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Empirical Evidence on Irreversibility and Non-convexities

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Abstract

This paper provides empirical evidence on the effect of irreversibility and non-convexities in adjustment costs on firm investment decision based on 1996-2002 firm level data from the Ethiopian manufacturing. It relies on a rich census based panel data set that gives the advantage of disaggregating investment into different types of fixed assets. We document evidence of a large percentage of inaction intermitted with lumpy investment, which is consistent with irreversibility and fixed costs but not with the standard convex adjustment costs. The inaction is higher and investment lumpier for small firms. We complement the descriptive analysis with two econometric methods: a capital imbalance approach and a machine replacement model. With the capital imbalance approach we estimate the investment response of firms to their capital imbalance using a non-parametric Nadaraya-Watson kernel smoothing method. With the machinery replacement approach using a proportional hazard model that takes unobserved heterogeneity into account, we estimate the probability of an investment spike conditional on the length of the interval from the last investment spike.

Key words: Investment, irreversibility and adjustment costs, manufacturing, Ethiopia

JEL-Classification: C14; E22; O12; N67

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1. Introduction

There has been a growing interest in modeling micro or firm level investment decisions in the last two decades. The introduction of adjustment costs following Eisner and Strotz (1963), with a main premise that capital cannot be adjusted without cost, has given way to a dynamic specification of investment models. The standard working assumption in this model is that the adjustment cost is strictly convex and differentiable. With a strictly convex adjustment cost assumption, the unit cost of investment rises as the scale of investment increases, making large and rapid investment extremely costly. Thus, a profit-maximizing firm tends to spread or smooth its investment over time in order to avoid increasing marginal costs. However, the prediction of this standard neoclassical investment model is at odds with the facts documented in different empirical studies.

Recent literature emphasizes the importance of non-convexity of adjustment costs including fixed and piecewise linear costs. Adjustment costs are fixed if the costs incurred are independent of the size of the investment.[1] The growing literature on irreversibility, started by Dixit and Pindyck (1994), provides another dimension that casts doubt on the standard assumption. Irreversibility arises from the difference between the purchasing and selling price of capital, mainly due to less developed markets for second-hand capital and the specificity of capital equipment. Irreversibility makes investments particularly sensitive to various forms of risks such as uncertainty regarding future product prices, input costs, tax structure, exchange rates, and regulatory activities.

[1] Rothschild (1971) shows the plausibility of fixed adjustment costs, e.g. costs of search and managerial decision, obtaining external financing, shutting down a plant while installing new equipment, and costs of information.

The departure from the neoclassical assumption has had a profound effect on our understanding of firm investment behavior. Unlike the incremental investment prediction of the strictly convex adjustment cost models, the irreversibility and fixed adjustment cost models suggest lumpy and intermittent investment. If adjustment costs are fixed average costs decrease with the size of investment and a rational firm reduces its cost by bunching its investments into a few periods. There are two important effects of irreversibility on investment behavior. First, with a negative shock the firm cannot disinvest in the presence of (total) irreversibility. Thus, gross investment is constrained to be non-negative even in the existence of excess capital. Second, there is a caution effect with regard to positive shocks. Firms do not respond immediately to small changes in fundamentals; rather, they tend to wait until certain thresholds are reached, which in turn extends the range of inaction. The range of inaction is particularly pronounced when irreversibility is combined with the presence of fixed costs.

A number of empirical studies that rely on micro level data have also documented inaction and lumpiness of investment that are difficult to match with convex adjustment costs (Doms and Dunne, 1994; Bortello and Caballero, 1994; Abel and Eberly, 1996; Caballero, Engel, and Haltiwanger, 1995; Cooper, Haltiwanger, and Power, 1999; and Nilsen and Schiantarelli, 2003). Most of these empirical works are, however, based on the Longitudinal Research Database for the USA manufacturing sector. Such empirical studies are scant in Sub-Saharan Africa (SSA hereafter).

Nonetheless, we argue that if there are any gains from diverging from the neoclassical investment models to irreversibility and non-convex adjustment costs, they should become clear when looking at developing countries, and particularly at SSA for the following reasons. First, the importance of irreversibility and non-convex adjustment costs on firm investment behavior should theoretically be pronounced in developing countries. This is due to limited and shallow secondary markets for capital goods, poor infrastructure, underdeveloped and often badly functioning financial markets, and a dense and uncertain regulatory environment often present in these economies. Second, the descriptive statistics in SSA manufacturing so far provide an exceptionally high range of inaction (i.e. on average about 58 percent of observations with zero investment episodes) in comparison to other regions (see Table A2). Third, SSA manufacturing firms invest less, with a median investment rate equal to zero despite high profit rates which is generally not explained by financial constraints (Gunning and Mengistae, 2001). We have also detected similar pattern (i.e. high profit rate but low investment rates) in our data for the Ethiopian manufacturing firms.

Why is the inaction rate exceptionally high and investment generally low in these economies, despite the presence of high profit rates? How important are irreversibility and adjustment costs in determining investment decision. The only paper we are aware of that explicitly investigates the effect of irreversibility and adjustment costs in SSA is Bigsten et al. (2005), which rely on a survey data from five SSA countries (Cameroon, Ghana, Kenya, Zambia, and Zimbabwe) manufacturing firms. They found that irreversibility has a significant impact on investment behavior, but no evidence of fixed costs. In this study we use different data set from Ethiopian manufacturing to show if their findings apply to other SSA countries. Unlike to Bigsten et al. (2005) our data is census based that covers all manufacturing firms with 10 and above workers and runs for longer period (7 years panel). Most importantly our data gives advantage of disaggregating investment by type of fixed assets: machinery and equipment, non-residential building, vehicle, fixture, and furniture investment. This is very important in understanding the pattern of capital adjustment given the heterogeneous nature of the capital stock.

In the descriptive analysis part, we document evidence of a large percentage of inaction intermitted with lumpy investment, which is consistent with irreversibility and fixed costs but not with the standard convex adjustment costs. In identifying the nature of adjustment costs and irreversibility, we applied two econometric methods: the capital imbalance approach following Caballero and Engel (1994) and the machine replacement model following Cooper, Haltiwanger, and Power (1999). The econometric models provide evidence that supports not only the irreversibility but also non-convex adjustment costs, particularly for the disaggregated capital.

The next section describes background and data source. Section 3 discusses the pattern and distribution of investment. Section 4 presents econometric evidence and the last section summarizes the findings.

2. Background and Data Source

The Ethiopian manufacturing sector underwent large structural changes in the last three decades. During the military regime (1975-91) the private sector was deliberately discouraged by the confiscation of industrial establishments, restriction on the activities allowed for the private sector participation, a capital ceiling imposed on the private sector investment of roughly quarter a million USD. The output, factor, and credit markets were also heavily regulated and priority was given to public enterprises in the allocation of credit, foreign exchange, and market access. As a result, the majority of medium and large manufacturing establishments (with 10 or more employees according to CSA definition) were state owned while the private sector shrunk. For example, in 1989 the private sector contribution in terms of production and employment in the formal manufacturing sector was only 4 percent and 8 percent respectively (CSA, 1990).

