



**UNIVERSITA' DEGLI STUDI DI BERGAMO**  
**DIPARTIMENTO DI SCIENZE ECONOMICHE**

**“Hyman P. Minsky”**

**Via dei Caniana 2, I-24127 Bergamo, Italy**

**Tel. +39-035-2052501; Fax: +39-035-2052549**

---

**Quaderni di ricerca del**  
**Dipartimento di Scienze Economiche**  
**“Hyman P. Minsky”**

**Anno 2002 n.3**

***Non-convexities in the adjustment of different capital inputs: a  
firm-level investigation***

**Alessandra Del Boca, Marzio Galeotti, Paola Rota**

**Comitato di Redazione**

Riccardo Bellofiore  
Piero Ferri  
Giancarlo Graziola  
Andrea Salanti

Annalisa Cristini  
Marzio Galeotti  
Riccardo Leoni

- La Redazione ottempera agli obblighi previsti dall'art.1 del D.L.L. 31.8.1945, n.660 e successive modificazioni.
- Le pubblicazioni del Dipartimento di Scienze Economiche dell'Università di Bergamo, consistenti nelle collane dei Quaderni e delle Monografie e Rapporti di Ricerca, costituiscono un servizio atto a fornire la tempestiva divulgazione di ricerche scientifiche originali, siano esse in forma definitiva o provvisoria.

# Non-convexities in the Adjustment of Different Capital Inputs: A Firm-level Investigation

Alessandra Del Boca    Marzio Galeotti    Paola Rota \*

First draft: February 2002; this draft: June 2002

## Abstract

Recent developments in investment research have highlighted the importance of non-convexities and irreversibilities in the firms' adjustment of quasi-fixed inputs. However, aggregation across capital goods may smooth out the discontinuities associated with the adjustment of individual assets. The lack of suitable data, is one of the reasons why empirical work has strongly relied on the assumption of capital homogeneity. In this paper we exploit a new data set of 1539 Italian firms which allows us to disaggregate across several capital types and consider separately purchases and sales of assets. We start from the basic disaggregation between equipment and structures and construct measures of fundamental Q to capture investment opportunities associated with each asset. To uncover the pattern of dynamic adjustment we use non-parametric techniques to relate each individual investment to own fundamental Q.

*Keywords:* Investment, Heterogenous Capital, Non-convexities, Fundamental Q, Panel Data.

*JEL Classification:* D24, G31, C33, C34.

---

\*Respectively: Università di Brescia, Università di Bergamo, Università di Brescia. We gratefully acknowledge financial support from a COFIN99-MURST grant n.9913467782. We thank Christopher Gilbert, Fabio Schiantarelli, Alessandro Sembenelli and especially Bob Chirinko and Plutarchos Sakellaris, along with participants at the workshop "Firms' Dynamic Adjustment with Nonconvexities and Irreversibilities" held in Bergamo, November 9-10, 2001 and at the NBER Summer Institute 2002 held in Cambridge, July 22-24, 2002. .

# 1 Introduction

Capital homogeneity is a critical assumption often made by static and dynamic studies on production and factor demands. However, the main problem is that various capital goods command different prices, display different depreciation patterns and receive different tax treatments. The possibility of combining different capital inputs into a single aggregate relies on a very restrictive assumption on the firm's technology, ie that capital inputs must be perfect substitutes. Consequently the firm can produce more output by applying more machines or, indifferently, more buildings. The assumption of capital heterogeneity is considered one of the reasons why structural models of investment, such as Tobin's Q and Euler equations, perform poorly when confronted with the data (Whited, 1994, 1998).

Very few studies analyze investment in heterogenous capital goods. Hayashi and Inoue (1991) relate the growth rate of a scalar index of several capital inputs to Tobin's Q and test the model using Japanese panel data. However, the theoretical model rests on the hypothesis of weak separability for the capital inputs within the firm's profit function. Chirinko (1993) uses U.S. aggregate data to estimate an equation in which the specific capital investment, relative to the aggregate stock, depends on Tobin's Q and on the ratios of the other capital investments to the aggregate stock. If capital is homogenous the coefficients of these investment regressors should be the same. Capital homogeneity is rejected when the author distinguishes between equipment and structures. Cummins and Dey (2000) adopt an Euler equations approach to study investment in equipment and structures on U.S. firm-level data. They postulate a translog technology and quadratic adjustment costs. Previously, Pindyck and Rotemberg (1983) fitted two Euler equations for equipment and structures to U.S. total manufacturing data. Bond and Cummins (2000) study U.S. firm investment in tangible and intangible capital. The authors develop and estimate a single equation model where the tangible investment-capital ratio depends linearly on Tobin's Q and on the ratio between intangible investment and tangible stock. However, due to the unobservability of the stock of intangibles, they need to consider the ratio between the two stocks to be time invariant.<sup>1</sup> A recent paper by Bontempi,

---

<sup>1</sup>In the case of studies on investment in fixed and R&D capital, and especially on financing constraints, a number of papers depart from the capital homogeneity assumption (see for instance Nickell and Nicolitsas, 1996 and Bond, Harhoff and Van Reenen, 1999).

Del Boca, Franzosi, Galeotti, and Rota (2001) show how Q models behave differently when estimated separately for equipment and structures. They also show a different behavior when compared to the Q model with homogeneous capital. All the above studies represent contributions to the literature sharing the assumption of quadratic adjustment costs. It is well-known that this framework implies a gradual adjustment of the actual capital stocks to their desired long-run levels.

Recent developments in investment research highlight the importance of non-convexities and irreversibilities in the adjustment of quasi-fixed inputs by individual firms: Dixit and Pindyck (1994), Abel and Eberly (1994, 1996), Caballero (1997), and Caballero and Engel (1999) among the others. In this stream of studies, the adjustment of the quasi-fixed inputs may or may not occur, depending on whether the marginal net benefit from investing exceeds (falls short of) a certain threshold value. Hence, the adjustment may be episodic and lumpy, rather than smooth for all the values of the marginal net benefits as implied by the traditional convex adjustment costs explanations of investment behavior. Fixed costs, irreversibilities, and other forms of non-convexities may explain why traditional models of investment do not perform empirically well. Non-convexities alter investment dynamics both at firm and aggregate level, making optimal investment a non-linear function of its fundamentals. For the U.S., the empirical evidence on non-convexities has been growing starting from the explorative work by Doms and Dunne (1998) up to the investigation by Cooper, Haltiwanger, and Power (1999) and to the "gap methodology" approach proposed by Caballero, Engel, and Haltiwanger (1995) and Caballero and Engel (1999).<sup>2</sup> While these papers typically use plant level data but do not estimate structural investment equations, more recent contributions adapt Tobin's Q models to take into account non-convex costs and estimate their extent using firm-level panel data. Papers in this area are those by Eberly (1997), Whited (1998), Barnett and Sakellaris (1998, 1999), and Abel and Eberly (2002). However, these studies still assume that different types of capital goods can be combined into a single aggregate. Even when they emphasize the importance of capital heterogeneity, they base the empirical investigation on single indexes of fixed capital (see, for instance, Eberly, 1997; Abel and Eberly, 2002; Goolsbee and Gross, 2000).<sup>3</sup>

---

<sup>2</sup>See also Nilsen and Schiantarelli (2000) on Norwegian data and Gelos and Isgut (2001a, 2001b) on Colombia and Mexico.

<sup>3</sup>Abel and Eberly (2002) explicitly entertain the issue of aggregation of different capital

Although the focus of the recent investment literature is on modelling idiosyncratic behavior, aggregation of capital inputs may also hide non-convex patterns in adjustment costs and irreversibilities. As shown in Bontempi et al. (2001), aggregation may also dilute the convexities that characterize the adjustment pattern of specific capital inputs. Indeed, the authors find that the standard Q model fits the data very well for equipment, but not for aggregate capital since it fails to adequately represent investment in structures.

This paper explicitly considers the possibility of non-convex adjustment costs and of a non-linear relationship between optimal investment and its determinants. It complements the previous study by Bontempi et al. (2001) and focuses on the issue of capital investment under input heterogeneity. In this paper we analyze the dynamic adjustment of capital inputs by imposing as little structure as possible on its shape. The previous paper assumed quadratic costs of adjustment, thus obtaining a linear relationship between the investment rate in individual capital inputs and the corresponding marginal Q. In this paper we maintain the basic disaggregation between equipment and structures and rely on the notion of Tobin's Q to summarize investment opportunities associated with each individual capital input. However, under capital heterogeneity and in the presence of unlisted small and medium size firms, Tobin's Q, based on stock market valuation, cannot be used (unlike in Eberly, 1997; Whited, 1998; Barnett and Sakellaris, 1998, 1999; Abel and Eberly, 1999). To capture firms' investment opportunities we rely on the fundamental Q approach originally suggested by Abel and Blanchard (1986) and Gilchrist and Himmelberg (1995, 1998). We construct measures of fundamental Q for equipment and structures and then use non-parametric techniques to study the nature of the dynamic adjustment of investment in each capital input.

The results show that the linear adjustment pattern implied by the traditional quadratic adjustment cost is not consistent with the data. This is true for all types of capital assets as well for net investment, purchases and sales of assets. While the case for sales is statistically weak, we find widespread irreversibilities in this case. As for purchases and for net investment, we find instead an initial *S-shaped* region of the firms' dynamic adjustment followed by a linear, positively sloped portion. This finding is in line with the evidence

---

goods and show how the Q model needs to be modified. However, adjustment costs apply separately to each type of capital but with a common coefficient.

from other recent studies of the "new" applied investment literature.

The paper is structured as follows. In the next section we describe the data we use in the empirical investigation. Section 3 discusses our choice of a proxy for investment opportunities based on the notion of fundamental Q. Section 4 presents the investment relationship on which we base our investigation of firms' dynamic adjustment of capital inputs and the methods we employ. In Section 5 we discuss the empirical results. Concluding comments and directions for future research end the paper.

## 2 Data Description

We use data from Italy's Company Accounts Data Service (CADS) which maintains a large database with information on the balance sheets and income statements of more than 52,000 Italian firms covering all industries from 1982 to 1995. In addition to company accounts the database contains information on firm's demographics, location, sector, type of organization, ownership status, the composition of the board of management and the board of auditors. CADS is representative of the population of Italian companies, covering over 50% of the value added produced by the firms included in the Census of the Italian Central Statistical Office.

