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The Impact of Market Structure and Irreversibility on Investment under Uncertainty: An Empirical Analysis

by

Sara Maioli

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The Authors

Sara Maioli is a Research Fellow in the Leverhulme Centre for Research on Globalisation and Economic Policy (GEP), University of Nottingham.

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Abstract

The empirical literature of investment under uncertainty has vastly neglected to account for the role played by market structure. Recently the theory has however started to merge real options theory with game theory to offer alternative explanations to strategic investment behaviour. This paper estimates an error correction model of investment under product price uncertainty for 23 French industries during the period 1977-1997 and represents the first empirical work that includes variables of market structure (in terms of degree of competition) in a model of investment under uncertainty. It is also one of the very first attempts to make explicit the empirical relationship between investment and uncertainty under different degrees of irreversibility. Although I find evidence that in general uncertainty has a negative impact on investment, the results show that the more concentrated industries are not significantly affected. Irreversibility, as predicted by theory, has a significant negative impact on investment, but when degree of competition and irreversibility are considered together it appears that the more concentrated industries can shield from the negative impact of uncertainty notwithstanding the presence of downward adjustment costs of capital. This seems in line with some of the recent developments proposed by the theory.

JEL classification: C33, D80, E22, L16, L60

Keywords: Investment, Uncertainty, Real Options, Market Structure, Herfindahl Index, Irreversibility, Error Correction Model, System GMM.

Outline

Non-Technical Summary

The aim of this work is to estimate a model of investment under uncertainty, where an observable variable of market structure has been introduced (Herfindahl index). The motivation is that the traditional literature on investment under uncertainty has been focussed on either monopolistic or perfectly competitive firms, neglecting the possibility that in oligopolistic markets firms may have different incentives to invest because of the strategic interactions existent with other rivals or potential competitors. Only recently has theory made advancements in this direction and recognised the importance of such strategic interactions. This has required the merger between real options theory and game theory.

My empirical analysis is derived from the theoretical model by Bloom et al. (2001), which although they estimated at firm-level is applicable to either aggregate or industry level. Empirically this model allows us to distinguish both the short run and the long run effects of uncertainty on investment dynamics. And it seems important to distinguish between them because they might be different, with the long run impact of uncertainty being theoretically ambiguous. When estimated in its basic specification (without considering market structure or irreversibility), the results indicate that the short run impact of uncertainty is negative and highly significant, whilst the long run effect of uncertainty on investment is not significantly different from zero.

The effect of market structure, or the degree of competition, is captured by interacting the uncertainty variable with a dummy that is one if the industry is highly concentrated. The dummy allows a shift in the slope parameter of uncertainty and captures the marginal effect of uncertainty only for concentrated industries. In addition, uncertainty is interacted with the change in the Herfindahl index over time. In this way it is possible to capture the effect of uncertainty on investment conditional on a change in market structure both between industries and within an industry. The results show that while the impact of uncertainty is still negative on average (that is the contemporaneous coefficient of the change in uncertainty is negative and significant) the coefficient on the dummy is positive and significant, meaning that the marginal effect of being a concentrated industry makes the investment-uncertainty positive. The total effect of uncertainty on investment for concentrated industries is however not significantly different from zero. This result is quite surprising and in contrast with the traditional theory of investment under uncertainty, but is in line with the more recent advancements of it (and with at least another empirical study).

Another unresolved issue in the literature of investment under uncertainty is how to translate empirically the theoretical impact of irreversibility on investment. A few contributions have attempted such task, but their approach has been considered unsatisfactory because it imposed a complex model structure. Thus, another novelty of this work is that I test the theory about the impact of irreversibility on the investment-uncertainty relation by constructing a very simple proxy of the degree of industry irreversibility, and I interact this with uncertainty. I therefore directly estimate in the investment equation the impact of irreversibility by interacting uncertainty with the change over time of an irreversibility ratio. This is constructed using information about the investment composition in terms of type of (presumably) irreversible capital accumulated. This interacted term should capture the within-industry effect of a change in the irreversibility ratio over time. In addition, I interact uncertainty with a dummy variable that captures whether the industry has on average a high irreversibility ratio (again, this shifts the slope parameter of uncertainty). From both these coefficients on the interacted terms I find strong support to the theory: irreversibility does play a role because in its presence the impact of uncertainty becomes negative and highly significant. Conversely, and quite interestingly, the other uncertainty terms that appear in the estimating equation without being interacted with irreversibility become insignificant. This probably means that the negative sign generally attributed to uncertainty is driven by a good deal by the presence of irreversibility. And, as already pointed out in the investment-uncertainty literature, this casts some doubts

on the empirical evidence of all those studies that simply correlate investment with some measure of uncertainty. The true relationship is probably concealed by a misspecification problem. Thus, my empirical results require further validation by additional empirical research, but they also seem to urge the introduction of measures of irreversibility when doing an empirical analysis of the impact of uncertainty on investment.

Lastly, I consider simultaneously the interaction of uncertainty with irreversibility ratio and Herfindhal index. I find that more concentrated industries do not suffer a negative impact of uncertainty even when characterized by a high degree of irreversibility in their capital. It seems instead that they are even positively affected. This could probably be explained again with the strategic real options theory, whereby markets that have high barriers to entry and high sunk costs are those where the interactions among players matter for the uncertainty-investment relationship. In fact it is possible to think that a firm might decide to commit itself to highly irreversible investment even when faced with uncertainty for the fear that if she does not invest, others will do it and she will lose market power (and market share).

1 – Introduction

Investment is a key determinant of long-run economic growth. For this reason investment is one of the topics with the longest history of studies in economics, and a main objective of policy concern. For example the current UK's Labour government considers the provision of "macroeconomic stability" as an important means of encouraging higher levels of private sector investment. In fact, there exists consensus that economic or financial instability discourages real investment. Economic theory has therefore analysed the impact of uncertainty on investment since the 1970s.

The literature on investment under uncertainty is quite vast and over the years it seems not to have diminished its importance in terms of quantity of papers presented at various international conferences, nor in terms of published articles (although probably the 90s were the decade which saw the publications of the highest number of contributions to this field in the very top world economics journals).

At the same time the development of the theory has been quite substantial as well, and I can see a thread linking the contributions in this way: the 1970s and 1980s were dominated by the Hartman-Abel framework, which postulated a positive impact of uncertainty on investment; the 1990s saw the path-breaking contribution of Dixit and Pindyck (1994) on the irreversibility of investment and the development of the real options theory of investment, which predicts a negative impact of uncertainty on investment due to the option value of delaying investment; and this is still at present the predominant theoretical framework that dominates all the empirical work, both at macro and micro level of analysis. Although the consensus is still concentrating on the merits of the irreversibility as a determinant of the investment behaviour under uncertainty, there is however a new interesting development to the theory that has started to propagate very recently (although the first contribution probably was made as early as 1991 – and it results to be still unpublished – the other works are dated mostly 2001 onwards). This recent strand of the literature has started to merge the real options theory with game theory in order to extend the Dixit-Pindyck framework, which assumes either monopolistic or perfectly competitive firms, to a context of oligopoly where strategic interactions among firms are crucial and each firm is not seen as an entity in isolation. Therefore the investment decisions taken by each firm, endowed to some extent of monopoly power, will take into considerations the reactions of the existing rivals or potential entrants in the market. Under some circumstances this leads the firm to precipitate investment even if faced with uncertainty, if it fears that by not doing so it might lose its dominant position or it suffers subsequent losses because of the entry of new competitors.

Against this setting we would expect a corresponding thriving empirical literature. Instead, although the topic of uncertainty is still investigated extensively, the contributions on this particular recent development are definitely lagging behind. In their survey of the literature on investment under uncertainty, Carruth *et al.* (2000) invoked in the last section the need for empirical studies to evaluate whether the uncertainty-investment relationship is dependent upon the degree of market power.
Aim of this paper is therefore to conduct an empirical study of investment under uncertainty where the market structure is somehow accounted for. I will use the degree of competition of an industry, as captured by the observable Herfindahl index, to accomplish this task. The results found are in contrast with what predicted by the traditional theory of the 90s [for example by Caballero (1991)], but is however in line with at least one other empirical study [Ghosal and Loungani (1996)], and I claim that this evidence is probably supporting the arguments of the very recent theoretical developments on strategic investment decisions.

In addition, I propose also to test the theory about the impact of irreversibility on the investment-uncertainty relation by constructing a very simple proxy of the degree of investment irreversibility, and I interact this with uncertainty. I therefore *directly* estimate in the investment equation the impact of irreversibility. My simple approach tries to overcome the complex framework and model structure imposed by previous studies that attempted to evaluate the effect of irreversibility *indirectly* and whose results were arguably affected by the econometric techniques employed.

The empirical analysis is conducted with a model that allows distinguishing both the short run and the long run effects of uncertainty on investment dynamics. And this seems important, since these effects might be different, with the long run impact of uncertainty being theoretical ambiguous (as demonstrated by a few studies cited below). The paper also contains the theoretical derivations of such an investment modelling, which accounts for both the short and the long run, based on a model by Bloom *et al*. (2001).

The data used in the empirical study are 23 manufacturing French industries, for the period 1977-1997 (for a description see the Appendix).

In spite of the fact that investment decisions are made at the firm level and most of the theory of investment under uncertainty applies to the representative firm, I think it is worth to investigate the behaviour of investment at this intermediate level of disaggregation because, besides being less investigated, uncertainty may affect investment also through the strategic interactions of firms in the same industry, as claimed above. Micro-econometric studies usually imply the selection of a limited number of firms in the market,[1] for which it results possible to collect data (usually these are listed companies or medium and large firms that are subjected to surveys). It seems obvious that this is equivalent to abstracting from the context of competition which they have to face, since only a portion of each market (industry) is represented in this way. Naturally a study of investment using industry data has its limitations as well. It might be criticised on the grounds that firm specific uncertainty, or other idiosyncratic shocks, are smoothed away in the process of aggregation, and the propagation mechanism from the firm to the industry of individual behaviour can be concealed since opposing effects cancel out. However, it can also be argued that if uncertainty is found to have some impact at this level of aggregation, then it surely has an impact also at the level of the firm. And in any case this is a first contribution to investigate the issues of market structure and irreversibility as set out above, to which future work may add validation.

[1] Unless access to datasets such as the Annual Respondent Database (ARD) held at the ONS is available. But this kind of datasets is accessible only on site, therefore requiring considerable more time and money to carry out the research, limiting the number of studies that use them. As far as I know, there are not studies yet on investment under uncertainty that are conducted using such extensive datasets.

The paper is organised as follows. Section 2 reviews the main contributions to the literature on investment under uncertainty (or at least the ones that are relevant for this work), while suggesting the thorough survey by Carruth *et al.* (2000) for a more extensive review.

Section 3 reviews in particular the work that has been done to relate empirically the impact of irreversibility to investment under uncertainty, in order to motivate the subsequent empirical work provided here.

Section 4 draws heavily on Bloom *et al.* (2001) since it recalls the derivation of the theoretical model underpinning the empirical application. It serves to put the issues at stake in a well-defined context, and derives the sign of most of the terms that will appear in the estimating investment equation, rendering explicit what are the testable predictions of interest. It also describes both the short run and the long run dynamics.

Section 5 outlines the empirical modelling, while sections 6 and 7 respectively explain how the market structure and irreversibility were explicitly accounted for in the model of investment. Section 8 defines the measure of uncertainty used in this study. Section 9 reports the empirical results while section 10 concludes and gives suggestions for further research. A data appendix follows, along with some plots of the measures of uncertainty, showing that they have quite a different pattern across sectors and therefore some heterogeneity might be expected across sectors.

2 – The Theory of Investment under Uncertainty: Keeping One's Options Open?

Understanding the impact of uncertainty, risk aversion and imperfect competition on a firm's investment decisions is an important aim of economic research. However the investment literature has not reached a consensus with regard to either the sign or the relative importance of the effects of uncertainty and imperfect competition upon investment behaviour.

Early contributions to this field of work were provided by Hartman (1972) and Abel (1983), 1984, 1985) who showed that an increase in output price uncertainty (which can be defined as a mean-preserving spread in prices) may increase the marginal profitability of capital of a risk-neutral[2] *competitive* firm and hence increase the firm's current investment. Given constant returns to scale in production, this result holds because they assumed that the marginal revenue product of capital is a convex function with respect to the uncertain price. In this way, by Jensen's inequality,[3] greater uncertainty raises the marginal valuation of one additional unit of capital, thereby increasing investment[4]. As Caballero (1991) showed, the Hartman-Abel results hold assuming either asymmetric costs of adjustment (i.e. it is more costly to adjust the capital stock downward than upward) or symmetric costs of adjustment.

Recent theoretical work, however, shows that changing the Hartman-Abel framework attenuates the positive relationship between price uncertainty and investment and it can actually make it negative.

In particular, Pindyck (1988) and Dixit and Pindyck (1994) have emphasised more traditional determinants of investment behaviour, such as the market value of the firm, or expected profits and the cost of capital, but they also formalised the concept of irreversibility of investment for firms that cannot dispose of installed capital. The intuition of irreversible investment is that if there are large sunk costs imbedded in new capital investment, uncertainty implies an option value of waiting, and therefore the firm is more likely to postpone its investment decisions in the face of increased uncertainty until more information becomes available (so called *option pricing theory of investment* or *real options theory*). The conventional wisdom emerging from these studies is that uncertainty will depress investment, either because risk averse firms cannot hedge completely against unfavourable prices, costs or demand

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[2] By contrast Craine (1989) showed that risk aversion and incomplete markets are likely to make the investment-uncertainty relationship negative.

[3] Jensen's inequality means that if x is a random variable and f(x) is a convex function of x, then E[f(x)]>f(E[x]). Thus if the expected value of x remains the same but the variance of x increases, E[f(x)] will increase. Dixit and Pindyck (1994, p. 49) made this example: with uncertainty over interest rates, if the expected value of next year's interest rate remains fixed but the uncertainty around that value increases, the expected present discounted value of a payoff received next year will increase.

[4] An important corollary of this framework is that uncertainty affects investment decisions only through Tobin's marginal *q* (Abel (1983); Abel and Eberly (1994). Caballero and Leahy (1996) however show that this conclusion does not hold in the presence of fixed or linear (as opposed to quadratic) costs of adjustment and departures from perfect competition. In such a general setting Tobin's marginal *q* is no longer a sufficient statistic for investment.

levels [Emerson *et al.* (1992)], or because uncertainty caused by those factors makes it more attractive to wait for further information before investing [Dixit and Pindyck (1994)].

Other contributors who highlighted the negative impact of uncertainty on investment are MacDonald and Siegel (1986), Bernanke (1983), Ferderer (1993), and many empirical studies cited by Carruth *et al.* (2000). However, Caballero (1991), Huizinga (1993) and Dixit and Pindyck (1994) have shown that in certain circumstances uncertainty may still have a positive effect.

In particular Caballero (1991) made clear that, for the irreversibility theory to produce a negative impact of uncertainty on investment, different assumptions from the Hartman-Abel framework are crucial. The latter assumes perfect competition and constant returns to scale, whereas the irreversibility theory assumes either imperfect competition or decreasing returns to scale (or both) if there are no costs of upward adjustment of capital (otherwise the size of the firm would be unbounded). Very importantly, Caballero theoretically showed that investment and *firm-specific uncertainty* are positively correlated even in case of irreversible investment, as long as the firm faces a very elastic demand curve[5] (and returns to scale are non-decreasing)[6]. However, assuming constant returns to scale, the combination of important degrees of imperfect competition and adjustment-costs asymmetry may reverse the positive correlation between uncertainty and investment, because as elasticity of demand falls the convexity of the marginal profitability of capital with respect to price uncertainty is reduced. In fact given imperfect competition, the investment-uncertainty correlation is more likely to be negative as the degree of asymmetry in adjustment costs (i.e. the degree of irreversibility) increases, while

[5] Although Caballero (1991) considered the price elasticity of demand as a discriminant variable in the investment-uncertainty relationship, he related elasticity directly to markup, which he then considered for defining the degree of imperfect competition. Markup in his model can be derived from the elasticity by a simple rearranging formula and considering the first order condition for profit-maximization, so there are no other variables included in markup *in addition* to elasticity of demand, as instead the IO theory postulates. Therefore, it is a measure of market power that Caballero had in mind, not the demand elasticity *per se*. This strengthens the idea that market structure in terms of degree of imperfect competition is a key variable in discerning the effects of uncertainty on investment.

[6] Pindyck (1993) however demonstrates that the value of the option to delay is no longer zero if shocks to the price of capital are *industry-wide*.