With the regime change in 1991, a structural adjustment program was adopted and a series of reforms have been taken. Industrial restructuring that include, de-regulation, trade opening and privatization has been the key elements of the structural adjustment program. Most price controls and restrictions on private investment have been lifted. The foreign exchange market has been liberalized starting with a massive devaluation over 150 percent in October 1992. A weekly auction system has been introduced whereby the exchange rate is determined. The financial market has also been liberalized by making lending rates market determined. This was anticipated to change the overall incentive structure in favor of exports, private investment and diversification of exports and output structure in favor of manufactured goods.

Following these and other broad reforms the Ethiopian GDP per-capita grew at annual average 2.3 percent between 1994 and 2002 (see Table 1). The service sector share of GDP in terms of value added increased from 35 percent to 48 percent while agriculture shrank from 55 to 40 percent in the same period. However, the industrial sector contribution stagnated at around 11 percent of GDP, with manufacturing accounting for no more than 7 percent.

The number of establishments in the formal manufacturing sector, with 10 or more employees, almost doubled between 1994 and 2002. The rise in the number of firms was due to the high entry rate in the private sector, which accounted about 85 percent of the firm population in 2002. However, the annual growth rate of real production and employment of this sector was only 4 percent and 1.4 percent respectively. This suggests that most of the new entering firms are smaller in size.

The data basis of this study is the Ethiopian manufacturing firms' annual census on medium and large scale manufacturing sector collected by the Ethiopian Central Statistics Authority (CSA) between 1996 and 2002. The survey covers all manufacturing establishments in the country which engage 10 and above workers and customarily defined as formal manufacturing sector. This seven years establishment level panel data comprises 5182 observations. Mainly due to our imposition of a requirement on each firm to be observed at least four consecutive years, for analytical purpose, the sample of this study contains 478 firms with 2845 observations. This means the sample covers about 55 percent of the original data in terms of number of firms but, in terms of permanent employment and investment expenditure on total fixed assets the sample constitute about 78 percent and 76 percent respectively (see Table A1).

The original data contains capital at the beginning of the year, investment, sold assets, depreciation, and end year capital by firm and type of fixed assets. However, to avoid inconsistency we take only the beginning year capital stock for the first year that the firm is observed in the data and subsequently construct the capital stock for each category of fixed assets using a perpetual inventory method. Throughout this study, investment refers to expenditure on fixed assets minus sales of fixed assets, i.e. net investment. Investment rate is then defined as the ratio of investment expenditure (net of sold assets) to end year capital stock (see data appendix for further explanation on the sample selection criterion, construction and definition of relevant variables).

3. Pattern and Distribution of Investment – a descriptive analysis

Figure 1 gives investment expenditure distribution by type of fixed asset. On average, machinery and equipment (M&E henceforth) investment accounts for about 44 percent of total investment in fixed assets. Vehicle purchases and furniture each accounts for about 19 percent of total fixed asset investment, followed by non-residential buildings at about 15 percent. This means that the investment outside machinery and equipment (non-machinery fixed assets, NMFA henceforth) accounts for more than half of the total fixed asset (TFA henceforth) investment. This justifies that our investment analysis should take into account the NMFA component of investment.

To examine the nature of non-smoothness of the investment pattern we categorize investment rates into seven groups that include negative and zero investments. Table 2 provides the distribution of the investment rates across these categories and their shares in total investment expenditure. The percentage of observations with zero investment episodes is about 59 for M&E and 55 for NMFA. This means that more than half of the firms in an average year refrain from investing. The inaction rate for Ethiopia is exceptionally high in comparison to the developed world, but similar to findings in other SSA countries (see Table A1). If we aggregate the investment expenditure to total fixed assets (TFA), zero investment episodes account for about 46 percent of all observations. This shows that aggregating investment on heterogeneous capital will underestimate the nature of intermittency of investment, though the inaction rate is still high.

We further assessed the investment rates and the frequency of zero investment episodes by size (not reported here for brevity). Small firms are defined as having fewer than 100 permanent employees, while large firms have 100 or more permanent employees. The proportion of observations with zero investment episodes among small firms in M&E is more than double (about 70 percent) that of large firms (about 27 percent). The difference is even greater (more than three times) for TFA with an inaction rate 56.6 and 14.5 percent for small and large firms respectively. This shows that inaction is higher among small firms.

Table 2 also presents the frequency of observations ever sells fixed assets, showing the extent of second-hand capital market. Only about two percent of the observations involve selling any type of fixed assets. Moreover, the percentage of observations of firms selling 10 percent or more of their fixed asset is negligible, accounting for only one percent. The high frequency of inaction and only a few negative investment rates is consistent with the existence of fixed adjustment costs and irreversibility, but not with convex adjustment costs.

But how lumpy is investment when it takes place? The proportion of large investment observations (investment rate of 20 or more percent) is only 12 to 14.5 percent, depending on the type of fixed asset (see Table 2). Observations of positive investment of less than 10 percent of capital, on the other hand, accounts for 21 to 29 percent, again depending on the type of fixed assets. Considering only observations with positive investment, the frequency of small investments accounts for above 50 percent. The high frequency of small investments is justified on the grounds that adjustment costs are negligible for small investments that are largely replacement investments, where as the fixed cost becomes important only for expansion investment.

An interesting outcome emerges when we compare the percent of observations involved and shares of investment outlay by certain intervals. For instance, the proportion of observations with investment rates of 20 or more percent is 12 percent and 14 percent for M&E and NMFA respectively, but their shares of total investment outlay are above 73 percent. This means that no more than 15 percent of the observations account for about three-quarters of total investment outlay, which provides some evidence of investment lumpiness.

However, this only tells us that on average there are few observations of large investments, but nothing about the within firm investment distribution and pattern over time. In a cross-sectional distribution of investment we can’t determine whether investment spikes are important for individual firms. Hence, it is vital to assess the episodes of investment of each firm over the years to further understand how lumpy individual firm investments are. Following Doms and Dunne (1998), we ranked investment rates of each firm over time from highest (1) to lowest (7).

Then we computed the average investment rates for each rank and the share of investment of that rank of total investment outlay. In order to have a clear understanding of the process, we concentrated on firms that stay in the data the full sample period. This balanced panel consists of 247 firms with 1,729 observations.

Table 3 gives the rankings and shares of investment rates by types of fixed assets. The average investment rate for the TFA in the highest rank (rank 1) is about 30 percent, which is four times the average investment rate and more than double the second highest investment rate rank. The first rank accounts for about 45 percent of the total fixed investments over the seven year period, which is double that of the second rank. This shows that investments are concentrated in a few years.

