Labor Market Frictions, Capital Adjustment Costs, and Stock Prices

Preliminary

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Abstract

The subject of this paper is the joint determination of investment in capital and the hiring of labor and its consequences for stock prices. It is studied in a model with labor market frictions and capital adjustment costs. The model's quantitative implications are explored using structural estimation and calibration, with aggregate time-series data for the U.S. corporate sector. The results provide for (i) better understanding of the stochastic relationship between investment and stock prices, and (ii) the quantification of the links between labor market variables and both investment in physical capital and stock prices.

The results suggest that allowing for labor market frictions to interact with capital adjustment costs leads to better performance of investment and production-based asset pricing equations. Using the estimated or calibrated convex adjustment cost function in the firms' Euler and asset pricing equations, we are able to account for the behavior of investment, hiring

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and asset values over the sample period. The estimated model captures the negative correlation between hiring and investment in the data. We find that hiring costs account for about 20% of firms' asset values on average and that capital adjustment costs account for most of asset value volatility.

Key words: investment, hiring, stock prices, adjustment costs, q-theory, match asset value, production-based asset pricing.

Labor Market Frictions, Capital Adjustment Costs and Stock Prices [1]

1. Introduction

The subject of this paper is the joint behavior of investment in capital and the hiring of labor and its relationship to stock price determination. It studies these issues by exploring the linkages between labor market frictions, capital adjustment costs and stock prices. The essential idea is that labor market frictions, adjustment costs for capital and the interaction between them affect firms' hiring and investment behavior. This behavior in turn determines firms' profits, including rents from job-worker matches, and hence firms' asset values. These connections are formalized in a model and structurally estimated using aggregate data for the U.S. corporate sector. The estimates yield time series of capital adjustment costs and firms' hiring costs as well as predicted investment rates, hiring rates, and stock prices. A calibration methodology reinforces the validity of the estimation results.

These issues are of interest for a number of reasons. First, the volatile behavior of aggregate investment has not been well accounted for by traditional models. Second, it has been difficult to link the behavior of stock prices to physical investment patterns. Third, while there is increasing acceptance of the idea that labor market frictions are useful for the understanding of cyclical fluctuations, little empirical work has been undertaken to quantify their effects. In particular, their operation in conjunction with capital adjustment costs and their implications for the stock market have not been studied. The contributions of the empirical work reported here include: better understanding of the stochastic behavior of investment and stock prices (and the relations

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between them), and the quantification of the relationships between labor market variables and both investment in physical capital and stock prices. One of these relations formulates the ratio of firms' market value to GDP as a function of GDP growth, discount rates, the corporate tax rate, and convex functions of the investment rate and the hiring rate. Put simply, the estimated model allows us to draw lessons from the hiring of labor and investment in capital to stock market value.

The economic intuition of the model is the following : the value of the firm is usually taken to be the value of its capital stock. Labor is not a part of this value as workers are fully paid their share in output. However, this approach ignores the cases in which the firm has rents from labor. There may be a number of reasons for the existence of such rents [see, for example Danthine and Donaldson (2002)]. Here we focus on labor market frictions which create rents that need to be shared between firms and workers. The part of the firm in these rents compensates it for the costs involved in forming the job-worker match. The expected present value of the flow of these rents may be termed 'the asset value of the job-worker match' and makes up part of the firm's asset value. Thus, the latter is made up of the value of capital, the value of the technology for adjusting the stock of capital, and the asset value of the match.

The data set used has a number of distinctive features: it makes use of gross worker flow data; data on physical investment and the capital stock, as well as asset value data, pertain to the non-financial corporate business sector rather than to broader, but inappropriate, measures of the U.S. economy; alternative, time-varying discount rates are examined; and taxes are explicitly taken into account. In terms of the estimation methodology, the use of alternative convex adjustment costs functions and structural non-linear estimation allow for a more general framework than the quadratic cost formulation that is prevalent in most of the literature.

The results suggest that allowing for labor market frictions to interact with capital adjustment costs leads to better performance of investment and production-based asset pricing equations. Using the estimated convex adjustment cost function we are able to replicate the negative correlation between investment and hiring rate and the behavior of asset values over the sample period. The key findings are that hiring costs account for about 20% of mean asset values and that capital adjustment costs account for most of asset value volatility. The traditional element of asset values (that does not depend on adjustment costs) accounts for roughly 70% of mean values and plays the same (small) role as hiring costs in asset value volatility.

The paper contributes to three strands of literature – reviewed below – which have, for the most part, developed separately: first, it extends search and matching models of the aggregate labor market to incorporate capital adjustment costs and shows how data on physical capital and on the stock market are important for the understanding of hiring behavior. Second, it shows that estimation results of the Q model have been biased by the omission of labor market frictions and demonstrates how its empirical performance is enhanced when these frictions are catered for. Third, it lends substantive support to the production-based asset pricing model and shows to what extent it can account for stock price behavior.

The paper proceeds as follows. Section 2 surveys the related literature and discusses the novel aspects of the current analysis. Section 3 presents the model. Section 4 discusses the data and the empirical methodologies. Section 5 presents the results, discussing alternative specifications. Section 6 derives the results' implications with respect to the adjustment costs function, hiring and investment behavior, and asset values. Section 7 concludes. Technical derivations and data definitions are elaborated in appendices.

2. Related Literature

As noted, the paper refers and contributes to three strands of literature. In this section we briefly survey the relevant papers and the relationship of the current paper to them.

2.1. Search and Matching Models

The search and matching approach to the aggregate labor market centers around the idea that trade frictions exist in the labor market [see Mortensen and Pissarides (1999) for a recent survey]. Because of these frictions, it takes time and resources for workers and firms to create a job-match.

