User cost elasticity of capital revisited

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May 18, 2010

Abstract

The response of business capital to user costs is central to economic evaluations of tax and monetary policies. Despite intensive research effort though, no consensus about the size of this elasticity has been achieved. The divergence in prior estimates may arise because previous studies have neglected cointegration among capital, its user costs, and sales. Using German firm-level panel data, this study shows that estimating a distributed lag (DL) model which is prevalent in prior literature, leads to low estimates of the user cost elasticity and important cash flow effects. Properly accounting for the equilibrium relationship in an error correction model (ECM), which is in other respects a full reparametrization of the DL model, yields a much larger estimate of the user cost elasticity close to -1, that is the neoclassical benchmark, and no response of capital to cash flow variables.

Keywords: Taxation; Business investment; User cost of capital; Dynamic specification
JEL Classification: E22; H25; H32

Acknowledgement: I thank Johannes Becker, Stephen Bond, Hermann Buslei, Viktor Steiner, and Alfons J. Weichenrieder, as well as seminar participants at the Oxford Center for Business Taxation, the Social Science Research Center Berlin, the DIW Berlin, and Berlin Network of Labor Market Researchers for their valuable comments.
Note: A previous version of this paper was entitled "Corporate taxation and investment: Explaining investment dynamics with firm-level panel data".

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1 Introduction

The response of long-run capital stock to its user cost is pivotal to any economic analysis of tax reforms and monetary policy. Prior literature has successfully identified the user cost elasticity of capital as a key parameter of the impact of tax policy on capital formation, yet two important issues in the empirical investment literature remain unsolved. First, empirical research has not reached consensus about the actual value of this key elasticity.[1] Early research by Jorgenson (1963) and Hall and Jorgenson (1967) builds on a Cobb-Douglas production function with a user cost elasticity equal to -1. Subsequent studies based on aggregate or micro-data on investment (e.g., Eisner and Nadiri 1968, Chirinko et al. 1999) find that this parameter, when freely estimated in distributed lag models, is well below unity in absolute terms. A second strand of research (Cummins and Hassett 1992, Cummins et al. 1994, 1996), focused on periods with major tax reforms, reports substantially larger estimates that are not statistically different from -1, which represents the neoclassical benchmark.[2] These disagreements about the empirical estimates of the user cost elasticity of capital leave open the question of whether taxes matter for business investment spending.

Second, in contrast with Modigliani and Miller's (1958) irrelevance theorem, some research suggests that a firm's financial structure is relevant to its investment decision when capital markets are imperfect. In particular, informational asymmetries and costly contract enforceability generate agency costs that cause external funds to be imperfect substitutes for internal funds; that is, firms with more internal funds available invest more *ceteris paribus*. Most empirical studies feature a firm's cash flow in their models to measure liquidity (e.g., Fazzari et al. 1988, 2000), even though cash flow effects conflict with neoclassical theory. Because cash flow may confound the internal funds available and future investment opportunities (e.g., Kaplan and Zingales 1997, 2000, Bond et al. 2003b), no

[1] For an overview of this discussion, see Bond and Van Reenen (2007), Chirinko (2002), and Hassett and Hubbard (2002).

[2] Using plant-level data and a very different estimation approach, Caballero et al. (1995) obtain a wide range of user cost elasticity estimates for equipment (-.01 to -2.0, with an average value of -1.0). Rather than an investment equation, they estimate a cointegrational regression of the natural log of the capital-to-output ratio on the cost of capital. This approach involves different assumptions, so these results are not directly comparable.

agreement exists regarding whether cash flow variables should be included into the investment equation.

I argue that these two discrepancies—the very low price sensitivity of business investment spending and cash flow as an important determinant of investment—actually reflect methodological shortcomings of previous studies. That is, studies that have estimated low user cost elasticities of capital and detected cash flow sensitivities ignore the cointegration among capital, its user costs, and sales. Properly accounting for the equilibrium relationship yields a much larger estimate of the user cost elasticity that approaches the neoclassical benchmark of -1, with no response of capital to the cash flow variables. My research offers an explanation for two empirical puzzles that seem in conflict with neoclassical theory; taking the equilibrium relationship between capital and its determinants into account helps bridge the gap between two strands of research in investment literature.

Using German panel data pertaining to manufacturing firms during 1987-2007, I compare the distributed lag (DL) model that is prevalent in prior literature (Chirinko et al. 1999) with an error correction model (ECM). In the DL model, both short- and long-term effects result from an empirical specification search rather than being imposed *ex ante*. The ECM provides a remedy, in that it explicitly models the equilibrium relationship among capital, its user cost, and sales, as follows from the definition of optimal capital stock in economic theory. Such an invariant relationship is not only suggested by theory but also revealed by a panel cointegration test (Westerlund 2007). In other respects, the ECM is a full reparametrization of the DL model, so any difference in the estimates of the DL model and the ECM can be attributed entirely to the neglect of cointegration in DL models.

The point estimates for the DL model herein are comparable to prior findings (e.g., Chirinko et al. 1999 for the US, Chatelain et al. 2003a, 2003b, Harhoff and Ramb 2001, Kalckreuth 2001 for Germany), but the ECM estimates of the user cost elasticity are approximately double the estimates obtained in the DL model. My preferred estimate of the long-run response of capital to changes in user costs equals -1.3, such that a decrease in the user cost of capital by 1 percent increases capital by 1.3 percent in the long run. This estimate is not statistically different from the neoclassical benchmark and very similar to the parameter estimates found by the second strand of research in investment literature

(Cummins and Hassett 1992, Cummins et al. 1994, 1996). Furthermore, cash flow effects are present in the DL model but vanish in the ECM. This evidence adds to the argument that cash flow variables pick up on future profitability and become insignificant when the investment equation is dynamically and correctly specified.

The remainder of this article is organized as follows: The next section briefly reviews empirical studies that attempt to identify the user cost elasticity of capital and notes the lack of consensus. Section 3 describes how the user cost of capital can provide sufficient variation to identify the user cost elasticity. I introduce the data set and the empirical methodology in Section 4, then in Section 5 I present the coefficients estimated in the DL model and the ECM. Section 6 summarizes the main results and concludes.

2 Empirical studies of the user cost elasticity

Despite nearly 50 years of active research, no consensus about the size of the user cost elasticity of capital has been achieved. Disagreement persists about whether Jorgenson's (1963) assumption of a Cobb-Douglas production function, with a user cost elasticity of -1, can be justified. The first challenge to this assumption came from Eisner and Nadiri (1968), who estimated an elasticity of -.33 to -.16. These very low estimates reject the assumption that capital is proportionally elastic to its user cost and oppose the view of policymakers who believe that tax rules influence investment behavior through the user costs of capital. Estimates in subsequent studies using aggregate investment data have not closed this gap but were generally small and well below unity in absolute terms (for an overview of these studies, see Chirinko 1993).[3] Aggregate data, however, suffer from several drawbacks, including problems of simultaneity between the user cost of capital and investment shocks (Goolsbee 1998, 2004), a limited amount of variation, and unobserved firm heterogeneity, which might bias estimates of the user cost elasticity downward.

To address these concerns, recent studies have explored large, firm-level panel data sets

[3] In a more recent study for the United Kingdom, Smith (2008) compares elasticities estimated with aggregate data against those found with dynamic panel data methods in an industry-level data set. His preferred estimate is in the neighborhood of -.4

and instrumental variable methods. Focusing on major tax reforms, Cummins and Hassett (1992) estimate an elasticity of -.28 for structures and -.93 for equipment. Auerbach and Hassett (1992) and Cummins et al. (1994, 1996) play on differences in the composition of investment across industries in the United States to identify the elasticity of capital with respect to its user cost. Cummins et al. (1994, 1996) also estimate significant effects of user costs and come up with an implied long-run elasticity of the capital stock of -.67. With a completely different approach, in which they estimate a cointegrational regression of the natural log of the capital-to-output ratio on the cost of capital, Caballero et al. (1995) report estimates ranging from -.01 to -2.0, with an average at about -1.0.[4]

Although the evidence in these micro studies is consistent with economically significant effects of taxes and the user cost of capital on capital in the long run, Hassett and Hubbard (1997) might have been premature in claiming a new 'consensus' with regard to the size and robustness of this effect: In their prominent study, also using micro data, Chirinko et al. (1999) establish an elasticity estimate of -.25 and thus reopened the debate about the "right" value. This study also revealed a second question for investment literature, namely, how imperfect capital markets might influence the user cost elasticity. That is Chirinko et al. (1999) relate investment not only to current and lagged values of the user cost and sales but also to cash flow. Referring to Fazzari et al. (1988), Chirinko et al. (1999) (p. 61) argue that cash flow as a measure of liquidity "should enter the model to account for access to internal funds that affect the timing of investment." Cash flow substantially reduces the user cost elasticity and is an important determinant of investment. Their findings thus sharpen the potential impact of two points still unsettled in investment literature: First, how can the divergence in the size of the estimated user cost elasticities be explained or bridged to reach consensus? Second, is cash flow the right measure to account for imperfect capital markets, or does it confound the internal funds available and future investment opportunities?

