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Abstract

In this paper we investigate if the predictions of three different models of capital adjustment costs are consistent with the observed investment patterns among manufacturing firms in five African countries. We document a high frequency of zero investment episodes, which is consistent with both fixed adjustment costs and irreversibility and inconsistent with quadratic adjustment costs. We model the decision to invest using a dynamic discrete choice model and find evidence of irreversibility and not fixed costs. We finally model the investment rate as a function of the size of the capital disequilibrium. The results confirm that irreversibility is an important factor affecting the investment behaviour of African manufacturing firms. Some implications of this finding are discussed.

KEYWORDS: investment, adjustment costs, irreversibility, hazard function, African manufacturing

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1. INTRODUCTION

Adjustment costs are central to modern investment theory, and how adjustment costs vary with investment has direct implications for the specification of the investment equation. Under quadratic adjustment costs (QAC), which is the most common functional form used in the literature, large investments are associated with very high adjustment costs, so the firm has an incentive to spread out a given adjustment of the capital stock over several periods. One implication of QAC is thus that investment is a smooth and serially correlated process. However, some authors have recently argued that it is more realistic to model the adjustment cost as fixed and thus invariant to the size of the investment, rather than a quadratic. Under fixed adjustment costs (FAC) the best policy for the firm is either to keep the capital stock unchanged or to undertake a large investment (or alternatively a disinvestment) concentrated to one or a few periods. Caballero and Engel (1999) argue that FAC is more consistent with plant-level data, which often indicate that investment is intermittent and lumpy rather than gradual (Doms and Dunne, 1998). Other authors have stressed the implications of investment being irreversible (Dixit and Pindyck, 1994). The idea here is that once a firm has acquired new capital, the associated cost is sunk (perhaps because there are no second hand markets for fixed capital) and cannot be recovered should the firm want to reverse the investment decision.

In this paper we use data on manufacturing firms in Cameroon, Ghana, Kenya, Zambia and Zimbabwe to investigate if there is any evidence that company investment in these countries is associated with QAC, FAC or irreversibility (IRR). Very informally, these three adjustment cost models can be thought of as representing different forms of 'sand in the wheels', which prevent the firm from adjusting its capital stock fully and instantaneously in response to, say, a demand shock. Firms in Sub-Saharan Africa (SSA) have to deal with quite a lot of sand in the wheels: the infrastructure in these countries is typically poor, the financial markets are underdeveloped and often badly functioning, and secondary markets for capital goods are limited or completely absent. There is also in these countries a legacy of interventionist industrial policies where many manufacturing activities required licences and permits. It would thus seem plausible that adjustment costs may be quite significant in Africa. Further, the size distribution of firms in Africa is heavily skewed to the right, with a much higher proportion of very small firms than elsewhere (see e.g. Tybout, 2000). To the extent that small firms are especially strongly affected by adjustment costs, one might expect to find quite clear evidence of such mechanisms in our sample. One contribution of the paper is thus to confront new theories with data from an environment which in many ways is ideal to look for empirical support of such models.

A common finding in previous research on investment in Africa based on firm-level data is that investment is quite hard to explain based on traditional models. Bigsten et al. (1999) estimate accelerator models and Euler equations based on a similar data set to that used in the current paper, and find that these models explain at most 17% of the variation in the investment rate. Pattillo (1998) further finds that proxies for uncertainty have some explanatory power in investment regressions, which is consistent with models of investment under irreversibility. In investigating whether QAC, FAC and IRR are important determinants of investment, the paper thus contributes to improving the understanding of the determinants of investment in Africa more broadly.

The paper is organised as follows. In Section 2 we discuss the theoretical underpinnings and the empirical framework. In Section 3 we analyse the patterns of investment and the extent to which investment is concentrated in intermittent periods of large expenditures. In Section 4 we report results from various dynamic discrete choice models which shed light on the dynamics of investment and the nature of the adjustment costs. In Section 5 we analyse how firms respond to contemporaneous imbalances in the capital stock. We provide conclusions in Section 6.

2. Analytical Framework

It is widely observed that firms do not immediately adjust their capital stocks in response to shocks to the 'fundamentals' (e.g. demand). The conventional explanation advanced in the literature is that capital investment is associated with adjustment costs.[1] The majority of previous empirical studies of investment behaviour have assumed QAC, hence the adjustment cost function is continuously differentiable and the marginal cost is constant in the investment rate. This model implies that the firm adjusts to the long run equilibrium gradually, by making continuous small adjustments every period. Over the last decade, however, the literature concerned with the implications for investment of IRR and FAC has grown rapidly. Under fixed costs there are increasing returns in the adjustment cost function, and the firm therefore waits and invests infrequently, in large lumps, in order to avoid paying the fixed costs in many periods. Similarly, partial or total irreversibility implies a discontinuity in the marginal cost to investment,

[1] Adjustment costs are costs associated with the sale, purchase or productive implementation of capital goods over and above the price of the goods. Such costs are associated with, for instance, searching for and deciding upon the adequate piece of equipment to be purchased, scrapping the obsolete machines, installing the new capital stock, reorganizing and training the workforce, etc. The largest share of adjustment costs is likely to consist of opportunity costs of foregone output during the period of adjustment (Hamermesh and Pfann, 1996).

which creates an inaction range within which fluctuations in marginal returns are insufficient for investment to respond. In models of IRR and FAC, firms refrain from adjusting their capital stock until the underlying disequilibrium reaches a certain threshold level, dictated by parameters related to demand and the degree of irreversibility, *inter alia*.[2] In contrast, under QAC there is no region of inaction, so investment in this model is continuous and gradual.