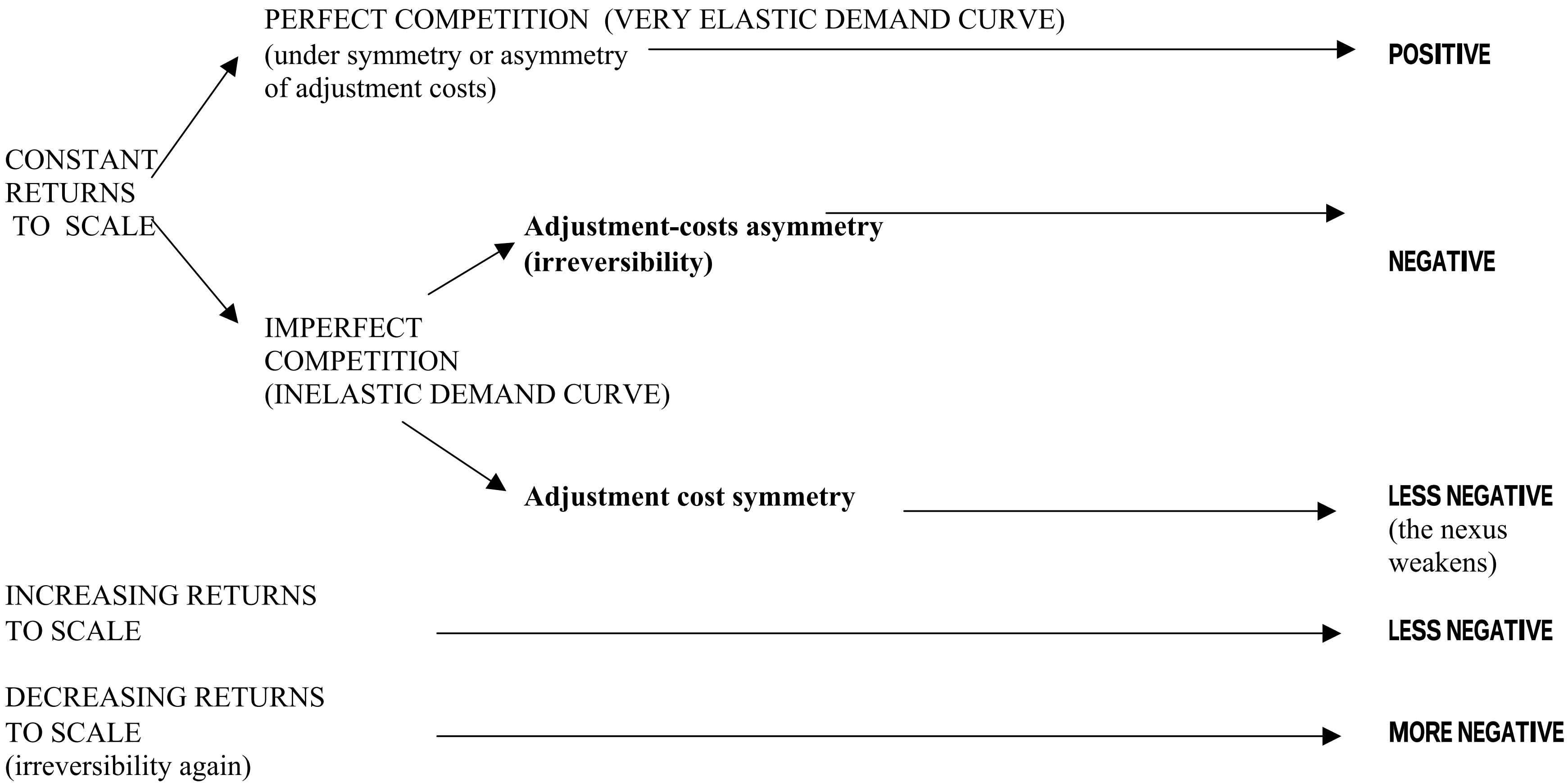
given symmetric costs of adjustment the nexus between investment and uncertainty progressively weakens.

Other important results highlighted by Caballero concern the role of increasing and decreasing returns to scale. He showed that the latter make a negative investment-uncertainty relationship more likely, whilst increasing returns make it less likely. For more clarity, I summarise in Figure 1 Caballero's theoretical findings.

However a different strand of literature found that *aggregation* is a key factor in the investment-uncertainty relationship. In fact, the theoretical contributions mentioned above are all referring to the firm-specific uncertainty and they focus on the consequent impact on firm-level investment. A somewhat less explored field by the theory is what happens when uncertainty is industry-wide and affects the sectoral investment.

Some empirical works explored this issue of aggregation from different perspectives. A recent paper by Henley *et al.* (2003) uses a panel of British listed companies to show how the industry-wide and the firm-specific uncertainty can have opposite impacts on investment. Other papers claimed the importance of aggregation. Bernanke (1983) had argued that aggregate and firm-specific shocks could conflict and cancel, altering the impact of uncertainty on investment behaviour. Bertola and Caballero (1994) found empirical evidence of this claim, while Caballero and Pindyck (1996) showed that the effects of uncertainty were usually stronger (if not clearer) at the disaggregated level. The survey by Carruth *et al.* (2000) compare the available empirical evidence, and shows that the aggregate studies of the investment-uncertainty relationship usually find a significant negative sign, while the overall empirical results obtained from the applied works based on disaggregated data are less conclusive.

Figure 1: Main Theoretical Predictions of the Impact of Firm-Specific Uncertainty on Investment for a Firm Under Risk Neutrality (from early studies)[7]



[7] See Caballero (1991), Hartman (1972) and Abel (1983), 1984, 1985).

Driver and Moreton (1991) found that different types of uncertainty have different types of effect: some short term, some long term, and not all have the same importance. Consequently, aggregation across different types of uncertainty will play a role. Also the source of uncertainty can make a difference. Eberly (1997) found that uncertainty about a firm's market value would depress its investment expenditures, whereas uncertainty about input or adjustment costs would have the opposite effects (unless capital is heterogeneous, in which case these two effects may get reversed).
To reinforce the aggregation argument, the paper by Darby *et al.* (1999) extends the Dixit-Pindyck model and shows how the impact of exchange-rate uncertainty will vary according to the characteristics of the industrial sector. For some industry types uncertainty will depress investment, but for some others it would foster it.[8] So there exists a problem of aggregation across industrial structures. These implications require more empirical studies to disentangle the effects of uncertainty on investment across industries.

Last but not least, all these results are very likely to be sensitive to the *degree of imperfect competition*. It appears that imperfect competition plays a major role in determining the sign of the uncertainty-investment relationship. In fact, some empirical evidence showing that this is the case is available in Ghosal and Loungani (1996), Guiso and Parigi (1999), Böhm*, et al.* (2000), and Henley *et al.* (2003). However, these studies reached opposite conclusions about the direction in which market power affects the uncertainty-investment relationship (but they also modelled different types of uncertainty).
Ghosal and Loungani (1996) use the four-firm seller concentration ratio (CR4) to measure the extent of product market competition in all US industries. They partition accordingly all the industries in sub-samples based on different industry concentration cut-off values of CR4. Estimating fixed-effects OLS panels separately for these sub-samples they find that, for industries that have low levels of seller concentration and thus are likely to be highly competitive, the estimated impact is negative and statistically significant, whilst for industries with high levels of seller concentration, the impact is always small and not significantly different from zero. They justify these results with the possible pre-emption behaviour of oligopolistic firms when deciding about investment expenditure: the timing of investment is viewed as strategic to deter possible entrants into the market or to discourage existing rivals to expand their market share.

[8] Industries are differentiated according to the scrapping price of capital, the entry costs in the market, and the opportunity costs of waiting.

However these findings are in contrast with Guiso and Parigi (1999) Böhm*, et al.* (2000) and Henley *et al.* (2003). Guiso and Parigi (1999) found evidence of a negative impact for all industries, but considerably smaller in absolute value, and less statistically significant, for firms with low market power, whilst the impact for firms with a high degree of market power was about twice as large in absolute terms and highly significant. Böhm *et al.* (2000) found empirical evidence that the impact of uncertainty upon capital accumulation turns out to be negative for firms operating in more concentrated industries. Their argument, along the lines of Caballero (1991), is that irreversibility *per se* is not sufficient to reverse the positive impact of uncertainty on investment ensuing from the convexity of the profit function. Indeed, even under asymmetric adjustment costs (which determine the degree of investment irreversibility) optimal investment by a competitive firm continues to be a non-decreasing function of uncertainty. But through the combination of irreversibility with the assumptions of imperfect competition or decreasing returns to scale (or both), the uncertainty-investment relationship can become negative by making the marginal revenue product of capital a decreasing function of the capital stock[9]. Finally, also Henley *et al.* (2003) divided the sample of firms in their study in a low-concentration group and a high-concentration group according to the five-firm concentration ratio and calculated both firm-specific uncertainty and industry-wide uncertainty. Whilst the firm-specific uncertainty affected investment positively in both groups, the industry-wide uncertainty had a statistical significant impact only in the high-concentration group, with a negative effect on investment.

So we can see that the empirical literature is divided about the effects of market structure on the investment-uncertainty relationship. The results of Ghosal and Loungani (1996) stand out from the remainder and hint at some other motivations not explored in the previous theory of investment under uncertainty: the importance of strategic interactions among firms in the same market.

Real option theory until recently has mainly considered single decision maker problems of firms operating in monopoly or perfect competition markets. But capital budgeting decisions can be strongly influenced by existing as well as potential competitors. The strategic value of an investment decision can be understood by pointing to the main difference between financial options and real options: real options in most cases are not

[9] The assumption that the marginal profitability of capital declines with the capital stock does not apply to a constant-returns perfectly competitive firm for which the marginal profitability of capital is, by construction, unrelated to the level of capital.

exclusive because several firms have the option to invest in the same project. The exercise of a given option by one party implies the termination of corresponding options held by other parties (think of an option to open an outlet in an attractive location).

As Hanley *et al.* (2003) argue, it may well be that an oligopolistic firm, when faced with increased industry-wide uncertainty, may desire to postpone investment, but if it expects its rivals not to do the same, it might change behaviour as a strategic move to protect itself from pre-emptive behaviour.

In this respect, there is a very recent strand of the literature, just in its infancy, which started to merge real options theory with game theory. Nielsen (2002) is one of the first contributors to this innovation.[10] He studies the impact of competition on the optimal investment strategy of the firm. He does so extending the duopoly model of Dixit and Pindyck (1994) for a strategic investment game under irreversibility and uncertainty, to allow for both positive and negative externalities of investment. He finds that the effects of competition are the same no matter the type of externality, but for very different reasons. When there is a negative externality, that is the investment decision of one firm lowers the profitability of other firms, the introduction of competition has two opposing effects: it lowers the expected profit flow from an investment and this tends to delay investment; but is also introduces a strategic benefit to investment, because by investing the firm deters other firms to invest. Nielsen finds an important result: the strategic effect always dominates and competition thus precipitates investment when entry reduces an incumbent's profits. So firms will invest sequentially as the market develops, and the first firm invests earlier than a firm with no competition would have done.

When there is a positive externality, instead, investments are mutually beneficial, and the optimal investment policy is essentially a question of coordination.[11] In equilibrium both firms invest early and simultaneously in anticipation that the other firm will invest early as

[10] The first to have had the intuition of relating irreversibility, uncertainty and competition was Smets (1991). In a real option context he considers an international duopoly where both firms can increase their revenue stream by investing. Two equilibria arise: a pre-emption equilibrium, where one of the firms invest early, and simultaneous equilibrium, where both firms delay investment. Dixit and Pindyck (1994, Lambrecht and Perraudin (1991) study the case of complete pre-emption and uncertainty regarding the investment costs of the other firm. Grenadier (1996) offers an alternative explanation for simultaneous investments: two firms rush to invest in the face of a downturn for the fear that the recession will leave space for only one of them. This explains the 'recession induced construction booms'. A survey of the early contributions that deal with the effects of strategic interactions on the option value of waiting associated to investment under uncertainty is provided by Grenadier (2000).

[11] Examples of markets that are more profitable when more than one firm has invested are the hardware and software markets (due to the complementarities of such commodities), or network markets.

well. This is for example typical of the rapid and sudden developments we have witnessed in the internet economy.
Another contribution to the new theory of strategic real options is given by Huisman *et al.* (2003), who established to what extent investments are delayed when technological progress is anticipated: depending on the probability of arrival of a new technology, pre-emption equilibrium, sequential equilibrium with different technologies or simultaneous equilibrium with both firms adopting the same technology can arise. They also show thatDixit and Pindyck (1994, Smets (1991) and Dixit and Pindyck (1994, Smets (1991) conclude wrongly when they say that, in case it is only optimal for one firm to invest, joint investment never occurs.

Hence, if interactions among firms are indeed considered, and the firm is not taken to be an isolated entity, the irreversibility argument and the strategic considerations may act in opposite directions. This results in an ambiguous net effect, as highlighted by Henley *et al.* (2003). It is clear that more empirical evidence is needed to solve these conflicting results. And this is the main motivation for this analysis.

In conclusion, the overall impact of uncertainty on investment depends on the relative strength of several critical factors like the industrial structure (i.e. the number of firms and the degree of competition), the level of aggregation, the type of returns to scale, the degree of risk aversion and of course the source of uncertainty itself. As a consequence, there can be no systematic results for all industries, or for all market conditions. Instead, the sign of the uncertainty-investment relationship remains ambiguous and we should expect uncertainty to have a negative impact in some cases, and a positive one in others. It is probably a matter of empirics to resolve this ambiguity.

3 – Irreversibility and the Investment-Uncertainty Relationship

The pioneering work by Dixit and Pindyck (1994) made clear that the standard Net Present Value (NPV) rule for investment was superseded in the face of irreversibility and uncertainty, therefore the ensuing option value of delay gave rise to the real options theory.

However the empirical implications of the option-based models of irreversible investment under uncertainty are not straightforward because such models do not describe the level of investment *per se*, but simply the factors that may affect the threshold at which investment should occur. In particular, an increase in the volatility of the stochastic process that determines the returns from investment will raise the trigger point of investment. Hence the irreversible investment literature deals with the *timing* of investment rather than the *level* of investment.

This has been clearly stated by Carruth *et al.* (2000, p. 126):

"The problem for the applied econometrician is the empirical implementation of the irreversibility concept and its implications. The problem is an acute one because the irreversibility effect makes the dynamic structure of investment behaviour dependent on the degree of volatility in returns. Moreover, under irreversibility and uncertainty, the underlying model describing optimal investment is non-linear. Furthermore, as Dixit and Pindyck (1994, p. 421) argue, since option-based models focus on the threshold at which investment should occur rather than on the long-run average rate of investment, then the models themselves cannot be directly tested by investigating simple equilibrium relationships between rates of investment and measures of risk or uncertainty. Any test will be a joint test of the option-based approach together with the underlying assumed specification for the capital accumulation process. In practice many studies appear to gloss over this point, preferring to investigate simple correlations of rates of investment with proxies of uncertainty – a strategy which is highly questionable since any observed significant relationship may be an artefact of underlying model misspecification."

The existence of threshold effects in the investment process may cause investment hysteresis because for some time the rates of investment remain persistently sluggish as firms exercise the option to wait [Dixit (1989) and Dixit (1992)]. And this phenomenon of hysteresis can be observed also for aggregate investment if individual firm uncertainty can in turn generate a self-fulfilling degree of aggregate uncertainty.[12] Bernanke (1983) claims, in fact, that microeconomic irreversibilities in the presence of idiosyncratic uncertainty are also relevant to aggregate investment dynamics. However in the process of aggregation of firms' investment, serially correlated errors result in the investment function.[13] Bertola and Caballero (1994) conduct an extensive investigation of the properties of aggregate investment in the face of microeconomic irreversibility and find that the introduction of

[12] As argued by Carruth et al. (2000, p. 127) if idiosyncratic factors are more important in affecting the timing of investment then, if anything, any observed empirical relationship should be stronger at the firm level than that detected in the aggregate analysis.

[13] Many previous empirical studies had rationalised this finding by assuming *ad hoc* adjustment costs.

binding irreversibility constraints can generate inertial or hysteresis effects and this is consistent with the observed serial correlation in actual aggregate data.

Also, very interestingly, Bertola and Caballero (1994) construct the hypothetical desired aggregate investment-capital stock ratio for the US during the period 1954-1986 under the assumption of frictionless or reversible investment and compare this to the observed investment ratio. They show that the calculated reversible rate of investment displays much greater cyclical volatility than does the actual series. And the actual series is affected by much greater first order serial correlation than the frictionless series. Thus, they conclude that the smooth and persistent nature observed for US aggregate investment can be due to the irreversibility constraints affecting firms' investment decisions. Indeed, to explain the smoothness and persistence of observed investment without irreversibilities would require unrealistically high levels of volatility in firms' *desired* levels of capital stock.

