, \left(\frac{U}{Q}\right)_{i,t}^{j}\right]$, where $j = B, M, V, F$. Moreover, we constructed the growth rate of the logarithm of the sales-output ratio; $\Delta \log\left(\frac{S}{Q}\right)_{i,t}$, where Δ stands for the first-difference operator.

Uncertainty, $(UNC)_t$, is proxied by the annual standard deviation of monthly changes in the (seasonally-adjusted) Economic Sentiment Indicator for Greece (*ESI*, hereafter). The (*ESI*) is a survey-based qualitative index that captures the overall tendency of sentiment among market participants regarding the future path of the economy[ii]. The scale of measurement of (*ESI*) is (-100, +100) and when it attains a negative (positive) value indicates that most of the respondents expect that the overall economic conditions will deteriorate (improve). Furthermore, apart from its sign, its absolute value also conveys useful information since the higher it is, the higher is the agreement among responders. Clearly, $\left(UNC\right)_t$ increases with the absolute size and frequency of changes in the (*ESI*). Higher frequency of changes in the (*ESI*) suggests that the overall sentiment is volatile, implying an unstable environment that leads agents to change their opinion quite often. Similarly, large changes are compatible with situations where agents feel that the conditions have been altered significantly.

This measure of uncertainty has also the following advantages: (i) it is an overall measure of uncertainty embodying various aspects of economic environment, (ii) it is as close to *ex ante* uncertainty as possible, since (*ESI*) is inherently forward-looking, (iii) it is a direct measure of *perceived* uncertainty since it is based on the answers of the business community rather than estimated, which does not impose any *ad hoc* assumptions regarding their expectations formation mechanism, and (iv) it is time-varying. The data cover the period from January 1993 to December 2001 and were collected from the **Business and Consumer Surveys** of the **Economic and Financial Affairs of the European Union.**

4. Activity of Second-Hand Markets and its Link with the Irreversibility of Capital

Irreversibility of investment decisions has been attributed either to a technological constraint that restricts the ability to substitute labour for capital (Lee and Shin, 2000), or to transaction costs that drive a wedge between the purchase and the selling prices of the installed undepreciated capital (Abel and Eberly, 1994, 1999; Bohm *et al*, 1999; Chirinko and Schaler, 2002; Cooper and Haltiwanger, 2005)[iii].

Determining the degree of irreversibility of capital has proved to be a rather thorny issue. As discussed earlier, the financial literature views irreversibility as the discount required to dispose installed capital. In other words, irreversibility is reflected in the price differential between the buying and the resale price (Abel and Eberly, 1999; Chirinko and Schaller, 2002). This differential, also known as irreversibility premium, is an increasing function of the user-specificity of capital (McDonald and Siegel, 1986; Pindyck, 1988; Dixit and Pindyck, 1994).

A similar view has been adopted by the Industrial Organization literature, where irreversibility is captured by the 'sunkenness' of capital. The extent to which capital expenditures are sunk is determined by the portion of capital which is irrecoverable (Kessides, 1990; Worthington, 1995).

The disposal of used capital presupposes the existence of a market for second-hand capital. Like any market, its 'thinness' or 'depth' is a fundamental determinant of the resulting equilibrium price and quantity. Thus, the intensity or activity of the resale market can be viewed as a proxy for the mobility and fungibility of the capital employed in a given sector (Kessides, 1990). Consequently, a measure of the intensity of the second-hand market, and therefore the reversibility of capital, can be based on the share of used capital expenditures over total capital expenditures. A high share would imply the existence of an active second-hand market and would signal a greater scope for disposing capital (Kessides, 1990; Worthington, 1995).

To the extent that heterogeneity of capital in terms of irreversibility exists, one would expect the activity of second-hand markets to differ across capital goods. Essentially, summing across all decision units such as firms, sectors etc., the presence of differential irreversibility can be assessed by comparing the intensity of second-hand market for each type of asset. For instance, consider N sectors $\left(i=1,....,N\right)$ where each sector invests on a number of asset categories K $\left(j=1,....,K\right)$. Each sector also spends an amount on used capital from these asset categories. Investment on new capital of type j, at time period t, of sector i is denoted by $\left(I_{i,t}^{j}\right)$. Investment on used capital is denoted by $\left(U_{i,t}^{j}\right)$. We then construct a metric of **Asset-Specific Reversibility**, defined as the average percentage of used capital over total investment (new + used) across all sectors, for a specific asset category:

$$AS\overline{R}^{j}=\frac{\sum_{i=1}^{N}U_{i,t}^{j}}{\sum_{i=1}^{N}\left(I_{i,t}^{j}+U_{i,t}^{j}\right)} \qquad \textbf{(2)}$$