The dataset originally available comprises 5,086 manufacturing firms continuously observed for the years 1982 through 1995; the final sample used in the empirical analysis is a balanced panel of 1,539 companies for the period 1982-1995.<sup>4</sup> Consistently with the Italian firm structure, our data refer mainly to non publicly traded companies: in the final sample we have 0.32% companies listed on stock exchange. This is in line with national figures: in 1995 a mere 0.13% of Italian manufacturing companies were listed on the Stock Exchange. This explains why the Fundamental Q approach is especially useful for the study of investment by Italian firms. Another aspect of our dataset is the inclusion not only of large firms, but also of small and medium-sized companies. At the national level, small and medium firms are very important: on average Italian manufacturing limited liability companies have 44 employees. The average number of employees in our final sample is

---

<sup>4</sup>Variable definition and construction, cleaning criteria, and trimming rules are discussed in appendices A.1 and A.2. In there it is explained why the usable sample contains only 1,539 companies.

166 and 30.15% of our companies have less than 50 employees. Further information about our sample is given in appendix A.2.

We define net investment as purchases minus sales of fixed capital, and gross investment, as purchases only; unlike gross investment, net investment may take negative values, when capital sales are larger than purchases.

Table 1 presents summary statistics for the variables we use, net investment ( $I/K_T, I/K_E, I/K_S$ ), gross investment or purchases ( $I/K_T^+, I/K_E^+, I/K_S^+$ ) and disinvestment or sales ( $I/K_T^-, I/K_E^-, I/K_S^-$ ), real sales ( $S/K_T, S/K_E, S/K_S$ ), and operating income ( $\Pi/K_T, \Pi/K_E, \Pi/K_S$ ). All these variables are divided by the stock of total capital ( $T$ ), equipment ( $E$ ), and structures ( $S$ ). The positive skewness suggests that investment is temporally concentrated; in particular, this is true for structures which exhibit a zero net investment rate in the first quartile. Purchases follow a similar pattern. Most of the disinvestment is small and have a markedly skewed distribution, with the highest degree in the case of structures. The mean annual rates of disinvestment are as low as 0.037, 0.040 and 0.035 respectively, with medians even lower, strongly affected by the high number of zero episodes. Given the high frequency of positive outliers due to the skewness of our data, we use pseudo-standard deviation which is a more robust as a measure of variability.<sup>5</sup>

---

<sup>5</sup>The pseudo-standard deviation is defined as the ratio of the interquartile range (Q3-Q1) and 1.349 where  $1.349=2*0.674$  is the interval containing 50% of the cases in a normal distribution.

Table 1: Descriptive Statistics

	$Q_1$	<i>Median</i>	$Q_3$	<i>Mean</i>	<i>Pseudo – s.dev.</i>	<i>Skewness</i>
$I/K_T$	0.066	0.129	0.228	0.178	0.120	3.632
$I/K_E$	0.065	0.157	0.289	0.221	0.166	4.199
$I/K_S$	0	0.037	0.181	0.177	0.134	4.258
$I/K_T^+$	0.083	0.155	0.274	0.215	0.141	7.724
$I/K_E^+$	0.076	0.168	0.304	0.261	0.169	6.723
$I/K_S^+$	0.003	0.044	0.194	0.212	0.142	7.727
$I/K_T^-$	0	0.002	0.014	0.037	0.010	22.601
$I/K_E^-$	0	0.002	0.011	0.040	0.008	21.202
$I/K_S^-$	0	0.0001	0.004	0.035	0.003	32.118
$S/K_T$	2.282	3.432	5.347	4.344	2.272	2.770
$S/K_E$	3.472	5.565	9.451	7.910	4.432	4.223
$S/K_S$	5.939	9.651	16.017	13.278	7.471	3.305
$\Pi/K_T$	0.235	0.365	0.563	0.459	0.243	3.863
$\Pi/K_E$	0.365	0.588	0.968	0.832	0.448	6.767
$\Pi/K_S$	0.591	1.015	1.741	1.449	0.852	5.156

In Tables 2 and 3 we report the Markovian transition probabilities for aggregate capital, equipment and structures distinguishing between purchases and sales, over the sample period. In the tables we consider two regimes: positive investment and zero investment (for instance in Table 2:  $I/K_{t+1}^+ > 0$  and  $I/K_{t+1}^+ = 0$  respectively). The transition matrices should be read as follows: the first cell in the first panel of Table 2 indicates that 8 firms did not purchase any capital in period  $t$  and continued not to purchase in period  $t+1$ . In the second line, in bold, we report the frequency, i.e. the probability of changing or remaining in the same state between one year and another. Both tables confirm that investment in structure is more episodic although it is not unusual. In general, sales are characterized by a higher number of transitions between the two different states, indicating that these may be consistent with a discrete decision process.



Table 2: Transition Matrix for Zero and Positive Investment - Purchases

	<b>Aggregate</b>	
	$I/K_{t+1}^+ = 0$	$I/K_{t+1}^+ > 0$
$I/K_t^+ = 0$	8	96
	<b>7.69</b>	<b>92.31</b>
$I/K_t^+ > 0$	104	15181
	<b>0.68</b>	<b>99.32</b>
	<b>Equipment</b>	
	$I/K_{t+1}^+ = 0$	$I/K_{t+1}^+ > 0$
$I/K_t^+ = 0$	39	382
	<b>9.26</b>	<b>90.74</b>
$I/K_t^+ > 0$	401	14568
	<b>2.68</b>	<b>97.32</b>
	<b>Structures</b>	
	$I/K_{t+1}^+ = 0$	$I/K_{t+1}^+ > 0$
$I/K_t^+ = 0$	1025	1614
	<b>38.84</b>	<b>61.16</b>
$I/K_t^+ > 0$	1475	11276
	<b>11.57</b>	<b>88.43</b>
Total no. of obs.	15390	

Table 3: Transition Matrix for Zero and Positive Investment - Sales

	<b>Aggregate</b>	
	$I/K_{t+1}^- = 0$	$I/K_{t+1}^- > 0$
$I/K_t^- = 0$	2289	2334
	<b>49.51</b>	<b>50.49</b>
$I/K_t^- > 0$	1357	9410
	<b>12.60</b>	<b>87.40</b>
	<b>Equipment</b>	
	$I/K_{t+1}^- = 0$	$I/K_{t+1}^- > 0$
$I/K_t^- = 0$	2642	2377
	<b>52.64</b>	<b>47.36</b>
$I/K_t^- > 0$	1415	8956
	<b>13.64</b>	<b>86.36</b>
	<b>Structures</b>	
	$I/K_{t+1}^- = 0$	$I/K_{t+1}^- > 0$
$I/K_t^- = 0$	3760	3038
	<b>55.31</b>	<b>44.69</b>
$I/K_t^- > 0$	2283	6309
	<b>26.57</b>	<b>73.43</b>
Total no. of obs.	15390	

In Table 4 we report the frequency of zero and negative net investment episodes, in order to better understand the different behaviour of investment in equipment and structures, and the problems that may derive from aggregation.<sup>6</sup> In the case of equipment, zero net investment episodes are markedly less frequent than positive and negative investment cases. On the contrary, structures show the highest incidence of inactivity and negative-investment episodes: 13.8% against the 0.52% of equipment and 11.77% against the 9.33% of equipment, respectively. This indicates the possibility that structures, more than equipment, are characterised by non-convex adjustment costs which affect the relationship between investment and fundamental Q. Aggregate net investment shows a lower incidence of zeros and negative-investment (0.43% and 2.37%, respectively) and this suggests that aggregation tends to smooth out the discontinuities which are likely to characterize

<sup>6</sup>Further investigations of zero and negative net investment episodes by industry and size are reported in Tables A.3.1-A.3.2 in the appendix.

structures. Recent studies (Abel and Eberly, 2002; Barnett and Sakellaris, 1998) show that fixed components in the adjustment cost function and partial irreversibility are likely to affect investment behavior. If this is the case, aggregation over different capital goods fails to account for differences in adjustment costs by smoothing out the adjustment paths. However, none of the above recent studies have focused on heterogeneous capital inputs.<sup>7</sup>

Table 4: Frequency of Zero and Negative Investment

	Aggr.	Equip.	Struc.
<b>a. Frequency of <math>I/K &gt; 0</math>, due to:</b>	<b>97.20</b>	<b>90.15</b>	<b>74.43</b>
$I/K^+ \neq 0$ and $I/K^- = 0$	27.63	30.32	28.88
$I/K^+ > I/K^-$ , given $I/K^+ \neq 0$ and $I/K^- \neq 0$	69.57	59.83	45.55
<b>b. Frequency of <math>I/K = 0</math>, due to:</b>	<b>0.43</b>	<b>0.52</b>	<b>13.80</b>
$I/K^+ = 0$ and $I/K^- = 0$	0.39	0.48	13.78
$I/K^+ = I/K^-$ , given $I/K^+ \neq 0$ and $I/K^- \neq 0$	0.04	0.04	0.02
<b>c. Frequency of <math>I/K &lt; 0</math>, due to:</b>	<b>2.37</b>	<b>9.33</b>	<b>11.77</b>
$I/K^+ = 0$ and $I/K^- \neq 0$	0.30	2.31	3.02
$I/K^+ < I/K^-$ , given $I/K^+ \neq 0$ and $I/K^- \neq 0$	2.08	7.02	8.75
<b>Number of observations</b>	16,929		

As we know, net investment is the result of buying and selling: zero and negative investment may therefore hide simultaneous buying and selling of capital goods. This is confirmed by the other rows of Table 4, where net investment is disaggregated in its components. Companies buy and sell capital in the same year: for instance, total capital shows 27.63% of cases in which capital is only purchased, 0.30% of cases in which there are sales only, and 71.69% of cases in which has both purchases and sales (69.57%+0.04%+2.08%). It is therefore important to separately consider purchases and sales of heterogeneous capital goods. Further information may be obtained from Table 5, where we show how many observations entail a zero level of gross investment and what is the fraction of gross investment

<sup>7</sup>See also Goolsbee and Gross (1997) for an estimation of adjustment costs with data on heterogeneous capital goods, even though the results reported refer to a single capital index.

activity associated with large variations in the capital stock.<sup>8</sup> Structures are characterised by a much higher number of zeros: 16.80% of observations against 2.79% in the case of equipment. Moreover, in the case of structures, the largest gross investment episode yields 48.37% of cumulative gross investment over the 11 years period; this fraction is twofold that of equipment. Thus, as in the case of net investment, aggregation over different types of capital goods tends to hide the lumpy nature of structures.

Table 5: Lumpiness of Purchases and Sales

	Aggr.	Equip.	Struc.
<b>Temporal concentration of purchases:</b>			
- frequency of $I/K^+ = 0$	0.69	2.79	16.80
- contribution of the largest $I/K^+$ to cumulative $I/K^+$ over the sample period	26.54	29.00	48.37
<b>Temporal concentration of sales:</b>			
- frequency of $I/K^- = 0$	28.02	30.80	42.66
- contribution of the largest $I/K^-$ to cumulative $I/K^-$ over the sample period	60.63	65.13	73.88

The high incidence of zero sales in all types of capital goods is apparent from the table. The highest percentage of zeros, 42.66%, again occurs in structures, along with the largest sales episode in any given year (that covers 73.88% of cumulative sales over the sample period). Given the largely concentrated nature of sales, the standard linear relationship between disinvestment and  $Q$  is likely not to perform well empirically relative to the case of purchases. This implies that the high number of zeros should be taken explicitly into account and that the standard strictly convex adjustment cost specification may not be appropriate when we look at sales of capital goods. These are indeed the econometric findings of Bontempi et al. (2001) and motivate the empirical investigation that follows.