Therefore it appears of crucial importance to find a way of modelling also the impact of irreversibility on investment.

Some attempts have been made in the literature, namely by: *i)* modelling the non-linearities, introduced in the investment function by irreversibility, with non-quadratic adjustment costs; and *ii)* investigating the existence of thresholds effects.

The first approach has been followed by Abel and Eberly (1994) who generalise a q-model of investment under uncertainty allowing adjustment costs that are fixed, liner or convex but not quadratic as the traditional models used.[14] They find that the relationship between investment and q is non-linear. Subsequently Eberly (1997) investigate the model misspecification of linear investment functions for 11 OECD countries using data for publicly traded companies. She estimates and compares the results of both linear and non-linear investment functions, where the latter allow fixed, linear and convex adjustment costs. She finds a significant role for non-linearities in adjustment costs for all but two countries (Netherlands and Spain) and the predictive power of non-linear models is superior to that of linear ones. Also Price (1996) followed this line by introducing non-linear dynamic adjustment into a function of aggregate UK investment. He tested whether during times of greater uncertainty the speed at which firms adjust to their desired steady-state level of investment will be slower, and may depend on whether the degree of uncertainty is above or below some threshold. His results are however unsatisfactory since he found an

[14] Quadratic adjustment costs generate a linear relationship between investment and marginal q.

implausible huge negative impact of uncertainty on investment in the long run (60% compared to the certainty case) and a statistically significant but quantitative small impact of uncertainty on the speed of investment adjustment.

The second approach has been followed by Pindyck and Solimano (1993), who calculate a measure of the marginal profitability of capital and use the volatility of this series as a proxy for uncertainty, while its extreme values are taken as an indicator of the threshold at which investment is triggered. The study is carried out for 29 countries (both OECD and LDCs) and what they find is that the volatility of the marginal profitability of capital significantly depresses investment for the less developed countries, but the impact of volatility is insignificant for the OECD countries. Also, they find that an increase of 0.05 in the standard deviation of the marginal profitability of capital is associated with a 5-15% increase in the investment threshold. As the authors themselves point out, the magnitude of this effect is 'qualitatively important (but not overwhelming)' (p. 281). Hubbard (1994) notes however that the proxies for the threshold used by Pindyck and Solimano (i.e. the extreme values of the marginal profitability of capital) will be correlated with the variance even if there is no causal relationship between investment and uncertainty. So this methodology is questionable.

Caballero and Pindyck (1996) apply the same methodology as Pindyck and Solimano (1993) to both 2-digit and 4-digit US industrial data. Their findings however are only weakly supportive of the predictions of the theory because, although they show that increased volatility in the returns to investment leads to higher required rate of return, the size of this effect is very small and not well determined.

Moreover, one drawback with this second approach in general is the need to impose a lot of model structure (like Cobb-Douglas production function, constant returns technology, perfect competition, etc.), which cannot be directly or separately tested.

All in all, while theory used strong arguments in convincing us that irreversibility is potentially important for investment behaviour, the empirical evidence is not compelling. And as pointed out by Carruth *et al.* (2000), all this work on irreversibility does not represent a direct test of the impact of increased uncertainty on investment, if that investment is irreversible. At most it has established that *q*-models of investment are not a good specification when irreversibilities are present, and that a full model of investment threshold behaviour is likely to be very complex in structure and consequently empirically intractable.

More empirical work is needed to evaluate in a more straightforward manner the role played by irreversibility. I will present in section 7 a simple empirical approach that attempts to do that.

I now introduce the theoretical model that underpins the empirical work presented in the subsequent sections.

4 –Theoretical Background and Model Specification

The empirical modelling is based on Bloom *et al.* (2001) who use micro firm-level data to build an accelerator model of investment under uncertainty and partial irreversibility in error-correction form.[15] However, as the authors claim, the empirical procedure that they develop can also be applied to other aggregated data sets at the industry or macro level.[16]

By using an error correction model is possible to distinguish between the role played by uncertainty on the *short-run* response of investment to changes in market conditions, and the role of uncertainty on the level of capital stock in the *longer term*. The impact might not be the same along the time horizon of investment.

I rule out the possibility of modelling investment using a standard investment Euler equation because it does not permit the type of kinked adjustment costs typical of partial irreversibility, hence assuming away any role for real options. In the same way, Tobin's q model of investment is not an option here, and the reason is twofold: from a theoretical point of view it assumes perfect competition and constant returns, therefore it eliminates any role for real options from the outset; and from an empirical point of view it would be unfeasible to collect meaningful data for the construction of q (like data on the replacement

[15] An Error Correction Model (ECM) for investment was used for the first time by Bean (1981) for UK aggregate data. Driver and Moreton (1992) used the ECM and a flexible accelerator for a study of investment under uncertainty at the industry level. Complete irreversibility means that the capital stock cannot be adjusted downwards. Partial irreversibility means that it possible to adjust the capital stock downwards but with an economic loss.

[16] Bloom *et al.* (2001), p. 7.

cost of capital) at the industry level. Instead I adopt a flexible accelerator model of investment, which outperforms most other investment models as shown by Clark (1979).[17]

Investment decisions are assumed to be partially irreversible and market conditions uncertain (as captured by the product price uncertainty).[18] This generates real options on the investment decision and the identification of two separate thresholds for investment and disinvestment, with no investment undertaken in between the thresholds.[19] The investment thresholds can be represented by a standard Jorgensonian user cost of capital for buying and selling capital, *b* and *s* respectively[20], an investment real options term $\phi_I > 1$, and a disinvestment real options term $\phi_D > 1$. Investment only happens when the marginal revenue product of capital hits the upper threshold and disinvestment only occurs when it hits the lower threshold. The thresholds are functions of the degree of uncertainty, irreversibility and also the current state of demand. Even low levels of uncertainty and irreversibility can lead these thresholds to be quite spaced apart compared to their position under complete certainty and costless reversibility. The existence of these thresholds leads to an optimal investment behaviour of firms that is lumpy and frequently zero, instead of being smooth and continuous. [21]

Higher levels of uncertainty increase the real option values associated with investment and disinvestments, making firms more prone to a wait-and-see behaviour when faced with market environment changes (that is, they become more cautious).[22]

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[17] The flexible accelerator model was introduced by the pioneering work of Chenery (1952) and Koyck (1954).

[18] Partial irreversibility makes the adjustment costs weakly convex and kinked at zero investment.

[19] Models that predict threshold investment behaviour are found, for example, in Pindyck (1988) for fully irreversible continuous investment, Dixit (1989) for partially irreversible investment, Bertola and Caballero (1994) for investment with stochastic demand and capital prices, and Dixit and Pindyck (1994) for a general survey of the literature.

[20] Even under certainty the user cost for buying capital will be above the user cost for selling capital in a partial irreversibility framework where the sale price of capital is assumed to be below the purchase price.

[21] The lumpiness of investment with frequent zeros has been particularly observed for smaller plants, using the US Longitudinal Research Database (LRD) and the UK Annual Respondents' Database (ARD). See for example Doms and Dunne (1998), and Attanasio *et al.* (2000).

[22] In a comparative static framework, Abel and Eberly (1996) build a model where a higher level of uncertainty widens the gap between the investment and disinvestment thresholds. Bloom et al. (2001) extend this result to a plant with multiple capital inputs. These studies (and also this work) therefore consider the effects of a change in the distribution of demand shocks in the current period, holding constant the distribution of demand shocks in all future periods. Obviously, however, to identify the effects of uncertainty on investment empirically we need to construct measures of uncertainty that vary over time for the same industry.

Also, the presence of (partial) irreversibility and uncertainty can give rise to non-linearity in the investment dynamics, strengthening the marginal investment response to larger demand shocks.

Aggregation across multiple investment decisions and different firms leads however to the loss of such a lumpiness in the total investment due to the imperfect correlation of idiosyncratic shocks and to heterogeneous technologies employed by firms (firms often operate multiple production lines and plants, each employing many types of capital goods). Nevertheless, a strand of the literature on macro investment and consumption has shown that aggregation does not dampen the effects of lumpy micro-level behaviour [see Caballero (1993), and Eberly (1994) on aggregation across consumer durables, and Bertola and Caballero (1994), Caballero and Engel (1999), Cooper *et al.* (1999), and Attanasio *et al.* (2000) on aggregation across plant-level investment].
This is good news for a study of industry-level investment, as we would expect that the effects of uncertainty and irreversibility on micro-level investment be transmitted to some extent to the macro-level investment.

Before specifying the empirical model to be estimated, I recall some theoretical foundations about the testable predictions that will ideally be verified by the data. As postulated by Bloom *et al.* (2001) for firm-level investment, here I adapt the same concepts definition to the industry-level investment.
First, let us define *F(x)* to be the cumulative density of capital within each industry that would respond to a positive demand shock of size $x \geq 0$.[23] This means that F(0)=0 because all capital will be either on or below the investment demand threshold and so will not respond to a size zero demand shock. In contrast, $F(\overline{\Delta p}) = 1$ implies that all capital will start accumulating (causing a positive investment) after a probably large demand shock of size $\overline{\Delta p}$.

Second, let us define $d \log K(x, \Delta p) = i(x, \Delta p)$ as the positive investment function for capital *at each point x* of the cumulative density *F(x)* in response to a positive demand shock of size $\Delta p \geq 0$, as follows:

[23] Equivalently, this can be defined as the proportion of all capital within an industry which would respond to a positive demand shock of size *x*.

$$i(x, \Delta p) > 0 \text{ if } \Delta p > x$$
$$i(x, \Delta p) = 0 \text{ if } \Delta p \leq x$$

In other words, $i(x, \Delta p)$ is the change in the logarithm of the capital stock for capital that would just start to invest in response to a shock of size *x*, if it actually faces a shock of size Δp. The right hand side conditions follow from the definition of *x* as the smallest demand shock required for capital to hit the investment threshold.

This investment function is increasing in the size of the demand shock so that $\frac{\partial i(x, \Delta p)}{\partial \Delta p} \geq 0$. If the investment function is also convex (increasing at an increasing rate) then the following derivative should be true: $\frac{\partial^2 i(x, \Delta p)}{(\partial \Delta p)^2} \geq 0$.

This convexity could stem from the assumption of supermodularity of capital in production, as justified by Bloom *et al.* (2001), whereby the employment of different capital inputs makes the marginal product of any individual line of capital increasing in the level of other lines of capital. [24]

Combining these two definitions, and using the approximation $d \log K = \frac{I}{K}$ where *I* is total industry investment and *K* is the total industry capital stock, the industry investment rate given a demand shock of size Δp is

$$\frac{I}{K} = \int_0^{\Delta p} i(x, \Delta p) dF(x) \qquad (1)$$

This is an investment function that has no closed form analytical solution, unless additional restrictions on the production function and the stochastic demand and productivity processes are imposed. However, for a fairly general class of investment problems[25] it is possible to derive the testable predictions about the industry-level investment dynamics from a second-order Taylor expansion of investment around uncertainty and the demand shock.

In the next two sub-sections I present the short run and long run dynamics of investment, from which we deduct the empirical implications.

[24] Dixit (1997) made the same assumption.

[25] See Bloom *et al.* (2001) for more details on which class of investment problems.

4.1 – Short Run Dynamics

Let us derive the short run response of industry-level investment to demand shocks and changes in the level of uncertainty. This is necessary in order to characterise the sign of such responses. Applying a Taylor expansion to investment, as defined in equation (1), around the industry-level demand shocks and uncertainty gives:

$$\partial \frac{I}{K} / \partial \Delta p = \int_0^{\Delta p} \frac{\partial i(x, \Delta p)}{\partial \Delta p} dF(x) \geq 0 \qquad (2)$$

That is, the first derivative of positive investment with respect to a demand shock is positive because of the impact on that capital already at the investment margin.

The second derivative of positive investment with respect to a demand shock is also positive

$$\partial^2 \frac{I}{K} / (\partial \Delta p)^2 = \int_0^{\Delta p} \frac{\partial^2 i(x, \Delta p)}{(\partial \Delta p)^2} dF(x) + \frac{\partial i(x, \Delta p)}{\partial \Delta p} |_{x=\Delta p} \, dF(\Delta p) \geq 0 \qquad (3)$$

because the first term is non-negative by the assumed supermodularity of different lines of capital in production, and the second term is non-negative by the non-decreasing nature of cumulative distribution functions.

What is instead the impact on investment of a temporary increase in uncertainty?

The first derivative of positive investment with respect to uncertainty is negative. The reason lies in the real option theory of investment: higher uncertainty raises the real option value associated with investment, hence makes the waiting more valuable and the investment threshold increases.[26] This is the caution effect.

This translates in a new investment function, $i'(x, \Delta p)$, defined according to the old distribution of capital *F(x)*, which with higher uncertainty is however less than the old investment function, resulting in $i'(x, \Delta p) \leq i(x, \Delta p)$.

The first derivative of positive investment with respect to uncertainty is therefore[27]

[26] See Bloom *et al.* (2001) for a more formal explanation, where demand uncertainty is defined in terms of second order stochastic dominance.

[27] The reason for *dσ→0* is because the increase in uncertainty is only temporary, so that only the effects of a change in the distribution of demand shocks in the current period are considered, while holding constant the distribution of demand shocks in all future periods.

$$\partial \frac{I}{K} / \partial \sigma = \lim_{d\sigma \to 0} \int_0^{\Delta p} \frac{i'(x,\Delta p) - i(x,\Delta p)}{d\sigma} dF(x) \le 0 \qquad (4)$$

Lastly, we need to consider the cross-product term in the Taylor expansion. It is possible to state that the cross effect of a positive demand shock and a temporary increase in uncertainty on positive investment is negative. The reason being that higher levels of uncertainty raise the investment threshold causing less lines of capital investing. But because of the supermodularity of capital in production, the investment response is reduced for all lines of capital that are investing, so that $\partial i'(x,\Delta p)/\partial \Delta p \le \partial i(x,\Delta p)/\partial \Delta p$. This relationship combined with equation (4) gives

$$\partial^2 \frac{I}{K} / \partial \sigma \partial \Delta p = \lim_{d\sigma \to 0} \int_0^{\Delta p} \frac{\partial i'(x,\Delta p)/\partial \Delta p - \partial i(x,\Delta p)/\partial \Delta p}{d\sigma} dF(x) \le 0 \qquad (5)$$

At this point of the analysis it would be possible to repeat the same derivations done for positive investment also for disinvestment. However this additional exercise does not provide much help for the empirical application because I do not have data on disinvestment, and investment is measured as gross fixed capital accumulation, i.e. it does not subtract the sales of capital goods. Therefore the following analysis will consider only the testable predictions considered so far for positive investment. It is enough to say, though, that had we derived the impact on disinvestment of a change in demand shocks or/and a change in temporary uncertainty, the signs of the derivatives would have been as shown in Table 1.[28]

Table 1 – The Short Run Sign of Demand Shock (Δp) and Uncertainty (σ) on Investment

Taylor expansion terms	Δp	Δp^2	σ Δp	σ
	$\partial \frac{I}{K} / \partial \Delta p$	$\partial^2 \frac{I}{K} / \partial \Delta p^2$	$\partial^2 \frac{I}{K} / \partial \sigma \partial \Delta p$	$\partial \frac{I}{K} / \partial \sigma$
Positive Investment	+	+	−	−
Disinvestment	+	−	−	+

[28] See Bloom *et al.* (2001), p. 16.

From Table 1 we can see that the second and fourth columns predict opposite signs on the level of total investment, whereas the first and the third column have unambiguous predictions: a positive demand shock (first column) should result in more investment (or less disinvestment), and a higher level of uncertainty (third column) should make the investment (or disinvestment) less responsive to a given demand shock.
Although from Table 1 the signs of accelerating demand (second column) and the level of uncertainty (fourth column) on investment dynamics should be ambiguous, I expect a positive and negative sign respectively, given the data I use in the estimation. I therefore proceed to test the predictions about positive investment only.

4.2 – Long Run Impact

In order to validate empirically the theoretical predictions about the short-run investment dynamics, the longer run effects on capital stock must be taken into account. Bloom (2000) derives a useful result in this context. He shows that the long run growth rates of the actual capital stock, K_t, and its hypothetical level under costless reversibility, K^*_t, will be equal, so that their levels are cointegrated. In this way it is possible to substitute in the model the long run behaviour of the actual capital stock under partial irreversibility with the much simpler hypothetical value of capital stock under complete reversibility, plus a stationary deviation:

$$\log K_t = \log K_t^* + e_t \qquad (6)$$

where e_t is a stationary and autocorrelated error term, which is bounded by the distance between the disinvestment and investment thresholds. It is not necessarily a mean zero error term, so the actual capital stock and its hypothetical reversible level may not be equal on average.