The technology based notion of irreversibility has been put forward by Hartman (1972, 1976) and Lee and Shin (2000) and is based on the substitutability between labour and capital. In particular, the potential to alter the combination of inputs in order to adapt to unforeseen events that render initial choices of capital suboptimal, determines the degree of reversibility. Therefore, for a given type of capital good, technological heterogeneity across sectors would manifest itself in second-hand capital usage heterogeneity. In other words, this would give rise to sector-specific irreversibility, over and above the asset-specific irreversibility. We define a metric of **Sector-Specific Reversibility** as the percentage of used capital over total investment for each asset category:

$$SS\overline{R}_{i,t}^{j}=\frac{U_{i,t}^{j}}{\left(I_{i,t}^{j}+U_{i,t}^{j}\right)} \qquad \textbf{(3)}$$

We then, classify a sector as facing technology that leads to higher (lower) irreversible investment when its SSR metric, $\left(SS\overline{R}_{i,t}^{j}\right)$, is below (above) the median value, $\left(SS\overline{R}^{j}\right)^{med}$, obtained from the distribution defined by all sectors. Hence, we construct a dummy to measure the degree of Sector-Specific Irreversibility as:

$$IRR_{i,t}^{j} = \begin{cases} 1, \text{ if } \left(SS\overline{R}_{i,t}^{j}\right) < \left(SS\overline{R}^{j}\right)^{med} \\ 0, \text{ if } \left(SS\overline{R}_{i,t}^{j}\right) > \left(SS\overline{R}^{j}\right)^{med} \end{cases} \qquad \textbf{(4)}$$

5. *Prima Facie* Evidence for Differential Irreversibility

As a prelude we calculated the average share of used capital expenditures over total capital expenditures (new + used) for each asset type, across all 22 sectors.

[Graph1]

After a tentative interpretation based on mean investment rates of used capital, Vehicles emerges as the most active second-hand market, suggesting that it is associated with the lowest degree of irreversibility, followed by Buildings, Machinery, and finally Furniture. Although such an ordering seems intuitive as well as compatible with the conventional wisdom among the profession regarding the degree of irreversibility of the above assets, the conclusion concerning Furniture is paradoxical. In fact, one would expect that Furniture would correspond to the most reversible type of asset among the four considered. In any case, our analysis at this stage serves solely as an *a priori* guide and by no means offers a definitive irreversibility ordering. The latter can only be constructed after formal econometric investigation.

Although the pictorial information in Graph 1 indicates that the intensity of second-hand markets varies across assets, a more concrete conclusion may be reached after applying formal statistical tests. In particular, we employ a standard t-test as well as the non-parametric Wilcoxon Matched-Pairs Signed-Ranks[iv] test in order to test a set of hypotheses, which describe an equal intensity of second-hand markets for each pair of asset types.

[Table 1]

Inspection of the results from the above table clearly suggests that the mean intensity of the second-hand markets is not equal across different asset categories. Using the t-test we emphatically reject the null hypothesis for all pairs considered, with the exception of the Buildings-Machinery pair. When the Wilcoxon test is used we are able to reject all, but one, of the hypotheses namely the Buildings-Furniture pair. Therefore, in our subsequent econometric analysis, we will investigate whether the aforementioned irreversibility ranking materialises. In particular, the hypotheses to be tested will be a) provided that irreversibility exists, each investment type should react negatively to uncertainty, and b) the absolute magnitude of this reaction is monotonically increasing with the degree of irreversibility.

Moreover, we have also calculated the share of used capital expenditures over total capital expenditures (new + used) for each sector, across the four asset types. This enables us to elicit useful information on the variability of the used capital expenditures ratio for each sector, and within an asset type.