<sup>8</sup>See Doms and Dunne (1998).

### 3 Investment Opportunities

In both the traditional literature and in the more recent literature which emphasizes the role of non-convexities and irreversibilities, investment is prompted by comparing the desired capital stock with its actual level, or by considering how much the Tobin's Q differs from unity. In the recent literature the former approach is often referred to as "gap methodology", first adopted in the fixed adjustment costs model by Caballero, Engel, and Haltiwanger (1995) Caballero and Engel (1999).<sup>9</sup> This model predicts that the firm's capital adjustment is a non-linear function of the imbalances between desired and actual capital.<sup>10</sup> In particular, the actual capital stock is referred to as mandated stock, while the desired stock is taken to be proportional to the frictionless stock. The frictionless capital stock, in turn, is the level of input that would hold in the absence of frictions at any time.

The papers by Eberly (1997), Barnett and Sakellaris (1998, 1999), and Abel and Eberly (2002) instead rely on the notion of Tobin's average Q. They exploit stock market data to compute the numerator of Q and rely on a number of assumptions which allow to use the average ratio *in lieu* of the theoretically relevant marginal ratio.

Our model of capital adjustment neither depends on the computation of a desired or frictionless capital stock nor on the stock market valuation required to compute the Tobin's average Q. The first approach is somewhat *ad hoc* since the target capital stock does not embed any consideration concerning expectations of the future forcing variables. Moreover, it requires the specification of both desired and frictionless capital stocks and the estimation of the latter is particularly problematic in a context of many capital inputs.<sup>11</sup>

Contrary to what is generally assumed in the literature, it can be shown that the models based on the average Q can also be applied to the case in which the production function is not linear homogeneous, competition in the output market is not perfect and the number of quasi-fixed inputs is

---

<sup>9</sup>The flexible accelerator model can be considered as the ancestor of the "gap methodology". The difference with the modern approach lies in the rate of adjustment. Note that also Tobin's Q models can be seen as applications of the "gap methodology", in the price space rather than in the quantity space. Under certain conditions one can establish a duality between these two approaches (Galeotti, 1987).

<sup>10</sup>This approach is also adopted by other authors, including Goolsbee and Gross (2000), Gelos and Isgut (2001a), and Carlsson and Laséen (2001).

<sup>11</sup>In most specifications the frictionless capital depends upon output and the capital-specific user cost. The latter is typically unobserved in firm or plant-level analyses.

greater than one (Galeotti and Schiantarelli, 1991). However, in order to be applicable, the Q model requires that the firm be quoted in the stock market, a condition not fulfilled in the present context.<sup>12</sup>

Our proxy for investment opportunities draws on Tobin's work and follows the fundamental Q approach proposed by Abel and Blanchard (1986) in the case of aggregate investment and by Gilchrist and Himmelberg (1995, 1998) who apply it to panel data. Investment in individual capital goods is the outcome of a firm's intertemporal optimization in which the profit opportunities of investing in a certain capital good are compared at the margin with its cost. These opportunities are represented by the shadow price of capital or fundamental Q, which is evaluated by means of the auxiliary model described below (see Bontempi et al., 2001).

Let  $\beta^s (1 - \delta_j)^{s-1} \equiv (\lambda_j)^s$  where  $\beta$  is the firm's discount rate and  $\delta_j$  the  $j$ -th capital good depreciation rate. Then the fundamental Q associated with the  $j$ -th capital input is given by the following expression:

$$FQ_{j,it} = E [q_{j,it} | \Omega_{it}] = E \left[ \sum_{s=1}^{\infty} \lambda_j^s \frac{\partial \Pi_{it+s}}{\partial K_{j,it+s}} \right] | \Omega_{it} \quad (1)$$

where  $\partial \Pi / \partial K_j$  indicates the marginal profit from the  $j$ -th capital type. Equation 1 shows that fundamental Q is unobserved in two respects: first, it entails an infinite sum of future values; second, the marginal profitability has to be estimated. Following Abel and Blanchard (1986) and Gilchrist and Himmelberg (1995), the first problem is dealt with by estimating a set of Vector Auto-Regression (VAR) equations for the state variables which we presume forecast the marginal profitability of capital.<sup>13</sup> As to the second aspect, to construct the expectations of the future marginal profitability of capital we assume that the firm's technology is Cobb-Douglas. Under perfect competition in the output market, we may relate marginal profits of capital to the observed variables as follows:

$$\frac{\partial \Pi_{it}}{\partial K_{j,it}} = \rho_{j,i} \left( \frac{\Pi_{it}}{K_{j,it}} \right) \quad (2)$$

---

<sup>12</sup>In addition the stock market is assumed to be efficient, although the Q model can be used to study the role of non-fundamentals for investment (Galeotti and Schiantarelli, 1994).

<sup>13</sup>See Holtz-Eakin, Newey and Rosen (1988) who extend the VAR methodology to longitudinal data.

where  $\rho_{j,i}$  is the output elasticity of capital. In equation 2, marginal profitability relating to each capital input is proportional to the corresponding average profitability. Profits in this paper are proxied by operating income. If, alternatively, imperfect competition is assumed, then we have:

$$\frac{\partial \Pi_{it}}{\partial K_{j,it}} = \sigma_{j,i} \left( \frac{S_{it}}{K_{j,it}} \right) \quad (3)$$

where  $S$  indicates sales and  $\sigma_{j,i} = (1 + \eta_i^{-1}) \rho_{j,i}$  with  $\eta_i$  representing the firm level price elasticity of demand. In this case marginal profitability of each capital input is proportional to the corresponding sales to capital ratio.<sup>14</sup>

Consider a vector  $x_{j,it}$  comprised of capital-specific operating income to capital and sales to capital ratios and any other variables containing information which is useful for forecasting the future marginal profitability of capital. More precisely, the vector  $x_{j,it}$  contains the right hand sides of 2 and 3, i.e. the operating income-based and the sales-based marginal profitability of each capital good. Assume that  $x_{j,it}$  follows a stationary stochastic process with a finite-order autoregressive representation that we write in its AR(1) companion form:

$$x_{j,it} = A_j x_{j,it-1} + f_{j,i} + d_{j,t} + u_{j,it} \quad (4)$$

where  $A_j$  is the matrix of coefficients specific for each type of capital goods. Cross sectional heterogeneity is captured by a vector  $f_{j,i}$  of firm unobservable

<sup>14</sup>Following Gilchrist and Himmelberg (1998), the technology and demand parameters,  $\rho_{j,it}$  and  $\sigma_{j,it}$ , are calculated as industry-level averages as follows:

$$\tilde{\rho}_{j,h} = \left( \frac{1}{N_h T} \sum_{i \in N_h} \sum_{t \in T_{j,it}} \frac{\Pi_{it}}{K_{j,it}} \right)^{-1} \frac{1}{N_h T} \sum_{i \in N_h} \sum_{t \in T_{j,it}} (r_{it} + \delta_{j,ht})$$

and:

$$\tilde{\sigma}_{j,h} = \left( \frac{1}{N_h T} \sum_{i \in N_h} \sum_{t \in T_{j,it}} \frac{S_{it}}{K_{j,it}} \right)^{-1} \frac{1}{N_h T} \sum_{i \in N_h} \sum_{t \in T_{j,it}} (r_{it} + \delta_{j,ht})$$

where  $j$  indicates the type of capital good;  $h$  denotes industry, and  $N_h T$  is the number of firm-year observations in industry  $h$ ;  $\delta_{j,ht}$  is the rate of physical depreciation which varies by industry and time;  $r_{it}$  is the interest rate on financial debt. Further details about variables construction are in the appendix A.1, while Table A.4.1 reports the computed values of  $\tilde{\rho}_{j,h}$  and  $\tilde{\sigma}_{j,h}$  by industry and the VAR(2) estimates are reported in Tables A.5.1 and A.5.2.

fixed effects, while  $d_{j,t}$  is a vector of shocks common to all firms for which we assume a finite-order autoregressive representation. Finally,  $u_{j,it}$  is a vector of disturbance terms that are orthogonal to  $x_{j,it-1}$ . Assume that variables dated  $t$  are part of the information set, i.e.  $x_{j,it} \in \Omega_{it}$ . Since we are assuming a stationary process and a finite-order autoregressive representation for both  $x_{j,it}$  and  $d_{j,t}$ , then the expectation of  $x_{j,it+s}$  given  $x_{j,it}$  may be written as:

$$E [x_{j,it+s} | x_{j,it}] = A_j^s x_{j,it} \quad (5)$$

where we have omitted the terms involving  $f_{j,i}$  and  $d_{j,t}$  and their related parameters which result to be nuisance for our analysis. Under the assumption of a one-period gestation lag, the shadow value of capital may be approximated as follows:

$$\begin{aligned} E [q_{j,it} | \Omega_{it}] &= \sum_{s=1}^{\infty} \lambda_j^s E [\pi_{j,it+s} | \Omega_{it}] \\ &= \sum_{s=1}^{\infty} \lambda_j^s E [c' x_{j,it+s} | x_{j,it}] \\ &= \sum_{s=1}^{\infty} c' \lambda_j^s A_j^s x_{j,it} \\ &= c' (I - \lambda_j A_j)^{-1} \lambda_j A_j x_{j,it} \\ &= FQ_{j,it} \end{aligned} \quad (6)$$

where, in the second row, the unobservable expected stream of marginal profit of each type of capital has been substituted by the expectation of the observable firm fundamentals useful in forecasting marginal profitability; the discounted value of the expectation of  $x_{j,it+s}$  given  $x_{j,it}$  is the capital-specific fundamental  $Q$ ,  $FQ_{j,it}$ . If the hypothesis of perfect competition holds and the operating income-based marginal profitability of capital is the first element of the information set  $x_{j,it}$ , then  $c$  is a vector with the first element equal to one and zeros elsewhere.<sup>15</sup> As discussed earlier, expression 6 is based on the

---

<sup>15</sup>If we assume that variables dated  $t$  are not part of the information set, the formula of fundamental  $Q$  in 6 is slightly different. If we compute fundamental  $Q$  in this way, the empirical results of the regressions reported in the next sections are somewhat inferior but the main conclusions hold true.



assumption of one-period gestation lag.<sup>16</sup> We will replace  $A$  with  $\widehat{A}$  obtained from estimation of VAR models for the case  $j = 1, 2$ , i.e. equipment and structures, as well as for the standard case of aggregate capital. We employ a GMM methodology and use first differences to eliminate the individual firm effects. We also include a vector of time dummies which capture aggregate shocks. Instruments are time dummies and lagged values (two and three lags) of operating income ( $oi$ ) and sales ( $s$ ), both divided by the relevant capital stock. The VAR(2) estimates are reported in Appendix A.5, tables A.5.1 and A.5.2. We then construct three fundamental Q's, one for each type of capital good, following expression 6. The term  $\lambda$  varies according to the type of capital:  $\lambda = 0.8614$  for total investment,  $\lambda = 0.8394$  for equipment and  $\lambda = 0.8944$  in the case of structures.<sup>17</sup> The resulting series,  $\widehat{FQ}_{j,it}$ , are the estimated capital-specific fundamental Qs.