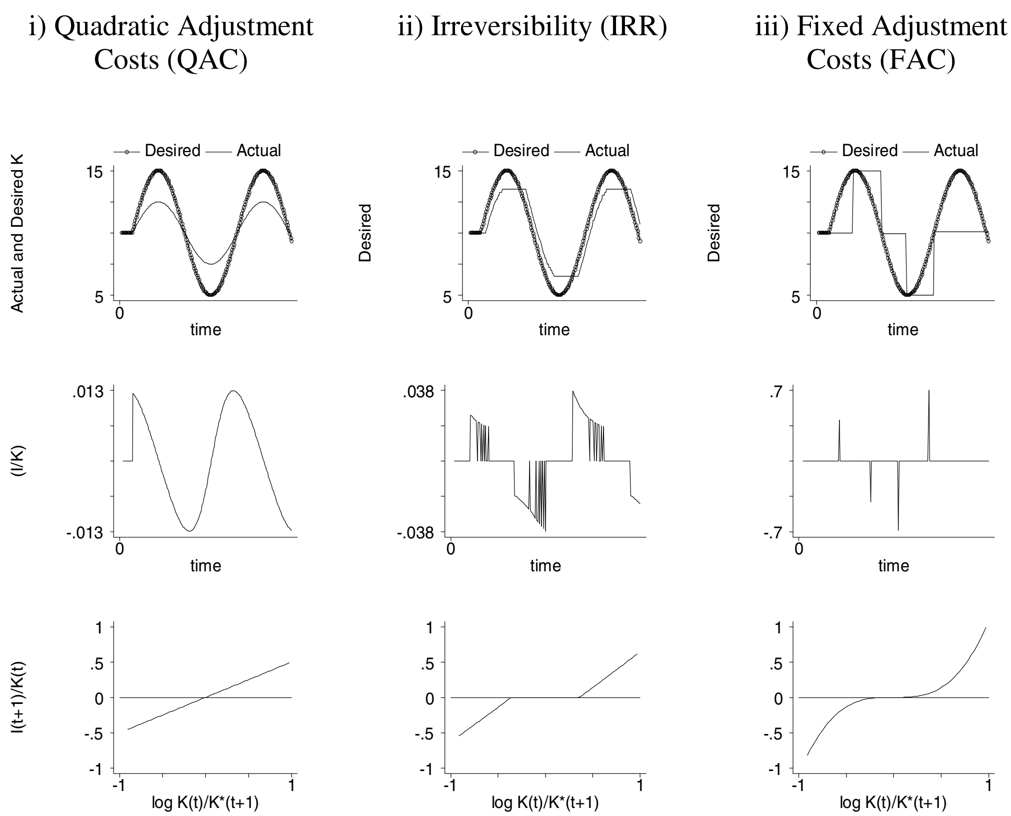
With QAC it is straightforward to derive an investment equation that is a linear function of the explanatory variables, e.g. Tobin's Q model (Hayashi, 1982). This is probably the main reason why this formulation has been so popular over the last two decades. In contrast, under IRR or FAC it is very difficult if not impossible to obtain a closed form analytical solution for investment without making several potentially strong assumptions, e.g. about technology, expectations formations and the underlying stochastic process. In what follows we provide a broad and fairly general characterisation of investment behaviour under QAC, FAC and IRR.

Drawing on Hamermesh and Pfann (1996), the first row of Figure 1 shows how the capital stock evolves over time, where the first column refers to QAC, the second to IRR and the third FAC. The line with o-symbols depicts how capital would change if there were no adjustment costs (i.e. without sand in the wheels), and the line without symbols shows the capital evolution under the three different adjustment cost models.[3] Under no adjustment costs, changes in capital track changes in the fundamentals. Under QAC, shown in column 1, the capital stock is continuously adjusted but always less so than under no adjustment costs. Under IRR, illustrated in column 2, there are periods where optimal capital does not vary, even though the fundamentals are changing. Inaction occurs because the firm does not wish to add to the capital stock if in the near future its demand for capital might decrease, since in that case the investment cannot be reversed. Finally, the third column illustrates the dynamics of capital with FAC. Only large changes in the fundamentals lead the firm to change capital, and when this happens the resulting investment is large.

[2] See e.g. Dixit and Pindyck (1994).

[3] For simplicity, it is assumed that agents have perfect foresight and that capital does not depreciate. However, the general mechanisms demonstrated in Figure 1 are not altered by adopting more realistic assumptions regarding expectation formations and capital depreciation.

Figure 1. *Adjustment Costs and Investment Patterns*



Note: The upper row of the figure is adopted from Hamermesh and Pfann (1996), the middle row is derived from the upper row, and the lower row is adopted from Goolsbee and Gross (2000).

The second row of Figure 1 graphs the dynamics of the investment rate (defined as investment divided by capital), derived from the path of capital, under the three models. This row relates to one of two dimensions of investment behaviour we will examine, namely how the probability of investment depends on past investments. The figure shows the smooth path of continuous investment under QAC, and the periods of inaction interrupted by periods of investment under IRR and FAC. Cooper, Haltiwanger and Power (1999) formulate a machine replacement problem and demonstrate how the solution to the firm's optimisation problem can be characterised by a hazard function, which is the rate at which machines are replaced conditional on the time since the previous replacement. In particular, Cooper et al. show that under FAC the hazard function exhibits positive duration dependence, i.e. that the hazard of replacement is increasing in the time since previous replacement. The reason is that in periods soon after an investment has been made, the productivity gains from an additional investment are small, while the cost is fixed, hence the present value of benefits is unlikely to exceed the costs. As time passes the likelihood of net gain (and thus investment) increases, as the productivity of the available leading edge technology begins to exceed that of the existing capital. In contrast, under QAC the firm spreads out a given adjustment over periods which yields positive serial correlation in investment. This is clear from the left figure in the second row in Figure 1, where investment rates of similar magnitudes occur in bunches. This translates into negative duration dependence and thus a downward sloping hazard function: the probability of (a large) investment in period *t* is higher if there was (a large) investment in period *t*-1 than if there was not. Under IRR, the dynamic adjustment pattern is similar to that under QAC in that the probability of investing will be higher if a firm has invested in the recent past, thus yielding negative duration dependence and a downward sloping hazard. This can be seen in the centre figure in the second row. One important difference compared to QAC, however, is the prevalence of periods of investment inactivity under IRR.

For the three adjustment cost structures, the third row of Figure 1 depicts the average investment rate as a function of the capital imbalance, i.e. the mandated investment, defined as the difference between desired and actual capital (from Goolsbee and Gross, 2000). Caballero and Engel (1999) show how, in a framework with stochastic FAC, average investment is an increasing, nonlinear function of mandated investment. This is depicted in the right picture in the third row, showing a region of inaction and a nonlinear function, where large deviations of actual from desired capital lead to proportionately larger changes in investment than small deviations. The relationship is linear under QAC (as firms close a constant part of the gap between desired and actual capital each period), and linear outside a region of inaction under IRR.

To summarize, over time both IRR and QAC yield positive autocorrelation in investment. This implies that the likelihood of investment in the current period is higher if the firm has invested recently, than if it has not. In other words, the hazard of investment falls with the length of investment inactivity, and so the investment process exhibits negative duration dependence. In contrast, with FAC the hazard rises with the length if investment inactivity, yielding positive duration dependence. Furthermore, in the imbalance state, both IRR and FAC lead to an inaction range, whereas QAC does not. Hence, we can distinguish between FAC on the one hand and IRR and QAC on the other, based on duration dependence analysis; and between QAC on the one hand and FAC and IRR on the other, based on an analysis of how actual investment responds to underlying imbalances. In order to differentiate between the three models it is thus necessary to examine adjustment in both the imbalance state and over time. This is the premise for the econometric analysis below. First we examine if descriptive statistics tell us anything about the nature of adjustment costs.

3. Data and Descriptive Statistics

This paper uses survey firm level data from Cameroon, Ghana, Kenya, Zambia and Zimbabwe, collected as part of the Regional Programme on Enterprise Development (RPED) organised by the World Bank. The contemporaneous data span the following periods: Cameroon, 1993-95; Ghana, 1991-93; Kenya, Zambia and Zimbabwe, 1992-94. Retrospective information enables us to construct longer time series than three years for certain variables, including investment. A total of 1208 firms have been surveyed at least once. We have discarded firms with too few observations over time and a few outliers, yielding a sample size of 821 firms, which we will refer to as the "full sample" throughout the analysis. All financial variables (e.g. investment and capital) have been converted to real 1991 U.S. dollars to ensure comparability across countries and over time periods. For details about sample selection and construction of variables, see Appendix.[4]

In Table 1 we report proportions of positive investments during a one-year period, by country and for four size classes.[5] For the pooled sample, the overall proportion with positive investment in the lower right corner is 0.42, which means that 58% of the observations are zero investment episodes. The particularly low investment propensity in Cameroon and Ghana and the high propensity in Zimbabwe can largely be attributed to differences in the size distribution of firms, as the propensity to invest is positively related to firm size. In Table 2 we report proportions of firms ever selling capital goods during the sample period.[6] All countries have an extremely low incidence of major disinvestment. Less than 2% of all sampled firms ever have a disinvestment rate in excess of 10%.