It is also possible that there exists a long run relationship between uncertainty and the level of capital stock. Abel and Eberly (1994), and Caballero (1999), among others, show that the impact of higher uncertainty on the average capital stock level in the long run is theoretically ambiguous in models with partial irreversibility, because higher uncertainty postpones downward as well as upward adjustments.

$$\frac{I_t}{K_{t-1}}$$

In addition, two other factors contribute to make the investment-uncertainty relation ambiguous: capital expandability and investment lags. Abel *et al.* (1996) show that even when capital is partially irreversible uncertainty on future marginal returns to capital has an ambiguous effect on current investment if it is costly to expand the capital stock, in the sense that the future purchasing price of capital might exceed its current value. Under such circumstances, increased uncertainty has two opposite effects: is raises the option value of postponing investment due to limited reversibility but increases the option value of anticipating investment due to limited expandability. The net effect is ambiguous and depends on the impact of increased uncertainty on the relative value of the two options. Bar-Ilan and Strange (1996) analyse the influence of investment lags that can make the effect of uncertainty ambiguous even in models with irreversible investment. With uncertain demand and long time to build or construction lags, firms have more incentive to accumulate capital to avoid facing a high demand with a too low stock of capital. The chances of this occurring increase with uncertainty, raising the incentive to invest, which counteracts the incentive to delay investment arising from irreversibility.

It is therefore important to use an econometric approach that allows estimating both the short run and the long run effects of uncertainty on investment dynamics.

5 – Empirical Specification

The empirical specification consists of an error correction model, which conveniently distinguishes between parameters describing the short run investment dynamics from those describing the long run evolution of capital stock.

The error-correction specification of the investment equation allows a dynamic accelerator model, where the lagged error correction term reflects the deviation of the capital/output ratio from its long run level.

The basic ECM has the following form

$$\frac{I_t}{K_{t-1}} \approx \Delta \log K_t = \alpha_0 + \alpha_1(L)\Delta \log K_{t-1} + \alpha_2(L)\Delta \log K_t^* + \alpha_3(\log K_{t-s}^* - \log K_{t-s)} + v_t \qquad (7)$$

where $\alpha_1(L)$ and $\alpha_2(L)$ are polynomials in the lag operator (L). This is consistent with an autoregressive moving average approximation to the stationary error term in (6).

The specification for industry *i*'s hypothetical capital stock under *complete reversibility* has this simple log linear form:

$$\log K_{it}^* = \log Y_{it} + \gamma_1 \sigma_{it} + \gamma_2 CU_t + A_i + B_t \qquad (8)$$

where Y_{it} is industry *i*'s real sales in period *t*, σ_{it} is a measure of uncertainty, CU_t is the aggregate capacity utilisation, A_i is an unobserved industry-specific effect and B_t is a time-specific effect, common to all industries.

The uncertainty term captures a possible long-run effect of uncertainty on the industry capital-sales ratio.

I follow Ghosal and Loungani (1996) in including the aggregate capacity utilisation to proxy for the investment opportunities available to the industry. Some studies [e.g. Driver and Moreton (1992)] used capacity utilisation as an additional accelerator model, with the short-term effect modified by the degree of capacity pressure. The latter variable has tended in some periods to be highly correlated with profitability [Panic and Vernon (1975)].[29]

Time effects B_t control for variation in costs of capital, as long as these are common to all industries. Industry effects A_i allow for example for variation across industries in the elasticity of demand, or some industry variation in relative prices.

Combining equations (7) and (8) gives a linear error correction model relating current investment rate to current and lagged changes in sales, uncertainty, capacity utilisation and a lagged error correction term.

Following Bloom *et al.* (2001) I add an additional interaction term between uncertainty and sales growth to the investment equation to test the theoretical prediction about the 'caution effect' of uncertainty (inactivity between the thresholds of investment and disinvestment) and its role in generating time and industry varying investment parameters.[30] In addition, a quadratic term in sales growth is included to test for the presence of non-linearity in the response of investment to demand shocks.[31] In this way we can test for heterogeneous and

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[29] Driver and Moreton (1992) include industry-specific capacity utilisation in a flexible accelerator model using survey data. I also calculated industry-specific measures of output gap using the Hodrick-Prescott filter on output series, but they performed worse than the aggregate capacity utilisation, therefore the results are not reported.

[30] Notice that it is assumed that the growth in real industry sales proxies for industry-level demand shocks.

[31] In order to be confident that the investment model is capturing the effects claimed above, Bloom *et al.* (2001) generate artificial data simulating a partial irreversibility model (where both capital and labour are

non-linear investment dynamics against the null hypothesis of a common, linear error correction specification, as discussed in section 4.1.

Using a general-to-specific modelling strategy whereby insignificant terms are excluded, leads to the following basic specification:

$$\frac{I_{it}}{K_{i,t-1}} = \beta_1 \Delta y_{it} + \beta_2 (\Delta y_{it})^2 + \beta_3 (\sigma_{it} \Delta y_{it}) + \beta_4 \Delta \sigma_{it} + \beta_5 \Delta CU_t + \beta_6 (y-k)_{i,t-1} +$$
$$+ \beta_7 \sigma_{i,t-1} + \beta_8 CU_{t-1} + a_i + b_t + u_{it} \qquad (9)$$

where $k_{it} = \log K_{it}$ and $y_{it} = \log Y_{it}$. The first four terms correspond to the effects on short run investment dynamics analysed in section 4.1 Recall that for positive investment the theoretical predictions are that $\beta_1>0$, $\beta_2>0$, $\beta_3<0$ and $\beta_4<0$. Moreover it is required that $\beta_6>0$ for the estimated model to be consistent with 'error correcting' behaviour (i.e. a capital stock below its desired level is associated with higher future investment). The long run effect of uncertainty on the level of the capital-sales ratio (β_7) is instead theoretically ambiguous. B_5 and β_8 are expected to be positive, since the higher the pressure on capacity level, the higher the need to accumulate new capital in order to expand that capacity.

6 – Market Structure and the Investment-Uncertainty Relationship

Equation (9) represents our basic model of investment under uncertainty. However I set out this work with the aim of taking into account also the market structure of the industry. This section therefore extends the basic specification by augmenting it with the inclusion of two variables that should capture the degree of competitiveness of an industry.

In order to do that, I consider as my 'strategic' variable the Herfindahl-Hirschman Index (HHI) of concentration. The HHI is a better measure than the four-firm seller concentration ratio (CR4) used for example by Ghosal and Loungani (1996) because it accounts for *all* firms in the industry, not only the four biggest firms, and in addition HHI meets all the criteria suggested by Hannah and Kay (1977) in order to establish whether a concentration

partially irreversible) to test the correctness of their hypothesis about the inclusion of quadratic and interaction terms. The simulated data turn out to detect the correct signs on these additional variables. Thus their estimation strategy, which is here adopted, seems consistent with their theoretical predictions. Moreover the simulated data they generate have the power to detect the short run dynamics implied by the theoretical model.

index is a good measure of the degree of monopoly power. Concentration ratios are one of the most common tools used to examine an industry's structure and, consequently, the ability of a group of companies to exercise some control over a market. HHI is calculated by summing the squares of the market shares of all firms in the industry. The higher the Herfindahl Index, the higher the potential for the exercise of market power.[32]

The first variable I include is the interaction term between the change in Herfindahl index and the level of current uncertainty. This should capture how the impact of current uncertainty on investment changes as the market structure changes over time. If the coefficient were positive and statistically significant, the marginal effect of uncertainty on investment would be positive, meaning that as the industry becomes more concentrated the investment-uncertainty relationship becomes weaker (assuming a negative impact of uncertainty on its own). Therefore this interaction term is meant to capture the impact of a change in the market structure *within* the industry on the investment-uncertainty relationship.

In this way we generate also another source of heterogeneity in the investment dynamics in addition to the one derived from the interaction of current uncertainty with sales growth, as discussed in section 4.1.

However, beyond the change over time in the concentration index within industries, each individual industry may be characterised by a different level of concentration on average. That is, the Herfindahl index may be different *between* industries. To capture this effect I include another interaction term composed by the change in uncertainty and a dummy variable called 'concentrated', which, not surprisingly, has a value of 1 if the industry is concentrated. In order to classify industries in classes of concentration I looked at the distribution of the HHI across industries calculating the 25th percentile, the median and the

[32] In the case of monopoly, HHI achieves its highest possible value of 100^2 = 10,000 (the market share of a monopoly is 100 percent). If 1000 firms each held 0.1 percent of the market, HHI = 1000x 0.01 = 10, and the industry would be considered extremely competitive. The HHI takes into account the relative size and distribution of the firms in a market and approaches zero when a market consists of a large number of firms of relatively equal size. The HHI increases both as the number of firms in the market decreases and as the disparity in size between those firms increases. The US Antitrust Authority for example considers an industry with Herfindahl Index below 1000 not to be a concentrated market. Industries with a Herfindahl Index between 1000 and 1800 are considered to have some degree of concentration. And finally if the Herfindahl Index is greater than 1800 the degree of monopoly power potentially exercised by the dominant companies is typically judged to be significant. Notice that in alternative the market shares can be expressed as decimal points, in this way the HHI would result to be divided by 10,000, so its maximum value would be 1. The data I have collected are expressed in this way.

75th percentile. Then I defined an industry as concentrated if the average value of the HHI was lying at or above the 75th percentile (or the top 25th percentile).[33]

The resulting augmented version of the model of investment under uncertainty with market structure variables is as follows:

$$\frac{I_{it}}{K_{i,t-1}} = \beta_1 \Delta y_{it} + \beta_2 (\Delta y_{it})^2 + \beta_3 (\sigma_{it} \Delta y_{it}) + \beta_4 \Delta \sigma_{it} + \beta_5 \Delta CU_t + \beta_6 (y-k)_{i,t-1} + \\ + \beta_7 \sigma_{i,t-1} + \beta_8 CU_{t-1} + \beta_9 \sigma_{it} \Delta HHI_{it} + \beta_{10} \Delta \sigma_{it} D_i^{CONC} + a_i + b_t + u_{it} \qquad (10)$$

where ΔHHI_{it} is the change in the Hirschman-Herfindahl index, and D_i^{CONC} is the dummy concentrated for each industry. What the coefficient β_{10} captures is the marginal effect of a change in uncertainty on investment for the more concentrated industries. So, for the industries that are concentrated the impact on investment stemming from a change in uncertainty will be, *ceteris paribus*, given by $\beta_4+\beta_{10}$.

Obviously the same analysis done for concentrated industries can be repeated for the more competitive industries, in order to check whether the impact of uncertainty alters significantly their investment behaviour compared to the estimated average parameters for all industries.
Equation (10) can be therefore re-written substituting the dummy 'concentrated' with the dummy 'competitive' which takes the value of 1 if the average HHI for the industry is below the bottom 25th percentile of the distribution of HHI over all industries:

$$\frac{I_{it}}{K_{i,t-1}} = \beta_1 \Delta y_{it} + \beta_2 (\Delta y_{it})^2 + \beta_3 (\sigma_{it} \Delta y_{it}) + \beta_4 \Delta \sigma_{it} + \beta_5 \Delta CU_t + \beta_6 (y-k)_{i,t-1} + \\ + \beta_7 \sigma_{i,t-1} + \beta_8 CU_{t-1} + \beta_9 \sigma_{it} \Delta HHI_{it} + \beta_{11} \Delta \sigma_{it} D_i^{COMP} + a_i + b_t + u_{it} \qquad (11)$$

Again, the marginal effect of a change in uncertainty on investment of the more competitive industries is given by the coefficient β_{11}, so the total impact of a change in uncertainty on the investment of such industries will be $\beta_4+\beta_{11}$.

[33] The reason why I did not follow the same guidelines as the Antitrust Authority as in footnote 32 is because the level of aggregation of my data is such that the industries result to be too competitive, and only two of them would meet the criteria of being above the 1800 threshold to be considered concentrated.

7 – Irreversibility and the Investment-Uncertainty Empirical Relationship

This section introduces a novelty in the vast literature of investment under uncertainty: the attempt to make explicit the impact of irreversibility on investment under uncertainty. This is a key issue, as I reviewed in section 3. As I stated there, it appears of crucial importance to find a way of modelling also the impact of irreversibility on investment given the unsatisfactory empirical evidence in the extant literature. But at the same time we need to avoid imposing too much structure on the modelling as was done in some previous studies because the empirics otherwise becomes intractable.

For this reason we need something simpler which can be tested empirically. I therefore introduce yet another variant to equation (9) to take into account of irreversibility. This is done by considering the composition of investment and it is of immediate intuition.

As Pindyck (1991) pointed out, the characteristics that makes an investment expenditure a sunk cost, and therefore irreversible, is the fact that the capital is firm or industry specific. If that is the case, it cannot be used productively by a different firm or in a different industry. The literature has stressed how different types of capital goods are affected by different degrees of irreversibility.

For example Guiso and Parigi (1999) claim that capital is likely to be a set of items differing in degree of specificity, liquidity, adjustment costs, and degree of substitutability with other production factors. Therefore treating total investment as a homogeneous good has little explanatory power, since it may be concealing the presence of firms hitting an irreversibility constraint that is binding for some types of investment but not for others. Using a sample of Italian firms Guiso and Parigi (1999) estimate investment equations under uncertainty for three different type of investment: structures, machinery and equipment, and vehicles, and separate the sample in two subgroups of firms with high or low irreversibility indicator. The irreversibility indicator is calculated in two alternative ways: the first is based on survey data about the firms' access to secondary market for their capital equipment. If there exists a secondary market for installed capital, its liquidation is easier when demand proves to be lower, and hence investment is considered less irreversible.[34] The second, and preferred, measure they use is the "comovement", that is the degree of cyclical correlation of the firms within an industry. The more correlated is a firm to its industry the more illiquid the firm's capital is likely to be. Industries instead where

[34] Obviously this is a proxy, which could not represent well irreversibility in cases where equipment is very specific to certain types of production and all firms producing similar goods are badly affected by the drop in demand. In fact the second measure of irreversibility they propose obviates to this problem.

there is a prevalence of idiosyncratic shocks (low comovement) will be characterised by a low degree of irreversibility. Guiso and Parigi (1999) find that the coefficient of uncertainty is negative as in the regression using all types of investment aggregated, but much larger in absolute terms (and significantly so) for the high irreversibility firms. Moreover, the impact of uncertainty is stronger for machinery and equipment than for structures or vehicles.

Goel and Ram (1999) use pooled annual data for 12 OECD countries and estimate fixed effects models for three different types of investment: (a) producer durables, (b) residential structures, and (c) non-residential structures, which are likely to have different degrees of irreversibilities. In particular they consider residential structures to be the least irreversible type of investment because, although fixed, there is a good market for residential structures, which do not seem firm specific or industry specific, and are unlikely to have the 'lemons' problem.

On the other hand, investment in machinery and equipment, which constitute the major component of producer durables,[35] appear more irreversible since such investment is likely to be firm specific and/or industry specific.

Investment in non-residential structures instead appears to be more irreversible than that in residential structures, but may be less irreversible than investment in producer durables. In fact, apart from being fixed, non-residential structures may be firm or industry specific to some extent, and therefore it might be specific to certain types of production.

The empirical evidence of the study by Goel and Ram (1999) validates this categorisation of degrees of irreversibilities and their relationship with investment under uncertainty. In fact the adverse effect of uncertainty on investment in producer durables, categorised as the more irreversible, is substantial and statistically significant. On the contrary, uncertainty appears to have little effect on investment in residential structures, categorised as the least irreversible. Finally, the effect of uncertainty on investment in non-residential structures is found to be moderate.

Thus, their result supports the prior that the adverse effect of uncertainty is more severe on investments that have a greater degree of irreversibility.

Along these lines I construct a variable capturing the degree of irreversibility for each industry, calculated as the ratio between investment in equipments and total investment. Being equipments the component of investment that is probably the most irreversible, it should serve well my purpose.

[35] The other components of producer durables are transport equipment and other machinery and equipment.

Obviously there can be slight variations in the degree of irreversibility of equipments across and within industries, but if we look at all the components of investment we see that this is likely to be the most irreversible of all. In fact, in a rather standard way, investment can be defined to be composed of:

1. inventories stock of finished goods, semi-manufactured goods, and raw materials in commercial premises, storehouses and producers' plants;
2. equipment for direct production of services and goods;
3. transport and auxiliary machineries;
4. office and general endowment for indirect workers and management;
5. any long-lasting improvement in those items;
6. industrial plants and service buildings;
7. other buildings.[36]

Obviously, inventories and other materials stocks can usually be sold, maybe with some time lag if there is downturn in the performance of the market and demand is stagnating, but they are certainly a reversible investment to a good extent. Items 3 to 5, depending on the existence of suitable second-hand markets, can be sold because they are not specific for the production of a particular good or service, and can be sold to firms belonging to different industries as well. The same if true for industrial plants, service and other buildings, which are generally (or at least to some extent) sellable once emptied and readapted for different use.