Thus, at any given moment there are unemployed workers and unfilled vacancies waiting to be matched. Two fundamental ideas underlie this approach: (i) optimizing agents undertake costly search; and (ii) matching is time-consuming. The creation of the match involves rents that need to be shared between the firm and the worker; rent-sharing is usually modeled as a solution to a bargaining problem. The empirical implementation of the model has focused mainly on the estimation of matching functions [see Petrongolo and Pissarides (2001) for a survey]. More directly related to this paper are the results in Yashiv (2000a,b) quantifying and validating the model using Israeli data and structural estimation.

The current paper caters for an oft-neglected issue in this literature – capital adjustment costs interacting with hiring costs in the formation of job-worker matches. Doing so it is able to link the asset value of the job-worker match and the asset value of the firm. This link relates concepts that have hitherto not been associated together, such as gross worker flows and stock prices.

2.2. The Q Model

Models of adjustment costs of capital – in particular, Tobin's Q [Tobin (1969) and Tobin and Brainard (1977)] – added the value of adjustment technology to the neoclassical approach, whereby the asset value of the firm is the value of its capital stock. These models relate to the firm's first-order condition equating the marginal cost of investment with the shadow price Q of installed capital . Hayashi (1982) presented conditions under which the unobservable shadow price of capital (marginal Q), is equal to Tobin's Q, the ratio of the market value of a firm's capital stock to its replacement value, which is observable (average Q). This result led to the use of stock market data to assess the marginal value of capital. The Q model has been extensively studied empirically [see Chirinko (1993) for a survey and Section 6 below for a report and discussion of key results]. The estimated investment equations are estimates of the (inverse of the marginal) cost of adjustment function, taking into account purchase costs as well as convex adjustment costs. The results were criticized for a number of features: low R^2, estimates of excessively high adjustment costs and the significance of other variables in the equation, such as those related to finance constraints, that were not predicted by the model. Later on, the convexity of adjustment costs was called into question [see the discussion in Caballero (1999)]. More recently, several papers have explored the Q approach within different broader frameworks with better results: Cochrane (1991, 1996) has shown that it can account for the behavior of asset prices, provided time-varying discount rates are applied to future streams; Christiano and Fisher (1998) show that when used as a component of a DSGE model it accounts relatively well for moments that connect the stock market and the business cycle; Erickson and Whited (2000) have shown that the model works well if measurement error in firms' value is properly accounted for; Abel and Eberly (2002), using firms' panel data, show that a model with an augmented adjustment costs function, allowing for fixed, linear and convex costs and catering for disinvestment, performs well; Cooper and Haltiwanger (2002), using LRD data, show that non-convexities matter for plant-level micro model but that an appropriate convex model does well in fitting the moments of aggregate investment behavior.

The current paper uses the basic Q framework with a number of essential modifications. First, it allows for the interaction of capital adjustment costs with firms' hiring costs.[2] Second, it caters for more general convex adjustment costs than typically used. Third, it uses a data set that focuses on the business sector (rather than on broader, but inappropriate, parts of the economy)

[2]Two papers – Dixit (1997) and Eberly and van Mieghem (1997) – provide a theoretical discussion of optimality conditions for joint hiring and investment behavior in the presence of adjustment costs on both factors. In empirical work, Nadiri and Rosen (1969) examined both capital and labor adjustment costs and since then a number of papers have done so. The most notable contribution in the current context is Shapio (1986), who used structural estimation. Our paper differs along several dimensions:(i) labor adjustment costs here pertain to gross costs and therefore are a function of gross worker flows into employment; in Shapiro (and other work) they pertain to net costs and relate to changes in the employment stock, which are considerably smaller; (ii) the current paper uses the asset values of firms in estimation while no such information is used in Shapiro; (iii) the latter paper uses linear-quadratic adjustment costs, a formulation found to be too restrictive here; (iv) Shapiro's uses data on manufacturing while here non-financial corporate business data are used; (v) the discount rate in Shapiro is a T-bill rate plus a risk premium, while here alternative time-varying rates are used.

and on firms' asset values that correspond to this sector.

2.3. Production-Based Asset Pricing

Cochrane (1991,1996) has shown that the Q-model can be used as a production-based asset pricing model. The earlier contribution [Cochrane (1991)] shows that investment returns equal stock returns according to the model and provides empirical support via correlation analysis, regressions at various frequencies and, mostly, forecasting regressions. The correlation analysis, for example, shows a 0.24 correlation at the quarterly frequency and 0.45 at the annual frequency between aggregate investment returns and stock returns. The later contribution [Cochrane (1996)] examines an investment-based asset pricing model whereby physical (capital) investment returns are factors in the stochastic discount factor. The empirical work uses returns for non-residential investment and residential investment as components of the stochastic discount factor that "prices" 10 portfolios of NYSE stocks. The results indicate that the model performs well, as well as two standard finance models and better than a consumption-based model.

The current paper lends stronger support to this view. Typically, specific adjustment cost processes have been assumed rather than estimated, and reduced-form relationships were examined. This paper estimates the adjustment costs function, incorporates labor market frictions (hitherto unexamined), and explicitly shows how stock prices are determined by hiring and investment in a model which is structurally estimated.

3. The Model

We delineate the model which serves as the basis for estimation. The parts concerned with the labor market follow the prototypical search and matching model within a stochastic framework.[3]

[3] See the details in Pissarides (2000).