Having found that a significant share of the firms refrain from investing during an entire year, we proceed by examining whether firms compensate by making relatively large (lumpy) investments once they decide to act. In Tables 3 and 4 we define seven categories of investment rates ranging from just above zero

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[4] All surveys deliberately oversampled large firms. In recognition, we control for differences between firm size categories in most of the empirical analysis.

[5] For Table 1 we use data from two years before the first survey year, in addition to contemporaneous data from the three survey years. This means that each firm has at least 3 observations and at most 5 observations, and the period covered is in effect 1989-1995.

[6] The sample period refers to the three years with contemporaneous data.

Table 1. *Pooled Investment Propensities, by Country and Firm Size*

Employment, L	Cameroon	Ghana	Kenya	Zimbabwe	Zambia	Total
1≤ L ≤5	0.21	0.31	0.44	0.53	0.29	0.36
	78	80	180	51	132	521
5< L ≤20	0.29	0.44	0.40	0.51	0.29	0.38
	143	167	193	122	177	802
20< L ≤100	0.24	0.48	0.41	0.63	0.28	0.40
	147	153	280	177	228	985
L >100	0.38	0.20	0.44	0.71	0.38	0.46
	146	363	264	543	189	1505
Total	0.29	0.32	0.42	0.66	0.31	0.42
	514	763	917	893	726	3813

Notes: The top number in each cell is the proportion of firms with positive investments during one year. The bottom number in each cell is the number of observations. The table is based on data from the full sample of 821 firms.

to more than 40%, and show the contribution of each category to each country's total investment. We also show in these tables the proportions of the non-zero investments that belong to each of the seven categories (i.e. these proportions sum to unity in a given column). That is, 38% of the non-zero investments in the pooled sample are in the category 0<(I/K) ≤0.05, 19% are in the category 0.05<(I/K)≤0.10, and so on. Table 3 provides a breakdown by country, while Table 4 distinguishes between two size categories. Table 3 shows that the largest proportion of the observations (firms in a given year) have investment rates less than 10%, suggesting that small maintenance and replacement investments are an important part of investment activity.[7] However, for 14% of the observations in the pooled sample, when there is investment, the investment rate is over 40%, and these observations make up 26% of the total investment in the sample. Adding

[7] Nilsen and Schiantarelli (2003) note that while the large fraction of observations with small positive investment rates may seem inconsistent with non-convex adjustment costs, it is reasonable if we assume that adjustment costs for replacement investment are very small, and fixed costs are relevant only for expansion investment.

Table 2. *Proportions of Firms Selling Equipment*

	Any Disinvestment			Disinvestment rate >10%		
	Small (L≤20)	Large (L>20)	All	Small (L≤20)	Large (L>20)	All
Cameroon	0.07	0.13	0.10	0.00	0.00	0.00
	60	53	113	60	53	113
Ghana	0.04	0.08	0.06	0.01	0.03	0.02
	70	67	137	70	67	137
Kenya	0.05	0.15	0.10	0.00	0.03	0.02
	83	96	179	83	96	179
Zimbabwe	0.15	0.36	0.31	0.05	0.01	0.02
	41	122	163	41	122	163
Zambia	0.07	0.12	0.09	0.00	0.02	0.01
	59	61	120	59	61	120
All	0.07	0.19	0.14	0.01	0.02	0.01
	313	399	712	313	399	712

Notes: The top number in each cell is the proportion of firms ever selling capital (left part of the table), or ever recording a disinvestment rate larger than 10% (right part of the table), during the three years over which the firms were surveyed. The bottom number in each cell is the number of observations. Due to incomplete observations, calculations are based on data for 712 of the 821 firms in the full sample.

over the three categories with the highest investment rates, it can also be observed that 27% of the observations in the pooled sub-sample of non-zero investments have investment rates larger than 20%. This suggests that disequilibria in capital stocks may be substantial for a non-negligible number of firms, and provides some evidence for the lumpiness of investment. Table 4 shows that this result is more pronounced for small firms: 32% of the observations of investing small firms have investment rates larger than 20%, compared to 25% for large firms.[8]

[8] These percentages are obtained by adding the proportions of non-zero investments across the three highest investment categories.

Table 3. *Distribution of Investment Rates and Contribution to Aggregate*

	CAM	GHA	KEN	ZIM	ZAN	All
	A. Sample distributions of non-zero investments, by country and pooled					
0 < (I/K) ≤ 0.05	0.27	0.41	0.40	0.36	0.46	0.38
0.05 < (I/K) ≤ 0.10	0.16	0.16	0.20	0.22	0.15	0.19
0.10 < (I/K) ≤ 0.20	0.19	0.16	0.16	0.17	0.12	0.16
0.20 < (I/K) ≤ 0.30	0.12	0.09	0.06	0.07	0.08	0.08
0.30 < (I/K) ≤ 0.40	0.04	0.05	0.04	0.07	0.02	0.05
0.40 < (I/K)	0.23	0.13	0.14	0.12	0.17	0.14
	B. Share of total investment, by country and pooled†					
0 < (I/K) ≤ 0.05	30%	12%	22%	16%	19%	17%
0.05 < (I/K) ≤ 0.10	28%	9%	23%	12%	6%	13%
0.10 < (I/K) ≤ 0.20	17%	43%	16%	24%	21%	24%
0.20 < (I/K) ≤ 0.30	9%	15%	11%	13%	6%	13%
0.30 < (I/K) ≤ 0.40	1%	12%	5%	9%	3%	8%
0.40 < (I/K)	16%	9%	24%	26%	45%	26%
Observations	514	763	917	893	726	3813

Note: The table is based on data from the full sample of 821 firms.
† Total investment is the aggregate investment expenditure over time in each country sub-sample (and pooled for the column "All").

Furthermore, the proportion of large firms making the lowest replacement and maintenance investments is larger than that of small firms (40% and 34%, respectively, of the non-zero investments fall into the lowest category for the two size groups).