[Graph 2]

It becomes obvious from the above graph that each sector spends different amounts across asset categories. This result mainly stems from the technological constraint in terms of the substitutability between labour and capital. In other words, different sectors are associated with heterogeneous abilities to substitute labour for capital, which causes different irreversibilities, and consequently different irreversibility premia. Hence, we expect the response of investment to uncertainty to also exhibit sectoral variation.

The above descriptive analyses provide *prima facie* evidence for heterogeneous irreversibility across asset types as well as across sectors. Therefore, holding sector characteristics constant, the ability to reverse investment on a particular asset will depend on the idiosyncratic characteristics of the asset type, and ii) focusing on a particular capital good, different sectors will be associated with different propensities to reverse their investment decisions reflecting their idiosyncratic characteristics.

6. Econometric Methodology

6.1 Investigating Asset-Specific Irreversibility

In our baseline model we project new investment on a set of state variables as suggested by economic theory (user-cost of capital, capital productivity, sales growth, and past investment), which will be used as control variables. In addition, we include our metric of uncertainty, whose coefficient will be the primary focus of our analysis. Recall that we will estimate five equations of this form, one for total new investment and the remaining four corresponding to each of the asset types. The typical equation is as follows:

$$\left(\frac{I}{Q}\right)_{i,t}^{j} = \beta_0^j + \beta_1^j \left(\frac{I}{Q}\right)_{i,t-1}^{j} + \beta_2^j \left(MEFF\right)_t + \beta_3^j \left(NLR\right)_t + \beta_4^j \Delta \log \left(\frac{S}{Q}\right)_{i,t} + + \beta_5^j \left(UNC\right)_{t-1} + \varepsilon_{i,t}^j \qquad \textbf{(5)}$$

Where, i denotes the cross section of sectors, t denotes time, j denotes asset category, $\beta's$ are unknown parameters to be estimated, and ε is an unobserved disturbance term.

Our priors regarding the signs of parameters are as follows: $\beta_1^j > 0$; indicating persistence in investment that would be consistent with *time-to-build* effects, $\beta_2^j > 0$; since higher capital productivity boosts the incentive to invest, $\beta_3^j < 0$; capturing the user-cost effect (Jorgenson, 1963; Hall and Jorgenson, 1967), and $\beta_4^j > 0$; since sales reflect future investment opportunities as proposed by the Sales Accelerator model (Abel and Blanchard, 1986).

As far as the parameters of interest, β_5^j are concerned, they are expected to carry a negative sign, implying the presence of irreversibility. Furthermore, any potential differences in the values of the parameter β_5 across asset types j would convey important information with respect to the impact of uncertainty as a function of the degree of irreversibility. Specifically, we anticipate uncertainty to exert a higher impact as irreversibility increases. In light of the discussion and findings in Section 5 we expect the estimated coefficients to satisfy the following conditions: $\beta_5^{MAC}, \beta_5^{BUI}, \beta_5^{VEH}, \beta_5^{FUR} < 0$ and $\left|\beta_5^{MAC}\right| > \left|\beta_5^{BUI}\right| > \left|\beta_5^{VEH}\right| > \left|\beta_5^{FUR}\right|$.

6.2 Investigating Sector-Specific Irreversibility

We employ an augmented version of equation (5), where we include the interaction between uncertainty and a metric of irreversibility on sectoral level. The model assumes the following form:

$$\left(\frac{I}{Q}\right)^{j}_{i,t} = \beta_0^j + \beta_1^j \left(\frac{I}{Q}\right)^{j}_{i,t-1} + \beta_2^j \left(MEFF\right)_t + \beta_3^j \left(NLR\right)_t + \beta_4^j \Delta \log \left(\frac{S}{Q}\right)_{i,t} +$$

$$+ \beta_5^j \left(UNC\right)_{t-1} + \beta_6^j \left(UNC * IRR\right)^{j}_{i,t-1} + \varepsilon^{j}_{i,t} \qquad \textbf{(6)}$$

Where, i denotes the cross section of sectors, t denotes time, j denotes asset category, $\beta's$ are unknown parameters to be estimated, and ε is an unobserved disturbance term.

For a given asset type, sector-specific irreversibility is embodied in the interaction term, whose coefficient is expected to be negative, $\beta_6^j < 0$. Hence, we anticipate a second-order effect of uncertainty on investment that varies across sectors. The sector-specific irreversibility amplifies the negative response of investment to uncertainty for a given capital good.