This paper offers an explanation for both phenomena, that is, low price elasticities and cash flow as important determinant of investment. Accounting for the equilibrium rela-

[4]This estimate is similar to that found using cointegration methods with aggregate manufacturing data, such as Bertola and Caballero (1994) and Caballero (1994).

tionship among capital, its user costs, and sales should yield a much larger point estimate of the response of capital to changes in its user cost and cause cash flow effects to vanish. This new approach thus can bridge the gap between the two strands of research and might help achieve a shared estimate of the user cost elasticity conjured by Hassett and Hubbard (1997).

3 Firm-specific variation in the UCC

My goal is to estimate the user cost elasticity of investment in a dynamic framework on the basis of the user cost of capital (UCC), which varies across firms and over time. Building on work by Jorgenson (1963), Hall and Jorgenson (1967), and King and Fullerton (1984), I define the UCC as the minimal rate of return a firm must earn on investments before taxes to start the project, which is a function of both economic variables and taxation.

The $UCC_{i,j,a,t}$ for firm i in industry j with asset a at time t is given by

$$UCC_{i,j,a,t} = \frac{p_t^I}{p_{j,t}^S} \frac{(1 - z_{a,t}) \left(\theta_{i,t}(r_{i,t}\kappa_{i,t}^{f,investor}) + \delta_{j,a,t}^e \right)}{1 - \tau_t}, \tag{1}$$

where p_t^I is a price deflator for investment goods at time t (same for all industries and assets), $p_{j,t}^S$ is the industry j-specific output price at time t, $\delta_{j,a,t}^e$ is the asset a and industry j-specific economic depreciation rate that captures the difference between physical depreciation and expected capital gains, and $z_{a,t}$ are asset a-specific depreciation allowances provided by the tax system.[5] I consider two types of assets a: property with buildings and fixed tangible assets. The tax rate τ_t includes the corporate income tax rate on retained earnings and the solidarity surcharge for Eastern Germany.[6] The Appendix provides details

[5]In Germany, an investment tax credit only exists for an initial investment in Eastern Germany (*Investitionszulage*). There is no investment tax credit for a replacement investment or investment in Western Germany.

[6]To keep the analysis manageable, I only include taxes on profit and do not consider the local business tax and the real estate tax. The real estate tax relates to the assessed tax value of property. The assessed tax value cannot be deduced from the corporate balance sheet information but is calculated by local tax authorities, based on the location, age, size, and characteristics of a property. Disregarding the local business tax and real estate tax clearly leads to an underestimation of the UCC but not a loss of generality for my estimations in first-differences, as long as the collection rates fixed by the municipality do not change

regarding the construction of the variables (Appendix A.1) and the evolution of corporate income tax and solidarity surcharge rates over time (Appendix A.2).

Firm-specific financial costs $\theta_{i,t}(r_{i,t}\kappa_{i,t}^{f,investor})$ are a weighted average of after-tax interest rates, where the weights $\kappa_{i,t}^{f,investor}$ are the proportion of capital accounted for by each financial source and type of investor.[7] There are three sources of finance f (retained earnings, debt, and new equity) and two types of investors (private and institutional shareholders). In Table 1, I list the after-tax interest rates for all combinations of the sources of finance and types of investor, depending on the firm's interest rate $r_{i,t}$ and taxation.[8]

Table 1: After-tax interest rate $\theta_t(r_{i,t})$ by source of finance and by type of shareholder

Financing through...	**Private shareholder**	**Institutional shareholder**
Retained earnings	$\theta_{i,t}^{retain,p}(r_{i,t}) = r_{i,t}$	$\theta_{i,t}^{retain,inst}(r_{i,t}) = r_{i,t}$
Debt	$\theta_{i,t}(r_{i,t})^{debt,p} = r_{i,t}(1-\tau_t)$	$\theta_{i,t}^{debt,inst}(r_{i,t}) = r_{i,t}(1-\tau_t)$
New equity		
until 2000	$\theta_{i,t}^{new,p}(r_{i,t}) = r_{i,t}(1-\tau_t)$	$\theta_{i,t}^{new,inst}(r_{i,t}) = \frac{r_{i,t}}{1-\tau_t^{distr}}(1-\tau_t)$
since 2001	$\theta_{i,t}^{new,p}(r_{i,t}) = r_{i,t}(1-\tau_t)$	$\theta_{i,t}^{new,inst}(r_{i,t}) = r_{i,t}(1-\tau_t)$

Source: King and Fullerton (1984), as well as own calculations.

Finally, the overall $UCC_{i,j,t}$ for firm i in industry j at time t is given by the weighted average of its asset-specific user costs:

$$UCC_{i,j,t} = \sum_a UCC_{i,j,a,t}\kappa_{i,t}^a, \tag{2}$$

where $\kappa_{i,t}^a$ is the firm-specific share of assets a in total assets. Thus I can calculate the user

over time. Because the collection rates are very stable over time (according to the property tax statistics), disregarding the local business tax and real estate tax should not change the results.

[7] In a world of distortionary taxes favoring debt over equity, a firm's financial cost differs from the market interest rate. This argument is in line with the pecking order theory of financing advocated by Myers and Majluf (1984): Firms prefer internal financing when available and prefer debt over equity if external financing is required. Because the marginal financial structure cannot be deduced from the data, I use the observable average shares in a given year as a proxy for the *marginal* ratios. I further assume that 70 percent of shareholder are institutional and 30 percent are private shareholders (Deutsches Aktieninstitut 2007). As a robustness check, I experiment with a 60 percent (80 percent) share of institutional shareholders and calculate the financial cost using the overall yield on corporate bonds. The results remain unchanged.

[8] Unfortunately, I am forced to neglect personal income taxation, because I lack information about a corporation's shareholders. However, the personal income tax is highly progressive in Germany, so comprehensive information on shareholders' other sources of income would be necessary to consider personal tax liabilities.

cost of capital for each firm. The UCC varies due to changes in taxation and macroeconomic factors. Yet most variation stems from varieties in the firms' financial structure and the asset mix they use.

4 Data and estimation strategy

4.1 Data

The principal data requirement for estimating the user cost elasticity of the capital stock is cross-sectional and time-series micro data regarding the user cost of capital and the gross investment rate. I therefore combine two data sources that each provide information in support of my objectives: detailed company accounting data from the Hoppenstedt firm information GmbH, and industry-level information maintained by the German Statistical Offices and the German Central Bank.

Hoppenstedt provides accounting data for most German corporations that are subject to publication requirements. At the time of writing, the Hoppenstedt company database contained financial statements from 1987 to 2007. I exclude companies that have changed their accounting year during this period, such that all sets of accounts cover a 12-month period. When I also exclude companies with fewer than five records[9] and restrict the sample to firms with limited liability, I obtain an unbalanced sample of 3,968 non-financial firms, with 24,762 annual observations. The number of records per firm varies between 4 and 21. In the Appendix, I provide descriptive statistics regarding the structure of the sample by number of observations per company (Table A.2), the distribution of observations over years (Table A.3), and the distribution of firms over industries (Table A.4).[10]

[9] As a maximum, I include three lags in my regression analysis. I consider changes in the explanatory variables, which means that the firm must have been in the data set in the four preceding years, such that I need at least five records per firm.

[10] Unfortunately, I cannot compute the coverage of the Hoppenstedt balance sheet database for the whole corporate sector, because aggregate investments of non-financial corporations are unknown in Germany. Information is available for mining, quarrying, and manufacturing firms (incorporated and non-incorporated companies), which invested about 47.7 billion Euros in 1997 (middle of the observation period). In the same year, Hoppenstedt corporations used in the estimations invested about 21.8 billion Euros. Mining, quarrying, and manufacturing firms together employed about 7.8 million persons, of which, 4.1 million were employed at corporations in the Hoppenstedt database.

The data set includes information about time-invariant firm characteristics, such as the industry, region, legal form, and year of foundation. Most important for my analysis, the data set describes balance sheet positions and firms' profit-and-loss accounts in great detail. In particular, it records the acquisition,[11] disposal, and withdrawal of fixed assets. To calculate the UCC as described, I complement the individual data with industry-level information obtained from the German Statistical Offices about the prices of investment goods (p_t^I) and output prices ($p_{j,t}^S$), as well as economic depreciation rates for buildings and fixed tangible assets ($\delta_{j,a,t}^e$).

Table 2 includes some descriptive statistics pertaining to the variables used in the estimation during 1987-2007. The firm-specific gross investment rate ($I_{i,t}$) is normalized by the replacement cost value of capital stock ($K_{i,t-1}$), estimated on the basis of historic cost data using the perpetual inventory method. Cash flow ($CF_{i,t}$), which is equal to income plus non-cash expenses like depreciation allowances, is also scaled by the beginning-of-period capital stock. I measure output as sales ($S_{i,t}$). Nominal sales data come from the Hoppenstedt net sales figure, and are deflated by an industry-specific output price deflator. The growth rate of sales (user cost of capital) is defined as $\Delta S_{i,t}/S_{i,t-1}$ ($\Delta UCC_{i,t}/UCC_{i,t-1}$). For details on the variables and the derivation of the replacement cost values of the capital stock, see the Data Appendix A.1.