3.1. The Economic Environment

The economy is populated by identical workers and firms who live forever. All agents have rational expectations. Workers and firms interact in the markets for goods, labor, and financial assets. This setup deviates from the standard neoclassical framework. That is, it takes time and resources for firms to adjust capital and for workers and firms to create a new job-match. A job-match is created each time a job-vacancy and an unemployed worker randomly meet. A matching function captures this matching process in a highly stylized fashion:

$$M_t = M(U_t, V_t), \quad M_t \leq \min(U_t, V_t), \tag{3.1}$$

The function states that in period t new matches M are produced using job-vacancies V and the total number of unemployed workers, U, as inputs. When M is CRS, the matching probability for a given vacancy, q, depends on the degree of labor market tightness θ—the ratio of job-vacancies to total unemployment:

$$q_t = \frac{M_t}{V_t} = q(\theta_t).$$

In what follows, capital letters denote aggregate variables, and small letters denote per-capita variables. All variables are expressed in terms of the output price level.

3.2. Hiring and Investment

Firms make investment and hiring decisions. They own the physical capital stock k and decide each period how much to invest in capital, i. They hire labor services from workers n, posting vacancies v in an effort to create new job-matches qv. Once a match is created, the firm pays the worker a per-period gross compensation wage rate w. Firms use physical capital and labor as inputs in order to produce output goods y according to a constant-returns-to-scale production function f:

$$y_t = f(n_t, k_t), \tag{3.2}$$

Hiring and investment involve costs. Hiring costs include advertising, screening, and training. Investment involves capital installation costs, learning the use of new equipment, re-assignment of old capital lowering efficiency, etc. Both involve disruptions to production. All of these costs are captured by an adjustment cost function $g[i_t, k_t, q_t v_t, n_t]$ and are assumed to reduce the firm's profits. We assume the adjustment cost function to have constant returns-to-scale and we allow for the interaction of hiring and capital adjustment costs. We specify its functional form in the empirical work below.

The capital stock depreciates at the rate δ_t and is augmented by new investment i. The capital stock's law of motion equals:

$$k_{t+1} = (1-\delta_t)k_t + i_t, \quad 0 \leq \delta_t \leq 1. \tag{3.3}$$

Similarly, the number of matches employed by a firm decreases at the rate ψ_t. It is augmented by newly created job-matches qv:

$$n_{t+1} = (1-\psi_t)n_t + q_t v_t, \quad 0 \leq \psi_t \leq 1. \tag{3.4}$$

Firms profits before tax, π, equal the difference between revenues net of adjustment costs and total labor compensation, wn:

$$\pi_t = [f(n_t, k_t) - g(i_t, k_t, q_t v_t, n_t)] - w_t n_t\,. \tag{3.5}$$

Every period, firms make after-tax cash flow payments cf to the owners of the firm. These cash flow payments equal profits after tax minus purchases of investment goods plus investment tax credits and depreciation allowances for new investment goods:

$$cf_t = (1-\tau_t)\pi_t - (1-\chi_t - \tau_t D_t)\,\widetilde{p}_t^I\, i_t\,, \tag{3.6}$$

where τ_t is the corporate income tax rate, χ_t the investment tax credit, D_t the present discounted value of capital depreciation allowances, and $\widetilde{p}_t^I$ the real pre-tax price of investment goods.

The representative firm's ex dividend market value in period t, s_t, is defined as follows:

$$s_t = E_t\left[\beta_{t+1}\left(s_{t+1} + cf_{t+1}\right)\right], \tag{3.7}$$

where E_t denotes the expectational operator conditional on information available in period t. The discount factor between periods $t+j-1$ and $t+j$ for $j \in \{1,2,...\}$ is given by:

$$\beta_{t+j} = \frac{1}{1+r_{t+j-1,t+j}}$$

where $r_{t+j-1,t+j}$ denotes the time-varying discount rate between periods $t+j-1$ and $t+j$. Appendix B contains a detailed description of how alternative values of discount rate r are computed in the empirical work. Using the time-varying discount rates, we can alternatively define the firm's market value in period t as the present discounted value of future cash flows[4].

$$s_t = E_t \left\{ \sum_{j=1}^{\infty} \left(\prod_{i=1}^{j} \beta_{t+i} \right) cf_{t+j} \right\} \tag{3.8}$$

The representative firm chooses sequences of i_t and v_t in order to maximize its cum dividend market value $cf_t + s_t$:

$$\max_{\{i_{t+j}, v_{t+j}\}} E_t \left\{ \sum_{j=0}^{\infty} \left(\prod_{i=0}^{j} \beta_{t+i} \right) cf_{t+j} \right\} \tag{3.9}$$

[4] In case of debt finance in addition to equity finance, the firm's value is given by:

$$\begin{aligned} s_t &= \widetilde{s}_t + (1+r_{t-1}^b)b_{t-1} \\ &= E_t \left\{ \sum_{j=1}^{\infty} \left(\prod_{i=1}^{j} \beta_{t+i} \right) cf_{t+j} \right\} \end{aligned}$$

$$\begin{aligned} \widetilde{s}_t &= E_t \left\{ \sum_{j=1}^{\infty} \left(\prod_{i=1}^{j} \beta_{t+i} \right) (cf_{t+j} - r_{t+j-1} b_{t+j-1}) \right\} \\ &\quad - r_{t-1}^b b_{t-1} \end{aligned}$$

where $\widetilde{s}_t$ is the equity value, r_{t-1}^b is the interest rate on bonds (adjusted for taxes), and b_{t-1} is the existing stock of bonds. See Bond and Meghir (1994, in particular the appendix) for the full derivation in a similar model. We do not pursue here issues such as bankruptcy risk, differential capital income taxation and tax advantages of debt finance.

subject to the definition of cf_{t+j} in equation (3.6) and the following constraints:

$$\begin{aligned} k_{t+1+j} &= (1-\delta_{t+j})\, k_{t+j} + i_{t+j} \\ n_{t+1+j} &= \left(1-\psi_{t+j}\right) n_{t+j} + q_{t+j} v_{t+j} \end{aligned} \qquad (3.10)$$

The Lagrange multipliers associated with these two constraints are Q^K_{t+j} and Q^N_{t+j}, respectively. These Lagrange multipliers can be interpreted as Tobin's marginal q for physical capital, and a Tobin's marginal q equivalent for employment, respectively.