7. Empirical Results

The parameters of equation (5) are estimated by applying the Arellano and Bond (1991) Generalized Method of Moments (GMM) dynamic panel technique. The actual estimation is based on the first-differences of all variables included in the model, which results in a new disturbance term exhibiting, by construction, first-order autocorrelation. The statistical adequacy of the model is established when two conditions are met: (i) the generated residuals do not exhibit second-order autocorrelation, property that is checked by the use of the m_2 statistic as developed by Arellano and Bond (1991), and (ii) the over-identifying restrictions are not rejected, a condition checked by applying the Sargan (1958) test. The estimated coefficients are reported in the following table.

[Table 2]

The models satisfy the over-identifying restrictions, as well as the insignificance of the second-order autocorrelation of residuals and hence, can be used to conduct inference on the recovered parameters. Examining the effect of control variables, in general they carry the 'correct' signs as predicted by economic theory. In particular, lagged investment carries the expected positive sign and is significant in three out of five cases indicating temporal persistence in investment. The coefficient on Marginal Efficiency of Capital is significant and positive in three cases, while the coefficient of Nominal Long-Term Interest Rate is significantly negative in three out of five cases capturing the standard user-cost effect. Finally, sales growth is associated with a positive coefficient in two cases, which is in accordance with the predictions of the Sales Accelerator model.

Moving now to the parameters of main interest, we observe that uncertainty exerts a negative and significant impact on total investment, as well as on investment on three types of capital goods (Buildings, Machinery, and Vehicles), while Furniture exhibits a positive investment-uncertainty link. In particular, the uncertainty coefficient on Machinery is -0.18, while for Buildings attains the value of -0.10, which is approximately 45 percent lower than that on Machinery. The coefficient on Vehicles is estimated as -0.01, which is about 10 times lower than that on Buildings. Finally, uncertainty is found to exert a positive effect with respect to investment on Furniture.

These findings indicate that engaging in new investment for three out of four types of capital is associated with some degree of irreversibility, as encapsulated by the negative coefficient on uncertainty. Moreover, a comparison between types of capital reveals substantial differences as regards the absolute impact of uncertainty, which highlights the presence of asset-specific irreversibility.

Table 3 reports estimation results for equation (6) that will assist us in assessing the presence of sector-specific irreversibility.

[Table 3]

The model satisfies the over-identifying restrictions as well as the insignificance of the second-order autocorrelation. Our findings with respect to the control variables remain largely unchanged. Additionally, our findings regarding the direct impact of uncertainty across asset types remain unaltered in terms of sign and ranking of absolute magnitudes.

The main parameters of interest *i.e.* the coefficients of the interaction terms, are estimated as being negative with the exception of Furniture. The negative coefficient of the interaction term indicates that for a given asset type, the overall uncertainty impact depends on the extent of second-hand market intensity between sectors. In other words, changes in uncertainty will be non-uniformly diffused across sectors even when identical capital goods are considered.

In Table 4 we summarize the total impact of uncertainty on investment decompose it into asset-specific and sector-specific irreversibility.

[Table 4]

A number of useful inferences can be drawn with regards to the inter-capital type irreversibility and the relationship between the asset and sector-specific effects. Firstly, the pattern of estimated coefficients across types of capital verifies the suspected ranking in terms of asset-specific irreversibility as concluded from the activity of second-hand markets. In particular, Machinery emerges as the asset with the highest degree of irreversibility followed by Buildings and Vehicles. In contrast, Furniture seems to behave differently from other assets, since it does not respond negatively to uncertainty suggesting that it is not associated with any irreversibility. Secondly, the sector-specific effect in terms of magnitude is considerably lower than that of the asset-specific effect. Thus, uncertainty exerts a first-order effect on investment, primarily driven by the characteristics of capital type. A second-order effect of uncertainty is encapsulated in the dimension of sectoral variations in terms of different production technologies adopted. As it turns out, the lion share of the overall uncertainty effect may be attributed to the asset-specific effect, ranging from 65 to 75 percent.

8. Conclusions

Utilizing investment expenditures on various types of new and used capital (second-hand) for various manufacturing sectors, we compared the intensity of second-hand markets *between* types of capital goods as an indicator of asset-specific irreversibility. Furthermore, *within a type of capital good*, we employed the variation of intensity of second-hand market across sectors as an indicator of sector-specific irreversibility.