As expected, the firm data variables are positively skewed. The average capital stock amounts to approximately 69 million Euros, which reflects the dominant sampling of large corporations in the Hoppenstedt company database. On average, a firm's gross investment represents 15.1 percent of its existing capital stock. This average rate and median gross investment to capital ratio (6.2 percent) are compatible with moderate capital stock growth.[12] Both mean and median sales grew very slowly, at rates of 0.1 percent and 0.6 percent, respectively. In the observation period, the user cost of capital grew slightly on average (+1.6 percent) but declined for the median company (-1.4 percent). A decline in the UCC should be expected, because tax reforms significantly reduced the corporate income tax rate for all companies. Cuts in statutory tax rates were financed by more strin-

[11] This category includes direct purchases of new fixed assets and those gained through acquisitions.

[12] The economic depreciation rate is approximately 3 to 5 percent for structures and 8 to 12 percent for fixed tangible assets.

gent depreciation allowances, and output prices and economic depreciation rates developed unequally over industries, so that it is, however, conceivable that the user cost of capital grew marginally for some firms.

Table 2: Descriptive statistics for micro data

Variable	Mean	Median	Within-firm stand. deviat.[a]	Firm-specific time variation[b]
$K_{i,t}$ (in 1,000 euro)	69,498	12,283	23,539	0.998
$I_{i,t}/K_{i,t-1}$	0.151	0.062	0.192	0.999
$S_{i,t}$ (in 1,000 euro)	268,000	70,700	191,067	0.996
$\Delta S_{i,t}/S_{i,t-1}$	0.001	0.006	0.202	0.995
$CF_{i,t}/K_{i,t-1}$	0.053	0.012	0.118	0.998
$UCC_{i,t}$	0.140	0.135	0.030	0.782
$\Delta UCC_{i,t}/UCC_{i,t-1}$	0.016	-0.014	0.282	0.940
Number of observations			24,762	

Notes: $I_{i,t}/K_{i,t-1}$ is the ratio of investment to the beginning-of-period capital stock, $S_{i,t}$ are firms' real sales in 1,000 euro, $\Delta S_{i,t}/S_{i,t-1}$ is firm sales growth, $CF_{i,t}/K_{i,t-1}$ is the ratio of firm cash flow to the beginning-of-period capital stock, $UCC_{i,t}$ is the user cost of capital, and $\Delta UCC_{i,t}/UCC_{i,t-1}$ is the percentage change in this variable.

[a] Using mean-differenced variables, the within-firm standard deviation measures variation in the time dimension of the panel only.

[b] Following Chirinko et al. (1999), this measure is computed as 1 minus the R^2 statistic from a regression of each mean-differenced variable on a set of time dummies.

Source: Hoppenstedt company database and own calculations, 1987 to 2007.

The within-firm standard deviation shows substantial variability over time, particularly for changes in the user cost of capital driven by tax reforms, financing costs, and price trends. Identification is mainly based on firm-specific variation. Drawing on calculations in Chirinko et al. (1999), I measure the firm-specific time variation as 1 minus the R^2 statistic from a regression of each mean-differenced variable on a set of time dummies. The firm-specific time variation in the data not due to aggregate time effects is in the last column of Table 2. This proportion is high for the variables in rows 1-5, reaching more than 99 percent. It is lower for the user cost of capital because, to a larger extent, variation in the UCC is determined by aggregate factors such as tax rates or price trends. Firm-specific variation is reduced further because information on economic depreciation rates or price indices is not available at the firm but at the industry-level only. These aggregate factors, albeit important, do not fully explain time-series variation in the user cost of capital. On the contrary, there is still substantial micro-level variation; 78 percent of the variation in the UCC (Table 2) is due to firm-specific factors.

4.2 Models and estimation strategy

Both the DL model commonly used in prior literature and the ECM rely less on theory, but they also offer the advantage of imposing less structure than Q or Euler equation models (Bond et al. 2003b). In particular, they do not require quadratic adjustment costs.[13] Even though the ECM cannot be derived explicitly from a dynamic optimization problem such as Q or Euler models, the long-term formulation of the capital stock is consistent with a simple neoclassical model of firms' demand for capital. This model of the equilibrium relationship between capital stock and its determinants makes ECM superior to the DL model, which has prevailed in empirical investment literature. In the following, I estimate both the ECM and DL model and argue that disregarding cointegration might have biased previous estimates of the user cost elasticity. Before briefly describing both models, I introduce the relationship among capital, the user cost of capital, and output.

4.2.1 Optimal capital stock

The demand for capital and, in a dynamic perspective, for investment can be derived from the first-order conditions of profit-maximizing behavior with static expectations (Eisner and Nadiri 1968). Using a production function with constant elasticity of substitution (σ) between capital and labor,[14] the optimal capital stock $K^*_{i,t}$ for firm i at time t can be written as (Arrow et al. 1961)

$$K^*_{i,t} = A_i T_t {S_{i,t}}^{\beta} UCC_{i,t}^{-\sigma}, \tag{3}$$

where $\beta = \sigma + \frac{1-\sigma}{\nu}$.

The optimal level of capital depends on a firm's level of output or sales $S_{i,t}$, a firm-specific distribution parameter A_i that explains firm-specific relative factor shares of labor

[13]Quadratic adjustment costs have been criticized as empirically implausible (Doms and Dunne 1998) and too strict in the context of investment under (partial) irreversibility (Dixit and Pindyck 1994).

[14]A production function with constant elasticity of substitution nests Leontief ($\sigma = 0$) and Cobb-Douglas ($\sigma = 1$) production functions.

and capital,[15] technology T_t, and the firm's user cost of capital UCC as defined in equations (1) and (2). In this partial analysis, the optimal capital stock is independent of the wage level, such that companies are assumed to be price-takers on the labor market.[16] The parameter of interest is the long-term elasticity of capital with respect to the UCC, given by $-\sigma$.

In a frictionless world, the log of the current optimal capital stock $k^*_{i,t}$ is simply a log-linear function of current sales in log ($s_{i,t}$), the logarithmized current user cost of capital ($ucc_{i,t}$), a firm-specific effect a_i, and a deterministic time trend that captures technological progress. If costs of adjustment and uncertainty are introduced though, the current capital stock depends on both current and past values of sales and user cost of capital in logs, as well as on past values of the capital stock.[17] Appending a stochastic error term $\varepsilon_{i,t}$, the current capital stock can be expressed as:

$$k_{i,t} = c + a_i + \sum_{h=1}^{H} \phi_h k_{i,t-h} + \sum_{h=0}^{H} \beta_h s_{i,t-h} - \sum_{h=0}^{H} \sigma_h ucc_{i,t-h} + \sum_{t=1}^{T-1} \tau d_t + \varepsilon_{i,t}. \tag{4}$$

Furthermore, expectational variables in the data generating process imply potential problems in the estimation of short-run effects and long-term solutions. The investment equation cannot be identified without knowledge of the series underlying the expectation formation process, because in that case, the explanatory variables are not contemporaneously uncorrelated with the error term for the parameters of interest, and short-run and long-term effects might not be estimated consistently. As Banerjee et al. (1993) show in detail, the non-stationarity of capital and cointegration among capital, sales, and user costs

[15]Beyond firm-specific relative factor shares, the parameter might capture a firm-specific price markup in monopolistic markets.

[16]In the econometric analysis, differences in the wage level over time and across firms are captured in the deterministic time trend and firm-specific effects.

[17]Adjustment costs are assumed to be a function of either the rate of gross or net investment and rationalized in reference to the costs of disruption, training of workers, management problems, and the like (e.g., Eisner and Strotz 1963, Lucas 1967, Gould 1968, Treadway 1969). They also may be justified by supply side factors, assuming the supply curve of capital goods to the firm is upward sloping (e.g., Foley and Sidrauski 1970, 1971). Nickell (1977) rationalizes lags by combining delivery lags and uncertainty. Harvey (1990) neatly distinguishes both effects: In a world with adaptive expectations, the optimal capital stock depends on lagged sales and the user cost of capital, whereas the currently optimal capital stock depends on lagged capital stock if the capital is only partially adjusted.

of capital can lead to consistent estimations of the long-term solution in an error correction framework, despite the lack of weak exogeneity. In the presence of expectational variables, the short-run coefficients remain misestimated in the ECM too. For this reason, I mainly focus on the long-run coefficients in the ECM that can be consistently estimated in either case.