## 4 Investment Relationship

Consider a value-maximizing firm which uses many capital inputs. The necessary condition for an optimal choice of investment requires equating, at each point in time, the marginal cost to the marginal benefit from investing in each capital input. This condition can be represented as follows:

$$E[q_{j,it} | \Omega_t] = p_{j,t} + G(I_{j,it}, K_{j,it}, \xi_{j,it}) \quad (7)$$

where the left hand side represents the benefit from investing in a unit of the  $j$ -th capital good, while the right hand side represents the corresponding cost, given by the sum of an installation and an acquisition component.<sup>18</sup> In

---

<sup>16</sup>We have also experimented the case of absence of gestation lags, which implies that today's investment becomes immediately productive. There were only qualitative differences but the one period gestation lag appeared to deliver more robust results.

<sup>17</sup>These values correspond to the sample average of firm and time specific discount factors, i.e.  $\tilde{\lambda}_j = \frac{1}{H} \sum_{h \in H} \frac{1}{N_h T} \sum_{i \in N_h} \sum_{t \in T} \beta_{it} (1 - \delta_{j,ht})$ , where  $H$  is the total number of industries. The discount rate  $\beta_{it}$  is calculated as  $[1 + (1 - \tau_t)r_{it} - z_{ht}]^{-1}$ , where  $\tau_t$  is the statutory tax rate on firm profits, and  $z_{ht}$  is the inflation rate (see appendix A.1 for variable definitions). We follow Abel and Blanchard (1986) and Gilchrist and Himmelberg (1995) who consider the average across firms and over time of the discount factor, arguing that any firm-specific and any year-specific effect is captured by the individual and temporal effects.

<sup>18</sup>In writing equation 7 we are implicitly assuming that the costs of installing capital goods of type  $j$  are not affected by investment in other varieties.

particular,  $p$  is the market price of new capital goods,  $I$  is investment and  $K$  the corresponding stock;  $\xi$  is a shock to installation costs. In view of its empirical implementation, we substitute the left hand side of equation 7 with the estimate of fundamental  $Q$ ,  $\widehat{FQ}_{j,it}$ , and, because we do not have firm-specific observations on prices, we use time dummies to capture price and other time-varying firm-invariant effects. Unobserved individual heterogeneity is captured by firm-specific effects. Following the literature, we assume that  $G(\cdot)$  is homogenous of degree zero in  $(I, K)$ . Thus, our empirical model is:

$$\frac{I_{j,it}}{K_{j,it}} = H(\widehat{FQ}_{j,it}) + \mu_{j,i} + \nu_{j,t} + \epsilon_{j,it} \quad (8)$$

The terms  $\mu_{j,i}$  and  $\nu_{j,t}$  represent the composite firm fixed effects and time effects resulting from the substitution of equation 6 into 7; the error  $\epsilon_{j,it}$  includes both the shock to the adjustment costs,  $\xi_{j,it}$ , and the error introduced by replacing the present value of future marginal profits of each type of capital goods with its proxy obtained through the VAR auxiliary forecasting model. The formulation 8 is essentially the same as those employed by Eberly (1997), Barnett and Sakellaris (1998, 1999) and Abel and Eberly (2002). The only difference is that it refers to investment in individual capital inputs and hence it depends on the own fundamental  $Q$  rather than on the average  $Q$ .

In order to investigate potential non-convexities in the investment function it is desirable to impose as little structure as possible on the form of  $H(\cdot)$ . Thus, we estimate this function in a non-parametric fashion. In particular, we fit a spline (piecewise linear) to equation 8. An obvious non-parametric alternative is represented by kernel and local linear estimators. The problem with these methods is that they do not easily allow us to condition on other control variables, such as firm and time dummies.

No previous study has used splines to examine potential non-convexities in investment models. However, two contributions have adopted a non-parametric approach. In the spirit of the "gap methodology", Goolsbee and Gross (2000) estimate kernel regressions of investment as a function of the gap using a panel of firms in the U.S. airline industry and data on heterogeneous types of capital.<sup>19</sup> The average investment function has a flat portion for negative and low levels of mandated investment and a positively sloped lin-

---

<sup>19</sup> Although this aspect does not emerge clearly, the authors do not appear to undertake separate non-parametric analyses for each capital input.

ear portion as mandated investment increases. According to the authors, this finding is consistent with irreversibilities or with large costs of disinvestment, and quadratic costs conditional on positive investment. The other example is represented by Gelos and Isgut (2001a) who derive non-parametric estimates of the average adjustment function for Colombian and Mexican firms using a kernel estimator. For any mandated investment rate, the method computes a weighted average of the observed investment rates in its neighborhood, with weights given by the kernel.<sup>20</sup> The pictures presented by the authors do not look very different from the estimates with U.S. data obtained by Goolsbee and Gross (2000): negative mandated investment rates do not coincide with negative actual investment, suggesting irreversibilities. In the range of positive investment rates, however, the shapes of the estimated adjustment functions are approximately linear. In any event, the estimated functions are clearly different from the theoretical case of quadratic adjustment costs.

## 5 Empirical Results

As stated, we estimate equation 8 for homogeneous capital, equipment and structures using splines. We consider a 4-knot spline obtained by calculating the value of the fundamental Q at the two-decile points (20%, 40%, 60% and 80%). In this case, omitting time and firm subscripts, we can write 8 as follows:

$$h^r(FQ) = \alpha^r + \beta^r FQ \quad r = 1, \dots, 5 \quad (9)$$

where, indicating the knot by K, we have that  $K^r \leq FQ \leq K^{r+1}$ ,  $K^1 = 0$  and  $K^6 = \infty$ . The functions  $h^r(FQ)$  may be defined to be linear, quadratic, or of some higher order. In our model we consider them linear. The condition specifying the knots is

$$\alpha^{r+1} = \alpha^r + \beta^r K^r - \beta^{r+1} K^{r+1} \quad r = 1, \dots, 4 \quad (10)$$

Note that if the  $\beta^r$  are all equal we obtain the basic linear investment-fundamental Q relationship. We use linear splines because they are more easily interpretable relative to higher-order approximations. The estimation of the linear spline is performed using GMM applied to a reparametrized

---

<sup>20</sup>While the authors control for firm and time specific effects when estimating the frictionless capital stock, they do not do so in their kernel investment regressions.

model which solves in the knot restrictions. We use first differences to eliminate the individual effects which are likely to be correlated with the lagged values of investment rates.<sup>21</sup>

We begin by considering the case of net investment, that is purchases less sales of assets. The first step is to ask whether the 4-knot specification is adequate for the data or if further simplification is warranted. Hence, for each type of capital we test a 4-knot spline specification against a 2-knot case and a simple linear regression of investment on the own fundamental  $Q$ . Of course, the last case corresponds to the traditional quadratic adjustment costs specification. In Table 6 we report the values of the J specification test computed on the basis of the Sargan test of overidentifying restrictions (see Newey and West, 1987, and Bond, Bowsher and Windmeijer, 2001).<sup>22</sup> The 2-knot spline is computed by maintaining the first and the last segment of the 4-knot spline and by collapsing the other segments corresponding to the two-decile points 40%, 60% and 80%, to a single one. In this way the three specifications are nested within each other. In each of the three columns, the J-tests reject simplification of the 4-knot spline specification. However, in the case of structures, the result is ambiguous in the sense that, had we confined attention solely to the linear and 2-knot specifications, we would have been unable to reject linearity. This leaves us with a suspicion that the 4-knot spline specification for structures may be over-parameterized.

---

<sup>21</sup>Instruments are lagged values of operating income and sales, appropriately divided into the five ranges representing the spline, and a set of dummies defining the ranges of the spline.

<sup>22</sup>This test is a likelihood ratio test equivalent for GMM and is given by the expression:

$$D_{RU} = N \left( J \left( \tilde{\theta}_2 \right) - J \left( \hat{\theta}_2 \right) \right)$$

where  $\hat{\theta}_2$  is the two-step GMM estimator in the unrestricted model and  $\tilde{\theta}_2$  is the two-step GMM estimator in the restricted model. Under the null hypothesis that the restrictions are valid,  $D_{RU}$  has an asymptotic  $\chi^2$  distribution with  $r$  degrees of freedom.

Table 6: J-test Results - Net Investment

	<b>Aggregate</b>	<b>Equipment</b>	<b>Structures</b>
	1	2	3
Linear model vs 4-knot: $\chi_4^2$	32.0 (0.00%)	25.5 (0.00%)	11.1 (2.55%)
2-knot vs 4-knot spline: $\chi_2^2$	6.60 (3.69%)	13.8 (0.10%)	8.2 (1.66%)
Linear model vs 2-knot spline: $\chi_2^2$	25.4 (0.00%)	11.7 (0.29%)	2.90 (23.46%)

Note: rejection frequencies in parentheses

Figure 1 illustrates the splines in the case of net investment (purchases-sales) for aggregate investment, equipment and structures respectively.<sup>23</sup>

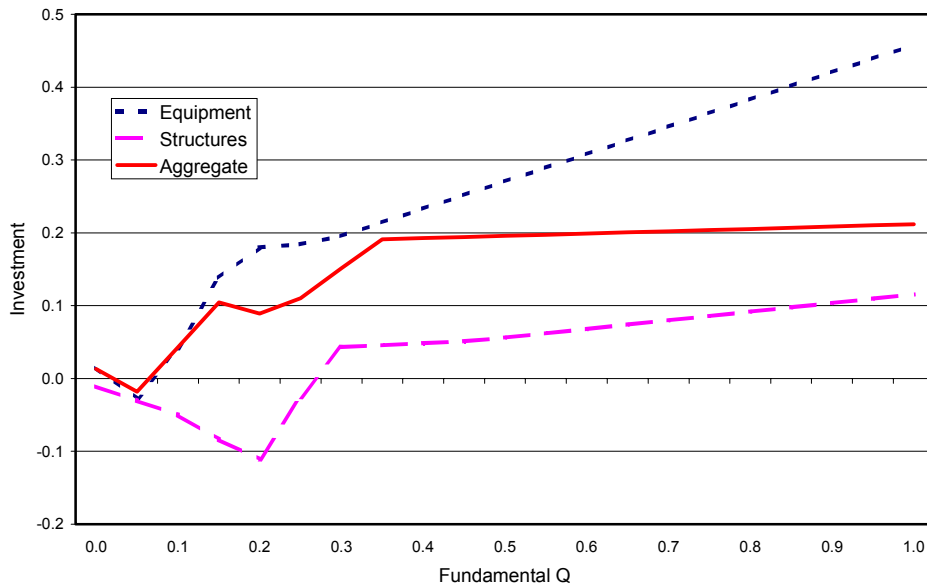


Figure 1: Figure 1: Net Investment - Purchases minus Sales

In the figure net investment is characterized by the following pattern: for values of the fundamental Q ranging between 0.0 and 0.4 net investment in equipment, structures and total assets displays a *S*-shape. For values larger

<sup>23</sup>Estimates are reported in Appendix A.6, Table A.6.1.

than 0.4 the relationship between investment and fundamental  $Q$  is linear, in particular it is positively sloped for equipment and structures, but it is almost flat for total assets. Before drawing any conclusion, however, we need to analyze the behavior of purchases and sales of assets separately.