The only type of investment that is very specific to the production process for which it was made is equipment. First because the technology embodied in specific equipment can be different (apart from vintage effects) and probably appropriate to the production of the specific good for which it was purchased. And secondly because if an industry is badly affected by recession, or more firms operating in the same *niche* are affected by a common adverse shock, it is difficult to disinvest specific equipment by selling them to direct competitors who can be in the same situation.

I therefore introduce in my basic model of investment under uncertainty, as specified by equation (9), an interaction term between the level of uncertainty and the change in the ratio

[36] This definition is on the website http://www.economicswebinstitute.org/main.htm, which offers a mini-encyclopaedia of economics concepts.

of irreversibility over time (the latter is indicated as IR_{it}). This should capture the varying effect of uncertainty as the ratio changes *within* the industries over time. At the same time I need to control for the different levels of the ratio across industries, so I introduce also an interacted term between the change in uncertainty and a dummy called 'irreversible' (D_i^{IR}) which takes the value of 1 if the industry has an irreversibility ratio that is in the top 25th percentile of the distribution of the mean (over time) of the irreversibility ratio across industries. The model to be estimated when irreversibility is explicitly accounted for is thus:

$$\frac{I_{it}}{K_{i,t-1}} = \beta_1 \Delta y_{it} + \beta_2 (\Delta y_{it})^2 + \beta_3 (\sigma_{it} \Delta y_{it}) + \beta_4 \Delta \sigma_{it} + \beta_5 \Delta CU_t + \beta_6 (y-k)_{i,t-1} + \\ + \beta_7 \sigma_{i,t-1} + \beta_8 CU_{t-1} + \beta_{12} \sigma_{it} \Delta IR_{it} + \beta_{13} \Delta \sigma_{it} D_i^{IR} + a_i + b_t + u_{it} \qquad (12)$$

In this way the marginal effect of a change in uncertainty on investment for the most irreversible industries will be given by the coefficient β_{13} and the total impact of a change in uncertainty on investment for such industries will be $\beta_4+\beta_{13}$.

Before proceeding to the estimation and the analysis of the empirical results, I need to discuss the measurement of uncertainty adopted in this study.

8 - Measuring Price Uncertainty

When analysing the investment-uncertainty relationship, the type of uncertainty that matters must be selected according to the level of aggregation of the data on investment. As the level of disaggregation of the data increases, the larger will be the impact of idiosyncratic shocks compared to economy-wide or industry-wide ones, at least for competitive industries.[37] Instead, when studying investment at a more aggregated level, as in this case at industry level, the uncertainty that matters would be the industry-wide one, because the

[37] See Caballero and Pindyck (1996) who compare the volatility of marginal profitability of capital for 2-digit industries and the mean of volatility for the 4-digit industries that make up each 2-digit sector, showing that the latter is always higher by a factor of two or three. They explain this with the fact that total uncertainty is made up of idiosyncratic shocks and aggregate uncertainty, and the idiosyncratic shocks are predominant at the more disaggregated level. Henley *et al.* (2003) find that firm-specific and industry-wide uncertainty effects on investment can be different and in particular these effects are found to work in opposite directions. However the effects of industry-specific uncertainty are found to be stronger only in concentrated industries.

individual idiosyncratic shocks at firm level are smoothed away in the process of aggregation.

It is also worth noting that in the literature there is no accepted best way to capture uncertainty: each and every measure suffers from some drawbacks and it is only too fair to say that, uncertainty being unobservable, one can only conjecture an econometric technique that proxies for the theoretical concept of uncertainty.[38] Therefore, according to data availability and the level of aggregation of the investment data used, there are a number of possibilities to measure uncertainty. For an excellent survey of the measures of uncertainty used in the literature see Carruth *et al.* (2000).

The measure of uncertainty used here is a measure of product price uncertainty, and is the same as in Ghosal and Loungani (1996). It consists of estimating a rolling standard error from the residuals of the following univariate, second-order autoregressive model to fit the growth rate of industry relative product price:[39]

$$p_{i,t} = \alpha_0 + \alpha_1 t + \alpha_2 p_{i,t-1} + \alpha_3 p_{i,t-2} + \varepsilon_{i,t} \qquad (13)$$

where p_{it} is the annual industry's product price relative to the economy-wide price, calculated as the logarithmic difference between the industry's producer price index (PPI) and the GDP deflator.[40]
t is a linear trend and ε_{it}~$(o,\sigma(\varepsilon_i)^2)$. Univariate autoregressive specifications are common in studies for example analysing the effects of inflation uncertainty [see Huizinga (1993), and the references contained there].

[38] For example a firm-level proxy for uncertainty extensively used in the literature is the volatility of the firm's daily share returns, which can be measured on a firm-year basis. However the usual drawbacks claimed against this measure are that: i) it is computable only for listed firms, which are usually the largest on the market, in this way excluding from the analysis the small or medium firms that are not listed; ii) the equity value of a firm, as traded in the stock exchange, might not respond to fundamentals and might deviate for long periods from its structural fundamental value due to noise traders, speculative bubbles or irrational exuberance, which are all sources of volatility that may not be relevant to a firm when making investment decisions.

[39] This specification is similar to that used by Huizinga (1993), although his detrending scheme is different.

[40] A comment about this industry price measure is in order. The industry price data used here is the PPI, but ideally one would want to use transaction prices to measure price uncertainty. However such a database is not available. Weiss (1977) examined the correlation between *changes* in transactions prices and the industry price deflator like the one used here. He found the two series to be highly correlated and that they do not differ importantly. This implies that examining growth rates in prices will provide meaningful price change information. Moreover, the aggregate PPI deflator could have been used in place of the GDP deflator. However the correlation coefficient between the two time series is 0.999, so the difference is negligible.

This way of measuring a variable uncertainty as a conditional standard deviation of that variable is consistent with the theoretical [see Dixit and Pindyck (1994)] and the empirical quantification of uncertainty. Apart from the mentioned Ghosal and Loungani (1996) study, previous empirical work in the investment under uncertainty literature that measures uncertainty as the conditional standard deviation of a variable is found in Pindyck (1982), Huizinga (1993), Ghosal (1995a, b), and Ghosal (1996). Pindyck and Solimano (1993) offer additional references and discussion.

Equation (13) means that we are assuming that firms attempt to forecast their product price and, to the extent that the price is forecastable, they can reduce the uncertainty faced. So the standard error from the residuals of the forecasting equation (13) is used as the measure of price uncertainty.

This equation should be interpreted as a filtering process of goods prices, which extracts a regular component from the pattern of prices over time, leaving an irregular component to proxy the unobservable component of uncertainty in prices. In fact, the measure of uncertainty is proxied for not by ε_t but by its standard error $\sigma(\varepsilon_i)$, which gives an average of the spread in prices. In this way the history of the variability in prices over a certain period is taken into account.

However, one drawback to this measure of uncertainty is that it is backward-looking instead of forward-looking as the theory assumes. It is possible to overcome this problem typically using survey data about future expectations of business performance with respect to production, market prices, etc., as done for example in Guiso and Parigi (1999) using a survey of the Bank of Italy, or Driver and Moreton (1992) using the CBI annual survey. But also this proxy of uncertainty, although forward-looking, is not immune from critics, for example about the fact that survey data contain only qualitative information on the forecasted performance[41], and this implies some degree of subjective discretion on how to translate this information in a quantitative measure of uncertainty; moreover not all firms on the market are obliged to respond to the survey, leaving out generally the smaller firms which can, in the aggregate, contribute to a great deal of investment; and finally it is not always guaranteed that the person involved in filling in the questionnaire is the one who has

[41] A typical survey question asks to indicate whether the concerned firm will perform better, worse or as well as the remainder firms in the industry, or whether the planned investment is going to increase, decrease or stay at the same level in the future as it is at present.

decision power inside the company, and therefore might not possess all the necessary information about the future strategies of the firm, its intended investment plans or production possibilities.

Following Ghosal and Loungani (1996), I use a rolling-regressions procedure in order to create a time series for the uncertainty variable for each industry. This procedure involves the estimation of equation (13) for each industry using annual data over the eighteen-year overlapping periods starting with 1961; i.e. 1961-78, 1962-79, …, 1980-97[42]. The standard errors of the rolling regressions become the measure of price uncertainty, indicated in notation $\sigma_{i,t}$, where "*i*" and "*t*" as before index the industry and time period. In this way, I obtain 20 time-series observations (1978-1997) on uncertainty for each industry.
Two lags are sufficient to catch the dynamics of prices: indeed the second lag is only significant for certain industries. Since its inclusion for those industries where it is not significant does not alter much the standard error of the regression, I decided to include it in order to have consistent measures across time for the same industry and across industries.
The third lag resulted to be never significant and therefore was omitted. There was no evidence of serial correlation or other heteroskedasticity in the residuals from these auxiliary regressions.

It is important to check whether there is enough within-industry variation in uncertainty. Table 2 reports the coefficients of variation of uncertainty for the 23 industries. On average, the representative industry has a coefficient of 23.7%, with the range being from 9.16% to 41.81%. There appears to exist a reasonable amount of variation in price uncertainty, which is encouraging for my empirical analysis.
Figure 2 in the Appendix shows the pattern of uncertainty for each industrial sector. It appears to be quite differentiated across industries.

[42] Ghosal and Loungani (1996) used a 14-year window instead of an 18-year one.

Table 2: Within-Industry Mean and Coefficient of Variation of Product Price Uncertainty

Ind.	*Mean (C.V.)*	*Ind.*	*Mean (C.V.)*	*Ind.*	*Mean (C.V.)*
T02	0.023056 (9.16)	**T10**	0.020329 (11.41425)	**T17**	0.017598 (10.57283)
T03	0.022056 (17.05665)	**T11**	0.070375 (18.79093)	**T18**	0.019228 (14.38752)
T04	0.09319 (23.67727)	**T12**	0.021235 (35.74192)	**T19**	0.023485 (27.66704)
T05	0.111 (17.97175)	**T13**	0.020959 (41.81356)	**T20**	0.022056 (30.31114)
T06	0.035194 (16.34748)	**T14**	0.016278 (39.23218)	**T21**	0.050927 (20.00433)
T07	0.061862 (13.21801)	**T15A**	0.016903 (18.99174)	**T22**	0.025049 (36.72416)
T08	0.092376 (17.92546)	**T15B**	0.016536 (20.15546)	**T23**	0.032882 (34.42719)
T09	0.0285 (37.39582)	**T16**	0.016127 (32.66134)		

Notice that by extracting a measure of uncertainty from the volatility of product prices, it implicitly means that I am considering both sides of the market: demand and supply conditions are reflected in equilibrium in the product price. This is exactly what I want to capture, since I am interested in highlightening the importance of market structure on the investment-uncertainty relationship. The uncertainty faced by a producer does not stem only from the demand side, but also from the change in the supply composition, for instance through the process of entry and exit of competitors, or the existence of collusive price agreements, and, in general, through the strategic interactions among the players in the market. The price changes over time in an industry are likely to reflect to some extent also changes in the market structure.

The estimation uses the system Generalised Method of Moments (GMM) estimator for dynamic panel data,[43] which extends the standard moment conditions in the first-differenced GMM estimator by Arellano and Bond (1991) by augmenting it with equations in levels [Arellano and Bover (1995) outlined the version which was then fully developed in Blundell and Bond (1998)].[44] Thus the system estimator combines equations in first-

[43] However it is possible to use system GMM even if there is no lagged dependent variable included in the estimation, like in this study. The estimations were carried out in Stata, using the instruction xtabond2.

[44] A problem with the original Arellano-Bond estimator is that lagged levels are often poor instruments for first differences, especially for variables that are close to a random walk. Arellano and Bover (1995) described

differences (from which the industry-specific effects are purged by the transformation), and equations in levels, for which the instruments used must be orthogonal to the unobserved industry-specific effects.

The reason for choosing this estimator is because there are some explanatory variables that may be endogeneous, like the Herfindahl index, or the proxy used to capture uncertainty, which is derived from prices. Effects on industry uncertainty generated by changes in investment should be controlled for by using System GMM, which makes use of lagged values of the variables as instruments and overcomes this problem of simultaneity. Notice that this problem of simultaneity has not been given the deserved attention by the extant literature, which has nearly exclusively considered uncertainty as completely exogenous.

9 – Econometric Results

Table 3 reports the econometric results estimated by system GMM for the basic specification of the model, as in equation (9), whilst Table 4 reports the results for the augmented model which takes into account market structure, as specified in equations (10) and (11). Additionally, the last column of Table 4 shows the regression results using equation (12) for the case in which irreversibility is explicitly accounted for. The instruments used are listed in the notes to the tables.[45]

The tables also report the Sargan-Hansen test for overidentifying restrictions, and the second-order residual serial correlation test.

A goodness-of-fit measure is also calculated, as suggested by Windmeijer (1995), by taking the square of the correlation between the predicted level of the investment rate and the actual investment rate. For IV regressions this is equivalent to the standard R^2 for OLS regressions.

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how it was possible to increase the estimator efficiency if the original equations in levels were added to the system, allowing additional moment conditions. In these equations, predetermined and endogenous variables in levels are instrumented with suitable lags of their own first differences. Blundell and Bond (1998) articulated the necessary assumptions for this augmented estimator more precisely and tested it with Monte Carlo simulations. The main assumption is that $E[a_i * \Delta u_{it}] = 0$, that is the unobserved group effects are not correlated with *changes* in the error term. See Bond (2002) for a clear exposition of these methods.

[45] However the results are very robust to different sets of alternative instruments.

Table 3 – Investment and Uncertainty for French Manufacturing Industries (1977-1997)

Dependent variable (I_t/K_{t-1})	(1)	(2)	(3)
Sales growth (Δy_t)	0.041*	0.042**	0.185**
	(0.022)	(0.019)	(0.072)
Change in CU (ΔCU_t)	0.005***	0.005***	0.005***
	(0.001)	(0.001)	(0.001)
Lagged CU (CU_{t-1})	0.007***	0.007***	0.008***
	(0.001)	(0.001)	(0.001)
Error correction term ($(y-k)_{t-1}$)	0.025***	0.025***	0.019***
	(0.004)	(0.004)	(0.004)
Sales growth sqrd. ($\Delta y_t \times \Delta y_t$)		0.004	
		(0.018)	
Change in uncertainty ($\Delta\sigma_t$)			-0.894***
			(0.295)
Lagged uncertainty (σ_{t-1})			-0.203
			(0.171)
Unc.x Sales grow. ($\sigma_t \times \Delta y_t$)			-1.500**
			(0.715)
Observations	460	460	437
Goodness of fit Corr. $(I/K, \widehat{I/K})^2$	0.30	0.30	0.37
2nd order serial cor.	0.086	0.090	0.160
Sargan-Hansen test	0.997	0.991	0.995

Notes to Table 3

The number of industries is 23, and the period of estimation is 1977-1997. A full set of time dummies is included in every specification. Levels of statistical significance are represented by * (10%), ** (5%) and *** (1%). The standard errors (s.e.) are indicated in parentheses.
Estimation uses the GMM system estimator. The coefficients reported are obtained from the one-step GMM estimator, and the standard errors are consistent to heteroskedasticity.
The instruments used for column (3) in the first-differenced equations are:
$(I/K)_{t-2}$, Δy_{t-2}, $(y-k)_{t-2}$, CU_{t-2}, and σ_{t-2}. The instruments used in the levels equations are $\Delta(I/K)_{t-1}$, $\Delta\Delta y_{t-1}$, ΔCU_{t-1}, $\Delta\Delta(y-k)_{t-1}$ and $\Delta\sigma_{t-1}$. Column (1) and (2) use this set of instruments less the uncertainty variables. Time dummies were used as additional instrumental variables for both equations in differences and levels.
The Sargan-Hansen statistic tests the joint null hypothesis that the model is properly specified and that the instruments are valid instruments (i.e. uncorrelated with the error term). The *p*-value of the Sargan-Hansen test for over-identifying restrictions is reported. The test for the null of no second order serial correlation in the first-differenced residuals is also reported (*p*-value).