Our analysis revealed a non-uniform impact of uncertainty on investment decisions. First, uncertainty shocks are unevenly diffused across types of assets depending on their degree of irreversibility. Hence, capital heterogeneity expressed in differential irreversibility leads to asymmetries in responses to uncertainty. Second, sectoral differences in terms of the ability to substitute a given type of capital with labour, introduces a second-order effect of uncertainty on investment. In other words, sector-specific irreversibility will accentuate the adverse effect of uncertainty generated by asset-specific irreversibility.

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Endnotes

[i] Provided, that the investment opportunity is not of the 'now-or-never' type.

[ii] One cannot help spotting a mistreatment, in terms of semantics, of the notion of 'uncertainty' in the empirical literature, which usually is equated to 'risk'. In terms of the 'Knightian' distinction, 'risk' is used to describe situations in which probabilities are available to guide choice and 'uncertainty' to describe situations in which information is too imprecise to be summarised by probabilities. We feel that by employing the Economic Sentiment Indicator our analysis is closer to the concept of Uncertainty rather than Risk.

[iii] Irreversibility may also be viewed as a 'lemons' problem, again in the context of the New Keynesian school, as the outcome of capital market imperfections taking the form of asymmetric information (Stiglitz and Weiss, 1981; Jaffee and Stiglitz, 1990).

[iv] Standard t-tests are very sensitive to deviations from the assumption of normality. The Wilcoxon test is a non-parametric test, and therefore surpasses the problem of specifying a particular distribution for the underlying population (Siegel, 1956; Hollander and Wolfe, 1973; and Hettmansperger, 1984).

Tables

Table 1 Tests for the Intensity Homogeneity of Second-Hand Markets by Capital Good

Hypothesis Testing	Wilcoxon test (p-values)	t-statistic (p-values)
$H_0: Buildings = Machinery$	-2.45 (0.01)	0.84 (0.40)
$H_0: Buildings = Vehicles$	-7.74 (0.00)	-2.98 (0.00)
$H_0: Buildings = Furniture$	0.74 (0.45)	3.17 (0.00)
$H_0: Machinery = Vehicles$	-7.69 (0.00)	-4.24 (0.00)
$H_0: Machinery = Furniture$	4.78 (0.00)	2.76 (0.00)
$H_0: Vehicles = Furniture$	9.86 (0.00)	8.62 (0.00)

Notes: The null hypothesis is that, for every given pair, the associated second-hand markets are of equal intensity.

Table 2 Estimation of Equation 5: Testing for Asset-Specific Irreversibility (Effective sample period 1993-2001, cross-sections 22)

Dependent Variable $\left(\frac{I}{Q}\right)^{j}_{i,t}$	Total Investment	Buildings	Machinery	Vehicles	Furniture
Regressor	**Coefficient Estimates (z-scores)**				
$(UNC)_{t-1}$	**-0.23*** (-3.84)**	**-0.10** (-2.24)**	**-0.18*** (-3.24)**	**-0.01*** (-6.22)**	**0.08*** (9.86)**
$\left(\frac{I}{Q}\right)^{j}_{i,t-1}$	0.25*** (4.20)	0.05 (1.59)	0.14*** (4.06)	-0.07*** (-2.78)	0.67*** (31.59)
$(MEFF)_t$	0.01* (1.72)	0.008*** (3.17)	-0.006 (-0.55)	-0.0006* (-1.83)	0.007*** (8.51)
$(NLR)_t$	-0.12*** (-8.66)	0.07*** (10.28)	-0.23*** (-11.39)	-0.008*** (-6.31)	0.07*** (20.20)
$\Delta\log\left(\frac{S}{Q}\right)_{i,t}$	0.008*** (3.26)	-0.002*** (-4.42)	0.009*** (16.14)	-0.00009 (-0.68)	-0.004*** (-3.76)
Diagnostics					
m_1	-2.72	-2.77	-2.67	-2.27	-1.34
m_2	0.59	-0.51	-0.88	1.60	0.97
Sargan (27 moment conditions)	15.05 (p-value: 0.96)	14.72 (p-value: 0.97)	17.39 (p-value: 0.92)	17.53 (p-value: 0.91)	21.02 (p-value: 0.78)
Observations	148	148	148	148	148

Notes: Numbers in parentheses denote z-scores, m_1 and m_2 are residual first and second order serial correlation tests, while Sargan stands for the over-identifying restrictions test (figure in parenthesis denotes degrees of freedom). One, two, three asterisks denote significance at the 10, 5, and 1 percent level respectively.