The lumpiness is also marked when we look at the disaggregated capital M&E and NMFA investments. The average investment rate of the first rank is 30 percent for M&E and 35 for NMFA, which is still more than double that of their second rank. The first rank accounts for 56 percent and 46 percent of the total investment expenditure over the seven years in M&E and NMFA respectively. This means that 56 percent and 46 percent of the total investment of an average firm in seven year period takes place in a single year for M&E and NMFA respectively. If we add the first two ranks, the same shares rise to about 79 percent and 70 percent respectively. This shows that investments are lumpy also at the firm level. It also reveals the importance of lumpy investments at firm level for aggregate investment.

We have also compared the lumpiness of investment by size (see Table 3). The first rank average investment rate for the small firms is about three times greater than that of the second rank, while for the larger firms the rate of the first rank is not more than twice that of the second rank. This shows that investment is lumpier for small firms. Combining this with our previous finding that inaction is also higher for small firms suggests that the intermittent nature of investment is pronounced in small firms.

Our results are consistent with previous findings considering the difference in the length of the period. Using U.S. data, Doms and Dunne (1998) found about 50 percent of total investment over 16 years is made in the three highest ranks. Nilsen and Schiantarelli (2003) documented that the three highest ranks account for about 53 percent of total investment outlay in machinery and equipment over 14 years in Norwegian manufacturing. Bigsten et al. (2005) reported that the first rank accounts for 50 percent of the investment outlay over five years for five African countries. Nilsen and Schiantarelli (2003) and Bigsten et al. (2005) also found that investment is lumpier for smaller firms. They argue that smaller firms are more affected by indivisibilities since these set lower limits on investments that leave firms with a choice of either a large investment or zero investment.

To sum up the descriptive analysis, we documented that the second-hand market for M&E is almost non-existent. M&E were sold in only two percent of the observations, and only one percent of the observations showed sales of at least 10 percent of the firm M&E capital. The proportion with zero investment episodes is very large, accounting for about half of the observations. When investment takes place it is found to be lumpy and concentrated to few observations and few periods. The intermittent nature of investment is pronounced for small firms. The existence of lumpy and intermittent investment is consistent with irreversibility and fixed adjustment costs. However, this is also consistent with other explanations; for example lumpy investments may be indicative of large shocks as well. The descriptive analysis should therefore be complemented by more structured econometric evidence. This is the task of the next chapter.

4. The Empirical Evidences

To infer the likely adjustment cost structure from the firm level data we use two econometric methodologies – known to be capital imbalance approach (following Caballero and Engel, 1994) and machine replacement model (following Cooper et al. 1999).[2] The following two sub-sections respectively discuss these methodologies and the empirical results.

4.1 The Capital Imbalance Approach: A non-parametric analysis

The capital imbalance approach initiated by Caballero and Engel (1994), the CE's model hereafter, explains how firms adjust their capital stock to deviations between their desired and actual capital stock (mandated investment, hereafter). Since firms do not adjust continuously and respond differently to similar capital imbalance over time and across firms, the response could better be captured by a probabilistic rather than a deterministic adjustment rule. Empirically this can be described by a state dependent hazard function, i.e. the probability of a firm adjusts its capital given the absolute value of the deviation of desired capital from its actual capital stock (Caballero, 1997).

This state-dependent hazard function takes different shapes and provides information about the nature of adjustment costs. The implied shape of different adjustment costs in this framework adopted from Goolsbee and Gross (1997) is given in Figure 2. Linearly increasing hazard is consistent with convex adjustment costs. Piecewise linear adjustment costs also predict a linear relationship, but with a certain range of inaction. Irreversibility generates a large flat portion (range of inaction). When large deviations of actual from desired capital lead to proportionately

[2] Cooper et al. (1999); Nilsen and Schiantarelli (2003); and Bigsten et al. (2005) among others used the machine replacement model in identifying the shape of adjustment costs. The capital imbalance approach, on the other hand, was employed by among others, Caballero et al. (1995) using data on U.S. manufacturing firms, Goolsbee and Gross (1997) using U.S. airline industry data, and Bigsten et al. (2005) on five African countries.

larger changes in investment than small deviations, then the hazard function increases non-linearly, consistent with the presence of fixed adjustment costs.

The CE model involves a two-step estimation: constructing mandated investment and then estimating non-parametrically the firm's actual investment response to its mandated investment.[3] First, we construct the mandated investment index, x, that measures the deviation of desired from actual (natural log of) capital stock at the plant level. A positive x reflects capital shortage, while negative values reflect excess capital.

$$x_{it} \equiv \tilde{k}_{it} - k_{it-1}, \qquad (4.1.1)$$

where $\tilde{k}_{it}$ and k_{it-1} represent the natural log of desired and actual capital, respectively, in plant i at time t (before adjustment).

Deriving the desired capital stock is one important challenge in this formulation. We assume that the desired capital stock is proportional to the stock of frictionless capital, k_{it}^*.

$$\tilde{k}_{it} = k_{it}^* + d_i, \qquad (4.1.2)$$

where d_i is a plant specific constant, the desired capital ($\tilde{k}_{it}$) refers to the stock of capital the firm would hold if adjustments costs were momentarily removed, and frictionless capital (k_{it}^*) refers to the stock of capital that the firm would hold if it never faced adjustment costs.

The frictionless capital can therefore be determined from a neoclassical expression that formulates capital as a function of output and cost of capital, assuming perfect competition, constant returns to scale, and no adjustment costs.

$$k_{it}^* = y_{it} - c_{it}, \qquad (4.1.3)$$

[3] Caballero et al. (1995) extensively discuss the theory and measurement of mandated investment. This section relies heavily on their model specification. A detailed derivation of the model can be obtained from their paper.

where y_{it} and c_{it} represent the natural logs of the value of output and cost of capital for firm i at time t respectively.

Substituting equation (4.1.3) into equation (4.1.2) yields the desired capital, as a function of output, cost of capital and firm specific effect:

$$\tilde{k}_{it} = y_{it} - c_{it} + d_i \,. \qquad (4.1.4)$$

There are two specification issues at this moment. First, since the desired capital is not observable, it needs to be approximated by another variable. The long-run desired capital can be derived from a regression of actual capital on a constant, output, and cost of capital.[4] The second concern arises from the lack of measure of cost of capital in our data set. One way to deal with this problem is to assume that the user cost of capital changes slowly and can be eliminated using a fixed effect model in the panel data setup.[5] Hence, the fitted value of the regression of actual capital on output in a fixed effect model provides a measure of desired capital. Then the mandated investment rate can be constructed by subtracting the beginning year capital from the derived desired capital, ($\tilde{k}_{it}$ - k_{it-1}).

The second step involves regressing the actual investment rate, I_{it} / K_{it-1}, on the mandated investment rate ($\tilde{k}_{it}$ - k_{it-1}):

$$I_{it} / K_{it-1} = f(\tilde{k}_{it} - \mathrm{k}_{\mathrm{it\text{-}1}}) + \lambda_{\mathrm{it}} \;\; . \qquad (4.1.5)$$

[4] Bertola and Caballero (1994) discuss on this point in detail. The firm specific constant that approximates the deviation of actual from estimated frictionless capital stock and therefore desired capital stock is assumed to be stationary. All the observable series are also expected to be co-integrated, because a large gap between actual capital and frictionless capital cannot be sustained infinitely. In the face of co-integrated series, the OLS estimate is consistent and we can reveal the desired capital from the fitted value of this specification.
[5] Bigsten et al. (2005) follow the same approach.