Beginning with purchases of capital goods, in Table 7 the test for aggregate investment indicates that the 2-knot specification is the preferred specification. The test rejects linearity and shows that there is no gain in considering a 4-knot spline. In the case of equipment, instead, the test fails to reject the 4-knot spline specification, while, when we consider structures, we find that linearity cannot be rejected. Thus, in the case of purchases, the linearity characterizing the equation for structures is smoothing the spikiness we associated with the equipment equation, making the 2-knot specification an acceptable approximation for aggregate investment.

Table 7: J-test Results - Purchases of Assets

	<b>Aggregate</b>	<b>Equipment</b>	<b>Structures</b>
	1	2	3
Linear model vs. 4-knot spline	40.85 (0.00%)	32.40 (0.00%)	6.90 (14.13%)
2-knot spline vs. 4-knot spline	1.77 (77.76%)	18.40 (0.01%)	4.60 (10.03%)
Linear model vs. 2-knot spline	39.07 (0.00%)	14.00 (0.09%)	2.30 (31.66%)

Note: rejection frequencies in parentheses

When we consider purchases of capital goods we find a pattern similar to that of net investment. Indeed, in Figure 2, which shows the 4-knot spline for aggregate capital, equipment and structures respectively, again we find an initial  $S$ -shape followed by a positively sloped linear pattern in all three cases.<sup>24</sup>

---

<sup>24</sup>Estimates are reported in Appendix A.6, Table A.6.2.

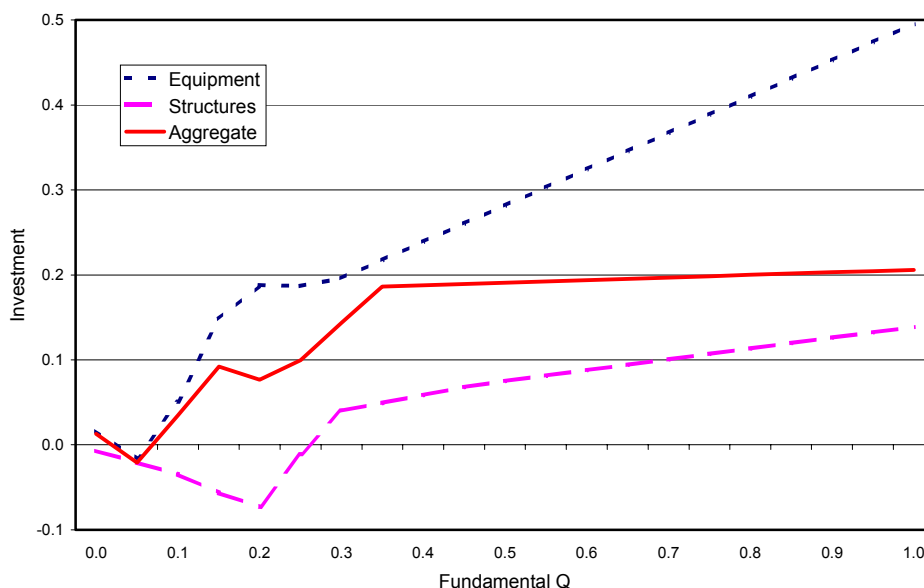


Figure 2: Figure 2: Purchases of Capital Assets

Consider now the case of sales of assets. In Table 8 we present the tests of the spline specifications. Despite the lack of precision in the estimates, the first two columns of the table suggest that the 4-knot spline specification is preferred. The same result appears to hold also for structures. However, as in the corresponding case reported in Table 2, the test fails to reject linearity relative to the 2-knot spline specification suggesting possible over-parameterization.<sup>25</sup>

<sup>25</sup>Estimates are reported in Appendix A.6, Table A.6.3. A few remarks concerning the econometric performance of the spline estimates are necessary. If we look at the specification tests in Tables A.6.1-A.6.3, we generally find support for our procedure. The only dubious cases are given by the Sargan tests in the net investment equation in the case of structures (column 3 in Table A.6.1), and more decisively the test for second order serial correlation for the net investment equation relating to total capital (column 1 in Table A.6.1). Turning to the estimated parameters, these are generally not significant in all the equations relating to sales (Table A.6.3) while the opposite happens in the case of net investment (Table A.6.1) and purchases (Table A.6.2). We find that structures perform less well than aggregate and equipment investments.

Table 8: J-test Results - Sales of Assets

	Aggregate	Equipment	Structures
	1	2	3
Linear model vs. 4-knot spline	13.80 (0.00%)	36.30 (0.00%)	14.50 (0.59%)
2 knot spline vs. 4-knot spline	8.00 (1.83%)	7.50 (2.35%)	14.20 (0.08%)
Linear model vs. 2-knot spline	5.80 (5.50%)	28.80 (0.00%)	0.30 (86.07%)

Note: rejection frequencies in parentheses

Sales of aggregate capital, equipment and structures are represented in Figure 3.

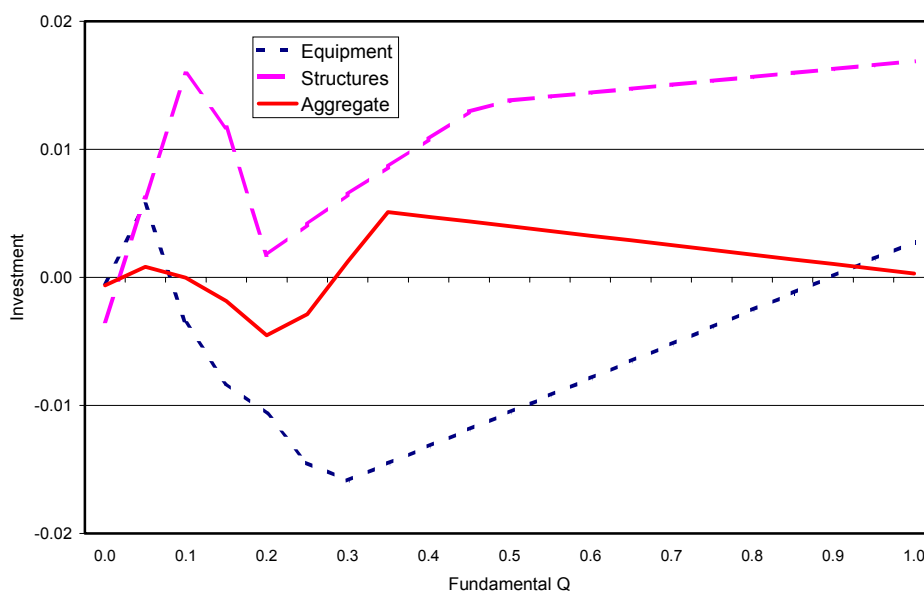


Figure 3: Figure 3: Sales of Capital Assets

Although we report the graphs for all the types of capital, the underlying estimated coefficients are not well-determined. The apparently highly non-linear behavior in the case of aggregate investment and structures is the



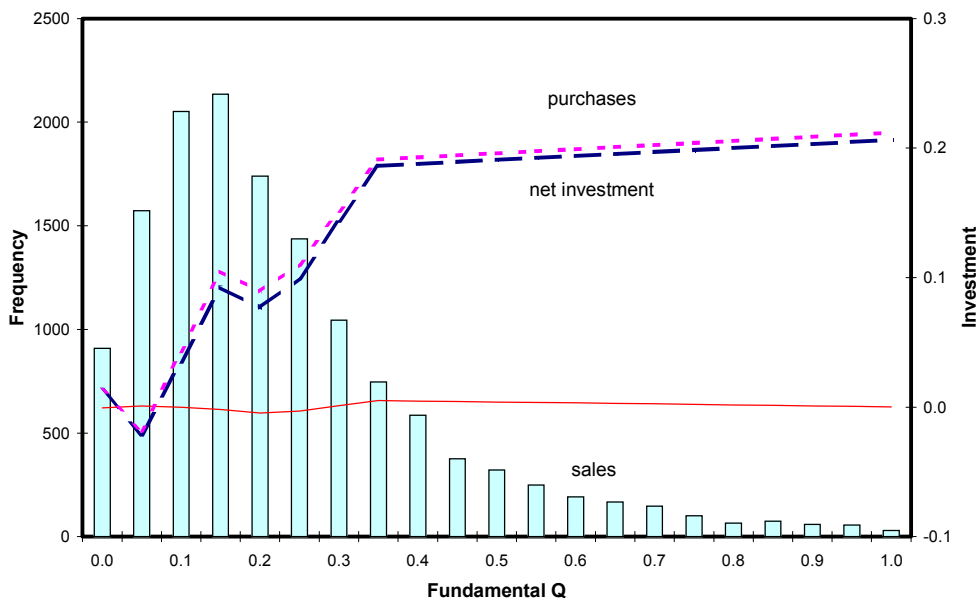


Figure 4: Figure 4: Firms' Distribution and 4-knot Spline - Aggregate Capital

consequence of lack of precision in the estimates. Interpreting this evidence in terms of the pattern of a firm's dynamic adjustment, therefore, appears of limited usefulness.

A very interesting exercise is represented by the following figures which show the distribution of the firms along the spline. In Figure 4 we present the case of aggregate investment (equipment plus structures) distinguishing between purchases, sales, and net investment. The graph shows that the highest percentage of firms is included in the region of values of the fundamental  $Q$  ranging between 0 and 0.4. This suggests that, in the case of net investment (purchases minus sales) and purchases, aggregate investment is typically non-linear. For the sake of completeness, we have also represented in the graph sales of aggregate capital, although, as explained earlier, the lack of precision in the estimates does not allow us to draw interesting conclusions.