Tables 3 and 4 show that there is a relatively large fraction of large investment rates in the sample. This could be consistent with either a few firms always making large investments, or alternatively that many firms occasionally having large investments. Hence these data cannot be used to determine how important are investment spikes for individual firms. To further assess the extent to which firms make infrequent but relatively large investments, we follow the method initiated by Doms and Dunne (1998). We rank each firm's investment rates over time from the highest year (rank 1) to the lowest year (rank 5), and

Table 4. *Distribution of Investment Rates and Contribution to Aggregate by Size*

	Employment ≤ 20	Employment > 20
	A. Sample distributions of non-zero investments	
0 < (I/K) ≤ 0.05	0.34	0.40
0.05 < (I/K) ≤ 0.10	0.18	0.20
0.10 < (I/K) ≤ 0.20	0.17	0.15
0.20 < (I/K) ≤ 0.30	0.09	0.07
0.30 < (I/K) ≤ 0.40	0.05	0.05
0.40 < (I/K)	0.17	0.13
	B. Share of total investment†	
0 < (I/K) ≤ 0.05	6%	18%
0.05 < (I/K) ≤ 0.10	9%	13%
0.10 < (I/K) ≤ 0.20	12%	24%
0.20 < (I/K) ≤ 0.30	9%	13%
0.30 < (I/K) ≤ 0.40	6%	8%
0.40 < (I/K)	58%	25%
Observations	1323	2490

Note: The table is based on data from the full sample of 821 firms.
† Total investment is the aggregate investment expenditure over time in each sub-sample defined by firm size.

compute the average investment rates for each rank and the share of each rank in a firm's total investments.[9] Table 5 shows that the average investment rate of the highest rank year is almost three times higher than that of the second highest year, and seven times higher than that of rank 3. The investments associated with the largest investment rate for each firm represents 50% of total investments, which further underlines the considerable importance of lumpy investments at the firm level for aggregate investments.[10] We have also looked at the mean investment rate for each rank separately for small and large firms. These results, which are

[9] Only firms with at least five years of observations were included in these computations.
[10] The average investment rates are for a five year period. Our results are similar to other studies. Doms and Dunne (1998) find that 50% of total investment over a 16 year period is contributed by the highest three ranks; Nilsen and Schiantarelli (2003) report that 46% of total investment over a 14 year period is accounted for by the highest three ranks; and Gelos and Isgut (2001) find that investment episodes in the highest three ranks account for 58% of total investment in the Mexican sample (11 years) and 61% in the Colombian sample (eight years).

Table 5. *Ranked Investment Rates, Persistence, and Share of Total*

Rank		Ghana	Kenya	Zimbabwe	Zambia	All
1	Mean (I/K)	0.27	0.27	0.32	0.31	0.29
(High)	Adjacent (I/K)	0.04	0.06	0.09	0.04	0.06
	Share of Total	0.50	0.45	0.49	0.80	0.50
2	Mean (I/K)	0.08	0.12	0.15	0.09	0.12
	Adjacent (I/K)	0.10	0.09	0.15	0.09	0.11
	Share of Total	0.33	0.29	0.25	0.15	0.25
3	Mean (I/K)	0.01	0.05	0.07	0.02	0.04
	Adjacent (I/K)	0.10	0.11	0.11	0.09	0.11
	Share of Total	0.17	0.18	0.11	0.04	0.12
4	Mean (I/K)	0.00	0.02	0.03	0.01	0.02
	Adjacent (I/K)	0.07	0.09	0.10	0.10	0.09
	Share of Total	0.00	0.06	0.10	0.01	0.09
5	Mean (I/K)	0.00	0.01	0.01	0.00	0.01
(Low)	Adjacent (I/K)	0.06	0.10	0.13	0.11	0.10
	Share of Total	0.00	0.03	0.06	0.00	0.05
Observations		97	123	147	69	436

Notes: Only firms with at least five observations on investments, and who invested at least once, were included. The Cameroonian sub-sample has too few firms with sufficient information to compute statistics of the type reported in the table, and therefore we confine attention to the other four countries in this particular case. Mean (I/K) are average investment rates across firms for each given rank; Adjacent (I/K) are average investment rates in the year(s) after and/or before the rank; Share of Total are shares contributed to aggregate investment by each rank, where aggregate investment has been calculated as explained in the note below Table 3.

not reported to conserve space, indicate that the highest ranked investment rate accounts for a larger share of total investments for small firms than for large firms, consistent with other evidence that investment tends to be lumpier for small firms. That zero investment episodes and lumpy investment appear to be more important for small firms appears plausible: indivisibility of capital goods is probably more important for smaller firms, and the intermittent, lumpy character of investment could be smoothed in large firms by the aggregation of different types of production processes that occur.

To document the degree of persistence in investments, we have calculated the average investment rates one year before and after observations for each rank. These calculations, shown in Table 5, 'adjacent (I/K)', also lend further support to the notion that investment is lumpy, since the average investment rates in the years immediately before and after the firm's highest investment are conspicuously low. The mean investment rate in the years before and after the highest rank is on average less than one fourth of the investment in the year of the highest rank. In contrast to the highest rank, however, there does seem to be some degree of persistence for the lower ranks.

To summarise, the data discussed in this section suggest that investment activity takes the form of quite large adjustments concentrated in a few periods. These descriptive statistics are consistent with an adjustment cost technology featuring non-convexities, possibly due to fixed costs.

4. ECONOMETRIC ANALYSIS OF INVESTMENT DYNAMICS

The fixed cost model developed by Cooper et al. (1999) predicts that the probability of investing increases with the time since the last investment. That is, using the terminology of transition data econometrics, the Cooper et al. model predicts an upward sloping hazard function. Under both IRR and QAC, however, investment will be positively serially correlated, and the hazard function will consequently be downward sloping: the probability of investing in time *t* is higher if there has been investment in time *t*-1 than if there has not.

In order to test and distinguish between these hypotheses, we use econometric methods for transition data analysis. A potential difficulty in the analysis of transition data is that failure to control for time invariant heterogeneity in explanatory factors across firms will result in inconsistent estimates, typically biasing the slope of the estimated hazard function downwards. Therefore we will pay close attention to unobserved heterogeneity, which, following Cooper et al., we will model by a semiparametric random effects approach. In contrast to Cooper et al. we recognise the endogeneity of the initial conditions, which if ignored can give inconsistent results.

To obtain an estimable representation of the investment decision, we define a dummy variable y_{it} equal to one if there is investment and zero if not, and specify the model as follows:

$$(1) \qquad y_{it} = \begin{cases} 1 \text{ if } \ \beta \cdot x_{it} + \delta \cdot D_{it} + v_i + u_{it} \geq 0 \\ 0 \ \text{ otherwise} \end{cases},$$

where β is a vector of coefficients associated with observed vector of exogenous variables x_{it}, δ is a vector of coefficients associated with a vector of duration dummies D_{it}, v_i is a firm-specific random effect that is unobserved to the econometrician, u_{it} is a serially uncorrelated logistic disturbance term, and i and t are firm and time indices, respectively. The jth element of the vector $D_{it} = (d_{1it}\ d_{2it}\ ...\ d_{Jit})$ is equal to one if the firm last invested in period t-j and zero otherwise.[11] With this definition of D_{it} the coefficients $\delta_1,\ldots,\delta_J$ determine the shape of the hazard: if the coefficients on the dummies for long durations are larger than those on short duration dummies, then the hazard function is upward sloping, and vice versa. This specification, which is similar to that adopted by Cooper et al., is quite flexible. Clerides et al. (1998) show that a similar approach can be used for the estimation of dynamic discrete choice models more general than single-spell duration models.