4.2.2 Prevalent model: Distributed lag (DL)

In the specification proposed by Chirinko et al. (1999), investment I_t comprises replacement components and net components. Replacement investment (I_t^r) is proportional to the capital stock available at the beginning of the year, because capital is assumed to depreciate geometrically at a firm-specific constant rate (δ_i). Net investment (I_t^{net}) is the change in capital between years t and $t-1$. The change in capital stock scaled by the existing stock thus equals

$$\frac{K_{i,t} - K_{i,t-1}}{K_{i,t-1}} = \frac{I_{i,t}}{K_{i,t-1}} - \delta_i. \tag{5}$$

Because firm-level data are usually right skewed and exhibit large differences in firm size, Chirinko et al. (1999) propose specifying the equation for capital with all variables as ratios or rates. Differencing equation (4), and omitting its auto-regressive part, with the log approximation ($log(K_t) - log(K_{t-1}) \approx \Delta K_t / K_{t-1}$) for the change in capital expressed in equation (5), and including cash flow relative to the existing capital stock as a measure of liquidity (cf. Fazzari et al. 1988, 2000), Chirinko et al. (1999) attain their DL investment equation:

$$\begin{aligned} \frac{I_{i,t}}{K_{i,t-1}} = \delta_i &+ \sum_{h=0}^{H} \beta_h \Delta s_{i,t-h} - \sum_{h=0}^{H} \sigma_h \Delta ucc_{i,t-h} \\ &+ \sum_{h=0}^{H} \gamma_h \frac{CF_{i,t-h}}{K_{i,t-h-1}} + \Delta\varepsilon_{i,t}. \end{aligned} \tag{6}$$

A significant cash flow effect in this model can indicate the presence of financing constraints on investment. However, its is well known that financial constraints are not the only possible interpretation of significant coefficients for the cash flow variables. If investment depends on expected future sales and cash flow acts as a proxy for the omitted expected future profitability variables, cash flow coefficients would be significant even in the absence of financing constraints (e.g., Kaplan and Zingales 1997, 2000).

In the estimation equation, the long-term user cost elasticity of capital is captured by the sum of the σs. There is no explicit model of the equilibrium relationship among capital, sales, and user cost of capital. The ECM provides a remedy.

4.2.3 Error correction model (ECM)

The ECM was first introduced in investment literature by Bean (1981), with the main idea of nesting a long-term specification of the firm's demand for capital (depending on sales and user cost of capital) in a regression setting that immediately yields parameters that can describe the extent of short-run adjustment to disequilibrium. In this sense, the ECM is a reparametrization of the DL model that also includes the equilibrium relationships if capital, sales, and the user cost of capital are cointegrated. Whether cointegration holds can be tested using a panel cointegration test (Westerlund 2007).[18] With cointegrated variables, the parameter estimates are consistent and follow the standard normal distribution asymptotically, with valid t-tests.

The "classical" ECM is estimated in two steps (Engle and Granger 1987). First, the long-term parameters are estimated with a static regression in levels. Second, the estimate of the dynamics uses the error correction term, which equals the residuals from the static regression. Stock (1987) and Banerjee et al. (1986) present evidence that this estimator is consistent if the variables are cointegrated but may lead to a finite sample bias. In practice, a finite sample bias might be of particular importance if the error term is autocorrelated. In either case, the result is inconsistent standard errors of the equilibrium estimates. To avoid biased estimates in small samples and facilitate the estimation of the equilibrium parameters, Bewley (1979) has proposed a one-step ECM that I adopt.

Reparameterizing equation (4),[19] reducing the auto-regressive component to one lag,

[18] I am aware that the test has higher power in samples where T is substantially larger than N. Even in small samples though, the Westerlund (2007) test outperforms residual-based panel cointegration tests.

[19] For reparametrization, subtract and add $\beta_h s_{i,t-h}$ and $\sigma_h ucc_{i,t-h}$, then rearrange.

again using the log approximation for the change in capital stock expressed in equation (5), and once more including cash flow relative to the existing capital stock as a measure of liquidity, I derive an ECM that can be estimated in a single step:

$$\begin{aligned} k_{i,t} = c + \phi k_{i,t-1} + \sum_{h=0}^{H} \mu_h \Delta s_{i,t-h} - \sum_{h=0}^{H} \alpha_h \Delta ucc_{i,t-h} + \sum_{h=0}^{H} \gamma_h \frac{CF_{i,t-h}}{K_{i,t-h-1}} \\ - \sigma' ucc_{i,t-1} + \beta' s_{i,t-1} + \sum_{t=1}^{T-1} \tau d_t + a_i + \varepsilon_{i,t}, \end{aligned} \tag{7}$$

where $\sigma' = -(\phi - 1)\sigma$, and $\beta' = -(\phi - 1)\beta$.

This estimation separates out the short and long-term effects of a change in sales or user cost of capital. Immediate effects of a change in the user cost of capital are captured by α_0, such that a reduction in the UCC by 1 percent will immediately increase capital by α_0 percent. Similarly, μ_0 gives the firms' short-term response to changes in sales. If cash flow is a determinant of investment, it will be captured by γ, and γ_0 again reflects the instant effect of cash flow on capital. The user cost elasticity, which refers to the response of the long-run capital stock to percentage changes in the user cost of capital, is not for direct reading but rather must be calculated as $-\sigma = \frac{\sigma'}{\phi-1}$. Because capital and output also have an equilibrium relationship, the long-run implications of a change in sales are captured by $-\beta = \frac{\beta'}{\phi-1}$. The standard error of both long-term multipliers can be derived with the help of the delta method.

4.2.4 Estimation strategy

The Bewley-transformed ECM includes the lagged dependent variable. Because the lagged dependent variable in panel data is necessarily correlated with a firm-specific effect,[20] a simple ordinary least squares (OLS) regression is biased and inconsistent. The estimation of the Bewley-transformed ECM thus calls for an instrumental variable (IV) technique.

In addition to including the lagged dependent variable, there are three reasons to use

[20]Such unobserved firm characteristics might include a firm's capacity for innovation or managerial abilities. The firm-specific effect can be interpreted as a component of the usual rate of investment at which the firm's adjustment costs are zero.

instruments. First, Goolsbee (2000) shows that the coefficient of the user cost of capital in an OLS regression is considerably biased towards zero because of measurement error in the UCC (attenuation bias). Second, firm-specific financial and asset structures, as well as firm-specific after-tax interest rates, are likely correlated with investment, making the user cost of capital endogenous. Third, with an upward sloping supply curve for capital, a reduction in tax rates drives up prices in the short run, which might inhibit an expected increase in investment (Goolsbee 1998, 2004). This simultaneity introduces a bias between the UCC and investment shocks that distorts the user cost elasticity towards zero. A similar argument suggests that simultaneity between investment shocks and interest rates biases the coefficient of the user cost of capital (Chirinko et al. 1999). Furthermore, investment shocks may be contemporaneously correlated with sales and cash flow. Both measurement error and simultaneity bias require an IV technique for the estimates to be consistent and unbiased.[21]

I therefore estimate the DL and ECM using the generalized method of moments (GMM); I report results for the heteroscedasticity-robust two-step System-GMM. This estimator uses the lagged levels of dependent and independent variables as instruments for the difference equation and the lagged difference of dependent and independent variables as instruments for the level equation (Blundell and Bond 1998).[22] Because standard errors in the usual two-step GMM estimator are downward biased in finite samples, I also apply the Windmeijer (2005) correction.

Only in the absence of higher-order serial correlation in the error term $\varepsilon_{i,t}$, does the GMM estimator provide consistent estimates of the parameters in the investment equation. To test for second-order serial correlation in the differenced residuals, I use the Arellano-

[21]As Caballero (1994) shows, long-run elasticities estimated by OLS in cointegrating procedures tend to be severely biased downward in small samples when adjustment costs are important.

[22]I do not report results estimated with Difference-GMM (Arellano and Bond 1991) or Forward-GMM (Arellano and Bover 1995). These estimators can be subject to large finite-sample biases, because the correlation between the explanatory variables in differences and their lagged levels grows weak in highly persistent series (Blundell and Bond 1998). An indication of whether these biases are likely to be serious can be obtained from OLS levels and within-group estimates that are biased upward and downward, respectively. These estimations show that firms' capital stocks are highly persistent: An OLS regression of the current capital stock on lagged capital leads to a coefficient of 0.95 and the within estimation to an estimate of 0.70.

Bond (1991) test.[23] I also report robust Sargan tests of overidentifying restrictions.

Finally, because I use panel data over a horizon of 20 years, firms drop out of the sample. The reasons for attrition are manifold, including bankruptcy, cessation of business, mergers, and falling below thresholds for disclosure. If firms are randomly missing, sample attrition will not bias results; the investment function could be estimated using the incomplete panel data set as if it were complete. However, unobservable characteristics might affect both the survival of firms and their size, which are relevant to publication requirements and the decision to invest.[24] In this case, the estimation of the investment function without an appropriate correction can be biased yet, this problem has received little research attention thus far. To allay doubts about bias in my estimates, I include a term that corrects for sample attrition. Following a three-step procedure proposed by Wooldridge (1995, 2002), I first use year-specific probit models to estimate the probability of dropping out of the sample in the following period.[25] Next I calculate the inverse Mills ratio for each period ($\lambda(x_i d_t)$) and add it to the estimation equation. Because usual standard errors are inconsistent, I bootstrap standard errors in all regressions.