The first column of Table 3 contains the basic linear error correction model augmented to include capacity utilisation. The error correction term is positive, and therefore correctly signed. Current sales growth and both the level and the change in the capacity utilisation variables are also positive and significant determinants of investment.
The second column adds in a non-linear term in squared sales growth, which is however insignificant, meaning that the model is not able to reject the null of a linear investment dynamics. This variable is therefore dropped in subsequent specifications because always insignificant.
The third column includes the uncertainty variables, namely the change in uncertainty, the lagged level of uncertainty, and the interaction between uncertainty and sales growth. The inclusion of uncertainty improves the goodness of fit of the model, meaning that the uncertainty does play a role in explaining the investment behaviour. Its inclusion additionally increases substantially the *p*-value of the test for the presence of second-order autocorrelation in the residuals.

The change in uncertainty is negative and significant at the 1% level, and this is consistent with the predicted short run effect of higher uncertainty on investment for positive investment.
The lagged level of uncertainty is negative but insignificant, consistent with the ambiguous impact of uncertainty on the level of capital stock in the long run.
Even more important is the sign of the interaction term between uncertainty and sales growth, and this is found to be negative and significant at the 5% significance level, supporting the prediction discussed in section 4.1 that uncertainty reduces the investment responsiveness to demand shocks.

Table 4, columns (1) and (2) present the estimates based on equation (10) and (11) respectively, that is the specification from equation (9) augmented to take into account the impact of variables of market structure on the investment-uncertainty relationship. The difference between column (1) and (2) is that the former captures the marginal effect of a change in uncertainty for the more concentrated industries, whilst the latter does the same thing for the more competitive industries.
The market structure is accounted for in two variables. The first is the interaction term between the level of uncertainty and the change in the Herfindahl index to capture

differences in the impact of uncertainty due to changes in the degree of concentration within an industry. The second is an interaction term between the change in uncertainty and the dummy concentrated (competitive) reported in column (1) [(2)].

As it appears clear from column (1) the terms that were appearing also in equation (9) are substantially unchanged both in terms of magnitude and statistical significance, except the interaction term between uncertainty and sales growth, which now becomes insignificant, and the change in uncertainty, whose magnitude in absolute value is much bigger (although it keeps the same significance and sign). The interaction term between the level of uncertainty and the change in HHI is positive and significant at the 10% level, meaning that as the industry becomes more concentrated over time the impact of uncertainty on investment has a positive marginal effect. So the more the Herfindahl index increases, the more likely is that the impact of uncertainty on investment turns eventually positive.

This is a general effect that appears to be significant for all industries (i.e. we are capturing a *within* industry effect of a change in the Herfindahl index). What is however interesting to know is also whether there is a different investment response to uncertainty *across* industries according to their degree of concentration. For this purpose I created the dummy 'concentrated', which is 1 if the mean of the Herfindahl index in the industry is in the 25^{th} top percentile of the distribution of the index across industries. By interacting this dummy with the change in uncertainty I can capture the marginal effect of uncertainty on investment only for concentrated industries, separating them from the remainder industries. In other words, the coefficient β_4 (for the change in uncertainty on its own) captures the average effect of a change in uncertainty on investment on all industries, while β_{10} only captures the marginal effect (or the additional effect) of uncertainty on investment for the concentrated industries. Since β_4 is negative and β_{10} is positive (and in absolute value slightly higher), a simple Wald test on the sum of these coefficients can reveal whether the total impact of a change of uncertainty on investment is positive or not significantly different from zero. As reported at the bottom of Table 4, the Wald test in this case turns out to have an $F(1,22)=0.31$, corresponding to a *p*-value of 0.583. So we are not able to reject the null that the total impact of a change in uncertainty on concentrated industries is not significantly different from zero. This is a result totally in line with what found by Ghosal and Loungani (1996), and contradicts the results found in Guiso and Parigi (1999).

Table 4 – Do Market Structure and Irreversibility affect the Investment-Uncertainty Relationship?

Dependent variable (I_t/K_{t-1})	(1)	(2)	(3)	(4)
Sales growth (Δy_t)	0.163*	0.203***	0.139*	0.183**
	(0.080)	(0.071)	(0.074)	(0.077)
Change in CU (ΔCU_t)	0.005***	0.005***	0.006***	0.006***
	(0.001)	(0.001)	(0.002)	(0.002)
Lagged CU (CU_{t-1})	0.008***	0.008***	0.008***	0.008***
	(0.001)	(0.001)	(0.001)	(0.001)
Error correction term $(y-k)_{t-1}$	0.018***	0.019***	0.013**	0.014***
	(0.005)	(0.004)	(0.005)	(0.005)
Change in uncertainty ($\Delta\sigma_t$)	-2.051***	-0.932**	0.047	-1.083**
	(0.485)	(0.337)	(0.709)	(0.422)
Lagged uncertainty (σ_{t-1})	-0.214	-0.184	-0.279	-0.238
	(0.163)	(0.179)	(0.181)	(0.192)
Unc. × Sales grow. (σ_t* Δy_t)	-1.140	-1.685**	-1.008	-1.588**
	(0.868)	(0.692)	(0.737)	(0.697)
Unc. × change HHI ($\sigma_t \times \Delta HHI$)	6.298*	5.425		
	(3.516)	(3.358)		
$\Delta\sigma$ × dummy concentrated	2.424***			
	(0.649)			
$\Delta\sigma$ × dummy competitive		2.944		
		(4.106)		
Unc.× change irreversi. ratio ($\sigma_t \times \Delta IR_t$)			-0.024***	
			(0.003)	
$\Delta\sigma$ × dummy irreversibile			-2.830***	
			(0.867)	
$\Delta\sigma$ × dummy concen. × dummy irreversib.				5.896**
				(2.302)
Unc. × change HHI × change irreversi. ratio ($\sigma_t \times \Delta HHI \times \Delta IR_t$)				3.898***
				(0.545)
Observations	437	437	437	434
Goodness of fit Corr. $(I/K, \widehat{I/K})^2$	0.38	0.37	0.39	0.40
Sargan-Hansen test	0.998	0.980	0.992	0.999
2nd order serial cor.	0.106	0.141	0.093	0.162
Wald test	0.583		0.0009	0.0347

Notes to Table 4

The number of industries is 23, and the period of estimation is 1977-1997. A full set of time dummies is included in every specification. Levels of statistical significance are represented by * (10%), ** (5%) and *** (1%). The standard errors (s.e.) are indicated in parentheses.
Estimation uses the GMM system estimator. The coefficients reported are obtained from the one-step GMM estimator, and the standard errors are consistent to heteroskedasticity.
The instruments used for columns (1) to (4) in the first-differenced equations are: $(I/K)_{t-2}$, Δy_{t-2} , $(y-k)_{t-2}$, CU_{t-2}, and σ_{t-2}; plus the instrument ΔHHI_{t-2} in columns (1), (2) and (4), and the ΔIR_{t-2} in column (3) and (4). The instruments used in the levels equations are $\Delta(I/K)_{t-1}$, $\Delta\Delta y_{t-1}$, ΔCU_{t-1}, $\Delta\Delta(y-k)_{t-1}$ and $\Delta\sigma_{t-1}$. As additional instrumental variables for both equations in differences and levels were used the time dummies for all columns, and the dummies D_i^{CONC} , D_i^{COMP} and D_i^{IR} for columns (1), (2), and (3) respectively. Colomn (4) uses D_i^{CONC} and D_i^{IR} .
The Sargan-Hansen statistic tests the joint null hypothesis that the model is properly specified and that the instruments are valid instruments (i.e. uncorrelated with the error term). The *p*-value of the Sargan-Hansen test for over-identifying restrictions is reported. The test for the null of no second order serial correlation in the first-differenced residuals is also reported (*p*-value).

The Wald test reports the *p*-value for the test of the null that the sum of the following coefficients is not significantly different from zero: $\beta_4 + \beta_{10}$ for column (1); and $\beta_4 + \beta_{13}$ for column (3).
Coefficients numerated as in equations (10) and (12).
For column (4) the Wald test is on the sum of the coefficient β_4 and the coefficient of the last but one regressor in that column.

Column (2) presents the same regression with the only difference being in the interaction term between the change in uncertainty and the dummy 'competitive'. The results on the other variables are substantially in line with column (3) of Table 3. The interaction term of uncertainty with the change in HHI is now statistically significant only at the 12% level, and the interaction term between the dummy competitive and the change in uncertainty is not significantly different from zero. This lends support to the conclusion that competitive industries are adversely and significantly affected by product price uncertainty. And also this result is the same as that one found in Ghosal and Loungani (1996).

Commenting now on column (3), which presents the regression results from specification in equation (12), it is apparent that the introduction of a proxy for irreversibility does change the main results. The coefficient of sales growth is only significant at the 10% level, the level and the change in capacity utilisation maintain the same sign, magnitude and significance as before, while the error correction term remains positive and significant but slightly smaller. However now we see a dramatic change in the impact of uncertainty: the change of uncertainty on its own, which has been significant across all specifications, is now insignificant. Also the interaction term of uncertainty in level and the sales growth is insignificant, meaning that the model does not capture any longer the heterogeneity across time and industry in the responsiveness of investment to demand shocks due to an increase in uncertainty. In other words, higher uncertainty does not imply a diminished responsiveness of investment to demand shocks. So there must be something else now capturing the negative effects on investment that before were attributed to uncertainty.

In fact, looking at the new terms included to capture the irreversibility effect, we see that they are negative and significant at the 1% level. The interaction term between uncertainty and the change in the irreversibility ratio should capture the fact that as the degree of irreversibility of investment in an industry increases (i.e. the portion of investment due to equipment, which is the most irreversible type of investment, out of total investment increases) the impact of uncertainty on investment becomes stronger and negative. As in the case of market structure, this is the within-industry effect because it captures the impact of uncertainty as the irreversibility changes over time and is the same across all industries. The interacted term between the change in uncertainty and the dummy irreversible is also negative and highly significant, meaning that if we calculate the marginal effect of uncertainty on investment only for those industries that have an average irreversibility ratio in the top 25th percentile, this marginal effect is negative and significant. The Wald test for the null that the sum of the coefficients of $\Delta\sigma_{it}$ is not significantly different from zero is rejected as shown at the bottom of column (3) in Table 3 [the statistic is $F(1, 22) = 14.73$].

Finally, the long run impact of uncertainty has remained negative but insignificant across all specifications. This supports the arguments that predict this coefficient to be ambiguous (trade-off between expandability and irreversibility on the option values to invest and divest, or the impact of investment lags).

After this analysis and comparing the results in column (1) and (2) with those obtained in column (3) of Table 4 the immediate next question arising is what would happen combining the interactions of uncertainty with market structure and irreversibility measures in the same estimation. Does irreversibility prevail also in industries characterised by a high monopoly power? Or are concentrated industries adversely affected by irreversibility as much as competitive ones?

To answer this question I run another estimation combining these effects, as shown in column (4). In particular I add two interactions terms to the basic specification as in equation (9). The first is the interaction of the level of uncertainty with the change in

Herfindahl index and the change in the irreversibility ratio. In this way I hope to capture the marginal effect of an increase in uncertainty when both irreversibility and concentration grow over time. This is the usual within-industry effect. The second interaction term is between the change in uncertainty and the dummy concentrated and the dummy irreversibile. In this way I can separate the marginal effect of a change in uncertainty on investment for those industries that have both high concentration and high degree of irreversibility.

The results are appalling. It appears that when both irreversibility and concentration (or market power) are at work at their maximum extent (as captured by the dummies I constructed) the positive impact stemming from the market structure prevails over the negative impact of irreversibility. The coefficient of the interaction term of a change in uncertainty with the dummies concentrated and irreversible is positive and significant at the 5% level. Also the coefficient on the other interaction term of the level of uncertainty with the change in the degree of concentration and the change in the degree of irreversibility is positive and significant at the 1% level. This means that both the within-industry effect (over time) and the between-industry effect point to the fact that the simultaneous increase in concentration and irreversibility reverts the sign of the impact of uncertainty on investment. The Wald test on the sum of the coefficient for the change in uncertainty on its own (β_4=–1.083) and the coefficient of $\Delta\sigma_{it}$ interacted with the dummy concentrated and irreversible (which is 5.896) is $F(1, 22) = 5.07$, with a *p*-value of 0.0347, implying that we do reject the null hypothesis that the sum coefficient is not significantly different from zero. Therefore the coefficient is positive and significant and supports the idea that when an industry suffers from high degrees of irreversibility but at the same time experiences high degrees of monopoly power the impact of uncertainty on investment is positive.

10 – Conclusions and Further Research

This is the first work that includes variables of market structure in a model of investment under uncertainty.[46] The need to feel such a gap has been requested by many studies in the investment-uncertainty literature for some time.

[46] I would have liked to claim that this was also the first work to include measures of irreversibility directly into the investment equation but I found out only after I had finished this work that there exists a working paper by Driver *et al.* (2002) which also calculates measures of industry irreversibility and interact them with the measures of industry uncertainty in a model of investment to test the real option theory. They regress separately investment equations for plant + machinery and buildings (claiming that the former are more irreversible). In particular for each 3-digit UK industry they measure irreversibility as the ratio of disposals to

The only few studies that tried to disentangle the effects of uncertainty on investment in industries characterised by different degrees of competition reached inconclusive results. This might be due to the fact that they only limited the analysis to a simple partition of the industries according to an index of competition, without considering the change over time of such a degree of competition within the industries for example, or maybe the partition itself was not accurate because too heterogeneous.

In this paper I also made one of the very first attempts to make explicit the relationship between investment and uncertainty under different degrees of irreversibility.

In a first step I estimated a basic model of investment under uncertainty without taking into consideration the market structure. Using a dynamic specification of industry level investment with error correcting behaviour, which separates the short-run from the long-run dynamics, I showed that the impact of a change in uncertainty on the investment rate is negative and significant. Also, higher uncertainty reduces the response of investment to demand shocks: the interaction term between uncertainty and sales growth is negative and highly significant, and robust across specifications. So investment behaviour seems to be affected by a caution effect due to uncertainty, which dampens the investment responsiveness to demand shocks when the level of uncertainty increases. In other words there is no common response of investment to demand shocks for high uncertainty and low uncertainty industries and time periods, and this confirms the heterogeneous behaviour of investment under uncertainty found also in Bloom *et al.* (2001). I found instead the coefficient for the quadratic term in sales growth to be always insignificant, so there is no evidence of a non-linear response of investment to demand shocks, contrary to what Bloom *et al.* (2001) find for firm-level investment. Therefore, notwithstanding the presence of (partial) irreversibility and uncertainty, I did not find any non-linearity in the investment dynamics with respect to demand shocks.

Also in line with Bloom *et al.* (2001) I find that the long run impact of uncertainty on investment is always insignificant, as theoretically predicted by some studies cited in

acquisitions of capital goods, alternatively they regress disposals on acquisitions and from the residual obtain the unobservable variable M_i which should capture the extent to which second-hand goods are marketable in the industry. Their results do accord with my study, since the interaction terms between uncertainty and irreversibility are negative and highly significant, supporting the prior that irreversibility should amplify the negative influence of uncertainty on fixed investment. They also find that this effect is even stronger for the type of capital that is more irreversible.

section 4.2. This is taken as evidence that uncertainty might have an impact only on the short run, while being insignificant in the long run. So, are the uncertainty effects only transitory? Probably more investigation of this issue is required in future research. For the moment we have evidence that the identification of short run and long run dynamics of investment under uncertainty is indeed an important and compelling one.

In a second step I augmented the basic specification of the investment model to account for the possible impact of market structure, or/and irreversibility. In particular I allow the impact of uncertainty to be different across industries, according to the market structure or/and the degree of irreversibility, through a shift in the slope coefficient of uncertainty. But I construct the dummy that shifts the slope parameter in a way to represent only the top (or bottom) 25^{th} percentile of the distribution across industries. In addition I do control for the change over time of the variable of market structure (Herfindahl index) or/and irreversibility ratio, capturing the within industry effect.

The results about the market structure (without considering irreversibility) are in line with those found by Ghosal and Loungani (1996): the impact of uncertainty is negative and significant for competitive industries, whilst for concentrated industries the impact is not significantly different from zero. This could lend some support to the very recent theoretical advancement in research on investment under uncertainty as mentioned in the introduction. As claimed by some recent contributions in the field of industrial organisation and game theory, when an industry is concentrated the strategic interactions among the players become more important also with respect to the investment decisions. The investment opportunities become strategic options to be exercised according to the competitive environment of the firm. The firm is no longer an entity in isolation, and it becomes affected by the market structure, increasing the responsiveness of its investment even when facing uncertainty. From a theoretical point of view, this translates into a lower positive investment threshold under certain conditions. More applied research is obviously needed in this area. While the study of the interactions between real options theory and game theory is just in its infancy, the empirical evidence is totally absent.