The assumption that the disturbance term is logistically distributed yields the logit model, implying that the probability of observing any investment, conditional on the random effect, is equal to

(2) $$H_{it} = \{1 + \exp\{-(\beta \cdot x_{it} + \delta \cdot D_{it} + v_i)\}\}^{-1}.$$

To integrate the random effect out of the likelihood function, we assume that v follows a discrete multinomial distribution with M points of support. Hence, the support points and the probabilities, which determine the entire distribution of the heterogeneity, are parameters to be estimated.[12] Because of the dynamics there is an initial conditions problem in that all past investment outcomes, including the condition at the first point of observation, will be correlated with the random effect. This implies that the likelihood will involve the conditional density of the random effect, rather than the unconditional density.[13]

Taking the above into account, the resulting individual likelihood can be written

(3) $$L_i = \Pr\left(y_{i0}^S\right)\sum_{m=1}^{M}\prod_{t=S}^{T} H_{it}(\cdot, e_m)^{y_{it}}\left(1 - H_{it}(\cdot, e_m)\right)^{1-y_{it}} \Pr\left(v_i = e_m \middle| y_{i0}^S\right),$$

---

[11] Hence $d_{1it} = y_{i,t-1}$ and, for j>1, $d_{jit} = y_{i,t-j}\prod_{q=1}^{j-1}\left(1 - y_{i,t-q}\right)$.

[12] This approach was suggested by Heckman and Singer (1984), and has subsequently been used in various microeconometric analyses of, for instance, dynamic discrete choice (Moon and Stotsky, 1993; Blau and Gilleskie, 2001; Cooper et al., 1999), duration data (Blau, 1994; Ham and LaLonde, 1996), and count data (Deb and Trivedi, 1997). One of the merits of this strategy is flexibility: Monte Carlo evidence indicates that this approach compares favourably to standard MLE correctly assuming normality, and that it performs better than MLE assuming normality when this is incorrect (Mroz and Guilkey, 1995; Mroz, 1999).

[13] Indeed, based on the unconditional density, maximum likelihood estimates will not be consistent unless the initial conditions are truly independent of the random effect or T is very large (see e.g. Hsiao, 1986, pp. 169-172).

where y_{i0}^{S} is a vector of lags of the endogenous variable at the first observation of the firm and Pr( ) denotes probability.[14] The resulting model is a dynamic panel logit allowing for unobserved firm effects and duration dependence in the investment decision for up to J periods. To determine the lag length J, we tried different specifications. Longer lags than four years always turned out to be insignificant, and so we decided on $J = 4$. Another important specification issue refers to the number of support points, M. In fact, there are no well-established criteria for determining the number of support points in models like these (see for instance Heckman and Walker, 1990), so we follow standard practice and increase M until there are at most marginal improvements in the log likelihood value. Usually, the number of support points is small; indeed, for $M = 1$, unobserved heterogeneity is absent and the parameters of interest can be estimated using the standard logit model. Experimenting with the data we could not find any significant increase in the sample log likelihood value beyond $M = 2$, and so the results below are based on two points of support for the heterogeneity distribution. Because the model contains an intercept, we normalise $e_1 = 0$ (see e.g. Mroz, 1999).

Throughout the empirical analysis we maintain two definitions of the 'event' we are modelling: whether or not the firm made any investment at all during the year, and whether or not a firm made a sufficiently large investment to constitute an investment "spike". Following Cooper et al. and Nilsen and Schiantarelli (2003), we define an investment spike as an investment/capital rate exceeding 0.10. In all models we include the following explanatory variables, assumed exogenous: firm age, (log of) size, the profit rate, and the change in employment (as a proxy for accelerator effects), as well as dummies for time, country and industrial sub-sector. Details on variable definitions are provided in the Appendix. Since the model is estimated with an intercept, we exclude the duration dummy for the longest interval, d_{4it}. The coefficients on $d_{1it}, d_{2it}, d_{3it}$ can thus be interpreted as intercept shifters of the logit index: positive coefficients imply that the likelihood of (a large) investment in the current period is higher if the most recent (large) investment occurred at any time over the last three years than if it occurred more than three years earlier; further, a higher coefficient on d_{1it} than on, say, d_{2it} implies that the likelihood of (a large) investment in the current period is higher if the most recent (large) investment happened in the previous year than if it happened two years earlier; and so on.

[14]The decomposition in (3) is due to Arellano and Carrasco (2003). The initial conditions of the process are left unrestricted, and the associated probabilities in the vector $\Pr(y_{i0}^{S})$ are parameters to be estimated.

Estimates of the logit parameters β and δ are reported in Table 6 (to conserve space we do not report the coefficients on the time, country and sector dummies). The ML (maximum likelihood) model does not control for unobserved heterogeneity, while the SPML (semiparametric maximum likelihood) model allows for random effects of the discrete Heckman-Singer form. The results indicate that the coefficients on the lags of the dependent variable are consistent with a downward sloping hazard: the likelihood that a firm makes an investment (or alternatively a spike) is highest if the previous investment (spike) occurred recently, and then declines as the time of inactivity increases. In the non-zero investment model, the heterogeneity term e_2 is highly significant, indicating that it is important to allow for unobserved heterogeneity. As for the effect of the lags, controlling for unobserved heterogeneity makes a difference: without such controls, the estimated coefficients (and hence the transition probabilities) are monotonically falling, but this is not the case when unmeasured heterogeneity is taken into account.

To facilitate interpretation of the estimated coefficients on the duration dummies, we show in Table 7 the predicted transition probabilities implied by the four specifications in Table 6. That is, using eq. (2) and the logit parameter estimates of β and δ we calculate the probability of investment for four possible duration dummy vectors: $D_{it} = [1\,0\,0]$; $D_{it} = [0\,1\,0]$; $D_{it} = [0\,0\,1]$; and $D_{it} = [0\,0\,0]$.[15] The first of these vectors represents a case where the most recent investment occurred in the previous year, and the last one where it happened more than three years before. Without controls for random effects, the probability of investment in period t given investment in t-1 is 0.66. If the most recent investment happened two or three years earlier, the probability of investment is 0.41. For a firm whose most recent investment occurred more than three years ago, the probability of investment is as low as 0.29. Thus, the likelihood of investment seems to fall with the time since the most recent investment, indicating negative duration dependence. When we control for unobserved heterogeneity in the form of random effects, the negative duration dependence becomes less pronounced. This is to be expected, for reasons discussed above. However, the effect is not strong enough to yield positive duration dependence. Tests (not reported) indicate that we can reject the hypothesis that lag coefficients are jointly zero.

[15] These probabilities are evaluated at sample means of the exogenous explanatory variables in the model.