Following Goolsbee and Gross (1997), we estimated equation (4.1.5) non-parametrically using the Nadaraya-Watson kernel smoothing method.[6] Figures 3a and 3b present the shape of the adjustment cost from the kernel regression for investment on M&E and TFA respectively. In both figures a large flat curve, in the range of negative mandated investment and a certain distance of positive mandated investment, is followed by a positive and steep curve. This larger range of inaction followed by a steeper curve suggests an impact of irreversibility and a broad category of non-convexities. However, this might be consistent with both piecewise linear costs and fixed adjustment costs. Further examination is therefore required regarding whether the piecewise linear or the fixed cost predicts the investment behavior better.

We use a parametric method to verify the existence of a non-linear relationship between actual and mandated investment rates. A non-linear relationship implies that the average response to larger disequilibria is proportionally larger than the response to small disequilibria, supporting fixed adjustment costs rather than piecewise linear costs. In this context, we estimate the actual investment rate over mandated investment and squared mandated investment for all observations and observations with positive investment separately. A significant coefficient of the squared mandated investment is considered to be evidence of fixed adjustment costs. We use a simple OLS method pooling the observations while controlling year variation.

Table 4 reports the estimation results. The first two columns give estimation results for both M&E and TFA, but conditional on positive investments, while the last two columns provide the estimation results for all observations including those with zero investments. In all estimations the coefficient of the squared mandated investment is positive and highly significant. The positive and significant squared mandated investment in both types of assets provides strong

[6] The regression uses the triangular kernel and the bandwidth is calculated with ($b = 2.347 * \sigma * n^{-.2}$), where sigma is the standard deviation of the independent variable and n is the number of observations. To correct for outliers we removed observations in the bottom and top 5 percentiles for the variable mandated investment.

evidence of a non-linear relationship between actual and mandated investment rates. This is consistent with the fixed adjustment cost prediction.

We next summarize the implications of the findings from the CE model. The large portion of inaction, as implied by the flat curve, shows that firms do not reduce their capital stock even if the desired capital is much smaller than the actual capital. This is a typical case of irreversibility. The strong non-linear relationship between actual investment and mandated investment gives evidence of non-convexities in the adjustment cost, but not of convex adjustment cost. Specifically, this is consistent with the fixed cost prediction, where large deviations of actual from desired capital lead to proportionately larger investment than small deviations. The existence of a threshold in capital imbalance implies that firms tend to bunch their investments in few periods.

4.2 The Machine Replacement Model: The hazard of investment spikes

The machine replacement model developed by Cooper et al. (1999), the CHP model hereafter, analyzes the probability of a second investment episode conditional on the length of the last investment episode. It assumes the productivity of capital, and therefore the profit function is influenced by the age of capital and productivity shock. The timing of an investment response to a productivity shock depends on the nature of the adjustment costs and on the persistence of the shocks.

With fixed adjustment costs, the model predicts that the hazard of investing increases with the time since the last investment, thus the hazard is upward sloping. This is because in the presence of fixed costs, the productivity gains from an additional investment in a period soon after the first investment are small. In the face of serially correlated shocks with convex costs, the firm level investment will be positively correlated; therefore the hazard is downward sloping.

On the other hand, with serially uncorrelated shocks and no adjustment costs, the hazard should be flat.

In this section we introduce the CHP method to examine if the probability of an investment spike increases with the time since the last investment spike using a discrete duration model. Let T_i be the length of firm i's spell between two investment spikes. The hazard, h_{it}, of exiting from the spell (i.e. the probability of an investment spike) of firm i at time t can be stated as follows:

$$h_{it} = \lim_{dt \to 0^+} \frac{prob(t + dt \succ T_i \geq t \mid T_i \geq t, x_{it})}{dt}, \qquad (4.2.1)$$

where x_{it} is a vector of additional conditioning variables.

Parameterizing the hazard function using a proportional hazard form gives:

$$h_{it} = h_0 \exp(x_i(t)'\beta), \qquad (4.2.2)$$

where h_o is the baseline hazard.

The probability that a spell of zero investment lasts until period t+1, given that it has lasted until period t in a discrete time can be written as:

$$p[T_i \geq t+1 \mid T_i \geq t, x_{it}] = \exp[-\exp\{(x_i(t)'\beta) + \gamma(t)\}], \qquad (4.2.3)$$

where $\gamma(t)$ a baseline hazard representing duration in discrete time.

The above equation gives the survival function, but could be easily modified to obtain the hazard of exiting from the spell. The probability of an investment spike by firm i in the interval (t, t+1], given that it doesn't occur until time t, is:

$$P[t < T_i \leq t+1 | T_i \geq t, x_{it}] = 1 - \exp[-\exp x_i(t)'\beta + \gamma(t))]. \qquad (4.2.4)$$

The log-likelihood function for a sample of N individuals can be written as:

$$l(\gamma, \beta) = \sum_{i=1}^{N} \left[\delta_i \log\left[1 - \exp\{-\exp[\gamma(k_i) + x_i(k_i)'\beta]\} - \sum_{t=1}^{k_{i-1}} \exp[\gamma(t) + x_i(t)'\beta]\right]\right], \qquad (4.2.5)$$

where δ_i =1 if $T_i \leq C_i$, and 0 otherwise, C_i is a censoring time indicator, and k_i = min(int(T_i), C_i)).

Estimating the log-likelihood function by standard techniques gives the parameter estimates of the covariates (β) and duration dummies (γ). One of the critical assumptions in this formulation is that there is no unobserved heterogeneity. However, ignoring unobserved heterogeneity could lead to an entirely different shape of the hazard due to selection bias (Vauple and Yashin, 1985), and would bias the hazard function downward. Hence, we need to take account of the unobserved heterogeneity effect in our estimation. We assume that the random effect (v_i) is independent of observed covariates and that it enters the hazard function multiplicatively. We further assume that the random effect follows a Gamma distribution with a mean equal to one and a finite variance.[7] The log-likelihood function with the presence of random effect becomes:

$$l(\gamma,\beta,v)=\sum_{i=1}^{N}\log\left\{\begin{array}{l}\left[1+v\sum_{t=0}^{k_{i-1}}\exp\{\gamma(t)+x_i(t)'\beta\}\right]^{-v^{-1}}\\ -\delta_i\left[1+v\sum_{t=0}^{k_i}\exp\{\gamma(t)+x_i(t)'\beta\}\right]^{-v^{-1}}\end{array}\right\}. \qquad (4.2.6)$$

In this empirical section we investigate investment spikes defined as an investment rate of 20 percent or more. This is because small investments that represent routine maintenance and replacement expenditure might not exhibit the timing pattern predicted by the machine replacement model. Although this threshold is arbitrarily set, it is intended to eliminate the

[7] There are different practices regarding the distribution of the random effect. The non-parametric approach following Heckman and Singer (1984) makes no assumption but approximates the unknown distribution of heterogeneity by a discrete distribution with a finite number of "mass points". The parametric approach on the other hand assumes certain types of distributions such as Gamma, Normal, and Gaussian. Meyer (1990) argues that unlike other distributions, the Gamma distribution is convenient since it gives a closed form expression for the likelihood of avoiding numerical integration.

routine maintenance and replacement expenditure from the investment analysis.[8] The model is estimated separately for investments on M&E, NMFA, and the aggregated measure TFA – each with and without unobserved heterogeneity.[9] The likelihood ratio test for a null that Gamma variance is equal to zero is readily reported along with the estimation results. A significant result in the LR test implies the existence of unobserved heterogeneity and vice versa.