In this paper I also showed that it is possible to test the theory about the impact of irreversibility on the investment-uncertainty relation by constructing a very simple proxy of the degree of industry irreversibility, and interacting it with uncertainty directly in the investment model.

The results are striking: not only does irreversibility strengthen the negative impact of uncertainty on investment, but it appears that once irreversibility is accounted for in the model of investment, uncertainty does not have a significant role to play on its own any longer. In other words, irreversibility amplifies the negative effect of uncertainty, but it also raises the question about the validity of all the previous studies that simply related a measure of uncertainty with the rate of investment. The true relationship might be driven by irreversibility, and therefore it is important to continue the empirical research in the footsteps of these findings, building measures of irreversibilities and including them in the investment equation.
These results also confirm what Carruth *et al.* (2000) had suspected when they claimed that the irreversibility effect makes the dynamic structure of investment behaviour dependent on the degree of volatility and that all the studies that prefer to investigate simple correlations of rates of investment with proxies of uncertainty without considering the underlying specification for the capital accumulation process (as dependent on irreversibility) are highly questionable since any observed significant relationship may be an artefact of the underlying model misspecification [see the quotation from Carruth *et al.* (2000) reported in section 7].

However a novelty in the empirical evidence has been introduced here by allowing the market structure and irreversibility to affect simultaneously the investment-uncertainty relation. The results show that industries with high degree of concentration can shield from the negative impact of irreversibility when facing investment decisions under uncertainty. Not only are they not negatively affected, but also the evidence I found lends support to the idea that they are positively affected. This is a striking result, probably to be taken with caution due to the simplicity of the measure of irreversibility I constructed. Since these results are based on a simple representation of irreversibility in the model of investment, I cannot exclude that the evidence might be consistent with other hypotheses as well (although I could not find alternative explanations). So my posture in regard to the reported estimates is one of humility. Nevertheless, these results accord with the very recent theoretical contributions that allow the real options theory to be affected by the interactions among the oligopolistic players using the tools of game theory.

More research is however needed to improve the specification for more sophisticated measures of market structures, ideally capturing other important variables like the elasticity of demand, the returns to scale and the degree of collusion that are very likely meant to play a role in the responsiveness of investment to uncertainty. One difficulty that might be encountered, though, in such a development is the fact that necessarily this would require the introduction of generated regressors in the estimating equation of investment. In fact, one great advantage of using the simple Herfindahl index is that it is observed and not estimated, therefore completely free from measurement biases and it is model independent (in the sense that there is no need to assume any specific production or costs functions or impose restrictions on the model parameters to reach identification like it might be the case for the other market structure variables).

References

Abel, A. B. (1983), 'Optimal Investment under Uncertainty', *The American Economic Review*, Vol. 73(1), pp. 228-233.

Abel, A. B., A. Dixit, J. C. Eberly and R. S. Pindyck (1996), 'Options, the Value of Capital, and Investment', *Quarterly Journal of Economics*, Vol. 111(3), pp. 753-777.

Abel, A. B. and J. C. Eberly (1994), 'A Unified Model of Investment Under Uncertainty', *The American Economic Review*, Vol. 84(5), pp. 1369-1384.

Arellano, M. and S. Bond (1991), 'Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations', *Review of Economic Studies*, Vol. 58(194), pp. 277-297.

Arellano, M. and O. Bover (1995), 'Another Look at the Instrumental Variable Estimation of Error-Components Models', *Journal of Econometrics*, Vol. 68(1), pp. 29-51.

Attanasio, O., I. Reduto Dos Resi and L. Pacelli (2000), 'Aggregate Implications of Plant Level Investment Behaviour: Evidence from the UK ARD', *mimeo*, Institute for Fiscal Studies.

Bar-Ilan, A. and W. C. Strange (1996), 'Investment Lags', *American Economic Review*, Vol. 86(3), pp. 610-622.

Bean, C. R. (1981), 'An Econometric Model of Manufacturing Investment in the UK', *The Economic Journal*, Vol. 91(361), pp. 106-121.

Bernanke, B. S. (1983), 'Irreversibility, Uncertainty, and Cyclical Investment', *The Quarterly Journal of Economics*, Vol. 98(1), pp. 85-106.

Bertola, G. and R. J. Caballero (1994), 'Irreversibility and Aggregate Investment', *Review of Economic Studies*, Vol. 61(2), pp. 223-246.

Bloom, N. (2000), 'The Real Options Effect of Uncertainty on Investment and Labour Demand', *IFS Working Paper*, W00/15.

Bloom, N., S. Bond and J. Van Reenen (2001), 'The Dynamics of Investment under Uncertainty', *IFS Working Paper*, No. 01/05.

Blundell, R. and S. Bond (1998), 'Initial Conditions and Moment Restrictions in Dynamic Panel Data Models', *Journal of Econometrics*, Vol. 87(1), pp. 115-143.

Bond, S. (2002), 'Dynamic Panel Data Models: A Guide to Microdata Methods and Practice', *Cemmap Working paper*, CWP09/02, published in *Portuguese Economic Journal*, Vol. 1(2), 2002.

Caballero, R. J. (1991), 'On the Sign of the Investment-Uncertainty Relationship', *The American Economic Review*, Vol. 81(1), pp. 279-288.

Caballero, R. J. (1993), 'Durable Goods: An Explanation for their Slow Adjustment', *Journal of Political Economy*, Vol. 101(2), pp. 351-384.

Caballero, R. J. (1999), 'Aggregate Investment', in M. Woodford *(Ed.), Handbook of Macroeconomics*, North Holland, Amsterdam.

Caballero, R. J. and E. M. R. A. Engel (1999), 'Explaining Investment Dynamics in U.S. Manufacturing: A Generalized (S,s) Approach', *Econometrica*, Vol. 67(4), pp. 783-826.

Caballero, R. J. and J. V. Leahy (1996), 'Fixed Costs: The Demise of Marginal *q*', *NBER Working Paper*, No. 5508.

Caballero, R. J. and R. S. Pindyck (1996), 'Uncertainty, Investment, and Industry Evolution', *International Economic Review*, Vol. 37(3), pp. 641-662.

Carruth, A., A. Dickerson and A. Henley (2000), 'What Do We Know About Investment Under Uncertainty?' *Journal of Economic Surveys*, Vol. 14(2), pp. 119-153.

Chenery, H. B. (1952), 'Overcapacity and the Acceleration Principle', *Econometrica*, Vol. 20(1), pp. 1-28.

Clark, P. K. (1979), 'Investment in the 1970s: Theory, Performance, and Prediction', *Brookings Papers on Economic Activity*, Vol. 1(pp. 73-113.

Cooper, R., J. Haltiwanger and L. Power (1999), 'Machine Replacement and the Business Cycle: Lumps and Bumps', *American Economic Review*, Vol. 89(4), pp. 921-946.

Craine, R. (1989), 'Risky Business: the Allocation of Capital', *Journal of Monetary Economics*, Vol. 23(2), pp. 201-218.

Darby, J., A. Hughes-Hallett, J. Ireland and L. Piscitelli (1999), 'The Impact of Exchange Rate Uncertainty on the Level of Investment', *The Economic Journal*, Vol. 109(454), pp. C55-C67.

Dixit, A. (1989), 'Entry and Exit Decision under Uncertainty', *Journal of Political Economy*, Vol. 97(3), pp. 620-638.

Dixit, A. (1992), 'Investment and Hysteresis', *Journal of Economic Perspectives*, Vol. 6(1), pp. 107-132.

Dixit, A. (1997), 'Investment and Employment Dynamics in the Short Run and the Long Run', *Oxford Economic Papers*, Vol. 49(1), pp. 1-20.

Dixit, A. and R. S. Pindyck (1994), *Investment under Uncertainty*, Princeton, NJ: Princeton University Press.

Doms, M. and T. Dunne (1998), 'Capital Adjustment Patterns in Manufacturing Plants', *Review of Economic Dynamics*, Vol. 1(2), pp. 409-429.

Driver, C., K. Imai, P. Temple and G. Urga (2002), 'Contrasts Between Classes of Assets in Fixed Investment Panel Equations as a Way of Testing Real Option Theory', *paper presented at the 10th International Conference on Panel Data*, Berlin.

Driver, C. and D. Moreton (1992), *Investment, Expectations and Uncertainty*, Oxford: Blackwell Publishers.

Eberly, J. C. (1994), 'Adjusment of Consumers' Durables Stocks: Evidence from Automobile Purchases', *Journal of Political Economy*, Vol. 102(3), pp. 403-436.

Eberly, J. C. (1997), 'International Evidence on Investment and Fundamentals', *European Economic Review*, Vol. 41(6), pp. 1055-1078.

Emerson, M., D. Gros, A. Italianer, J. Pisani-Ferry and H. Reichenbach (1992), *One Market, One Money*, Oxford University Press.

Ferderer, J. P. (1993), 'The Impact of Uncertainty on Aggregate Investment Spending: An Empirical Analysis', *Journal of Money, Credit, and Banking*, Vol. 25(1), pp. 30-48.

Ghosal, V. (1995a), 'Input Choices under Price Uncertainty', *Economic Inquiry*, Vol. 33(1), pp. 142-158.

Ghosal, V. (1995b), 'Price Uncertainty and Output Concentration', *Review of Industrial Organization*, Vol. 10(6), pp. 749-767.

Ghosal, V. (1996), 'Does Uncertainty Influence the Number of Firms in an Industry?' *Economics Letters*, Vol. 50(2), pp. 229-236.

Ghosal, V. and P. Loungani (1996), 'Product Market Competition and the Impact of Price Uncertainty on Investment: Some Evidence from U.S. Manufacturing Industries', *The Journal of Industrial Economics*, Vol. 44(2), pp. 217-228.

Goel, R. K. and R. Ram (1999), 'Variations in the Effect of Uncertainty on Different Types of Investment: An Empirical Investigation', *Australian Economic Papers*, Vol. 38(4), pp. 481-492.

Grenadier, S. R. (1996), 'The Strategic Exercise of Options: Development Cascades and Overbuiding in Real Estate Markets', *Journal of Finance*, Vol. 51(5), pp. 1653-1679.

Grenadier, S. R. (2000), *Game Choices: The Intersection of Real Options and Game Theory*, London, United Kingdom: Risks Books.

Guiso, L. and G. Parigi (1999), 'Investment and Demand Uncertainty', *The Quarterly Journal of Economics*, Vol. 114(1), pp. 185-227.

Hannah, L. and J. A. Kay (1977), *Concentration in Modern Industry: Theory, Measurement and the UK Experience*, London: MacMillan.

Hartman, R. (1972), 'The Effects of Price and Cost Uncertainty on Investment', *Journal of Economic Theory*, Vol. 5(2), pp. 258-266.

Henley, A., A. Carruth and A. Dickerson (2003), 'Industry-Wide versus Firm-Specific Uncertainty and Investment: British Company Panel Data Evidence', *Economics Letters*, Vol. 78(1), pp. 87-92.

Hubbard, R. G. (1994), 'Investment Under Uncertainty: Keeping One's Options Open', *Journal of Economic Literature*, Vol. 32(4), pp. 1816-1831.

Huisman, K. J. M., P. M. Kort, G. Pawlina and J. J. J. Thijssen (2003), 'Strategic Investment Under Uncertainty: Merging Real Options with Game Theory', *CentER Working Paper*, No 2003-06, Tilburg.

Huizinga, J. (1993), 'Inflation Uncertainty, Relative Price Uncertainty, and Investment in U.S. Manufacturing', *Journal of Money, Credit, and Banking*, Vol. 25(3), pp. 521-557.

Koyck, L. M. (1954), *Distributed Lags and Investment Analysis*, Amsterdam: North Holland.

Lambrecht, B. and W. Perraudin (1991), 'Real Options and Preemption under Incomplete Information', *Birbeck College Working Paper*, London.

Lienhardt, J. (1999), *L'Industrie dans les Comptes Nationaux: Séries Longues 1977-1997 en base 1980 - Tome1: données agrégées*, Paris: INSEE.

MacDonald, R. and D. Siegel (1986), 'The Value of Waiting to Invest', *Quarterly Journal of Economics*, Vol. 101(pp. 707-727.

Nielsen, M. J. (2002), 'Competition and Irreversible Investments', *International Journal of Industrial Organization*, Vol. 20(5), pp. 731-743.

Panic, M. and K. Vernon (1975), 'Major Factors Behind Investment Decisions in British Manufacturing Industry', *Oxford Bulletin of Economics and Statistics*, Vol. 37(3), pp. 191-209.

Pindyck, R. S. (1988), 'Irreversible Investment, Capacity Choice and the Value of the Firm', *American Economic Review*, Vol. 78(pp. 969-985.

Pindyck, R. S. (1991), 'Irreversibility, Uncertainty and Investment', *Journal of Economic Literature*, Vol. 29(3), pp. 1110-1148.

Pindyck, R. S. (1993), 'A Note on Competitive Investment Under Uncertainty', *American Economic Review*, Vol. 83(1), pp. 273-277.

Pindyck, R. S. and A. Solimano (1993), 'Economic Instability and Aggregate Investment', *NBER Macroeconomics Annual*, pp. 259-303.

Price, S. (1996), 'Aggregate Uncertainty, Investment and Asymmetric Adjustment in the UK Manufacturing Sector', *Applied Economics*, Vol. 28(11), pp. 1369-1379.

Smets, F. (1991), 'Exporting versus FDI: The Effect of Uncertainty, Irreversibilities, and Strategic Interactions', *mimeo*, Yale University.

Weiss, L. W. (1977), 'Stigler, Kindahl and Means on Administered Prices', *American Economic Review*, Vol. 67(4), pp. 610-619.

Windmeijer, F. (1995), 'a Note on R^2 in the Instrumental Variables Model', *Journal of Quantitative Economics*, Vol. 11(pp. 257-261.

Appendix - The Data Set

The source of the industry data is the Department of National Accounts of the INSEE in Paris (Institut National de la Statistique et des Etudes Economiques). Before the introduction of the ISIC harmonised classification[47], INSEE used to classify national data according to its own system, called NAP40 (Nomenclature d'Activités et des Produits). NAP 40[48] is uses in this study because a benchmark revision according to the European-harmonised industrial classification had not yet been completed at least at the time of this study (so no data are available before 1978). Under the older national classification, instead, I could collect coherent time series over longer periods, and in particular I collected production series (at both constant and current prices) from 1959, from which I calculated the producer price index series for each industry.

NAP 40 is structured in 14 units (U items) and 36 sub-units (T items).

Table 5 shows the T-items classification and links the code given to each industry with its name description. Although the whole economy is classified, in this present paper I have considered only the manufacturing sector (including the mining and oil refining industries) plus the electricity, gas and water utilities, which includes the items T02 through T23 (23 industries in total, because T15 is divided in T15A and T15B).

The data collected for the investment estimation are the following:

<u>INSEE source</u>

- **Gross fixed capital formation** at current prices (1970-1997);
- **Gross fixed capital formation** at constant prices;
- **Net capital stock** at current prices ;
- **Net capital stock** at constant prices;
- **Production** at current prices ;
- **Production** at constant prices;
- **Sales** at current prices;
- **Investment** in equipment at current prices.

For all the series at constant prices, the base year is 1980. All series are for the period 1977-1997 except production prices, which are available for the period 1959-1997.

[47] The International Standard Industrial Classification (ISIC) was introduced in February 1989 by the United Nations Organisation.
[48] Called in the INSEE jargon "Base 80", because the constant prices series take 1980 as the base year.

Table 5: NAP 40 Classification

T01	Agricultural, forestry, fishery	**T18**	Textiles and clothing
T02	Industries of meat and milk	**T19**	Leather and footwear
T03	Other food industries	**T20**	Wood, furniture, miscellaneous industries
T04	Solid mineral fuels, coke	**T21**	Paper, board
T05	Oil and natural gas	**T22**	Press, edition
T06	Electricity, gas and water	**T23**	Rubber, plastic
T07	Ferrous ores and metals	**T24**	Building; civil and agricultural engineering
T08	Non ferrous ores and metals	**T25 – T28**	Trade
T09	Sundry minerals, building materials	**T29**	Motor car trade and repairs
T10	Glass industry	**T30**	Hotels, cafes, restaurants
T11	Chemical, synthetic fibres	**T31**	Transports
T12	Parachemicals and pharmaceuticals	**T32**	Telecommunications and post
T13	Foundries and metalworking	**T33**	Business services
T14	Mechanical engineering	**T34**	Market services to households
T15A	Industrial electrical and electronic equipment	**T35**	Lettings
T15B	Consumer durables	**T36**	Insurance
T16	Ground transport equipment	**T37**	Services of financial institutions
T17	Shipbuilding, aeronautics, armament	**T38**	Non market services

The **Herfindahl-Hirschman Indexes** were provided by INSEE with a NAP600 classification for the period 1978-1992 and NAF700 for the period 1993-1998. I recalculated them according to a NAP100 classification, as explained below.