Table 6. *Dynamic Panel Logit Results*

	ML Estimates (No unobserved heterogeneity)		SPML Estimates (Semiparametric random effects)	
	1. Pr(I/K)>0	2. Pr(I/K)>0.10	3. Pr(I/K)>0	4. Pr(I/K)>0.10
d_1	1.549***	1.266***	1.089***	1.155***
	(0.141)	(0.16)	(0.191)	(0.314)
d_2	0.520***	0.413*	0.513**	0.377
	(0.186)	(0.231)	(0.207)	(0.281)
d_3	0.498**	0.182	0.596**	0.030
	(0.231)	(0.313)	(0.251)	(0.348)
Firm Age (years)	-0.01**	-0.025***	-0.010*	-0.026***
	(0.005)	(0.006)	(0.005)	(0.007)
Employment (log)	0.225***	0.123***	0.252***	0.128**
	(0.042)	(0.051)	(0.049)	(0.055)
Profit Rate	0.047*	0.147***	0.053*	0.146***
	(0.025)	(0.027)	(0.027)	(0.028)
Δ Employment	0.429***	0.520***	0.473***	0.514***
	(0.129)	(0.164)	(0.139)	(0.168)
e_2			2.569***	1.758
			(0.644)	(3.048)
$\Pr(v_i=e_2 \mid y_{i0}^S=w_1)$			0.325***	0.058
			(0.096)	(0.266)
$\Pr(v_i=e_2 \mid y_{i0}^S=w_2)$			0.000	0.000
			(0.001)	(0.000)
$\Pr(v_i=e_2 \mid y_{i0}^S=w_3)$			0.000	0.164
			(0.000)	(0.415)
$\Pr(v_i=e_2 \mid y_{i0}^S=w_4)$			0.038	0.000
			(0.045)	(0.001)
P_{w1}	0.465***	0.258	0.465***	0.258***
	(0.017)	(0.016)**	(0.017)	(0.016)
P_{w2}	0.122***	0.079	0.122***	0.079***
	(0.011)	(0.010)**	(0.011)	(0.010)
P_{w3}	0.055***	0.045	0.055***	0.045***
	(0.008)	(0.007)**	(0.008)	(0.007)
P_{w4}	0.358***	0.618	0.358***	0.618***
	(0.017)	(0.017)**	(0.017)	(0.017)
log likelihood	-1909.9	-1453.8	-1901.0	-1452.8
Exogenous initial conditions (*p*-value)			0.001	0.558

Notes: Asymptotic standard errors in parentheses. Significance at 1%, 5%, and 10% is indicated by ***, **, and *, respectively. Dummies for time, country and sector are included in the regressions but not reported in the table to conserve space. $w_1,\ldots, w_4$ denote possible realisations of the vector of duration dummies $d_1,\ldots,d_3$ at the first observation of the firm: $w_1 = [1\ 0\ 0]$, $w_2 = [0\ 1\ 0]$, $w_3 = [0\ 0\ 1]$, $w_4 = [0\ 0\ 0]$. The test for exogenous initial conditions is a log likelihood ratio test where in the restricted version of the model $\Pr(v_i=e_2 \mid y_{i0}^S=w_1) = \Pr(v_i=e_2 \mid y_{i0}^S=w_2) = \Pr(v_i=e_2 \mid y_{i0}^S=w_3) = \Pr(v_i=e_2 \mid y_{i0}^S=w_4)$.

Table 7. *Predicted Investment Probabilities*

	Prob(Investment>0)			Spike: Prob[(I/K)>0.10]		
Most recent investment occurred…	No R.E.	Random Effects		No R.E.	Random Effects	
…one year ago	0.66	0.53	0.94	0.32	0.29	0.7
…two years ago	0.41	0.39	0.89	0.16	0.16	0.52
…three years ago	0.41	0.41	0.9	0.14	0.12	0.43
…more than three years ago	0.29	0.27	0.83	0.12	0.11	0.43

Notes: R.E. = Random Effects. Investment probabilities are evaluated at mean values of the exogenous explanatory variables.

As for the effect of exogenous variables, firms with higher profit rates have a significantly higher probability of investing, which is consistent with the findings of Bigsten et al. (1999), and squares well with fact that most firms finance investments by internal means. Further, the propensity to invest is significantly higher in larger and growing firms, and significantly lower in older firms.

Looking in more detail at the distribution of the heterogeneity, the two 'types' of firms considered here are quite different. It can be seen in column 3, Table 6, that the likelihood of having $v_i = e_2$, rather than $v_i = 0$, is about 0.36. The group of firms with $v_i = e_2$ tend to have much a higher likelihood of investment than those with $v_i = 0$. Regardless of the investment history, the likelihood of investment for an average firm with $v_i = e_2$ never goes below 0.83. In contrast, for the majority of firms (i.e. those for which $v_i = 0$), the likelihood of investment is 0.53 if there has been investment in the previous period and only 0.27 if there has been no investment during the last three years. Finally, we assess the importance of dealing with the initial conditions problem discussed above. Given how we have written down the likelihood function (3), exogeneity of the initial condition in this context is equivalent to imposing the restriction that the probability that $v_i = e_2$ is independent of the initial condition. Testing whether such a restriction is accepted by the data can thus be viewed as a test of the null hypothesis that the initial conditions are exogenous. A casual look at the relevant probabilities reported in Table 6 strongly suggests that that such a test will be rejected, and this is indeed confirmed by a formal log likelihood ratio test (the log likelihood value of the restricted model is -1909.6, which with three degrees of freedom implies rejection at the 1% level). Interestingly, the point estimates of the coefficients on the duration dummies in the restricted model (not reported) are nevertheless quite similar to those in the unrestricted model.

Turning to the results of the spike model, these are qualitatively similar to those of the investment propensity model: duration dependence is negative, the age coefficient is negative, and the coefficients on employment, profits and the change in employment are positive. However, one important difference is that no significant unobserved heterogeneity is found, since the e_2 coefficient is insignificant (also the log likelihood values are similar). We tried parametric forms as well (e.g. assuming the random effects to be normally distributed), but this did not alter the results. It would seem, then, from these findings that the model ignoring unobserved heterogeneity is acceptable in the context of modelling spikes in our application.

Summing up, the dynamic logit results imply no evidence of upward sloping hazard functions in our sample, neither for non-zero investments nor for investment spikes. This is in accordance with the predictions of the irreversibility and QAC models, but not consistent with FAC.

5. Investment and the Capital Imbalance: A non-Parametric Analysis

In the Caballero-Engel (1999) model with FAC, a firm's average investment is an increasing function of the log difference between desired and actual capital. Caballero et al. (1995) define mandated investment as the deviation between desired and actual capital:

$$(I/K)_{it}^{MANDATED} = k_{it}^* - k_{i,t-1}$$

where k_{it}^* and $k_{i,t-1}$ are the log of desired and actual capital. As we have seen in Figure 1, the relationship between actual and mandated investment is linear under QAC, and non-linear under both IRR and FAC. Desired capital, of course, is not directly observable. We follow Goolsbee and Gross (2000) and assume that desired capital is proportional to 'frictionless' capital, defined as the level of capital the firm would choose if it never faced adjustment costs. Frictionless capital is a function of output, the cost of capital, and a firm-specific constant, and so can easily be estimated. In this first stage we use actual capital as the dependent variable and interpret the regression as determining long-run desired capital. We do not have an adequate measure of the firm's user cost of capital, but since this can reasonably be assumed constant, or at least slow changing, we use a fixed effects approach to eliminate it.[16] Hence, our measure of firm's desired capital is the predicted value from the regression of actual capital on output allowing for fixed effects.[17] In estimation, we impose no restrictions on the output elasticity. The regression results are available on request from the authors.