Table 3 Estimation of Equation 6: Testing for Sector-Specific Irreversibility (Effective sample period 1993-2001, cross-sections 22).

Dependent Variable $\left(\frac{I}{Q}\right)_{i,t}^{j}$	Total Investment	Buildings	Machinery	Vehicles	Furniture
Regressor	**Coefficient Estimates (z-scores)**				
$(UNC)_{t-1}$	**-0.14*** **(-1.79)**	**-0.08**** **(-2.13)**	**-0.15***** **(-2.92)**	**-0.01***** **(-3.92)**	**0.05***** **(3.67)**
$(UNC*IRR)_{i,t-1}^{j}$	**-0.22***** **(-6.58)**	**-0.04***** **(-4.19)**	**-0.05***** **(-2.83)**	**-0.005***** **(-4.33)**	**0.05***** **(5.13)**
$\left(\frac{I}{Q}\right)_{i,t-1}^{j}$	0.33*** (7.46)	0.09** (2.57)	0.16*** (4.56)	-0.07*** (-3.94)	0.58*** (9.38)
$(MEFF)_t$	0.003 (0.21)	0.009*** (4.03)	-0.005 (-0.52)	-0.0006 (-1.17)	0.005*** (5.54)
$(NLR)_t$	-0.11*** (-4.85)	0.07*** (8.57)	-0.23*** (-8.33)	-0.006*** (-4.16)	0.06*** (9.38)
$\Delta\log\left(\frac{S}{Q}\right)_{i,t}$	0.01*** (3.64)	-0.002*** (-4.29)	0.009*** (20.01)	-0.0008*** (-3.19)	-0.002 (-1.44)
Diagnostics					
m_1	-2.75	-2.93	-2.69	-2.21	-1.41
m_2	0.60	-0.44	-0.73	1.50	0.95
Sargan (27 moment conditions)	12.48 (p-value: 0.99)	14.20 (p-value: 0.97)	15.99 (p-value: 0.95)	11.94 (p-value: 0.99)	17.48 (p-value: 0.91)
Observations	148	148	148	147	148

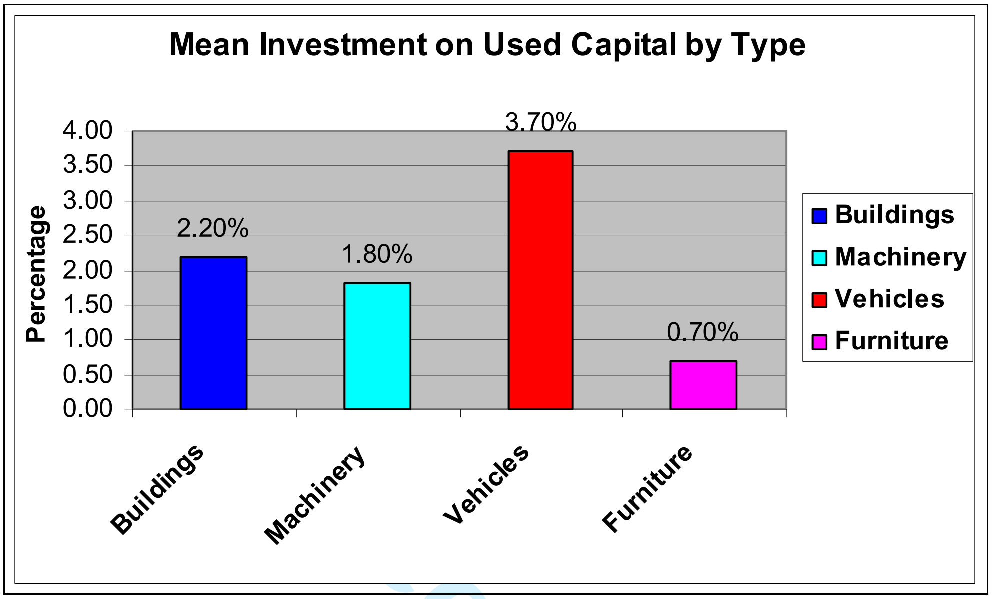
Notes: Numbers in parentheses denote z-scores, m_1 and m_2 are residual first and second order serial correlation tests, while Sargan stands for the over-identifying restrictions test (figure in parenthesis denotes degrees of freedom). One, two, three asterisks denote significance at the 10, 5, and 1 percent level respectively.