5 Results

To present the regression estimates of the user cost elasticity of the capital stock, I begin with the results for the prevalent DL model, which does not consider cointegration among capital, user cost of capital, and sales, as revealed by the Westerlund (2007) panel cointegration test. Including this additional restriction in the Bewley-ECM delivers a much larger estimate of the user cost elasticity. My preferred point estimate is -1.3.

[23]For consistent estimations, the error term $\varepsilon_{i,t}$ must be serially uncorrelated. If $\varepsilon_{i,t}$ are serially uncorrelated, then $\Delta\varepsilon_{i,t}$ are correlated with $\Delta\varepsilon_{i,t-1}$, but $\Delta\varepsilon_{i,t}$ will not be correlated with $\Delta\varepsilon_{i,t-k}$ for $k \geq 2$. If the estimation requirements are fulfilled, I expect to reject the Arellano-Bond test for zero autocorrelation in the first-differenced errors at order 1 but not at order 2.

[24]If attrition only operates through the firm-specific, time-invariant effect a_i (δ_i), first-differencing the estimation equation solves for selection. In contrast, if attrition operates both through a_i (δ_i) and $\varepsilon_{i,t}$, a correction term is needed.

[25]Explanatory variables in this estimation are as follows: firm size (number of employees, balance sheet total), variables indicating economic difficulties (reduction in employees by more than 10 percent compared with prior year, annual losses), and year of foundation.

5.1 Comparable estimates (DL model)

In Table 3 I present the System-GMM estimates of equation (6), with and without cash flow. The instruments were at least twice lagged values of the explanatory variables, which allows for contemporaneous correlation between them and shocks to the investment equation, as well as correlation with unobserved firm-specific effects.

Table 3: System-GMM estimates for the distributed lag model

$I_{i,t}/K_{i,t-1}$	**Excluding cash flow**	**Including cash flow**
$\lambda(x_i d_t)$	0.033	0.076
	(0.038)	(0.030)
$\Delta ucc_{i,t}$		
σ_0	-0.188	-0.279
	(0.055)	(0.093)
σ_1	-0.228	-0.277
	(0.074)	(0.109)
σ_2	-0.130	-0.139
	(0.074)	(0.074)
σ_3	-0.014	0.045
	(0.161)	(0.159)
SUM(σ)	**-0.559**	**-0.651**
	(0.264)	**(0.221)**
$\Delta s_{i,t}$		
β_0	0.043	0.060
	(0.048)	(0.045)
β_1	0.048	0.047
	(0.055)	(0.053)
SUM(β)	**0.091**	**0.106**
	(0.096)	**(0.092)**
$CF_{i,t}/K_{i,t-1}(\gamma)$	-	0.138
	-	(0.002)
Number of firms	3,968	3,968
(Number of observations)	(24,762)	(24,762)
Sargan-Test (p-value)	0.999	0.787
Arellano-Bond-test (p-value), order 1	0.090	0.155
Arellano-Bond-test (p-value), order 2	0.791	0.637

Notes: The estimates use micro data and System-GMM, as described in the text. A full set of time dummies is included. Bootstrapped standard errors are in parentheses. The instruments for the first-differenced regression are the values (in levels) of $\Delta ucc_{i,t}$ and $\Delta s_{i,t}$ lagged for two through seven years; in the specification including cash flow, $CF_{i,t}/K_{i,t-1}$ is lagged two years and additionally used as an instrument.
Source: Hoppenstedt company database and own calculations, 1987 to 2007.

The estimates in Table 3 are directly comparable to existing literature using DL models.

As noted previously, the (long-term) user cost elasticity in this model is given by the sum of σs. Estimating the model without cash flow, I find an elasticity of -.56, which rises to about -.65 when I include cash flow. In the model without cash flow, the null hypothesis of capital being inelastic with respect to its user cost can be rejected at the 5 percent level, though the variable is significant at every conventional significance level in the model that includes cash flow.

The point estimate for German corporations is approximately twice as much as the elasticity of -.25 estimated by Chirinko et al. (1999) for the United States. Compared with the point estimates of -.66 to -.40 found for German corporations in previous studies (e.g., Chatelain et al. 2003a, 2003b, Kalckreuth 2001, Harhoff and Ramb 2001), my point estimates are surprisingly similar, though these studies did not account for sample attrition and used different databases.[26]

Similar to previous findings, the sum of the coefficients of sales is clearly less than 1 (point estimate of .09 without and .11 with cash flow).[27] The point estimate for cash flow, in contrast, is statistically significant and relatively large: Increasing cash flow by 1 percent immediately increases capital by .14 percent. Insofar as cash flow seems to be an important determinant of investment, omitting it from the estimation equation leads to an omitted variable bias in the estimated user cost elasticity if the user cost of capital and cash flow are correlated.

In general, cash flow effects can be interpreted as either evidence for the importance of financial constraints (e.g., Fazzari et al. 1988, 2000) or a proxy for future profitability (e.g., Kaplan and Zingales 1997, 2000). Differentiating the "financial" versus the "fundamental" determinants of investment is fruitful, because financial frictions might translate into important efficiency costs of profit taxation (Keuschnigg and Ribi 2009). In the following, I argue that cash flow effects may result from dynamic misspecification, in that

[26] These studies all used the German Central Bank's corporate balance sheet database, which can be sampled differently because it relies not on publication requirements but instead originates from the Central Bank's credit assessments, within the scope of its rediscount-lending operations (for details and additional references, see Kalckreuth 2001). Previous studies also rely on consolidated and not individual financial statements.

[27] Constant returns to scale imply a point estimate of 1. A point estimate of less than 1 implies increasing returns to scale.

they disappear once investment dynamics are correctly specified within the ECM. Bond et al. (2003b) offer similar findings in the context of financial factors and investment.

The correction term ($\lambda(x_i d_t)$) is statistically significantly different from 0 at the 5 percent level in the specification that includes cash flow, yet the non-random sample attrition does not seem to affect the user cost elasticity. Comparing the regression results from Table 3 with the coefficients estimated in a model without selection correction does not reveal any important differences.[28]

5.2 Cointegration in the ECM

The Westerlund panel cointegration test (Table A.5) suggests that capital, user cost of capital, and sales have an equilibrium relationship not modeled in previous studies. The Bewley ECM, in other respects a reparametrization of the DL model, imposes this restriction while also acknowledging that capital does not immediately adjust to changes in user cost or sales. The System-GMM results for the one-step ECM in equation (7) are summarized in Table 4. To keep the estimation results of the DL model and ECM directly comparable, both estimations are based on the same method (GMM) and set of instruments. The two models differ only in the consideration of cointegration between capital and its determinants in the ECM.

The regression results in column (1) reflect the specification without cash flow. All point estimates have the expected sign. The long-term user cost elasticity is calculated as $-\sigma'$ divided by $-(1-\phi)$, which yields a statistically significant long-term multiplier of -1.29 (standard error of .18). That value implies that an increase in the user cost of capital by 1 percent will decrease capital by about 1.3 percent in the long run. A two-sided Chi-square test further suggests that the elasticity is not statistically different from the neoclassical benchmark, -1 (p-value = .107).[29]

Comparing the point estimate with the coefficient estimated by a DL model, I find that

[28] These results are available on request.

[29] Of course, the model also could be estimated according to the restriction of a Cobb-Douglas production function. To allow for maximum flexibility, I estimate the model without restriction but use the parameter estimate for a plausibility check.

Table 4: System-GMM estimates for the one-step ECM

$k_{i,t}$	**Without cash flow** (1)	**With cash flow** (2)
$k_{i,t-1}(\phi)$	0.318	0.294
	(0.057)	(0.054)
Selection correction ($\lambda(x_i d_t)$)	-0.082	-0.087
	(0.018)	(0.019)
User cost of capital (σ')	-0.881	-0.861
	(0.138)	(0.145)
Sales (β')	0.447	0.448
	(0.072)	(0.075)
$\Delta ucc_{i,t}$		
α_0	-0.537	-0.515
	(0.079)	(0.084)
α_1	-0.139	-0.137
	(0.034)	(0.035)
α_2	-0.050	-0.050
	(0.017)	(0.017)
$\Delta s_{i,t}$		
μ_0	0.283	0.277
	(0.059)	(0.063)
μ_1	0.070	0.072
	(0.021)	(0.022)
μ_2	0.035	0.038
	(0.014)	(0.015)
$CF_{i,t}/K_{i,t-1}$		
γ_0	-	-0.014
	-	(0.011)
Constant	2.051	2.483
	(1.254)	(1.298)
Number of firms	3,968	3,968
(Number of observations)	(24,762)	(24,762)
Sargan-Test (p-value)	0.775	0.642
Arellano-Bond-test (p-value), order 1	0.002	0.007
Arellano-Bond-test (p-value), order 2	0.366	0.273

Notes: The estimates use micro data and System-GMM, as described in the text. A full set of time dummies is included. Bootstrapped standard errors are in parentheses. The instruments for the first-differenced regression are the values (in levels) of $\Delta ucc_{i,t}$ and $\Delta s_{i,t}$ lagged two through seven years; in the specification including cash flow, $CF_{i,t}/K_{i,t-1}$ is lagged two years and additionally used as an instrument.
Source: Hoppenstedt company database and own calculations, 1987 to 2007.