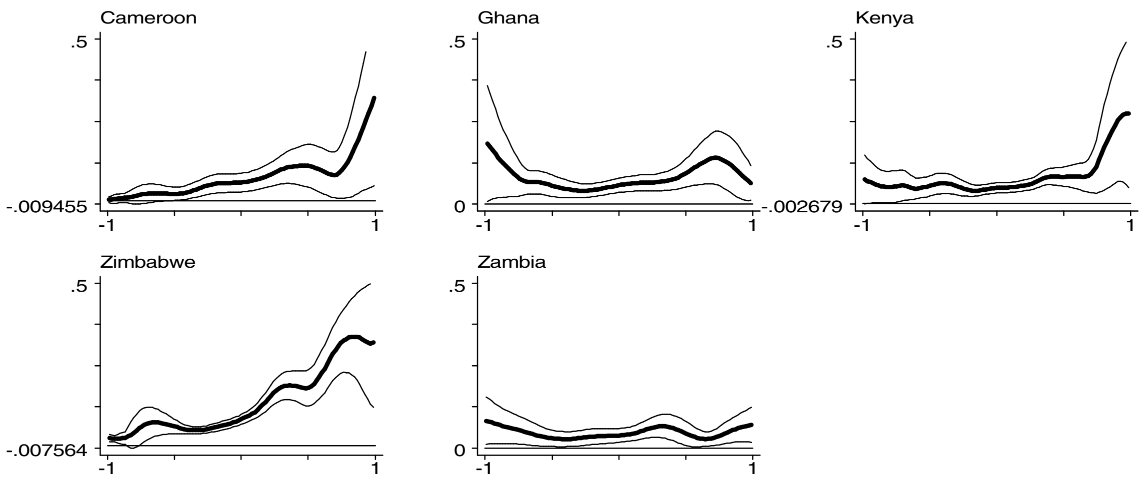
The second step is to estimate the firm's investment to capital rate as a function of mandated investment, the log difference between desired and actual capital. Following Goolsbee and Gross (2000), we use a Nadaraya-Watson kernel estimator which puts very little restriction on the shape of the function. A nonparametric approach is attractive in this context, mainly because our purpose is to analyse if there is any evidence of a non-linear relationship between mandated and actual investment. In particular, we seek to establish whether or not there is evidence in the data of a range of inaction, which would show up as a flat segment of the estimated curve. Recall that a flat segment would be consistent both with IRR and FAC. We can therefore view this part of the analysis as a robustness check on the result in previous section that irreversibility appears to play an important role in determining investment. Furthermore, investigating the relationship between actual and mandated investment may enable us to distinguish between FAC and IRR. Caballero and Engel (1999) show that with stochastic fixed costs, the average response to large disequilibria should be proportionally larger than the response to small disequilibria. That is, there will be a nonlinear relationship between actual and mandated investment even outside the range of inaction. In contrast, under irreversibility the relationship between actual and mandated investment is linear outside the range of inaction.

Figures 2a and 2b plot the nonparametric regressions for each country separately, and pooled over all countries, respectively. The results are quite mixed. For Cameroon, Kenya and Zimbabwe, the average investment rate is a convex function of mandated investment. In Kenya, average investment increases substantially for firms with the largest disequilibria. In Cameroon and Zimbabwe,

[16] Bond and Meghir (1994), though in a different modelling framework, also assume the cost of capital to be a fixed effect. We also experimented with using the profit rate as a proxy for the user cost of capital. Given that most firms in our sample are financially constrained and rely largely on internal funds to finance investment, this is more relevant than lending rates. The results were very similar.

[17] With this approach the scale of the imbalance state is not identified, since desired capital (unobserved) differs from frictionless capital (computed) by a constant (Goolsbee and Gross, 2000). Therefore, it would not be inconsistent to observe, say, an increasing function for negative values of mandated investment. The fact that the scale is unidentified is not important, since it is the *shape* of the function that is informative of the adjustment cost structure.

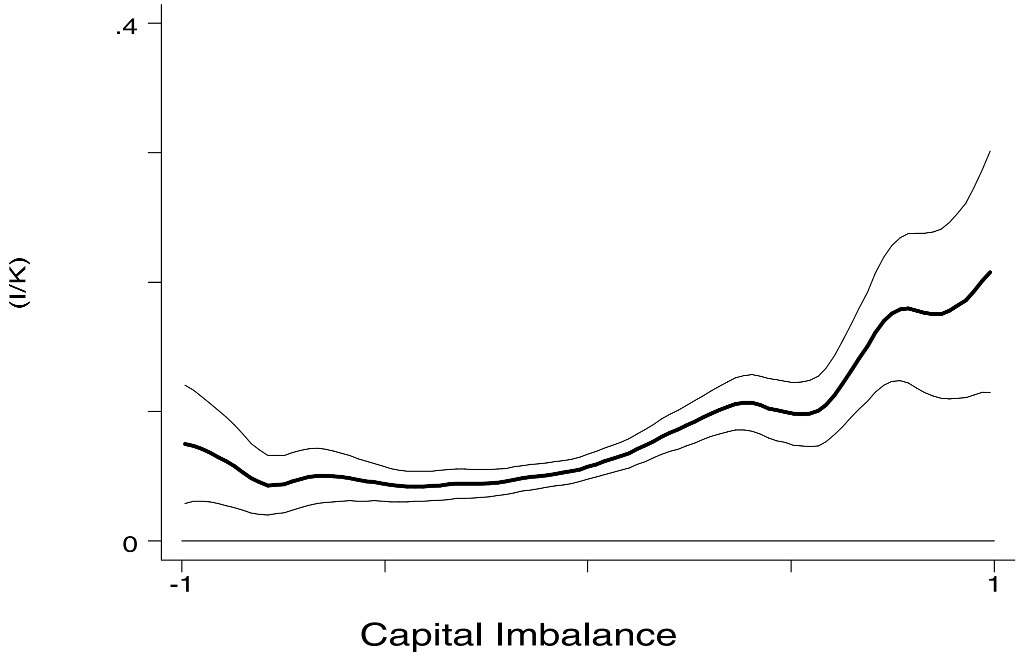
Figure 2a. *Nonparametric Average Hazard Regressions, by Country*



Notes: The model is (I/K)=f [$(I/K)^{MANDATED}$] + error. The investment to capital ratio is plotted along the vertical axes, and the capital imbalance along the horizontal axes. The kernel is triangular, and not sensitive to the choice of kernel. The thin lines indicate pointwise confidence intervals with 95% confidence level, calculated using the XploRe[18] macro "regci".

[18] See http://www.xplore-stat.de/.