In Figure 5 we describe the behavior of investment in equipment and maintain the distinction between purchases, sales, and net investment. The

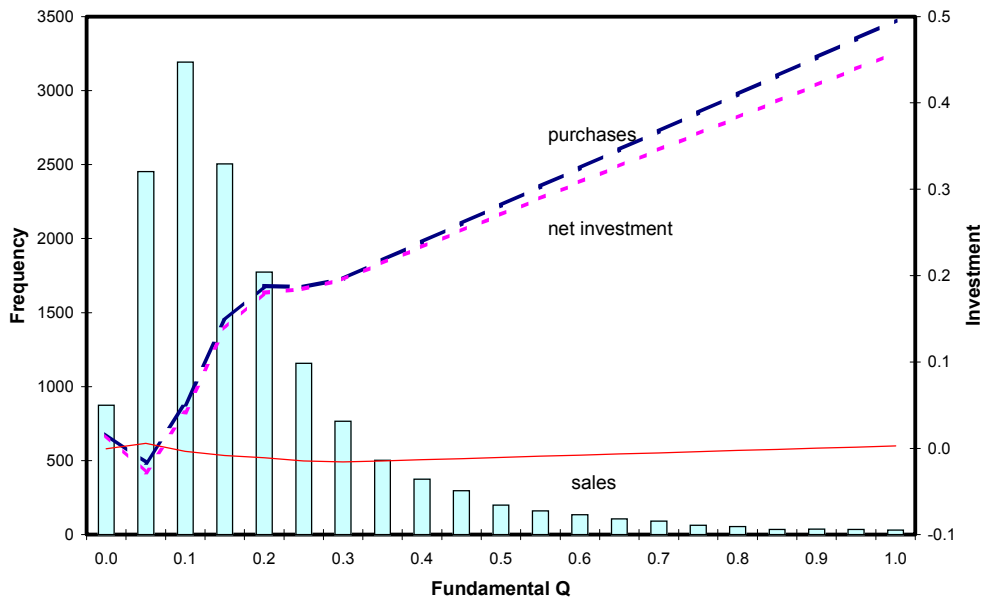


Figure 5: Figure 5: Firms' Distribution and 4-knot Spline - Equipment

values of the fundamental  $Q$  which describe the investment opportunities of the majority of the firms in our sample range between 0 and 0.3. The graph indicates that, in the case of equipment, net investment and purchases typically follow an S-shaped pattern. As in the previous graph, the lack of precision in the estimates of sales does not allow us to draw definitive conclusions on the pattern of dismissal of equipment.

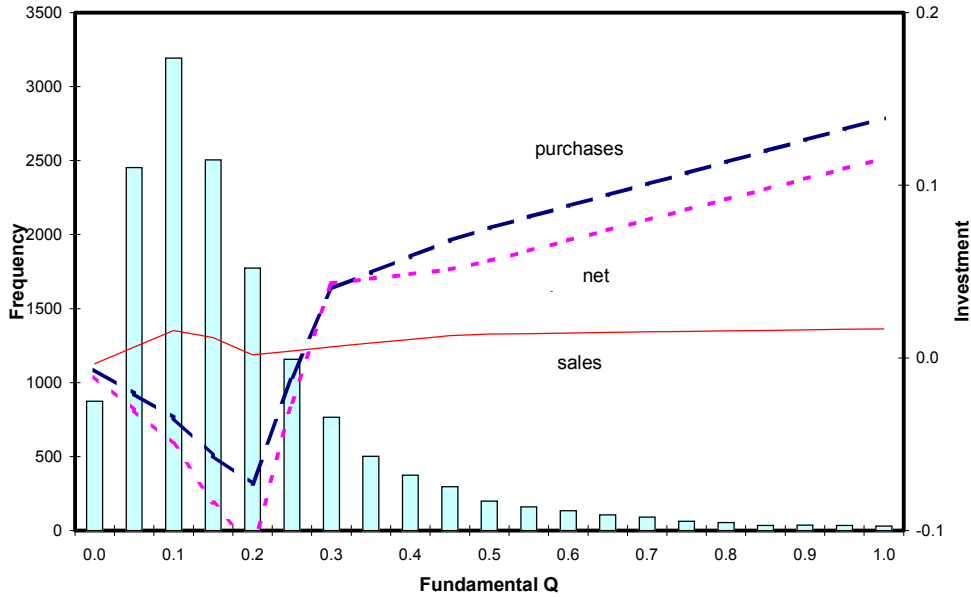


Figure 6: Figure 6: Firms' Distribution and 4-knot Spline - Structures

In Figure 6 we represent the 4-knot model in the case of structures. In the range of the fundamental  $Q$  between 0 and 0.3, while sales remain largely unidentified, we observe that purchases and net investment are characterized by a non-linear pattern.

The graphical representation of the spline estimation allows us to draw the following tentative conclusions. Firstly, in order to understand investment behavior it is not only very important to consider heterogeneous capital but also it is essential to distinguish between purchases and sales of assets. Secondly, the dynamic adjustment of capital goods is typically non-linear. Thirdly, if we restrict our attention to the case of purchases of assets and net investment (the pattern of the latter is dominated by purchases), we find that for an initial range of values of the fundamental  $Q$  between 0.0 and 0.4, the dynamic adjustment follows an *S*-shape. This implies that investment is much more responsive to (very) low values of  $Q$  and becomes less reactive to higher values of  $Q$ . Fourthly, the linear portion of the adjustment, which would be consistent with the traditional hypothesis of quadratic adjustment costs, is an acceptable representation for only a small number of firms. Fi-

nally, the underlying estimated coefficients for sales of capital goods are not well-determined. The apparently highly non-linear behavior in the case of aggregate investment and structures is the consequence of lack of precision in the estimates.

How do the above findings compare to those of other papers? Our initial *S*-shape region is consistent with the "convex for low *Q*s, concave for high *Q*s" pattern of Barnett and Sakellaris (1998). Interestingly, these authors consider purchases of assets as well as net investment. They adopt the Tobin's average *Q* methodology and estimate their model using U.S. data.<sup>26</sup> Our findings can also be comparable to those in Abel and Eberly (2002) who, as in the work by Barnett and Sakellaris, consider the U.S. case and the stock market-based average *Q*. In their homogeneous capital case, looking at purchases of assets, the authors find a decreasing response of investment to high values of *Q*.<sup>27</sup> They also find a statistically weak relationship between sales of capital assets and the Tobin's *Q*, in a Tobit framework.<sup>28</sup> Our results are also similar to those by Goolsbee and Gross (2000) who consider the U.S. airline industry and by Gelos and Isgut (2001), who analyze Colombian and Mexican plant-level data. Both studies adopt the gap methodology. They find that investment adjustment is characterized by an initial flat region followed, when investment becomes positive, by a positive linear portion consistent with quadratic costs of adjustment. Also in their case, therefore, linearity throughout the model is rejected.

---

<sup>26</sup>Barnett and Sakellaris (1998) use a technically more sophisticated approach than ours, which allows for endogenous thresholds or investment regimes. This complexity represents, however, the reason why the authors do not take into account the possibility of endogeneity of the Tobin's *Q*.

<sup>27</sup>Abel and Eberly (2002) obtain this results by estimating a parametric investment-*Q* relationship wich exploits an isoelastic specification of the adjustment cost function. This choice prevents the authors from obtaining *S*-shaped dynamic adjustment patterns.

<sup>28</sup>We do not make any reference, in this paper, to the heterogeneous capital goods case studied by Abel and Eberly (2002). The reason is that the authors start from the maintained assumption of a *linear* relationship between each asset-specific investment and the average *Q*. The non-linear pattern emerges through aggregation of individual assets because of different thresholds.

## 6 Conclusions

Much of the investment literature is based on the assumption of quadratic adjustment costs which implies linearity in the dynamic adjustment of the firm's capital inputs. Recent research on investment has highlighted the importance and the role of non-convexities and irreversibilities in capital inputs where the adjustment may be episodic and lumpy, and, as a consequence, be related non-linearly to fundamentals.

Several papers have attempted to validate these new approaches empirically. However, these investigations have all been based on the hypothesis of capital homogeneity and use data on a single aggregate capital input. Aggregation may hide non-convex patterns in adjustment costs and irreversibilities and smooth out the discontinuities of the individual adjustment of various capital inputs.

In this paper we have explicitly considered non-linear dynamic adjustment patterns for heterogeneous capital: our capital input is disaggregated in equipment and structures. We rely on the notion of fundamental  $Q$  to summarize investment opportunities associated with each individual capital input. Specifically, we use spline functions, to study the nature of the dynamic adjustment of investment in each capital input.

Our results confirm that the linear adjustment pattern implied by the quadratic adjustment cost assumption is generally contradicted. In particular, we find clear evidence of non-linear behavior in the case of purchases of different capital goods. Firms show an  $S$ -shaped pattern for purchases of capital goods and net investment in relation to our measure of fundamental  $Q$ . Our findings are in line with the evidence found in recent studies of corporate investment decisions in which patterns of aggregate investment may be very different from those in individual capital assets. We find that it is crucial to distinguish between purchases and sales of assets and conclude that it is essential to consider all these types of disaggregation if we are to understand firms' investment decisions.