the ECM delivers an estimate twice as large. The user cost elasticity of capital thus appears to have been underestimated in previous studies that fail to account for the equilibrium relationship among capital, user cost of capital, and sales. This finding is corroborated by other research that integrates methods other than the DL model. Using micro data and exploiting cointegration methods, Caballero et al. (1995) also estimate the long-term relationship between a logarithmized capital-output ratio and user cost of capital. They report an average elasticity of investment with respect to capital of -1.0, the neoclassical benchmark. Cummins et al. (1994) use tax reforms as natural experiments to evaluate the responsiveness of investment to its user cost on the firm level and find long-term elasticities between -.5 and -1.0. These estimates are similar to early estimates that use cointegration methods and aggregate manufacturing data. Both Bertola and Caballero (1994) and Caballero (1994) report an elasticity of the capital-output ratio to the user cost of capital close to -1.[30]

The long-term response of capital to changes in sales also is encouraging. The estimate is unreasonably low in the DL model, but it is much larger in the error correction framework, equal to .65 (standard error of .10).[31] The effect of output on capital in equilibrium still implies increasing returns to scale though; a two-sided Chi-square test rejects the null hypothesis of constant returns to scale at any conventional level (p-value = .000). Because the data in this study mainly refer to large corporations that potentially benefit from increasing returns to scale, a point estimate just less than 1 is plausible.[32]

As noted, short-run coefficients potentially will be misestimated in the presence of expectational variables. I do not go into detail on this point, but estimates for α_0 (μ_0) imply that firms, after a change in user cost of capital (sales), immediately close half of the gap between their current and optimal stock of capital. This finding offers important insights for policymakers who might stimulate short-term capital spending and stabilize business fluctuations by lowering the user cost of capital.

[30]Researchers who work with aggregate data have had great difficulty providing empirical evidence that taxes matter for capital formation (Chirinko 1993; Caballero 1999; Hassett and Hubbard 2002). The reasons for this failure seem various: insufficient variation in the user cost of capital to identify tax effects, measurement error because the investment depends on observed current and expected future values of many fundamentals, and small sample problems of cointegrating procedures that tend to bias the user cost elasticity downward, particularly when adjustment costs are important.

[31]The effect is calculated analogously to the user cost elasticity, as $-\beta'$ divided by $-(1-\rho)$.

[32]This plausibility does not conflict with an equilibrium perspective, because optimal, finite firm size might be defined by other factors, such as managerial capacity limits or provisions on the employment rights of employees operating the machines, which are more generous for employees working for larger firms (e.g., entitled to a works council). Firm growth may be limited by legal rules or antitrust regulations.

Turning to the regression including cash flow, Column (2) in Table 4 shows that including cash flow in the regression equation does not change results. The point estimate for cash flow is close to zero and insignificant,[33] which contradicts the claim that cash flow is an important determinant of capital spending in the DL model but matches results reported in prior research. Without the user cost of capital, Bond et al. (2003b) analyze the effects of output and cash flow on capital in different countries. They remark that significant cash flow effects appear in restricted reduced-form specifications but vanish in more complete dynamic specifications. Therefore, they conclude, "there is some indication that the cash-flow variables proxy for omitted dynamics in simpler dynamic specifications" (Bond et al. 2003b, p. 160).[34] That is, financial variables may appear significant in DL models, even though they play no role in the structural model for investment but instead merely help forecast future values of the fundamental determinants of investment.

Accounting for cointegration among capital, user cost of capital, and sales thus is very important: It leads to a larger user cost elasticity, produces a more reasonable estimate of the long-term response of capital to changes in sales, and clarifies the impact of cash flow variables. Neglecting nonrandom sample attrition is less a concern. Even though the coefficient of the selection term is highly significant, point estimates remain virtually unchanged, whether or not a selection term is included in the investment equation.[35]

6 Conclusion

This paper sheds light on some of the reasons that estimates of the user cost elasticity of capital have diverged for nearly 50 years; it also investigates the role of cash flow variables in investment equations. Although policymakers believe that tax rules influence investment

[33]Similar to the results in other tables, the estimation results have undergone several robustness check and are not sensitive to instrumentation choices. Both results hold even if several lags of cash flow are introduced.

[34]Another literature stream associates significant cash flow effects with measurement errors in Q-models. For example, Bond et al. (2004) find that cash flow effects disappear when analysts' earnings expectations are included in the investment regression. Similarly, Erickson and Whited (2000) use information in higher-order moments to control for measurement error in q and obtain insignificant cash flow coefficients. An overview appears in Cummins et al. (2006).

[35]Results regarding the investment equation without a selection term are available on request.

behavior through the user cost of capital and economists regularly assume a Cobb-Douglas production function in which capital is proportionally elastic to its user cost, empirical researchers are far from agreeing about whether capital significantly responds to its user cost. The discrepancies between these two strands of research, one fostering the view that capital is (more or less proportionally) elastic to its user cost and the other rejecting any significant reaction, may be traced back to neglect of the equilibrium relationship among capital, its user cost, and sales. Properly accounting for cointegration in an error correction model (ECM) yields a much larger estimate of the user cost elasticity that is close to -1, or the neoclassical benchmark. Thus, approaching the investment equation with an ECM bridges the gap between the two strands of investment literature.

Using panel data pertaining to German manufacturing firms, I compare the user cost elasticity of capital estimated by an ECM with the point estimate obtained in a DL model (Chirinko et al. 1999). My benchmark point estimates for the DL model are comparable to previously documented results, but properly accounting for the equilibrium relationship in the ECM, which is in other respects a full reparametrization of the DL model, yields a much larger estimate of the user cost elasticity. The point estimate of -1.3 means that a decrease in the user cost of capital by 1 percent increases capital by 1.3 percent in the long run. The null hypothesis of capital as proportionally elastic to its user cost cannot be rejected an any conventional significance level.

In recognition of imperfect capital markets, many empirical studies enter a firm's cash flow into the model to measure internal funds available. Even though including cash flow is an *ad hoc* extension of the investment equation not supported by the formulation of optimal capital in neoclassical theory, significant cash flow effects in these models generally are interpreted as evidence of financing constraints. In this study, I show that when cointegration is modeled correctly, cash flow effects vanish. The lack of cash flow effects on investment in the error correction model adds to the argument that cash flow variables do not reliably measure internal funds available but instead proxy for future profitability.

A Appendix

A.1 Data

This appendix describes the calculation of the principle variables and the data sources.

(Gross) Investment $I_{i,t}$

Gross investment is defined as the additions to fixed tangible assets and structures, less disposals from fixed tangible assets and structures.

Sales $S_{i,t}$

Sales is measured by revenue/turnover from Hoppenstedt, deflated by industry-specific output price indices provided by the German Statistical Office.

Cash flow $CF_{i,t}$

Cash flow is the sum of several variables from Hoppenstedt:

1. Income before extraordinary items
2. Depreciation
3. Deferred taxes
4. Extraordinary items and discontinued operations.

Income before extraordinary items and depreciation are seldom missing from firms' profit-and-loss accounts. If information about these two items is missing, cash flow also is assumed to be a missing value. The other two items (deferred taxes and extraordinary items) are missing for many companies. Following Chirinko et al. (1999), I assume values equal to 0 when they are missing. Most firms' profit-and-loss accounts follow the whole expenditure method. Depreciation for these firms refers to total depreciation in a given year, whereas deprecation for firms that apply the cost of sales method only refers to depreciation attributable to goods sold. These differences in definition are neglected in the construction of my cash flow variable.

Capital stock $K_{i,t}$

Capital input is measured by the real replacement value of equipment and structures. The real replacement value of capital is not available in the data and must be estimated from historic cost data. The replacement cost value of tangible fixed assets and structures are assumed to equal their historic costs in the first year a firm appears in the data set (adjusted for previous years' inflation). Thereafter, the replacement cost value is updated using the perpetual inventory formula:

$$P_t^I K_t = (1-\delta) P_{t-1}^I K_{t-1} \frac{P_t^I}{P_{t-1}} + P_t^I I_t, \tag{8}$$

where $t = 1987, ..., 2007$,

K_t = capital stock,
P_t^I = price of investment goods,
I_t = real investment, and
δ = depreciation rate.

On the basis of OECD (1991) data, I assume depreciation rates of 12.25 percent per year for fixed tangible assets and 3.61 percent per year for buildings. As a sensitivity test, I recalculated the capital stock, taking a depreciation rate of 8 percent from Bond et al. (2003a), but the change did not alter the regression results.

Price indices p_t^I and $p_{j,t}^S$

There are two price indices: a national price index for investment goods (p_t^I) and a price index for output goods ($p_{j,t}^S$). The German Statistical Office constructs p_t^I on the country level only (*Investitionsgüterindex*), whereas $p_{j,t}^S$ is available for manufacturers on a disaggregate level (*Erzeugerpreisindex*). Firms must declare their price of sale for approximately 1,600 representative types of goods. On the basis of these prices, the Statistical Offices calculate detailed sales price information for each industry j. I use this information at the four-digit industry level.