Table 4 Decomposition of the Overall Uncertainty Effect

	Asset-Specific Effect (1)	Sector-Specific Effect (2)	Sum of Effects (3) = (1)+(2)	Percentage due to Asset (1)/(3)	Percentage due to Sector (2)/(3)
Machinery	-0.15	-0.05	-0.20	75.00	25.00
Buildings	-0.08	-0.04	-0.12	66.66	33.33
Vehicles	-0.01	-0.005	-0.015	66.66	33.33
Furniture	0.05	0.05	0.10	50.00	50.00

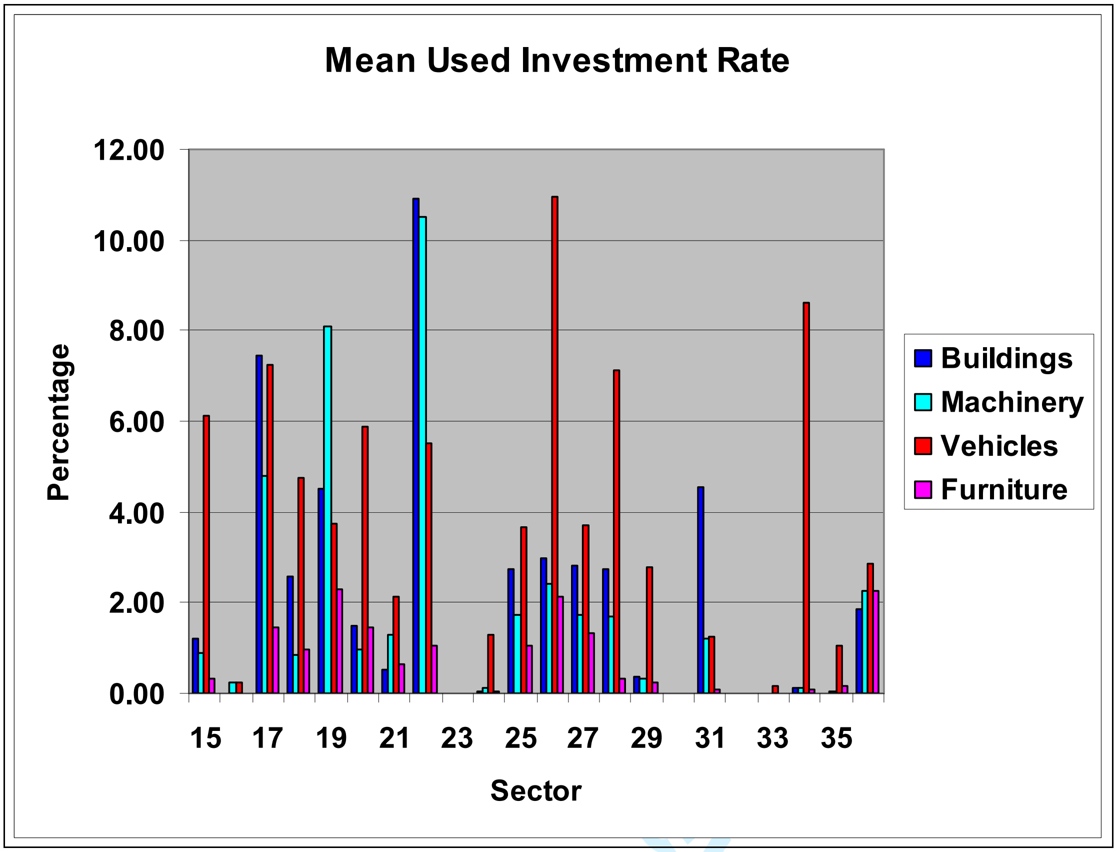
Graphs

Graph 1



<u>Notes</u>: Sample mean of used capital by type over (new + used) across all sectors and years.

Graph 2



Notes: Sample mean of used capital by type over (new + used) for each sector across all years.