## References

- Abel, A.B. and O.J. Blanchard (1986), "The Present Value of Profits and Cyclical Movements in Investment", *Econometrica*, 54, 249-273.
- Abel, A.B. and J.C. Eberly (1994), "A Unified Model of Investment Under Uncertainty", *American Economic Review*, 84, 1369-1384.
- Abel, A.B. and J.C. Eberly (1996), "Optimal Investment with Costly Reversibility", *Review of Economic Studies*, 63, 581-593.
- Abel, A.B. and J.C. Eberly (2002), "Investment and  $q$  with Fixed Costs: An Empirical Analysis", University of Pennsylvania, mimeo, revised.
- Barnett, S.A. and P. Sakellaris (1998), "Non-Linear Response of Firm Investment to  $Q$ : Testing a Model of Convex and Non-Convex Adjustment Costs", *Journal of Monetary Economics*, 42, 261-288.
- Barnett, S.A. and P. Sakellaris (1999), "A New Look at Firm Market Value, Investment, and Adjustment Costs", *Review of Economics and Statistics*, 81, 250-260.
- Bond, S., C. Bowsher, and F. Windmeijer (2001), "Criterion-based Inference for GMM in Autoregressive Panel-data Models", *Economics Letters*, 73, 379-388.
- Bond, S.R., D. Harhoff, and J. Van Reenen (1999), "Investment, R&D and Financial Constraints in Britain and Germany", Institute for Fiscal Studies Working Paper N.99/5.
- Bond, S.R. and J.G. Cummins (2000), "The Stock Market and Investment in the New Economy: Some Tangible Facts and Intangible Fictions", *Brookings Papers on Economic Activity*, 1, 61-108.
- Bontempi, M.E., A. Del Boca, A. Franzosi, M. Galeotti, and P. Rota (2001), "Capital Heterogeneity: Does It Matter? Fundamental  $Q$  and Investment on a Panel of Italian Firms", Fondazione Eni Enrico Mattei Working paper N.88.01.
- Caballero, R.J. and E.M.R.A. Engel (1999), "Explaining Investment Dynamics in U.S. Manufacturing: A Generalized (S,s) Approach", *Econometrica*, 67, 783-826.
- Caballero, R.J. (1997), "Aggregate Investment", National Bureau of Economic Research Working Paper N.6264, forthcoming in J.B. Taylor and M. Woodford (eds.), *Handbook of Macroeconomics*, Amsterdam: North-Holland.
- Caballero, R.J., E.M.R.A. Engel, and J.C. Haltiwanger (1995), "Plant-Level Adjustment and Aggregate Investment Dynamics", *Brookings Papers on Economic Activity*, 2, 1-39.

Carlsson, M. and S. Laséen (2001), "Capital Adjustment Patterns in Swedish Manufacturing Firms: What Model Do They Suggest?", mimeo, Department of Economics, Uppsala University.

Chirinko, R.S. (1993), "Investment, Tobin's  $Q$ , and Multiple Capital Inputs", *Journal of Economic Dynamics and Control*, 17, 907-928.

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

Cummins, J.G. and M. Dey (2000), "Taxation, Investment, and Firm Growth with Heterogenous Capital", mimeo.

Davidson, R. and J.G. MacKinnon (1993), *Estimation and Inference in Econometrics*, Oxford: Oxford University Press, 1993.

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

Doms, M., and T. Dunne (1998), "Capital Adjustment Patterns in Manufacturing Plants", *Review of Economic Dynamics*, 1, 409-429.

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

Galeotti, M. (1987), "On the Dual Relationship between Flexible Accelerator and  $Q$  Theories of Investment: A Note", *Rivista Internazionale di Scienze Economiche e Commerciali*, XXXIV, 771-776.

Galeotti, M. and F.Schiantarelli (1991), "Generalized  $Q$  of Investment", *Review of Economics and Statistics*, 73, 383-392.

Galeotti, M. and F.Schiantarelli (1994), "Stock Market Volatility and Investment: Do Only Fundamentals Matter?", *Economica*, 61, 147-165.

Gelos, R.G. and A. Isgut (2001a), "Irreversibilities in Fixed Capital Adjustment. Evidence from Mexican and Colombian Plants", *Economics Letters*, 74, 85-89.

Gelos, R.G. and A. Isgut (2001b), "Fixed Capital Adjustment: Is Latin America Different?", *Review of Economics and Statistics*, 83, 716-726.

Gilchrist, S. and C. Himmelberg (1995), "Evidence on the Role of Cash Flow for Investment", *Journal of Monetary Economics*, 36, 541-572.

Gilchrist, S. and C. Himmelberg (1998), "Investment, Fundamentals and Finance", National Bureau of Economic Research Working Paper N.6652.

Goolsbee, A. and D.B. Gross (2000), "Estimating Adjustment Costs with Data on Heterogenous Capital Goods", National Bureau of Economic Research Working Paper No.6342, Revised.

Hayashi, F. and T. Inoue (1991), "The Relation between Firm Growth and  $Q$  with Multiple Capital Goods: Theory and Evidence from Panel Data on Japanese Firms", *Econometrica*, 59, 731-753.

Holtz-Eakin, D., W. Newey, and S. Rosen (1988), "Estimating Vector Autoregressions with Panel Data", *Econometrica*, 56, 1371-1395.

Newey, W.K. and K.D. West (1987), "Hypothesis Testing with Efficient Method of Moments Estimation", *International Economic Review*, 28, 777-787.

Nickell, S. and D. Nicolitsas (1996), "Does Innovation Encourage Investment in Fixed Capital?", LSE Centre for Economic Performance Discussion Paper N.309.

Nilsen, Ø.I., and F. Schiantarelli (2000), "Zeroes and Lumps in Investment: Empirical Evidence on Irreversibilities and Non-convexities", Department of Economics Working paper No. 337, Boston College, Revised.

Pindyck, R.S. and J.J. Rotemberg (1983), "Dynamic Factor Demands under Rational Expectations", *Scandinavian Journal of Economics*, 85, 223-238.

Whited, T.M. (1994), "Problems with Identifying Adjustment Costs from Regressions of Investment on  $q$ ", *Economics Letters*, 46, 339-344.

Whited, T.M. (1998), "Why, and to What Extent, Do Investment Euler Equations Fail?", *Journal of Business and Economic Statistics*, 16, 479-488.



# A Appendix

## A.1 Variable Specification

- **Aggregate variables**

$\delta_T, \delta_E, \delta_S$ : depreciation rates of total fixed assets, equipment and structures by year and 2-digit manufacturing industry (source: **ISTAT**, Italian Statistical Office).

$p_T, p_E, p_S$ : price indexes for investment in total assets, equipment and structures by year and 2-digit manufacturing industry (1995=1), (source: ISTAT).

$pp$ : output price index for the 13 sub-sectors of the manufacturing industry. This price index is normalized to unity for 1995, (source: ISTAT).

$z$ : output price rate of inflation for the 13 sub-sectors of the manufacturing industry (1995=1), (source: ISTAT).

$\tau$ : statutory corporate tax rate on firm profits, equal to 46.368% in 1985-1990; 47.826% in 1991, 52.2% in 1992-1994; and 53.2% in 1995.

- **Firm-specific variables:**

$r$ : effective interest rate on financial debt, computed as interest expenses on bank loans, factoring and leasing divided by the corresponding stock of debt.

$\tilde{K}_T, \tilde{K}_E, \tilde{K}_S$ : end of period book values of gross total fixed assets, equipment (which includes plant+machinery+equipment), and structures (which include land+buildings). Total fixed assets are equal to the sum of plant, machinery, equipment, land and buildings.

$N\tilde{K}_T, N\tilde{K}_E, N\tilde{K}_S$ : end of period book values of net total fixed assets, equipment and structures. For period 1991-95, the book values of both gross and net capital goods are available in the dataset. For period 1982-1990, we only have book values of gross equipment and structures; the disaggregated book values of net capital goods are obtained by subtracting the corresponding share of book value of accumulated depreciation.

$I_T^+, I_E^+, I_S^+$ : capital expenditures on total fixed assets, equipment and structures. This measure includes only direct purchases of new fixed assets and it does not include fixed assets acquired through takeovers and acquisitions.

$I_T^-, I_E^-, I_S^-$ : sales of total fixed assets, equipment and structures. These variables measure the sale value, and not the historical cost, i.e. it amounts to the remaining book value of sold assets (acquisition minus the book value of accumulated depreciation of assets that are sold or dismissed during the year) plus the difference between the historical acquisition cost and the market price of the sale.

Given that we only have total purchases and sales, we use the method proposed by Bond and Meghir (1994) in order to disaggregate investment and disinvestment. We use the change in gross fixed assets to estimate purchases and sales of plant and machinery and equipment according to:

$$I_{E,it}^+ = I_{T,it}^+ \frac{\tilde{K}_{E,it} - \tilde{K}_{E,it-1}}{\tilde{K}_{T,it} - \tilde{K}_{T,it-1}}$$

where  $E$  indicates equipment, subscript  $T$  refers to total investment or capital,  $i$  indicates firms, and  $t$  and  $t - 1$  are time subscripts.

Gross investment in structures is obtained by the difference:

$$I_{S,it}^+ = I_{T,it}^+ - I_{E,it}^+$$

The same procedure applies to the case of sales,  $I_{E,it}^-$  and  $I_{S,it}^-$ .

$I_T, I_E, I_S$ : net investment in total fixed assets, equipment and structures. Net investment is computed as the difference between direct purchases,  $I_{j,it}^+$ ,  $j = T, E, S$ , and sales,  $I_{j,it}^-$ ,  $j = T, E, S$ , of capital goods.

$K_T, K_E, K_S$ : replacement cost values of total fixed assets, equipment and structures. These values are estimated from historic cost accounts by using an iterative perpetual inventory formula, modified in order to take into account the "Visentini Law", which allowed firms to revalue the book values of their capital stock in 1982 and 1983. Thus, to obtain starting values for the iterative procedure we adopt the following rule: 1) we assume that the replacement cost values are equal to the historic cost values in 1982 if firms chose to revalue in 1982 or if they did not revalue at all; 2) otherwise we consider 1983 as the starting year if companies revalue their capital stock in 1983.

The iterative perpetual inventory formula used to calculate the replacement cost values of each type of capital is the following:

$$K_{j,it+1} = K_{j,it} (1 - \delta_{j,ht+1}) (p_{j,ht+1}/p_{j,ht}) + I_{j,it+1}$$

where  $j = T, E$  and  $S$ ,  $h$  indicates industry, and the initial  $K_j$  is equal to the net book value of capital good  $j$  in 1982 or 1983.

Investment and capital stocks are all expressed at constant prices using the relevant price indices  $p_{j,ht}/p_{j,ht+1}$ .

$S_T, S_E, S_S$ : real sales as a proxy for the nominal value of output deflated by the output price index,  $pp$ , disaggregated at 2-digit industry level.

$\Pi_T, \Pi_E, \Pi_S$ : operating income as a proxy for marginal product of capital, deflated by the output price index,  $pp$ , disaggregated at 2-digit industry level. Operating income is defined as: income before depreciation allowances, financial and extraordinary items, discontinued operations, taxes, and preference dividends.

## A.2 The Dataset and Cleaning Criteria

The original sample is a balanced panel of 5,086 manufacturing limited liabilities companies for the years 1982 through 1995; we chose firms with 12-month balances in order to standardise all stock balances and flow items. The final dataset we obtained after applying cleaning criteria is a balanced panel of 1,539 manufacturing companies for period 1985-1995<sup>29</sup>. Our trimming rules were the following:

- We eliminate firms with missing data on the beginning-of-period aggregated and disaggregated capital stock, investment and disinvestment, sales, and operating income. This eliminates 37.30% of the firms.
- Firms with negative replacement values of the capital stock are also eliminated since they are generated when net investment is greater than lagged capital stock as a consequence of large sales of capital goods. This criterion implies an additional loss of 23.44% of companies.