The accompanying first-order necessary conditions for dynamic optimality are the same for any two consecutive periods $t+j$ and $t+j+1$, $j \in \{0, 1, 2, ...\}$. For the sake of notational simplicity, we drop the subscript j from the respective equations to follow:

$$Q^K_t = E_t \beta_{t+1} \left\{ (1-\tau_{t+1}) \left[f_{k_{t+1}} - g_{k_{t+1}} \right] + Q^K_{t+1} (1-\delta_{t+1}) \right\} \qquad (3.11)$$

$$Q^K_t = (1-\tau_t) \left(g_{i_t} + p^I_t \right) \qquad (3.12)$$

$$Q^N_t = E_t \beta_{t+1} \left\{ (1-\tau_{t+1}) \left[f_{n_{t+1}} - g_{n_{t+1}} - w_{t+1} \right] + \left(1-\psi_{t+1}\right) Q^N_{t+1} \right\} \qquad (3.13)$$

$$Q^N_t = (1-\tau_t) \frac{g_{v_t}}{q_t} \qquad (3.14)$$

where we use the real after-tax price of investment goods, given by:

$$p^I_{t+j} = \frac{1 - \chi_{t+j} - \tau_{t+j} D_{t+j}}{1-\tau_{t+j}} \tilde{p}^I_{t+j}. \qquad (3.15)$$

Dynamic optimality requires the following two transversality conditions to be fulfilled

$$\begin{aligned} \lim_{T \to \infty} \beta_T\, Q^K_T\, k_{T+1} &= 0 \\ \lim_{T \to \infty} \beta_T\, Q^N_T\, n_{T+1} &= 0. \end{aligned} \qquad (3.16)$$

We can summarize the firm's first-order necessary conditions from equations (3.11)-(3.14) by the following two expressions:

$$F1 \; : \; (1-\tau_t) \left(g_{i_t} + p^I_t \right) = E_t \beta_{t+1} (1-\tau_{t+1}) \left[f_{k_{t+1}} - g_{k_{t+1}} + (1-\delta_{t+1})(g_{i_{t+1}} + p^I_{t+1}) \right]$$

$$F2 \; : \; (1-\tau_t) \frac{g_{v_t}}{q_t} = E_t \beta_{t+1} (1-\tau_{t+1}) \left[f_{n_{t+1}} - g_{n_{t+1}} - w_{t+1} + (1-\psi_{t+1}) \frac{g_{v_{t+1}}}{q_{t+1}} \right].$$

Solving equation (3.11) forward and using the law of iterated expectations establishes a link between the marginal contribution of an additional unit of physical capital in the following period to the firm's pre-dividend market value in period t, Q_t^K, and the expected present discounted value of future net surpluses arising from adjusting physical capital:

$$Q_t^K = E_t \left\{ \sum_{j=0}^{\infty} \left(\prod_{i=0}^{j} \beta_{t+1+i} \right) \left(\prod_{i=0}^{j} (1 - \delta_{t+1+i}) \right) (1 - \tau_{t+1+j}) \left(f_{k_{t+1+j}} - g_{k_{t+1+j}} \right) \right\}. \tag{3.17}$$

It is straightforward to show that in the special case of time-invariant discount factors, no adjustment costs, no taxes, and a perfectly competitive market for capital, Q_t^K equals one. Similarly, solving equation (3.13) forward and using the law of iterated expectations yields the marginal contribution of a job-match in the following period to the pre-dividend market value of the firm in period t, Q_t^N:

$$Q_t^N = E_t \left\{ \sum_{j=0}^{\infty} \left(\prod_{i=0}^{j} \beta_{t+1+i} \right) \left(\prod_{i=0}^{j} (1 - \psi_{t+1+i}) \right) (1 - \tau_{t+1+j}) \left(f_{n_{t+1+j}} - g_{n_{t+1+j}} - w_{t+1+j} \right) \right\}. \tag{3.18}$$

This marginal increase in the firm's value equals the expected present discounted future stream of surpluses arising to the firm from an additional job-match. In the special case of time-invariant discount factors, no adjustment costs, no taxes, and a perfectly competitive labor market, Q_t^N equals zero.

3.3. Tobin's Q Interpretation: Investment and Hiring Equations

Given that investment and hiring are costly, our analytical setup implicitly contains an investment function and a hiring function. In particular, the firm's first-order necessary condition for investment establishes a link between the investment-to-capital ratio and Q^K, Tobin's marginal Q for capital. Similarly, the optimality condition for new hires links the hiring-to-employment ratio to Q^N, a Tobin's marginal Q equivalent for employment.