All data, unless the Herfindahl-Hirschman indexes, were taken from Lienhardt (1999)[49]. For year 1977 the indexes were forecasted using autoregressive models of the Herfindahl index times series, inverted in a way that the beginning year corresponds in reality to year 1997, and the last observed year available is 1978, so as to forecast the year 1977.

Table 6 lists which forecasting model was applied to each industry.

[49] However this book does not have an electronic support for the data it contains available to the public. Hence, the data were supplied by INSEE.

Table 6- Fitted models of Herfindahl Indexes for Prediction Of Observation in Year 1977

Industry	Fitted model	Industry	Fitted model
T02	AR(2)	T16	AR(2)
T03	AR(2)	T17	AR(3)
T04	AR(2) without constant	T18	AR(1)
T05	AR(2)	T19	AR(1)
T06	AR(1) with a dummy in 1985	T20	AR(1) with inclusion of a trend
T07	AR(2)	T21	AR(1) with inclusion of a trend
T08	AR(2)	T22	AR(1)
T09	AR(1)	T23	AR(1) with a dummy in year 1984 and its lead
T10	AR(3) with a dummy in year 1978	T24	AR(3) with a dummy in year 1982
T11	AR(3) with a dummy in year 1982 and its lead	T25-T28	AR(3)
T12	AR(2)	T31	AR(2) with a dummy in year 1984 and its lead
T13	AR(1) with a dummy in year 1982	T32	No model fitting since in 1978 there was only 1 firm operating in the industry, hence also for 1977 the HHI index was assumed to be 1
T14	AR(1)	T34	AR(1) with a dummy in year 1981
T15	AR(1)	T37	AR(3) with a dummy in year 1988 and its lead
T15b	AR(1)		

Given that it was not possible to convert the data from the NAP 600 classification to the NAF 700 classification, in order to obtain a consistent time series for the whole period under consideration I recalculated the indexes according to the 3-digit NAP100 classification (as detailed in Table 7). I then aggregate them further to obtain *weighted* Herfindahl indexes according to the NAP40 classification, where the weights are given by the relative market share of each sub-industry. Since the data on labour, intermediate inputs, capital and output are available only at the NAP40 level for the time span employed, the use of weighted Herfindahl indexes reflecting the NAP100 classification at least in part mitigates the aggregation bias when calculating market concentration.

<u>OECD source</u>[50]

- Capacity utilisation (1976-1997)[51];
- GDP deflator at market prices (1959-1997).

[50] Data taken from OECD (2000).
[51] I obtained this series averaging the quarterly series called "BSS capacity utilisation rate /Quantum (non-additive or stock figures) /Business tendency surveys'.

Table 7- Breakdown of NAP40 industries in NAP100 sub-industries

T01 **Agricultural, forestry, fishery**

T02 **Industries of meat and milk**
S35 - Meat industry
S36 - Dairy products

T03 **Other food industries**
S37 - Fish, potatoes, fruits and pulses
S38 - Bread and pastries
S39 - Cereals, food for animals, biscuits, industrial pasta, and malt.
S40 - Oils, fats and margarine, sugar, chocolate, jams, tea, coffee, seasonings, sauces, infant and diet foods.
S41 - Bottled water, soft drinks, alcoholic drinks (wine excluded).
S42 - Tobacco.

T04 **Solid mineral fuels, coke** – *S04*

T05 **Oil and natural gas** – *S05*

T06 **Electricity, gas and water**
S06 – Electricity
S07 - Gas
S08 -Water

T07 **Ferrous ores and metals**
S09 - Extraction of iron minerals.
S10 - Iron metallurgy.
S11 - Production of steel pipes, wires and first stage steel transformation.

T08 **Non ferrous ores and metals**
S12 - Extraction of uranium and non-ferrous ores and metals.
S13 - Production of nuclear materials, non-ferrous ores and metals.

T09 **Sundry minerals, building materials**
S14 - Extraction of minerals for the chemical industry, production of salt, and peat.
S15 - Extraction of stones, sand, clay; production of pottery, bricks, tiles, cement, plaster and concrete.

T10 **Glass industry** – *S16*

T11 **Chemical, synthetic fibres**
S17 - Basic chemical industry and basic pharmaceutical industry.
S43 - Production of synthetic fibres.

T12 **Parachemicals and pharmaceuticals**
S18 - Agrochemical products, paints, soaps, detergents, perfumes, explosives, gelatines and glues, chemical products for photography, abrasives.
S19 - Medicines and other pharmaceutical products.

T13 **Foundries and metalworkin**g
S20 - Production of cast iron pipes; foundries.
S21 - Metallic elements for building; forge, stamping, pressing, powders metallurgy; treatment of metals, general mechanics; cutlery and tools; other metal works; production of arms.

T14 **Mechanical engineering**
S22 - Production of agricultural machinery.
S23 - Mechanical tools, machine tools.
S24 - Metallic tanks, boilers and radiators;
steam generators, nuclear boiler making, boiler piping; mechanical equipment; ovens and burners, industrial refrigerators wrapping equipment, conditioning equipment, sundry general use machinery; specific use machinery (for agribusiness, textiles, paper and board, printing, plastic materials, and other).
S25 - Equipment for lifting and maintenance; metallurgic machinery, and machinery for extraction and building.
S34 – Production of precision material

T15A **Industrial electrical and electronic equipment**
S27 - Maintenance and repair of office machinery and data processing material; production of office machinery and computers.
S28 – Production of electric material
S291 – Professional and household electronic material

T15B **Consumer durables**
S292 - Apparels for reception, recording and reproduction of sounds and images.
S30 - Household appliances.

T16 **Ground transport equipment** –*S31*

Table 7 - Breakdown of NAP40 industries in NAP100 sub-industries (cont.)

T17 **Shipbuilding, aeronautics, armament**
S26 - Armament.
S32 - Navigation aid equipment; construction and repair of war and civil ships.
S33 - Aerospace construction.

T18 **Textiles and clothing**
S44 – Textiles
S47 Clothing

T19 **Leather and footwear**
S45 – Leather
S46 - Footwear

T20 **Wood, furniture, miscellaneous industries**
S48 - Wood working
S49 – Furniture
S54 - Miscellaneous products

T21 **Paper, board** – *S50*

T22 **Press, edition** – S51

T23 **Rubber, plastic**
S52 – Tyres and other rubber products
S53 – Plastic materials transformation

T24 **Building; civil and agricultural Engineering** – *S55*

T25 – T28 **Trade**
S57 – Wholesale food trade
S58 – Wholesale non-food trade
S59 – Wholesale inter-industry trade
S60 – Middlemen trade
S62 – Specialised food retail trade
S63- Non-specialised food retail trade
S64 – Specialised non-food retail trade

T29 **Motor car trade and repairs** – *S65*

T30 **Hotels, cafes, restaurants** – *S67*

T31 **Transports**
S68- Railway transport
S69 – Road transport, urban transport and transport by driver
S70 – Inland navigation
S71 – Naval transport
S72 – Transport by air
S73 – Activities linked to transport and depots.
S74 - Activities auxiliaries to transport and travel agencies.

T32 **Telecommunications and post** – *S75*

T33 **Business services**
S56 – Credit recovery
S76 – Business administration
S77 – Consulting and assistance activities
S78 – Auxiliaries activities of insurance and finance, portfolio and assets management
S79 – Real estate
S80 – Car rental; other transport equipment rental; machinery and equipment leasing; other leasing.
S82 – Tuition and training
S83 – Research and development

T34 **Market services to households**
S66 – Repairing activities
S84 – Private healthcare
S86 – Cultural, recreational and sports services
S87 – Other private services

T35 **Lettings** – *S81*

T36 **Insurance** – *S88*

T37 **Services of financial institutions** – *S89*

T38 **Non market services** – *S90 ÷ S99*

Figure 2: Pattern of uncertainty for each industrial sector

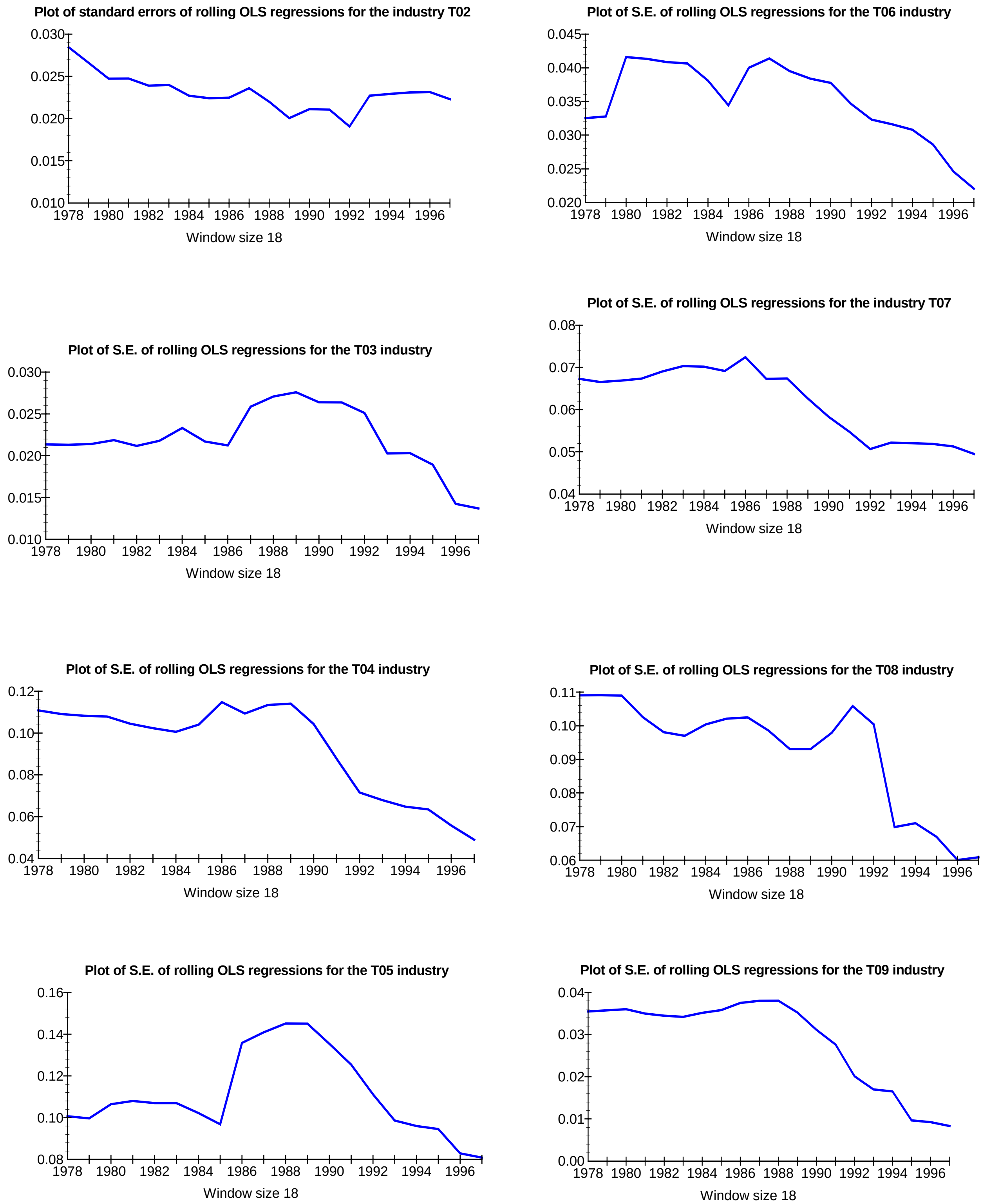
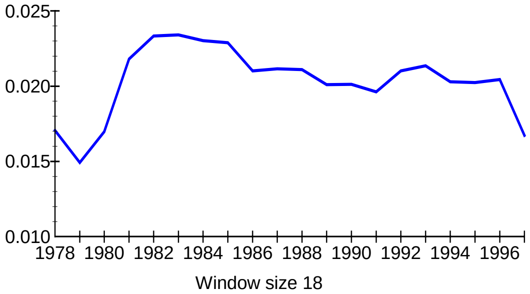
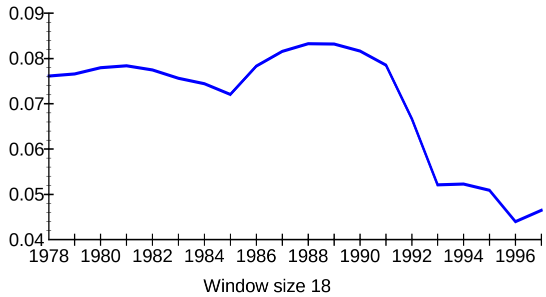


Figure 2 (cont.)

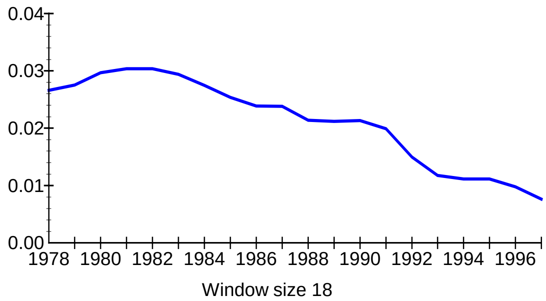
Plot of S.E. of rolling OLS regressions for the T10 industry



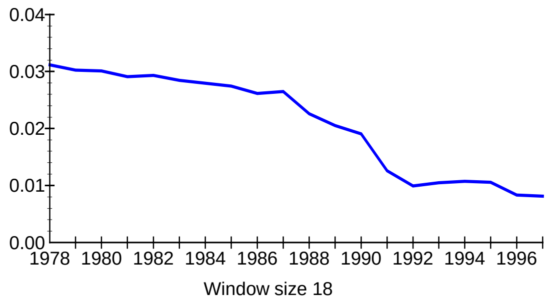
Plot of S.E. of rolling OLS regressions for the T11 industry



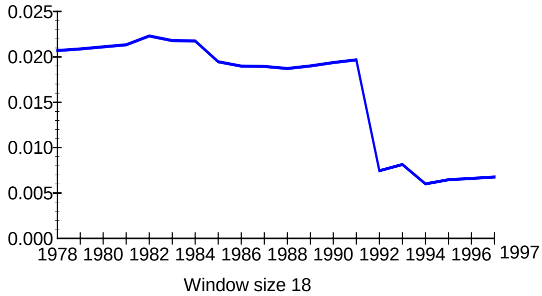
Plot of S.E. of rolling OLS regressions for the T12 industry



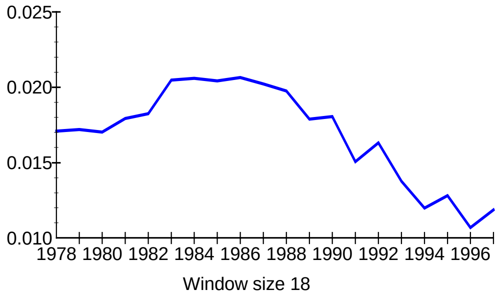
Plot of S.E. of rolling OLS regressions for the T13 industry



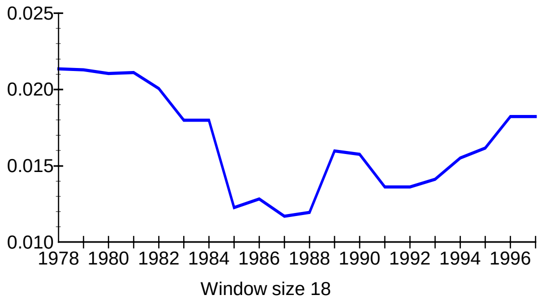
Plot of S.E. of rolling OLS regressions for the T14 industry



Plot of S.E. of rolling OLS regressions for the T15 industry



Plot of S.E. of rolling OLS regressions for the T15B industry



Plot of S.E. of rolling OLS regressions for the T16 industry

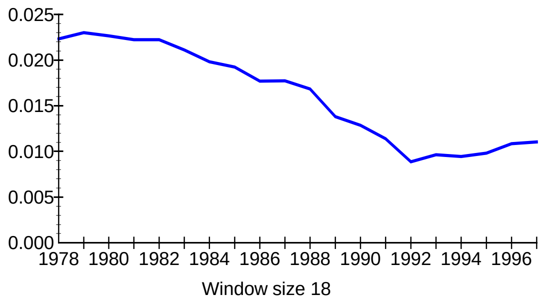


Figure 2 (cont.)