Rate of economic depreciation $\delta_{a,j,t}^e$

The rate of economic depreciation $\delta_{a,j,t}^e$ can be derived from information obtained from the national accounts' capital stock (*Kapitalstockrechnung*), provided by the German Statistical Office. The rate varies across assets a, including fixed assets and structures; industries j (four-digit level); and time. I calculated this rate as economic depreciation for asset a in prices of 2000, divided by the stock of asset a in 2000 prices.

Depreciation allowances $z_{a,t}$

These allowances follow different methods in Germany: Structures are depreciated on a straight-line basis, whereas fixed assets could be depreciated according to the declining-balance method until 2007. Firms could change from the declining-balance to the straight-line method once the latter was beneficial. The rates of depreciation are set in the German income tax law and industry-specific tables issued by the Federal Ministry of Finance. When calculating the discounted value, I took the different methods and changes in rates into account and also corrected for inflation, because historical cost depreciation increases taxes with inflation.

Due to data restrictions, I can only consider regular depreciation allowances. Accelerated depreciation allowances for investment in Eastern Germany, introduced after reunification;[36] extraordinary depreciation allowances for some industries (e.g., agriculture); and additional depreciation allowances for small and medium-sized businesses cannot be taken into account.

Until 2000, the taxation-relevant lifetime of structures was 25 years. Since 2001, this lifetime has been prolonged to $33\frac{1}{3}$ years.

Until 2000, the yearly rate for the declining-balance method was 0.3 (since 2001: 0.2) for fixed assets. Unfortunately, there is no information about the relevant lifetime for different fixed assets, which vary considerably. I therefore assumed a relevant lifetime of 10 years (year 1997) on average. An investigation of depreciation allowances in Germany concludes that reforms in 1998 and 2001 worsened depreciation allowances by approximately 30 percent (Oestreicher and Spengel 2002). I therefore scaled the average lifetime accordingly (1998 to 2000: 13 years, 2001 to 2008: 16.9 years).

Firm-specific interest rate $r_{i,t}$

The firm-specific interest rate $r_{i,t}$ is approximated as interest payments in a given year, divided by long-term debt at the end of the year.

Overall yield on corporate bonds r_t

In a robustness check, I used the overall yield on corporate bonds r_t, as provided by the

[36] See *Fördergebietsgesetz*.

German Central Bank in its series "Yields on debt securities outstanding issued by residents / Corporate bonds / Monthly average" (WU0022).

A.2 Statutory tax rates

Table A.1 shows the evolution of tax rates over time.

Table A.1: Statutory tax rates 1987-2008

year	Corporate income tax on retained profits	Corporate income tax on distributed profits	Solidarity surcharge
1987	56%	36%	-
1988	56%	36%	-
1989	56%	36%	-
1990	50%	36%	-
1991	50%	36%	3.75%
1992	50%	36%	3.75%
1993	50%	36%	-
1994	45%	30%	-
1995	45%	30%	7.5%
1996	45%	30%	7.5%
1997	45%	30%	7.5%
1998	45%	30%	5.5%
1999	40%	30%	5.5%
2000	40%	30%	5.5%
2001	25%	25%	5.5%
2002	25%	25%	5.5%
2003	26.5%	25%	5.5%
2004	25%	25%	5.5%
2005	25%	25%	5.5%
2006	25%	25%	5.5%
2007	25%	25%	5.5%
2008	15%	15%	5.5%

Sources: Own presentation, corporate income tax law, 1987 to 2008, solidarity surcharge law, 1991 to 2008.

Corporate income taxation has not only undergone changes in tax rates but also a fundamental change in the tax system: The German corporate tax system applied the tax-credit method until 2000, and taxation has followed the half-income method since 2001.[37]

[37]Under the tax credit method, the tax burden on the corporate level was only meant to ensure taxation of capital income and was credited against the personal income tax of the shareholder. Retained profits were taxed at a much higher rate than distributed profits. Under the half income method, the corporate income tax rate is uniform and lower for both retained and distributed profits. In return, the corporate income tax has been definite since 2001. Half of the dividends are subject to personal income tax.

A.3 Additional descriptives

My sample consists of 3,968 firms that offer at least five records in the data set (Table A.2). Table A.3 shows the distribution of observations over years. Most firms have their headquarters in Western Germany; only about 13 percent of all firms are located in Eastern Germany. All companies could be allocated to 13 industries, according to their main activity, as shown in Table A.4.

Table A.2: Number of records per company

Number of records per company	Number of companies
5	297
6	404
7	375
8	382
9	297
10	245
11	217
12	242
13	309
14	293
15	124
16	113
17	83
18	63
19	86
20	143
21	295
Total	3,968

Source: Hoppenstedt company database and own calculations, 1987 to 2007.

Table A.3: Composition of the sample: Years

Year	Number of observations with at least three lags
1991	868
1992	1,047
1993	1,060
1994	1,095
1995	1,122
1996	1,141
1997	1,178
1998	1,932
1999	1,823
2000	1,728
2001	1,674
2002	1,639
2003	1,685
2004	1,781
2005	1,871
2006	1,886
2007	1,232
Total	24,762

Source: Hoppenstedt company database and own calculations, 1987 to 2007.

Table A.4: Composition of the sample: Industries

Industry	Number of companies
Agriculture, forestry, fishery	23
Mining, quarrying	26
Consumer goods, goods for intermediate	
Consumption goods industry	676
Producers goods	680
Electricity and water supply	478
Construction	90
Wholesale and retail trade, repair of goods	388
Hotels and restaurants	24
Transport, storage and communication	235
Financial intermediation	54
Real estate and renting	455
Services for private sector	541
Services for public sector and households	298
Total	3,968

Source: Hoppenstedt company database and own calculations, 1987 to 2007.

Table A.5: Westerlund panel cointegration test

Westerlund test statistic	Value	z-value	p-value
Group-mean tests			
Gt[a]	-2.904	-28.416	0.000
Ga[a]	-128.683	-573.736	0.000
Panel tests			
Pt[b]	-9.550	-40.686	0.000
Pa[b]	-18.152	-66.146	0.000

Notes: Calculated with the Stata command xtwest (Persyn and Westerlund 2008).

[a] For group tests $H_0^G : \alpha_i = 0\ \forall i$ versus $H_1^G : \alpha_i < 0$ for at least some i; a rejection provides evidence of cointegration for at least one of the cross-sectional units.

[a] For panel tests $H_0^P : \alpha_i = 0\ \forall i$ versus $H_1^P : \alpha_i < 0\ \forall i$; a rejection is evidence of cointegration for the panel as a whole.

Sources: Hoppenstedt company database and own calculations, 1987 to 2007.

References

Arellano, M. and Bond, S.: 1991, Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations, *The Review of Economic Studies* **58**, 277–297.

Arellano, M. and Bover, O.: 1995, Another look at the instrumental variable estimation of error-components models, *Journal of Econometrics* **68**, 29–51.

Arrow, K. J., Chenery, H. B., Minhas, B. S. and Solow, R. M.: 1961, Capital-labor substitution and economic efficiency, *The Review of Economics and Statistics* **43**(3), 225–250.

Auerbach, A. and Hassett, K. A.: 1992, Tax policy and business fixed investment in the United States, *Journal of Public Economics* **47**, 141–170.

Banerjee, A., Dolado, J. J., Galbraith, J. W. and Hendry, D. F.: 1993, *Co-integration, error correction, and the econometric analysis of non-stationary data*, Oxford University Press, Oxford.

Banerjee, A., Dolado, J. J., Hendry, D. F. and Smith, G. W.: 1986, Exploring equilibrium relationships in econometrics through static models: some Monte Carlo evidence, *Oxford Bulletin of Economics and Statistics* **48**, 253–277.

Bean, C. R.: 1981, An econometric model of manufacturing investment in the UK, *The Economic Journal* **91**(361), 106–121.

Bertola, G. and Caballero, R. J.: 1994, Irreversibility and aggregate investment, *The Review of Economic Studies* **61**(2), 223–246.

Bewley, R.: 1979, The direct estimation of the equilibrium response in a linear dynamic model, *Economics Letters* **3**, 357–361.

Blundell, R. and Bond, S.: 1998, Initial conditions and moment restrictions in dynamic panel data models, *Journal of Econometrics* **87**, 115–143.

Bond, S., Harhoff, D. and Van Reenen, J.: 2003a, Investment, R&D and financial constraints in Britain and Germany, *Technical Report*, Centre for Economic Performance No. 0595.

Bond, S., Elston, J. A., Mairesse, J. and Mulkay, B.: 2003b, Financial factors and investment in Belgium, France, Germany, and the United Kingdom: a comparison using company panel data, *The Review of Economics and Statistics* **85**, 153–165.