---

<sup>29</sup>The loss of three years at the beginning of the sample is due to the replacement value formula for capital stock (see previous section) and to the construction of investment rates based on capital lagged one period.

- In order to minimize measurement errors we only consider: investment rates between -1% and 5%; ratio of real output to capital between 20% and 150%; operating earnings between -50% and 75% of sales; marginal productivity of capital between -27% and 127.5%. These final criteria cut 9% of companies. Elimination of strong outliers is necessary for disaggregating investment. Our procedure uses changes in gross capital stocks: these include not only investment but also mergers, acquisitions, divestitures, selloffs and other miscellaneous transactions.

In Table A.2.1 we show the distribution of firms by 2-digit industry and the distribution of firms by size, measured by the number of employees.

Table A.2.1: Distribution of Firms by Industry and Size

<b>Industry</b>	<b>No. of firms</b>	<b>Frequency</b>
Food, drinks and tobacco	167	10.85
Textile and clothing	177	11.5
Leather and footwear	31	2.01
Timber and wooden furniture	34	2.21
Paper and printing	82	5.33
Oil, chemicals and fibres	128	8.32
Rubber and plastic	101	6.56
Minerals	116	7.54
Metal and metal goods	108	7.02
Mechanical engineering	384	24.95
Electric materials and precision instrum.	93	6.04
Motor vehicles and other transport equip.	36	2.34
Other manufacturing	82	5.33
<b>Size</b>		
0-49	454	29.71
50-249	875	57.26
$\geq 250$	199	13.02

### **A.3 The Frequency of Zero and Negative Investment by Industry and Size**

In Tables A.3.1 and A.3.2, we further analyse the frequency of zero and negative net investment by sectors and size.

Table A.3.1: Zero Net Investment by Industry and Size

<b>Industry</b>	<b>Aggregate</b>	<b>Equipment</b>	<b>Structures</b>
Food, drinks and tobacco	0.16	0.22	10.45
Textile and clothing	0.51	0.56	16.90
Leather and footwear	0.59	0.88	26.39
Timber and wooden furniture	0.53	0.53	10.43
Paper and printing	0.33	0.33	11.09
Oil, chemicals and fibres	0.50	0.64	11.43
Rubber and plastic	0.27	0.36	11.16
Minerals	0.71	0.78	11.68
Metal and metal goods	0.17	0.25	10.10
Mechanical engineering	0.59	0.73	16.93
Electric materials and precision instruments	0.39	0.39	15.25
Motor vehicles and other transport equip.	-	-	16.16
Other manufacturing	0.22	0.33	10.86
<b>Size</b>			
0-49	0.56	0.72	18.84
50-249	0.43	0.50	2.09
≥250	0.14	0.14	1.92

Table A.3.2: Negative Net Investment by Industry and Size

<b>Industry</b>	<b>Aggregate</b>	<b>Equipment</b>	<b>Structures</b>
Food, drinks and tobacco	2.34	10.18	11.38
Textile and clothing	2.77	10.73	11.66
Leather and footwear	3.23	8.21	12.90
Timber and wooden furniture	2.94	11.23	10.43
Paper and printing	3.10	9.42	11.31
Oil, chemicals and fibres	2.20	9.16	11.79
Rubber and plastic	2.97	9.99	12.69
Minerals	2.12	9.01	13.48
Metal and metal goods	2.02	8.42	10.10
Mechanical engineering	2.32	9.16	11.91
Electric materials and precision instruments	1.27	6.74	12.02
Motor vehicles and other transport equip.	3.03	9.60	10.86
Other manufacturing	1.88	8.87	11.42
<b>Size</b>			
0-49	3.08	9.99	11.69
50-249	2.09	9.06	11.54
$\geq 250$	1.92	8.95	12.88

Null net investment in structures ranges from 10.10 percent in "Metal" to 26.39 percent in "Leather"; inactivity in equipment never occurs in "Motor vehicles" and reaches 0.88 percent in "Leather". Negative net investment in structures ranges from 10.10 percent (in "Metal") to 13.48 percent (in "Minerals"), while negative net investment in equipment ranges from 8.21 percent in "Leather" to 11.23 percent in "Timber". In general, we do not observe great concentration by industry. As far as size is concerned, inaction is relatively more frequent in small companies, while net sales of structures are more frequent in large firms.

#### A.4 Calculation of $\tilde{\sigma}_{j,h}$ and $\tilde{\rho}_{j,h}$ at the Industry Level

Table A.4.1: Estimates of  $\tilde{\sigma}_{j,h}$  and  $\tilde{\rho}_{j,h}$  by Industry

Industry	$\tilde{\sigma}_{j,h}$			$\tilde{\rho}_{j,h}$		
	Agg.	Eq.	Str.	Agg.	Eq.	Str.
Food, drinks and tobacco	0.046	0.028	0.013	0.617	0.380	0.166
Textile and clothing	0.069	0.038	0.020	0.660	0.372	0.184
Leather and footwear	0.051	0.034	0.14	0.647	0.440	0.170
Timber and wooden furniture	0.095	0.055	0.027	0.844	0.495	0.231
Paper and printing	0.088	0.063	0.021	0.753	0.541	0.174
Oil, chemicals and fibres	0.051	0.032	0.018	0.478	0.300	0.156
Rubber and plastic	0.082	0.049	0.022	0.712	0.425	0.190
Minerals	0.101	0.066	0.024	0.754	0.499	0.179
Metal and metal goods	0.072	0.047	0.020	0.701	0.468	0.193
Mechanical engineering	0.064	0.036	0.019	0.578	0.325	0.167
Electric materials and precision instruments	0.065	0.039	0.018	0.479	0.286	0.131
Motor vehicles and other transport equip.	0.064	0.038	0.015	0.587	0.333	0.137
Other manufacturing	0.072	0.040	0.024	0.763	0.422	0.260



## A.5 VAR(2) Estimation

In these and the following tables time dummies are not reported, standard errors are in parentheses, and single, double, and triple asterisks denote 10%, 5% and 1% levels of significance respectively. Sargan stands for the test of overidentifying restrictions, whereas AR(1) and AR(2) are tests of first and second order residual autocorrelation. The estimation period is 1987-1995. Estimation is in first differences. Instruments are time dummies and lagged values (two and three lags) of operating-income-based marginal profitability (indicated by  $oi$  in the tables) and sales-based marginal profitability (indicated by  $s$  in the tables).

Table A.5.1: VAR(2) - Operating Income-Based Marginal Profitability

Variables	Coefficients		
	(1) Aggregate	(2) Equipment	(3) Structures
$oi(-1)$	0.691** (0.040)	0.588** (0.057)	0.654** (0.064)
$oi(-2)$	-0.029 (0.023)	-0.055 (0.041)	-0.020 (0.0387)
$s(-1)$	0.018 (0.048)	-0.071 (0.076)	0.101 (0.079)
$s(-2)$	-0.104* (0.038)	0.006 (0.055)	-0.081 (0.069)
<b>no. of observations</b>	12312	12132	12312
<b>Sargan <math>\chi^2</math></b>	31.32	48.35**	40.51
<b>AR(1) N(0,1)</b>	-12.87**	-5.51**	-7.39**
<b>AR(2) N(0,1)</b>	0.40	0.18	1.03

Table A.5.2: VAR(2) - Sales Based Marginal Profitability

Variables	Coefficients		
	(1) Aggregate	(2) Equipment	(3) Structures
$oi(-1)$	0.016 (0.022)	-0.008 (0.037)	-0.013 (0.033)
$oi(-2)$	-0.001 (0.015)	-0.021 (0.034)	0.009 (0.025)
$s(-1)$	0.816** (0.043)	0.636** (0.081)	0.824** (0.058)
$s(-2)$	-0.133** (0.032)	-0.064 (0.057)	-0.059 (0.047)
<b>no. of observations</b>	12312	12132	12312
<b>Sargan <math>\chi^2</math></b>	50.89	60.66**	46.38*
<b>AR(1) N(0,1)</b>	-8.46**	-6.48**	-7.35**
<b>AR(2) N(0,1)</b>	-0.24	0.86	0.98

## A.6 Spline estimates

Table A.6.1: Spline5 - Net Investment

	Coefficients		
	(1) Aggregate	(2) Equipment	(3) Structures
Q1	-0.628 (0.259)	-0.853 (0.670)	-0.390 (1.013)
Q2	1.739 (0.446)	2.402 (1.116)	-0.828 (0.930)
Q3	-0.307 (0.447)	1.774 (0.983)	1.711 (0.681)
Q4	0.825 (0.255)	0.087 (0.535)	0.332 (0.332)
Q5	0.032 (0.050)	0.374 (0.107)	0.118 (0.013)
<b>no. of observations</b>	13851	13851	13851
<b>Sargan test <math>\chi^2_{220}</math></b>	249.6	197.5	271.1*
<b>AR(1) N(0,1)</b>	-13.52**	-13.50**	-15.38**
<b>AR(2) N(0,1)</b>	-5.142**	0.8247	1.151

Table A.6.2: Spline5 - Purchases

	Coefficients		
	(1) Aggregate	(2) Equipment	(3) Structures
Q1	-0.685 (0.270)	-0.658 (0.688)	-0.278 (1.042)
Q2	1.623 (0.522)	2.252 (1.106)	-0.522 (1.01)
Q3	-0.312 (0.516)	1.839 (0.928)	1.236 (0.748)
Q4	0.885 (0.284)	-0.024 (0.505)	0.186 (0.350)
Q5	0.031 (0.047)	0.427 (0.109)	0.127 (0.088)
<b>no. of observations</b>	13851	13851	13851
<b>Sargan test <math>\chi^2_{220}</math></b>	240.6	182.8	271.0
<b>AR(1) N(0,1)</b>	-6.191**	-9.546**	-7.540**
<b>AR(2) N(0,1)</b>	-1.709	0.777	0.898

Table A.6.3: Spline5 - Sales

	<b>Coefficients</b>		
	<b>(1)</b> <b>Aggregate</b>	<b>(2)</b> <b>Equipment</b>	<b>(3)</b> <b>Structures</b>
Q1	0.029 (0.057)	0.122 (0.244)	0.193 (0.247)
Q2	-0.030 (0.181)	-0.325 (0.276)	-0.230 (0.278)
Q3	-0.053 (0.152)	-0.011 (0.199)	0.047 (0.197)
Q4	0.081 (0.067)	-0.076 (0.113)	0.043 (0.069)
Q5	-0.007 (0.008)	0.026 (0.019)	0.006 (0.012)
<b>no. of observations</b>	13851	13851	13851
<b>Sargan test</b> $\chi^2_{220}$	176.9	160.9	187.4
<b>AR(1) N(0,1)</b>	-3.435**	-4.234**	-2.801**
<b>AR(2) N(0,1)</b>	0.144	-0.291	1.019