The primary interest of this analysis is to investigate the shape of the baseline hazard, represented by the coefficients of the duration dummies $\gamma(t)$. Less negative values are associated with higher hazards. D=0 describes the two spikes that occur in adjacent periods, and D=1 indicates a one year gap between the two spikes. In our estimation we suppress the constant, and are thus able to include the maximum possible duration dummies, 6 periods.[10]

We have included a number of important variables into the model to control for observed heterogeneity due to shocks and initial conditions. These are profit rate, size, age and industry dummies. Profit rate is defined as the ratio of profit to capital measured by total fixed assets. Size is defined as the number of permanent employees in the firm, and age refers to number of years since the initial establishment. Both size and age are initial values and in logarithm form. We have also included 12 industry dummies.

It is worth noting at this moment that in preparing the data for the hazard estimation, the sample is reduced significantly for the following reasons. First, we use only the first spell, which means that any observation after the second investment spike is discarded. Second, firms without

[8] It is common (among others CHP, 1999; Nilsen and Schiantarlli, 2003) to use a 20 or more percent investment rate as a threshold. These studies have also made a distinction between absolute spike (20 or more percent) and relative spike (when the investment rate exceeds 2.5 times the median investment rate for each firm).

[9] In estimating this discrete time proportional hazard regression model we use *pgmhaz8* in Stata 8.2. This program is developed by Stephen P. Jenkins at the University of Essex. It provides simultaneously both the results with and without unobserved heterogeneity. The built-in model in this program is the Prentice-Gloeckler (1978) model with and without incorporating a gamma mixture distribution.

[10] We have also estimated all models excluding the first duration and including the constant, but we found no qualitative difference particularly on the shape of the hazard.

any investment spikes throughout the sample period are also excluded from the data. Third, given that the analysis involves the duration since the last spike firms with an investment spike in the last period are also deleted. As a result, the proportion of firms included in the investment spike estimation is between 42 and 48 percent depending on the type of fixed assets. This means that estimations of the hazard models depend on few firms, which could possibly lead to a loss of efficiency.

Table 5 reports the estimation results of the proportional hazard model with and without unobserved heterogeneity for M&E, NMFA, and TFA separately. For both disaggregated fixed assets (M&E and NMFA), the null hypothesis that the gamma variance is equal to zero is rejected suggesting the importance of unobserved heterogeneity. In the presence of a heterogeneity effect, the magnitude of the coefficients of the duration dummies and the shape of the hazard are found to be entirely different between the models with and without unobserved heterogeneity. Following the model with unobserved heterogeneity, the shape of the investment spike hazard in both types of assets, M&E and NMFA, is monotonically increasing throughout (but only until the fifth period in the latter). This upward sloping hazard of investment spike is consistent the fixed adjustment costs but not with convex adjustment costs.[11]

Unlike the disaggregated types of fixed assets, we are not able to detect any significant problem of unobserved heterogeneity in the estimation on TFA. The hazard of investment spike on TFA shows a generally declining trend but not monotonically. This is consistent with convex costs but not with fixed costs. The declining hazard from TFA might be due to the fact that the probability of the second spike increases when aggregating investment expenditures of different

[11] In a similar specification that allows for unobserved heterogeneity, CHP (1999) found increasing hazard immediately after the initial drop from duration zero to duration one. Nilsen and Schiantarelli (2003) also found a J-shaped hazard for relative spike definition from duration one and onward. Both are considered to be evidence of the importance of fixed adjustment costs.

types into total fixed assets. This suggests that aggregation of heterogeneous capital might affect the shape of the adjustment cost mainly by smoothing the hazard to imply convex adjustment costs, and also obscures the non-convexity nature of investment pattern. Doms and Dunne (1998) reported in their comparison of plants, firms, and lines of business in US manufacturing, that the higher the level of aggregation, the smoother the capital adjustment.

Table 5 also reports test results on the duration coefficients. Given that we do not have a constant in the model, the relevant test for a flat hazard is to find whether the coefficients of the duration dummies are significantly different from each other. The null that all duration coefficients are equal cannot be rejected for M&E and NMFA, while that of the TFA is strongly rejected. This is mainly due to the fact that when controlling the unobserved heterogeneity is important, the standard errors are typically quite large. Recall that we found a large effect of unobserved heterogeneity when we estimated the hazard for the disaggregated capital. Although the hazard of investment spike for M&E and NMFA is increasing, the fact that we can not reject the null that the hazard is flat implies that the evidence in favor of fixed adjustment costs is weaker.

When we look at the effect of other variables, size of a firm affects positively and significantly all types of fixed asset investment spikes. Age is negatively associated with investment in M&E, but is insignificant for investment in NMFA and TFA. The profit rate coefficient is positive and significant for TFA, but not for the disaggregated assets.

5. Conclusions

In this paper we examined whether irreversibility and fixed cost of adjustment are important determinants of investment decisions in the Ethiopian manufacturing sector. The descriptive analysis shows that the second-hand market for M&E is almost non-existent, implying that investment is largely irreversible. The percentage of observations with zero investment episodes is very high, ranging from 46 to 60 percent depending on the type of fixed assets. When investment takes place it appears to be lumpy and concentrated in few periods. The inaction is higher and investment lumpier for smaller firms. The large inaction alternating with lumpy investment gives evidence of investment being largely irreversible and of the presence of fixed adjustment costs. Such an investment pattern is also consistent with theories of irreversibility under uncertainty, where firms remain liquid until the marginal return of capital exceeds a certain threshold level.

We applied two econometric methods in identifying the nature of adjustment costs and irreversibility. In the capital imbalance approach we used a non-parametric Nadaraya-Watson kernel smoothing method for investment in two categories of fixed assets, M&E and TFA. For both categories we found a large portion with a flat shape, followed by a positive and non-linearly increasing portion of the adjustment cost curve. The large flat portion represents a longer period of zero investment and suggests that firms do not reduce their capital stock even if the desired capital is much smaller than the actual capital, which is a typical case of irreversibility. The non-linear response of actual investment to capital imbalance is also evidence that firms adjust proportionately more to large deviations of actual from desired capital than to small deviations. Investment is therefore bunched into few periods. This is consistent with irreversibility and fixed adjustment costs.