In order to illustrate the presence of an investment function, we focus on the non-stochastic steady state version of equation ($F1$) and make the following simplifying assumptions: g_i is a function of the investment-to-capital ratio only, and the corporate income tax rate τ is zero. We can then rewrite equation $(F1)$ as

$$g_i\left(\frac{i}{k}\right)(r+\delta) = f_k - g_k - p^I(r+\delta). \tag{3.19}$$

A simple rearrangement yields

$$\frac{i}{k} = (g_i)^{-1}\left(\frac{f_k - g_k - p^I(r+\delta)}{r+\delta}\right) \equiv I\left(Q^K - 1\right), \tag{3.20}$$

where $Q^K = \left[f_k - g_k + \left(1-p^I\right)(r+\delta)\right]/(r+\delta)$, and $I'\left(Q^K-1\right) > 0$.

Equation (3.20) states that the investment-to-capital ratio increases with Q^K. The latter equals one if the marginal adjustment costs of capital is zero and p^I equals one.

We can derive a hiring function in an analogous manner. To illustrate this function, we assume that g_v is a function of the hiring-to-employment ratio, and the corporate income tax rate τ is zero. Then we can express the steady-state version of equation $(F2)$ as follows:

$$\frac{g_v\left(\frac{qv}{n}\right)}{q}(r+\psi) = f_n - g_n - w. \tag{3.21}$$

Rearranging this equation yields

$$\frac{qv}{n} = (g_v)^{-1}\left[\frac{f_n - g_n - w}{r+\psi}q\right] \equiv H\left[\left(Q^N - 1\right)q\right], \tag{3.22}$$

where $Q^N = \left[f_n - g_n - (w - r - \psi)\right]/(r+\psi)$, and $H'\left[\left(Q^N-1\right)q\right] > 0$.

According to equation (3.22), hiring rates increase with Q^N. The hiring rate also rises with the probability of a vacancy leading to a new job-match, q. Q^N equals one if the marginal adjustment costs of employment is zero and labor is paid its marginal product.

It should be emphasized that the above is but a simple illustration. In fact it turns out that the interaction between investment and hiring rates is essential, and therefore g_i and g_v are functions of both investment and hiring rates.

3.4. Implications For Asset Values

We use standard asset-pricing theory to derive the implications of the model for the links between the asset value of the firm and the asset value of the job-worker match. As stated in equation (3.7), the firm's period t market value is defined as the expected discounted pre-dividend market value of the following period:

$$s_t = E_t\left[\beta_{t+1}\left(s_{t+1} + cf_{t+1}\right)\right]. \tag{3.23}$$

The firm's market value can be decomposed into the sum of the value due to physical capital, ϑ_t^k, and the value due to the stock of employment, ϑ_t^n. We label the latter fraction of the firm's asset value the asset value of the job-worker match and express s_t as

$$s_t = \vartheta_t^k + \vartheta_t^n = E_t\left[\beta_{t+1}\left(\vartheta_{t+1}^k + cf_{t+1}^k\right)\right] + E_t\left[\beta_{t+1}\left(\vartheta_{t+1}^n + cf_{t+1}^n\right)\right], \tag{3.24}$$

where

$$cf_t = (1-\tau_t)\left[f(n_t, k_t) - g\left[i_t, k_t, h(v_t, q_t v_t), n_t\right] - w_t n_t - p_t^I i_t\right] \tag{3.25}$$

Using the constant returns-to-scale properties of the production function f and of the adjustment cost function, g, this stream of maximized cash flow payments can be rewritten as

$$\begin{aligned} cf_t &= (1-\tau_t)\left(f_{k_t}k_t + f_{n_t}n_t - w_t n_t - p_t^I i_t - g_{k_t}k_t - g_{i_t}i_t - g_{n_t}n_t - g_{v_t}v_t\right) \\ &= (1-\tau_t)\left[\left(f_{k_t}k_t - p_t^I i_t - g_{k_t}k_t - g_{i_t}i_t - r_t^b b_t^k\right) + \left(f_{n_t}n_t - w_t n_t - g_{n_t}n_t - g_{v_t}v_t\right)\right] \\ &\equiv cf_t^k + cf_t^n. \end{aligned}$$

In order to establish a link between the firm's value and its stock of capital and employment using the first-order necessary condition (FONC) we manipulate the latter equation to obtain (see Appendix A for the full derivation):

$$s_t = \vartheta_t^k + \vartheta_t^n = k_{t+1}Q_t^K + n_{t+1}Q_t^N. \tag{3.26}$$

where Q_t^K and Q_t^N are defined in equations (3.17) and (3.18), respectively.

Alternatively, we can express the firm's market value in period t as follows:

$$\begin{aligned} s_t &= k_{t+1}E_t\left[\beta_{t+1}\left(1-\tau_{t+1}\right)\left[f_{k_{t+1}}-g_{k_{t+1}}+(1-\delta_{t+1})(p^I_{t+1}+g_{i_{t+1}})\right]\right] \\ &+n_{t+1}E_t\left[\beta_{t+1}\left(1-\tau_{t+1}\right)\left(f_{n_{t+1}}-g_{n_{t+1}}-w_{t+1}+\frac{(1-\psi_{t+1})g_{v_{t+1}}}{q_{t+1}}\right)\right] \end{aligned} \tag{3.27}$$

We turn now to explore the empirical implications of the model.

4. Data and Methodology

The main idea underlying the empirical work is to explain firms' joint hiring and investment behavior and to relate it to their asset value. We present the methodology and the key relations to be studied empirically, including a discussion of the data and the alternative specifications used.