Figure 2b. *Nonparametric Average Hazard Regressions, Pooled*



Notes: See Figure 2a.

the slope increases more gradually over the range of mandated investment. For Ghana and Zambia, however, the plots are non-monotonic and the patterns are not consistent with any specification of adjustment costs. The confidence intervals indicate that the estimates are less precise at very large disequilibrium levels, which is to be expected since there are relatively few data points at these levels. When pooling all countries (Figure 2b) we obtain a convex function, which is more precisely estimated than the country-specific relationships. We infer, albeit somewhat tentatively, from these results that the relationship between actual and mandated investment is essentially flat for small imbalances, and that as the demand for investment increases, actual investment eventually responds. It is quite clear, however, that the estimates are not precise enough to enable us to distinguish between fixed costs and irreversibility along the lines discussed in the previous paragraph.

6. CONCLUSIONS

In this paper we have analysed investment data from five African countries, seeking to document if there is any empirical support for three different adjustment cost models, namely QAC, FAC and IRR. In the descriptive analysis we have documented the importance of zero investment episodes and lumpy investment at the firm level. The average investment rate of firms highest ranked investment is almost three times higher than that of the second highest, and represents half of total investment. This pattern of zeros and lumps is decisively at odds with models based on QAC. This leaves us with FAC and IRR as potentially important forms of adjustment costs. We used a transition data model to examine how the hazard of investing, or alternatively having an investment spike, depends on the length of time since the last investment or spike. Our results indicate that the investment hazard is downward-sloping, supporting a pattern of slow adjustment which stretches over several periods. Using the Caballero-Engel (1999) modelling framework, we found that investment responds very little to changes in mandated investment unless the underlying disequilibrium is rather large.

Taken together, our empirical findings are thus fully consistent only with IRR, for which we believe there is fairly strong evidence. While FAC may not be literally ruled out - at some very low level of aggregation fixed costs or alternatively indivisibility problems may very well be prevalent - it is clear that these are not significant enough to yield a dynamic investment pattern in line with the FAC model, when we use annual data on what is, compared to most other studies, very small firms. Because at this moderate level of aggregation fixed costs cannot be identified, we would argue that fixed costs are not of primary importance for understanding investment behaviour among African manufacturing firms. Irreversibility, however, has a significant impact on investment behaviour. Firms refrain from investing during extended periods of time, rarely sell off capital stock, and adjust slowly to a new long-run equilibrium.

APPENDIX

A1. Definition of Variables

i) Investment

Investment expenditure is defined as the expenditure on equipment and machinery. In each of the three survey rounds, information was obtained about investment in the previous year. Further, in the first year, retrospective information on investment was obtained either by the question "What is the date [year] of the most recent acquisition of equipment?" (Cameroon, Kenya, Zambia, and Zimbabwe), or alternatively by extracting information about investment during each of a fixed number of pre-sample years (Ghana). With the exception of Cameroon, in subsequent survey rounds retrospective information on investment stretching back two years or more before the first survey was obtained.

The investment rate, (I/K), is defined as investment divided by the replacement value of capital (see below for the latter).

ii) Replacement value of capital

Reported values from the question on replacement value of equipment were used. Missing values could sometimes be replaced by values calculated from a perpetual inventory formula, see below.

iii) Employment

First, the number of employees at the time of survey was used, and second, when the first source was missing and for years prior to the sampling period, retrospective information was used. For the Cameroonian sub-sample, there exist retrospective information about employment in 1982, 1987, and 1992; for Ghana, there exist data on employment in 1983 and 1988; for Kenya, 1981, 1986, 1990, and 1991; for Zimbabwe, 1981, 1986, 1991, and 1992; and for Zambia, 1981 1986, 1990, and 1991. In addition, there is information about employment at the time of start-up of the firm, which in some cases makes it additionally possible to fill in holes in the series.

iv) Output

In each of the three survey rounds, information was obtained about output, defined as the output value at current market prices, in the previous year. Whenever output data were missing we used retrospective data: for Cameroon we used output data for 1992; for Kenya, we used data on the value of sales in 1990 and 1991; and for Zimbabwe we used the value of sales in 1991. The only set of results that are partially based on these retrospective data are the average hazard regressions in Table 7.

v) Profit

Profit is calculated by subtracting the cost of raw materials, total indirect costs, and wages from the output value. Output is defined as under (iv) above. Indirect costs involve costs for rent, electricity, water, telephone, liquid and solid fuel, and transportation. Wages does not include allowances; when missing, it was replaced by wages including allowances.

Since there exist no retrospective data on either of cost of raw materials, indirect costs, or wages, the profit variable can only be obtained for the years within the sampling period.

The profit rate is defined as profit divided by the replacement value of capital.

vi) Age

Age is defined as current year minus start-up year of firm, plus one.

A2. Sample Selection

A2.1. Criteria for Exclusion from Sample

Combining the five country data sets results in a pooled data set with 1208 firms, distributed across countries as follows: Cameroon, 239; Ghana, 215; Kenya, 276; Zimbabwe, 203; and Zambia, 275. Since a central element of the paper is dynamic analysis, we have deleted firms with less than 3 contiguous observations on investment. This reduces the sample by 157 firms. Further, in the regression analysis we cannot use firms with missing observations in any of the following variables: sector, age, employment, profit rate, and the change in (log of) employment. In some cases we have imputed values for employment and the profit rate (see A2.2 for details), however, in other cases we do not have sufficient information to construct imputed values, hence such observations have been deleted. The resulting sample, which we refer to as the "full sample", consists of 821 firms, distributed across countries as follows: Cameroon, 117; Ghana, 161; Kenya, 197; Zimbabwe, 186; and Zambia, 160.

A2.2. Missing Values and Outliers

Some of the observations in the data set either constitute sizable outliers, or signal measurement errors. This has been addressed as follows.

i) Investment

Whenever the investment rate (I/K) is larger than one, we replace the investment rate by 1, and accordingly set the investment expenditure equal to the replacement value of capital. This procedure affected approximately 2% of the observations in the full sample.

ii) Replacement value of capital

Whenever this variable was missing, we have calculated it from data on investment and capital stock from other years according to the perpetual inventory formula

$$p_{t+1}^{I} K_{t+1} = \frac{(1-\delta) p_{t+1}^{I}}{p_{t}^{I}} p_{t}^{I} K_{t} + p_{t+1}^{I} I_{t+1}$$

where δ is the depreciation rate. Consumer price indices were used as deflators, and a depreciation rate of 0.06 was assumed.

iii) Employment

For missing values in the employment variable, we used the panel dimension and replaced missing values by linear interpolation. This procedure was based on the two closest values on either side of the missing observation and the number of years between these two data points. For missing value having observations on only one side, we replaced them by the closest value on that side. This imputation procedure affects 18% of the observations in the full sample, which is a considerable share. However, this mainly affects Tables 1 and 4, where we show descriptive statistics of the investment variable over size pooled over time. In the regressions, the share of imputations in the employment variable is far smaller, since employment does not enter with a lag and the imputations mainly affect pre-sample years.

iv) Output and profit

Analysing value-added, defined as profit plus wages, and in particular its relation to the capital stock, provides useful information about the quality of the profit data. We consider data unreliable if any of the following is true:

a) Value-added is negative;
b) The capital to value-added ratio is less than 0.05; or
c) The capital to value-added ratio is larger than 50.

Whenever any of (a)-(c) is fulfilled, we discard the associated profit value.

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