In the second approach we estimated a proportional hazard model with and without unobserved heterogeneity for a discrete time to test if the probability of investment spikes conditional on the length of the last investment spike exhibits positive duration dependence. In the presence of fixed costs, the productivity gains from an additional investment in the period soon after the first investment are small; thus, the hazard should be upward sloping. In the disaggregated capital, M&E and NMFA, we found an upward sloping hazard consistent with fixed adjustment costs. However, the test for the null that the hazard is flat cannot be rejected, implying that the fixed effect prediction is weaker. For TFA the hazard is declining, which is consistent with convex adjustment costs. The downward hazard in TFA could be due to aggregation of heterogeneous capital. The results from the CHP model however should be taken with some caution, given that the estimation of the hazard model depends on few firms due to our reliance on single spell and that a large proportion of firms do not even see a "beginning" of a spell.

Overall, this study reveals the adverse effect of irreversibility and fixed adjustment costs on the investment decisions of Ethiopian manufacturing firms. A large number of potential investors tend to postpone their investments in an effort to avoid costly mistakes. This partly explains the paradox of the low investment but high profit rates documented. Hence, boosting investment requires policy intervention particularly in reducing uncertainty, improving the second-hand market for M&E, and providing better infrastructure since the effects of irreversibility and fixed adjustment costs are more pronounced when there are problems in these areas.

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Table 1 GDP growth, sectoral shares and manufacturing sector performance indicators

	1994	1995	1996	1997	1998	1999	2000	2001	2002	average
GDP growth	3	6	11	5	-2	6	6	9	2	5.1
GDP per capita growth	0	3	8	3	-4	4	3	6	-2	2.3
Industry, value added (% of GDP)	10	9	9	10	11	10	9	11	11	10.0
Services value added (% of GDP)	35	34	33	37	43	42	43	43	47	39.7
Agriculture value added (% of GDP)	55	56	58	53	46	47	48	47	43	50.3
Formal manufacturing sector (employment 10 and above)										
public	154	157	139	127	131	126	118	115	121	
private	323	323	406	491	516	511	517	552	688	
Total number of firms	477	480	623	703	725	743	739	766	883	
Number of firms growth		1	30	13	3	2	-1	4	15	9
Employment growth		2	0	3	1	0	1	-2	5	1.4
Output growth				4	16	6	-2	4	-2	4.3

Source for GDP growth and sectoral shares is World Development indicators, 2006 (World Bank 2006), while for the manufacturing is the Central Statistical Authority of Ethiopia (CSA)

Table 2 Investment rate and share of investment distribution

	Machinery and equipment (M&E)		Non-machinery fixed assets (NMFA)		Total fixed assets (TFA)	
investment rate	frequency	share	frequency	share	frequency	share
<0	2.25	-3.21	1.99	-3.69	2.07	-2.78
=0	58.6	0	54.8	0	45.56	0
0<I/K<0.05	15.22	6.19	16.98	5.65	20.49	5.87
0.05=<I/K<0.10	5.45	7.72	5.62	8.35	8.96	15.16
0.10=<I/K<0.20	6.15	14.99	6.61	15.19	8.26	17.5
0.20=<I/K<0.30	3.83	11.86	4.32	16.87	5.41	15.93
I/K>=0.30	8.51	62.44	9.67	57.64	9.24	48.32
Total	100	100	100	100	100	100

Table 3 Ranking of investment episodes and contribution to aggregate by size

Rank		M&E			NMFA			TFA		
		small	large	All	small	large	All	small	large	All
1 (Highest)	Mean (I/K)	0.26	0.35	0.30	0.3	0.43	0.35	0.29	0.32	0.3
	share	48.76	57.49	55.9	74.97	41.73	46.04	53.42	43.03	44.91
2	Mean (I/K)	0.08	0.19	0.13	0.1	0.21	0.14	0.11	0.18	0.14
	share	26.27	22.55	23.22	18.94	24.18	23.51	24.22	21.63	22.1
3	Mean (I/K)	0.03	0.09	0.06	0.05	0.13	0.08	0.05	0.13	0.08
	share	13.98	9.86	10.61	8.2	19.17	17.75	16.82	14.54	14.95
4	Mean (I/K)	0.01	0.05	0.03	0.02	0.07	0.04	0.02	0.09	0.05
	share	4.92	8.16	7.57	5.22	8.58	8.14	3.07	10.95	9.53
5	Mean (I/K)	0.01	0.03	0.01	0.01	0.04	0.02	0.01	0.06	0.03
	share	4.54	3.78	3.92	3.27	6.3	5.91	4.51	7.06	6.6
6	Mean (I/K)	0	0.01	0.01	0.01	0.02	0.01	0	0.03	0.01
	share	1.29	1.82	1.72	1.47	2.76	2.59	1.02	4.67	4.01
7 (Lowest)	Mean (I/K)	-0.02	-0.02	-0.02	-0.03	-0.02	-0.02	-0.03	0	-0.02
	share	0.22	-3.65	-2.95	-12.1	-2.72	-3.93	-3.06	-1.87	-2.09
average	Mean (I/K)	0.05	0.1	0.07	0.06	0.13	0.09	0.06	0.12	0.08
Number of observations		1087	642	1729	1087	642	1729	1087	642	1729

Table 4 Test of non-linearity of investment response to capital imbalance

	Observations with only positive investment		All observations	
	M&E	TFA	M&E	TFA
x_{it}	0.310***	0.180***	0.064***	0.071***
	(0.0485)	(0.043)	(0.024)	(0.027)
x_{it}^2	0.073***	0.033*	0.044***	0.042**
	(0.021)	(0.020)	(0.015)	(0.019)
Constant	0.639***	0.348***	0.251***	0.180*
	(0.187)	(0.152)	(0.089)	(0.096)
N	920	1228	2097	2162
Year dummy	yes	yes	yes	yes

Notes: the dependent variable is investment rate, and x_{it} stands for mandated investment. Values in parentheses are standard errors. ***, **, and * show significance at the 1%, 5% and 10% level respectively.