4.1. Parameterization

To quantify the model we need to parameterize the relevant functions. For the production function we use a standard Cobb-Douglas:

$$f(n_t,k_t)=n_t{}^{\alpha}k_t^{1-\alpha},\ 0<\alpha<1. \tag{4.1}$$

We parameterize the adjustment cost function g as follows:

$$g(\cdot)=\left[\frac{g_1}{\eta_1}(\frac{i_t}{k_t})^{\eta_1}+\frac{g_2}{\eta_2}(\frac{q_tv_t}{n_t})^{\eta_2}+\frac{g_3}{\eta_3}(\frac{i_t}{k_t}\frac{q_tv_t}{n_t})^{\eta_3}\right]f(n_t,k_t). \tag{4.2}$$

This generalized convex function is linearly homogenous in i,k,v and n. It postulates that costs are proportional to output, and that they increase in investment and hiring rates. The third term in square brackets expresses interaction of capital and labor adjustment costs. The parameters g_i, $i=1,2,3$ express scale, and η_i express the elasticity of costs with respect to the different arguments. The function encompasses the widely used quadratic case for which $\eta_1=\eta_2=2$. This generalized functional form proved useful in structural estimation of the search and matching model presented in Yashiv (2000a). The estimates of these parameters will allow the quantification of the derivatives g_{i_t} and g_{v_t} that appear in the firms' FONC.

4.2. The Data

Our data sample is quarterly, corporate sector data for the U.S. economy in the period 1976:1-1997:4. In what follows we briefly describe the data set and emphasize its distinctive features; for full definitions and sources see Appendix B.

For output (f), capital (k) and investment (i) we use a relatively new data set on the non-financial corporate business (NFCB) sector recently published by the BEA.[5] We use a BEA/NFCB computed series for depreciation (δ_t). This data set leaves out variables that are sometimes used but that are not consistent with the above model, such as residential or government investment.

For gross hiring flows (qv) we use adjusted CPS data as computed by Bleakely et al (1999). Two aspects of the data merit attention: (i) We use flows into employment from both unemployment and out of the labor force; the latter flow is sizeable, and in terms of the model is no different from unemployment to employment flows. (ii) The data flows are adjusted to cater for misclassification and measurement error; see Bleakely et al (1999) for an extensive discussion of the adjustment methodology. Note that the gross hiring flows are substantially bigger than net flows: the former has a mean of 8.9% per quarter, while the latter averages 0.5% per quarter. We derive the separation rate (ψ_t) by solving it out of the dynamic equation of labor (equation 3.4 above). For employment (n) we use two alternative employment CPS measures. For the labor share of income $\frac{wn}{f}$ we use the sum of wages and salaries as part of national income (from NIPA).

For the asset value (s) we use the market value of non-farm, non-financial business. This value is the sum of financial liabilities and equity less financial assets. The data are taken from Hall (2001) based on the Fed Flow of Funds accounts. For the discount rate (r) we use three alternatives: a weighted average of the returns to debt (using a commercial paper rate) and to equity (using CRSP returns), the SP500 rate of change, and the rate of non-durable consumption growth, which serves as the discount rate in a DSGE model with log utility. Table 1 presents summary statistics.

Table 1

[5] See www.bea.doc.gov/bea/ARTICLES/NATIONAL/NIPAREL/2000/0400fxacdg.pdf

4.3. Methodologies

We use two methodologies:

(i) We structurally estimate the firms' first-order necessary conditions $(F1)$ and $(F2)$, and the asset pricing equation (3.27) using Hansen's (1982) generalized method of moments (GMM). The moment conditions estimated are those obtained under rational expectations. That is, the firms' expectational errors are orthogonal to any variable in their information set at the time of the investment and hiring decisions. The moment conditions are derived by replacing expected values with actual values plus expectational errors (j) and specifying that the errors are orthogonal to the instruments Z i.e. $E(j_t \otimes Z_t) = 0$.

We formulate the equations in stationary terms.[6] Thus the estimating equations are (where j_1, j_2 and j_3 are the relevant expectational errors):

$$\frac{\left(p_t^I + \left[g_1\left(\frac{i_t}{k_t}\right)^{\eta_1 - 1} + g_3\left(\frac{i_t}{k_t}\frac{q_t v_t}{n_t}\right)^{\eta_3 - 1}\frac{q_t v_t}{n_t}\right]\frac{f_t}{k_t}\right)}{\frac{f_{t+1}}{k_{t+1}}}(1-\tau_t) \tag{4.3}$$

$$= \beta_{t+1}(1-\tau_{t+1})\left\{\begin{array}{c} \left(\begin{array}{c} (1-\alpha) + \left[g_1\left(\frac{i_{t+1}}{k_{t+1}}\right)^{\eta_1} + g_3\left(\frac{i_{t+1}}{k_{t+1}}\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_3}\right] \\ -(1-\alpha)\left[\frac{g_1}{\eta_1}\left(\frac{i_{t+1}}{k_{t+1}}\right)^{\eta_1} + \frac{g_2}{\eta_2}\left(\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_2} + \frac{g_3}{\eta_3}\left(\frac{i_{t+1}q_{t+1}v_{t+1}}{k_{t+1}n_{t+1}}\right)^{\eta_3}\right] \end{array}\right) \\ +(1-\delta_{t+1})\left(\frac{p_{t+1}^I}{\frac{f_{t+1}}{k_{t+1}}} + \left[g_1\left(\frac{i_{t+1}}{k_{t+1}}\right)^{\eta_1 - 1} + g_3\left(\frac{i_{t+1}}{k_{t+1}}\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_3 - 1}\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right]\right) \end{array}\right\} + j_1$$