Bond, S., Klemm, A., Newton-Smith, R., Syed, M. and Vlieghe, G.: 2004, The roles of expected profitability, Tobin's Q and cash flow in econometric models of company investment, *Technical Report*, Institute for Fiscal Studies No. W04/12.

Bond, S. and Van Reenen, J.: 2007, Microeconometric models of investment and employment, *in* J. J. Heckman and E. E. Leamer (eds.), *Handbook of econometrics*, Vol. 6, Elsevier North Holland, London, pp. 4417–4498.

Caballero, R., Engel, E. and Haltiwanger, J.: 1995, Plant level adjustment and aggregate investment dynamics, *Brookings Papers on Economic Activity* **2**, 1–54.

Caballero, R. J.: 1994, Small sample bias and adjustment costs, *The Review of Economics and Statistics* **76**(1), 52–58.

Caballero, R. J.: 1999, Aggregate investment, *in* J. B. Taylor and M. Woodford (eds.), *Handbook of macroeconomics*, Elsevier North-Holland, London, pp. 813–862.

Chatelain, J.-B., Hernando, I., Generale, A., von Kalckreuth, U. and Vermeulen, P.: 2003a, Firm investment and monetary transmission in the euro area, *in* I. Angeloni, A. K. Kashyap and B. Mojon (eds.), *Monetary policy transmission in the Euro area*, Cambridge University Press, Cambridge.

Chatelain, J.-B., Hernando, I., Generale, A., von Kalckreuth, U. and Vermeulen, P.: 2003b, New findings on firm investment and monetary transmission in the euro area, *Oxford Review of Economic Policy* **19**(1), 1–11.

Chirinko, R. S.: 1993, Business fixed investment spending: modeling strategies, empirical results, and policy implications, *Journal of Economic Literature* **31**(4), 1875–1911.

Chirinko, R. S.: 2002, Corporate taxation, capital formation, and the substitution elasticity between labor and capital, *National Tax Journal* **55**, 339–355.

Chirinko, R. S., Fazzari, S. M. and Meyer, A. P.: 1999, How responsive is business capital formation to its user cost? An exploration with micro data, *Journal of Public Economics* **74**, 53–80.

Cummins, J. G. and Hassett, K. A.: 1992, The effects of taxation on investment: new evidence from firm-level panel data, *National Tax Journal* **45**, 243–252.

Cummins, J. G., Hassett, K. A. and Hubbard, R. G.: 1994, A reconsideration of investment behavior using tax reforms as natural experiments, *Brookings Papers on Economic Activity* **1994**(2), 1–74.

Cummins, J. G., Hassett, K. A. and Hubbard, R. G.: 1996, Tax reforms and investment: a cross-country comparison, *Journal of Public Economics* **62**, 237–273.

Cummins, J. G., Hassett, K. A. and Oliner, S. D.: 2006, Investment behavior, observable expectations, and internal funds, *The American Economic Review* **96**(3), 796–810.

Deutsches Aktieninstitut: 2007, *Factbook 2007*, Deutsches Aktieninstitut, Frankfurt.

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

Doms, M. E. and Dunne, T.: 1998, Capital adjustment patterns in manufacturing plants, *Review of Economic Dynamics* **1**, 409–429.

Eisner, R. and Nadiri, M. I.: 1968, Investment behavior and neo-classical theory, *The Review of Economics and Statistics* **50**(3), 369–382.

Eisner, R. and Strotz, R. H.: 1963, Determinants of business investment, *in* Commission on Money and Credit (ed.), *Impacts of Monetary Policy*, Prentice Hall, Englewood Cliffs, NJ, pp. 60–138.

Engle, R. F. and Granger, C. W. J.: 1987, Co-Integration and error correction: representation, estimation, and testing, *Econometrica* **55**, 251–276.

Erickson, T. and Whited, T. M.: 2000, Measurement error and the relationship between investment and q, *Journal of Political Economy* **108**(5), 1027–1057.

Fazzari, S., Hubbard, R. G. and Petersen, B.: 1988, Investment, financing decisions, and tax policy, *The American Economic Review* **78**(2), 200–205.

Fazzari, S. M., Hubbard, R. G. and Petersen, B. C.: 2000, Investment-cash flow sensitivities are useful: A comment on Kaplan and Zingales, *The Quarterly Journal of Economics* **65**, 695–705.

Foley, D. K. and Sidrauski, M.: 1970, Portfolio choice, investment and growth, *The American Economic Review* **60**(1), 44–63.

Foley, D. K. and Sidrauski, M.: 1971, *Monetary and Fiscal Policy in a Growing Economy*, Macmillan, New York.

Goolsbee, A.: 1998, Investment tax incentives, prices, and the supply of capital goods, *The Quarterly Journal of Economics* **113**, 121–148.

Goolsbee, A.: 2000, The importance of measurement error in the cost of capital, *National Tax Journal* **53**, 215–228.

Goolsbee, A.: 2004, Taxes and the quality of capital, *Journal of Public Economics* **88**, 519–543.

Gould, J. P.: 1968, Adjustment costs in the theory of investment of the firm, *The Review of Economic Studies* **35**, 47–56.

Hall, R. E. and Jorgenson, D. W.: 1967, Tax policy and investment behavior, *The American Economic Review* **57**, 391–414.

Harhoff, D. and Ramb, F.: 2001, Investment and taxation in Germany–evidence from firm-level panel data, *in* D. Bundesbank (ed.), *Investing today for the world of tomorrow - Studies on the investment process in Europe*, Springer, Heidelberg, pp. 47–84.

Harvey, A.: 1990, *The econometric analysis of time series*, MIT Press, Cambridge, MA.

Hassett, K. A. and Hubbard, G. R.: 1997, Tax policy and investment, *in* A. J. Auerbach (ed.), *Fiscal policy. Lessons from economic research*, MIT Press, Cambridge, MA.

Hassett, K. A. and Hubbard, R. G.: 2002, Tax policy and business investment, *in* A. J. Auerbach and M. Feldstein (eds.), *Handbook of Public Economics*, Vol. 3, Elsevier North-Holland, London, pp. 1293–1343.

Jorgenson, D. W.: 1963, Capital theory and investment behavior, *The American Economic Review* **53**(2), 305–360.

Kalckreuth, U.: 2001, Monetary transmission in Germany: New perspectives on financial constraints and investment spending, *Technical Report*, Economic Research Centre of the Deutsche Bundesbank No. 19.

Kaplan, S. N. and Zingales, L.: 2000, Investment-cash flow sensitivities are not valid measures of financing constraints, *The Quarterly Journal of Economics* **65**, 707–712.

Kaplan, S. and Zingales, L.: 1997, Do financing constraints explain why investment is correlated with cash flow?, *The Quarterly Journal of Economics* **62**, 169–215.

Keuschnigg, C. and Ribi, E.: 2009, Profit taxation and finance constraints, *Technical Report*, Universität St. Gallen No. 2009-05.

King, M. and Fullerton, D.: 1984, *The taxation of income from capital*, Chicago University Press, Chicago.

Lucas, R. E.: 1967, Optimal investment policy and the flexible accelerator, *International Economic Review* **8**, 78–85.

Modigliani, F. and Miller, M.: 1958, The cost of capital, corporate finance, and theory of investment, *American Economic Review* **48**, 261–297.

Myers, S. C. and Majluf, N. S.: 1984, Corporate financing and investment decisions when firms have information that investors do not have, *Journal of Financial Economics* **13**, 187–221.

Nickell, S. J.: 1977, Uncertainty and lags in the investment decisions of firms, *The Review of Economic Studies* **44**, 249–263.

OECD: 1991, *Taxing profits in a global economy. Domestic and international issues*, Organisation for Economic Cooperation and Development, Paris.

Oestreicher, A. and Spengel, C.: 2002, Analyse handels- und steuerrechtlicher Abschreibungsregeln. Anforderungen an Abschreibungsvorschriften im modernen Wirtschaftsleben, Internationaler Vergleich. mimeo.

Persyn, D. and Westerlund, J.: 2008, Error-correction-based cointegration tests for panel data, *Stata Journal* **8**(2), 232–241.

Smith, J.: 2008, That elusive elasticity and the ubiquitous bias: Is panel data a panacea?, *Journal of Macroeconomics* **30**, 760–779.

Stock, J. H.: 1987, Asymptotic properties of least squares estimators of cointegrating vectors, *Econometrica* **55**, 1035–1056.

Treadway, A. B.: 1969, On rational entrepreneurial behaviour and the demand for investment, *The Review of Economic Studies* **36**, 227–239.

Westerlund, J.: 2007, Testing for error correction in panel data, *Oxford Bulletin of Economics and Statistics* **69**, 709–748.

Windmeijer, F.: 2005, A finite sample correction for the variance of linear efficient two-step gmm estimators, *Journal of Econometrics* **126**, 25–51.

Wooldridge, J. M.: 1995, Selection corrections for panel data models under conditional mean independence assumptions, *Journal of Econometrics* **68**, 115–132.

Wooldridge, J. M.: 2002, *Econometric analysis of cross section and panel data*, MIT Press, Cambridge, MA.