Table 5 Proportional hazard model results for investment spikes

	Investment spike Non-machinery fixed assets		Investment spike Machinery and equipment		Investment spikes Total fixed assets	
	Unobserved heterogeneity		Unobserved heterogeneity		Unobserved heterogeneity	
Hazard	without	with	without	with	without	with
D0	-2.785***	-3.842***	-2.475***	-3.325**	-2.522***	-2.522***
	(0.485)	(0.938)	(0.464)	(1.631)	(0.432)	(0.434)
D1	-3.235***	-3.565***	-2.886***	-2.054	-3.1212***	-3.121***
	(0.505)	(0.841)	(0.484)	(1.376)	(0.462)	(0.464)
D2	-3.432***	-3.378***	-3.296***	-1.53	-2.941***	-2.941***
	(0.535)	(0.881)	(0.535)	(1.645)	(0.465)	(0.467)
D3	-3.523***	-3.127***	-3.035***	-0.307	-4.003***	-4.003***
	(0.582)	(0.978)	(0.543)	(2.137)	(0.642)	(0.644)
D4	-3.110***	-2.299**	-2.750***	1.259	-2.872***	-2.872***
	(0.609)	(1.139)	(0.586)	(2.966)	(0.558)	(0.559)
D5	-3.596***	-2.452	-2.547***	3.060	-3.302***	-3.302***
	(1.118)	(1.617)	(0.732)	(4.150)	(1.078)	(1.079)
Profit rate	0.0889	0.046	0.011	-4.78E-06	0.113***	0.113***
	(0.063)	(0.056)	(0.058)	(0.132)	(0.046)	(0.046)
Size	0.242***	0.549**	0.430***	1.6125	0.353***	0.353***
	(0.083)	(0.225)	(0.094)	(1.077)	(0.079)	(0.079)
Age	0.044	-0.043	-0.252**	-1.283	-0.098	-0.098
	(0.097)	(0.191)	(0.101)	(0.950)	(0.091)	(0.091)
gamma variance		2.410		6.849		1.28E-06
		(1.529)		(5.461)		(0.0008)
gamma var=0 χ^2(01)		4.29***		6.21***		-4.6e-06
Log Likelihood	-243.94		-237.05	-233.95	-254.42	-254.42
AIC	0.928		0.9878		0.904	
BIC	-2994.90		-2994.07		-3252.96	
# observations	569	569	567	567	607	607
Test1 χ^2(5)	8.01	2.63	7.53	2.74	12.77**	12.77**

- (***), (**) and (*) represent the 1%, 5% and 10% significance levels. Numbers in parentheses are standard errors. We have included 11 industry dummies in the estimation but have not reported them here for brevity.
- D0, D1 … D5 represent duration. D0 refers to adjacent year.
- Test4 is LR test for H_0 where all duration dummies are equal each other.

Figure 1: Investment share by type of fixed assets

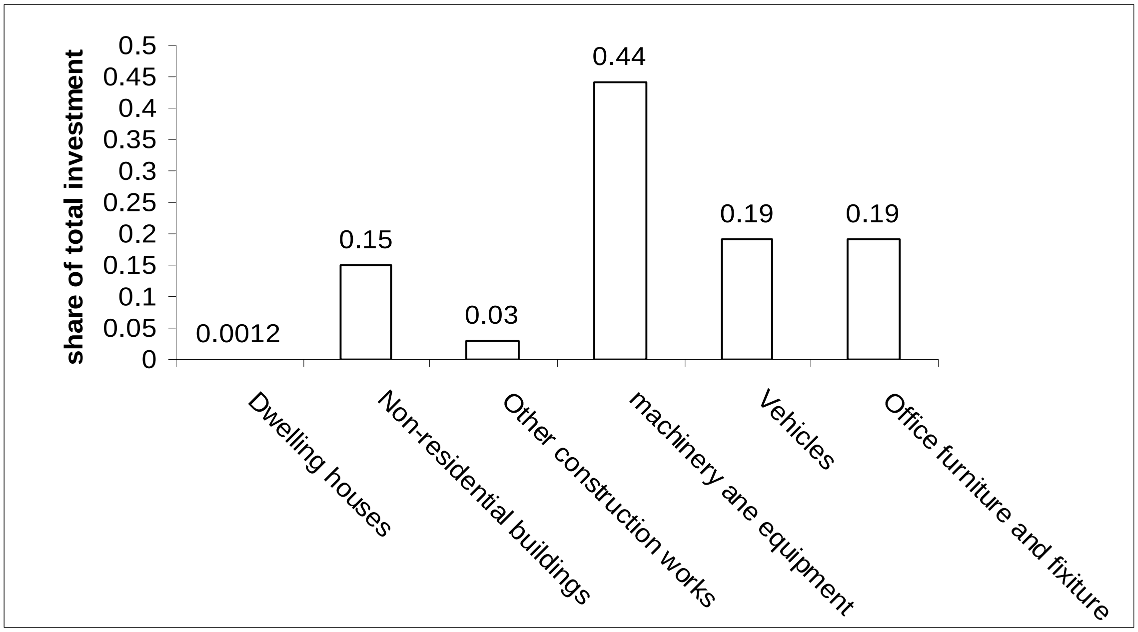


Figure 2: Implied shape of various adjustment costs

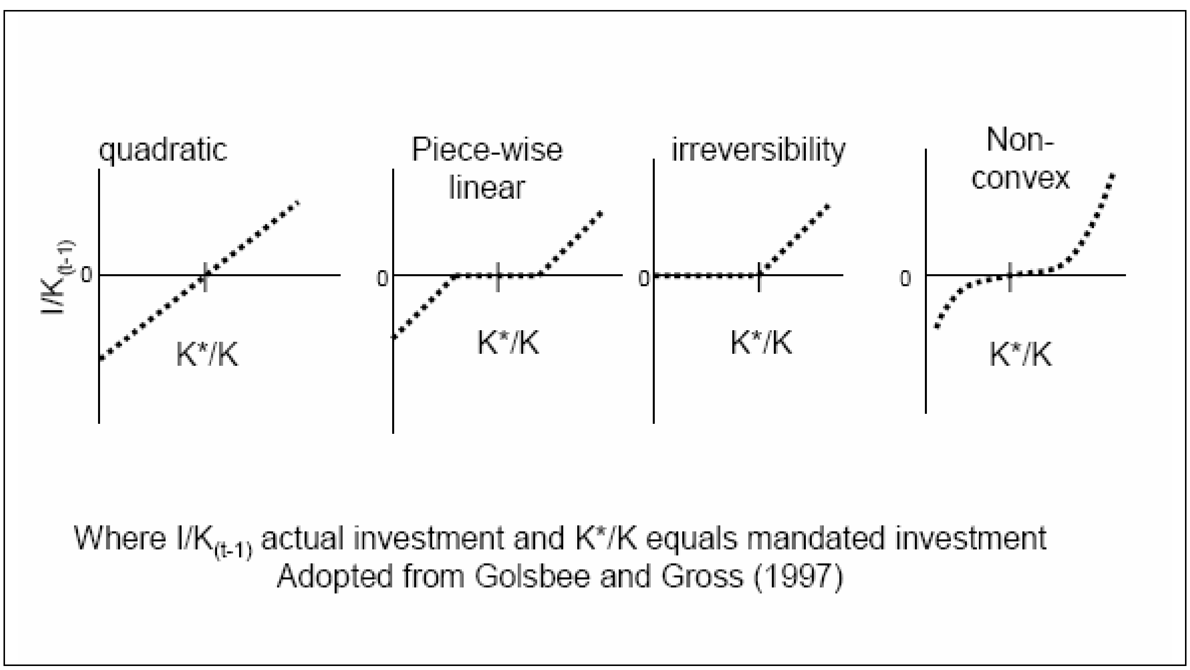


Figure 3a: Kernel estimation of mandated investment (machinery and equipment)