$$\frac{\left[g_2\left(\frac{q_t v_t}{n_t}\right)^{\eta_2 - 1} + g_3\left(\frac{i_t}{k_t}\frac{q_t v_t}{n_t}\right)^{\eta_3 - 1}\frac{i_t}{k_t}\right]\frac{f_t}{n_t}}{\frac{f_{t+1}}{n_{t+1}}}(1-\tau_t) \tag{4.4}$$

$$= \beta_{t+1}(1-\tau_{t+1})\left[\begin{array}{c} \alpha - \frac{w_{t+1}n_{t+1}}{f_{t+1}} + \left[g_2\left(\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_2} + g_3\left(\frac{i_{t+1}}{k_{t+1}}\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_3}\right] \\ -\alpha\left[\frac{g_1}{\eta_1}\left(\frac{i_{t+1}}{k_{t+1}}\right)^{\eta_1} + \frac{g_2}{\eta_2}\left(\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_2} + \frac{g_3}{\eta_3}\left(\frac{q_{t+1}i_{t+1}v_{t+1}}{k_{+1t}n_{t+1}}\right)^{\eta_3}\right] \end{array}\right.$$
$$\left. +(1-\psi_{t+1})\left[g_2\left(\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_2 - 1} + g_3\left(\frac{i_{t+1}}{k_{t+1}}\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_3 - 1}\frac{i_{t+1}}{k_{t+1}}\right]\right] + j_2$$

[6] In order to induce stationarity we divide the FONC for capital by $\frac{f_{t+1}}{k_{t+1}}$ and the FONC for labor by $\frac{f_{t+1}}{n_{t+1}}$. We divide the asset pricing equation throughout by the level of output, f.

$$\frac{s_t}{f_t} = \beta_{t+1}(1-\tau_{t+1})\frac{f_{t+1}}{f_t}\left[\begin{array}{c} (1-\alpha) + \left[g_1(\frac{i_{t+1}}{k_{t+1}})^{\eta_1} + g_3(\frac{i_{t+1}}{k_{t+1}}\frac{q_{t+1}v_{t+1}}{n_{t+1}})^{\eta_3}\right] \\ -(1-\alpha)\left[\frac{g_1}{\eta_1}\left(\frac{i_{t+1}}{k_{t+1}}\right)^{\eta_1} + \frac{g_2}{\eta_2}\left(\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_2} + \frac{g_3}{\eta_3}\left(\frac{i_{t+1}}{k_{t+1}}\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_3}\right] \\ +(1-\delta_{t+1})(\frac{p^I_{t+1}}{\frac{f_{t+1}}{k_{t+1}}} + \left[g_1(\frac{i_{t+1}}{k_{t+1}})^{\eta_{1-1}} + g_3(\frac{i_{t+1}}{k_{t+1}}\frac{q_{t+1}v_{t+1}}{n_{t+1}})^{\eta_3-1}\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right]) \\ +\alpha - \frac{w_{t+1}n_{t+1}}{f_{t+1}} + \left[g_2(\frac{q_{t+1}v_{t+1}}{n_{t+1}})^{\eta_2} + g_3(\frac{i_{t+1}}{k_{t+1}}\frac{q_{t+1}v_{t+1}}{n_{t+1}})^{\eta_3}\right] \\ -\alpha\left[\frac{g_1}{\eta_1}\left(\frac{i_{t+1}}{k_{t+1}}\right)^{\eta_1} + \frac{g_2}{\eta_2}\left(\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_2} + \frac{g_3}{\eta_3}\left(\frac{i_{t+1}}{k_{t+1}}\frac{q_{t+1}v_{t+1}}{n_{t+1}}\right)^{\eta_3}\right] \\ +(1-\psi_{t+1})\left[g_2(\frac{q_{t+1}v_{t+1}}{n_{t+1}})^{\eta_2-1} + g_3(\frac{i_{t+1}}{k_{t+1}}\frac{q_{t+1}v_{t+1}}{n_{t+1}})^{\eta_{3-1}}\frac{i_{t+1}}{k_{t+1}}\right] \end{array}\right] + j_3 \qquad (4.5)$$

We explore a number of alternative specifications:

1) *The degree of convexity.* While the literature has for the most part assumed the quadratic form, we allow the powers $(\eta_{1,}\eta_{2,}\eta_3)$ to take other values (determined by estimation).

2) *Instrument sets.* We use alternative instrument sets in terms of variables and number of lags. The instrument sets differ across the three equations and include lags of variables appearing in the corresponding equation.

3) *Variables' formulation.* We check the effect of using alternative time series for some of the variables, which have multiple representations. These include δ, ψ and β.

To judge the quality of the estimates – beyond using Hansen's (1982) J-statistic – we solve equations (4.3), (4.4), and (4.5) period by period to generate time series for $\frac{i_{t+1}}{k_{t+1}}, \frac{q_{t+1}v_{t+1}}{n_{t+1}}$ and $\frac{s_t}{f_t}$ and compare these "fitted" series to the actual ones. Note that the solution for $\frac{s_t}{f_t}$ is simply the RHS of (4.5) without the error; to get solutions for $\frac{i_{t+1}}{k_{t+1}}$ and $\frac{q_{t+1}v_{t+1}}{n_{t+1}}$ we need to solve the relevant polynomial expressions in (4.3) and (4.4) period by period.