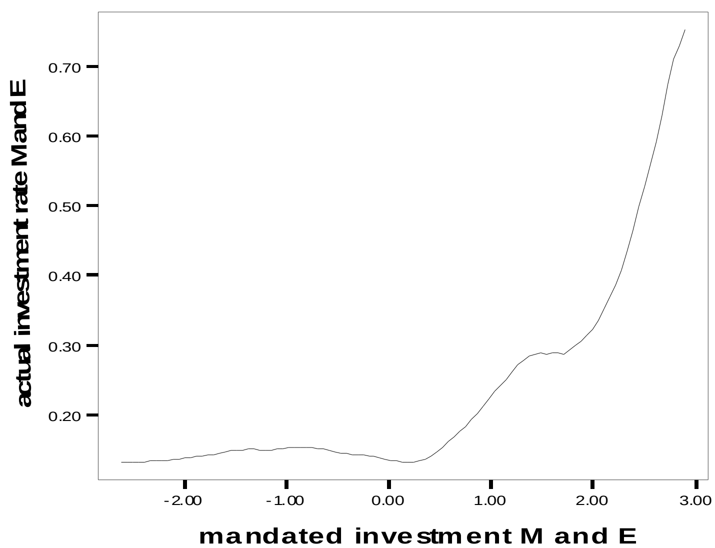
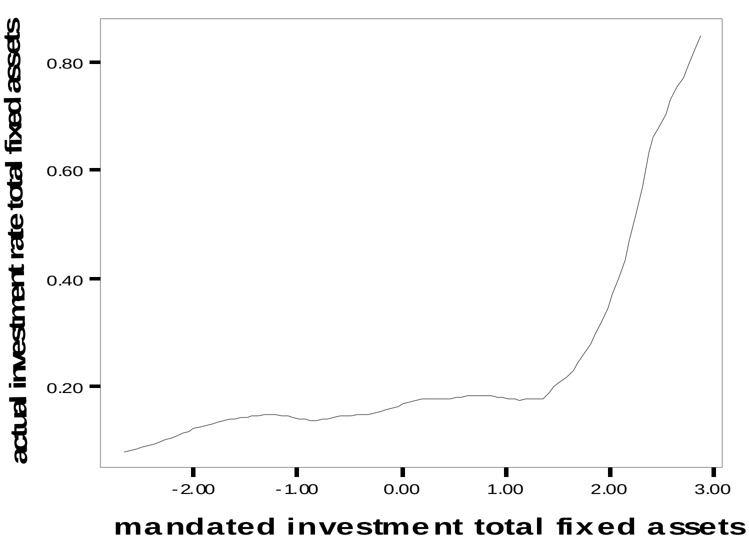


Figure 3b: Kernel estimation of mandated investment (total fixed assets)



Data Appendix

Sample selection criterion

The original data consist of 5,182 firm-year observations with 740 firms on average per year. By the very nature of the census, establishments with less than 10 persons engaged are excluded from the data. Since this study involves dynamic analysis we impose a restriction on firms to stay in the data set at least four consecutive years. Due to this restriction 1,832 observations are excluded. We further refined our sample using outlier criteria at which firms with capital stock less than 1000 Ethiopian Birr or firms with negative value added for more than one year are excluded. As a result the final sample contains 478 firms (with 2,845 observations) of which 247 firms are observed the full sample period – seven years.

Table A1 Share of the sample to the census data by year

Year	Share of the sample to the census data			
	No. of firms	employment	Investment (M&E)	Investment (TFA)
1996	0.51	0.80	0.66	0.77
1997	0.53	0.78	0.78	0.82
1998	0.59	0.81	0.68	0.74
1999	0.64	0.81	0.68	0.73
1900	0.60	0.79	0.59	0.64
2001	0.55	0.75	0.84	0.86
2002	0.44	0.71	0.68	0.74
Average	0.55	0.78	0.71	0.76

Capital stock construction

The original data contains capital at beginning of the year, investment, sold assets depreciation, and capital at end of the year. However, due to inconsistency in this construction we take only the beginning year capital stock for the first year where the firm is observed in the data. We subsequently construct the capital stock for each category of fixed assets using a perpetual inventory method.

$$K_{it}^{j} = K_{it-1}^{j}(1-\delta^{j}) + I_{it}^{l} - SK_{it}^{j}$$

In this formula K_{it}^{j} and K_{it-1}^{j} denote capital stock at the beginning and end of the year respectively for each category of fixed assets, δ^{j} is depreciation rate for j type of asset and SK_{it}^{j} denotes asset j sold during the year if any. I_{it}^{j} is deflated investment at year t in asset j. We use depreciation rates of 8% for machinery and equipment, 10% for vehicles and furniture and for fixture, and 5% for buildings.

Definition of variables

Investment (I_{it}) is defined as expenditure minus sales of fixed assets; residential buildings, non-residential buildings, other construction works, machinery and equipment, vehicles and furniture and fixture by firm i at year t. This expenditure is deflated by a GDP deflator (due to absence of separate investment deflator).

The **investment rate** (I_{it}/K_{it}) is calculated by the ratio of the net real investment to the capital stock at the end of the year for the respective category of fixed assets for each firm. When we construct the non-machinery investment rate as a sum of three different categories (non-residential buildings, vehicles, and furniture and fixture) we add the deflated investment and constructed capital stock to take the ratio of these sums. The total fixed assets investment rate is also constructed from all categories by the same method.

The **profit** is found by subtracting total wages and salaries paid (for permanent and temporary workers) plus cost of employee benefits from value added at factor cost, and the **profit rate** is defined as a ratio of this profit to total fixed asset capital stock.

Age of a firm is found by subtracting the startup year from current year plus one.

Table A2 International comparison of investment and profit rates

Country	% of observations with: zero investment	% of observations with: I/K>=20%	$I/K_{(t-1)}$: mean	$I/K_{(t-1)}$: median	profit rate: mean	profit rate: Median	% of observations sold M&E: any	% of observations sold M&E: >=10% of capital
Belgium			0.13		0.24			
France			0.11		0.22			
Germany			0.12		0.22			
UK			0.12		0.20			
USA	8.1	18	0.12					
Norway	21	12						
Spain	18	24.7						
Cameroon	71		0.12	0	1.56	0.36		
Ghana	68		0.13	0.004	3.70	0.71		
Kenya	58		0.12	0	1.96	0.32		
Zimbabwe	34		0.13	0.03	0.92	0.42		
Zambia	69							
5 Africa countries average	58		0.13	0.01	1.98	0.40	0.14	0.01
Ethiopia	60	13	0.15	0	2.19	0.48	0.06	0.01

Notes: the source for the first four European countries is Bond, Elston, Mairesse, and Mulkay (1997), for Norway Nilsen and Schiantarelli (2003), for Spain Rocio Sanchez-Mangas (2002), for USA Cooper and Haltiwagner (2000). The source for the five African countries is Bigsten et al. (2005), whereas the mean investment rate and profit rate is based on four of the indicated African countries and is found from Bigsten et al. (1999). The source for Ethiopia is Central Statistical Authority of Ethiopia but own calculation.

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