(ii) We use a calibration methodology as follows: we pick a range of reasonable values for total and marginal adjustment costs (elaborated below). For each set of values we solve the following three equations:

$$\frac{g}{f} = \frac{g_1}{\eta_1}\left(\frac{i}{k}\right)^{\eta_1} + \frac{g_2}{\eta_2}\left(\frac{qv}{n}\right)^{\eta_2} + \frac{g_3}{\eta_3}\left(\frac{i}{k}\frac{qv}{n}\right)^{\eta_3} \qquad (4.6)$$

$$\frac{g_i}{f/k} = g_1(\frac{i}{k})^{\eta_1 - 1} + g_3(\frac{i}{k}\frac{qv}{n})^{\eta_3 - 1}\frac{qv}{n} \tag{4.7}$$

$$\frac{g_v}{f/n} = g_2(\frac{qv}{n})^{\eta_2 - 1} + g_3(\frac{i}{k}\frac{qv}{n})^{\eta_3 - 1}\frac{i}{k} \tag{4.8}$$

The values we pick are the LHS of each equation. We then use the sample average values of $\frac{i}{k}$ and $\frac{qv}{n}$ and constrain η_1, η_2 and η_3 to take values elaborated below, to solve for g_1, g_2 and g_3. Thus we get a solution triple (g_1, g_2, g_3) for each set of calibrated values of $\left(\frac{g}{f}, \frac{g_i}{f/k}, \frac{g_v}{f/n}\right)$. We then use these values to repeat the solution procedure explained above, i.e. we solve equations (4.3), (4.4), and (4.5) period by period to generate time series for $\frac{i_{t+1}}{k_{t+1}}, \frac{q_{t+1}v_{t+1}}{n_{t+1}}$ and $\frac{s_t}{f_t}$ and compare these "fitted" series to the actual ones. There are a number of payoffs to this calibration methodology: it is free of instrument choice, it can be adjusted to generate better fit of the relevant series, and it provides useful information for the setting of initial values in the GMM estimation procedure.

5. Results

We start with the presentation of alternative specifications (5.1) and then examine variations on a preferred specification (5.2).

5.1. Alternative Specifications

The aim of the empirical work is essentially to estimate the parameters of the adjustment costs function g. These estimates generate hiring, investment and asset value series using the first order conditions and the asset pricing equation. A key question here is to determine what are the correct powers – η_1, η_2 and η_3– to use. The literature has typically used the quadratic formulation but it turns out that this specification can be improved upon. We report below alternative specifications, including unconstrained powers or alternative forms of constrained parameters. For the calibration procedure, we had to constrain the powers in order to get a solution.

Table 2 reports the results of joint GMM estimation of equations (4.3), (4.4), and (4.5) using alternative specifications of the power parameters. The table presents the following alternative formulations: free powers (i.e. estimating η_1, η_2 and η_3), two free parameters η_1 and η_2, with η_3 constrained to equal η_2, one free power (η_2) and the others constrained to satisfy $\eta_1 - 1 = \eta_2 = \eta_3$, and a constrained set: $\eta_1 = 3, \eta_2 = \eta_3 = 2$. These different constraints emerged from some experimentation. We also look at two specifications which serve as a comparison to the literature: in one there are adjustment costs on capital only ($g_2 = g_3 = 0$) and the function is quadratic ($\eta_1 = 2$); in the second there are quadratic investment and hiring costs and a linear interaction ($\eta_1 = \eta_2 = 2, \eta_3 = 1$).[7] The table presents the parameter estimates, their standard errors, and the test statistics – Hansen's J-statistic and its p-value, the correlations between actual and "fitted" investment rates $\frac{i}{k}$, hiring rates $\frac{qv}{n}$, and asset values $\frac{s}{f}$, and the variance of fitted asset values relative to the variance of actual asset values.

Table 2

We analyze the results according to their data fit and the preciseness of the estimates. First, note that the production function labor parameter α is estimated at values around 0.70, which is a reasonable point estimate. The power estimates, when unconstrained, point to a formulation of $\eta_1 = 3$ and $\eta_2 = \eta_3 = 2$. Next, note that the conventional quadratic specification with no hiring costs (i.e. $\eta_1 = 2$ and $g_2 = g_3 = 0$, as reported in column 5) performs poorly. It has a negative correlation with asset values and a low (0.23) correlation with the investment rate series. The other specifications differ with respect to the constraints imposed on the power parameters. Column 1 imposes no constraints. Its g_1 estimate is imprecise and it generates a poor fit of hiring behavior. Column 2 does better but the hiring rate fit is still poor. The constrained specification of column 4 ($\eta_1 = 3, \eta_2 = \eta_3 = 2$) performs better but not as well as the others. It appears as though the

[7] We have also tried a quadratic formulation that takes into account gross hiring costs but does not allow for interaction with capital adjustment costs (i.e. $\eta_1 = \eta_2 = 2$ and $g_3 = 0$) but there was no convergence of the GMM procedure.

constrained specification of column 6 ($\eta_1 = \eta_2 = 2, \eta_3 = 1$) performs well but it turns out that it implies negative costs of adjustment. The best fit is provided by column 3 (with η_2 free). It generates a reasonably good fit of all series: correlation of almost 0.8 between the "fitted" and actual $\frac{s}{f}$ with a good "fit" of the variance and a correlation of around 0.5-0.6 for both hiring and investment rates.

Table 3 presents the results of the calibration methodology. The calibrated values (LHS of equations $4.6 - 4.8$) are chosen to be in the range $[0.2, 2]$. This range for the value of marginal investment costs ($\frac{g_i}{f/k}$) corresponds to the results in the Q literature (surveyed below). There is far less information on marginal hiring costs ($\frac{g_v}{f/n}$) but the structural estimates in Yashiv (2000a) and the literature discussed there implies that a similar range is plausible. Total adjustment costs ($\frac{g}{f}$), including gross hiring, have not been studied so we use the same range as a reasonable approximation. Thus we get a grid of values – using intervals of 0.2 in the above range – that has 10^3 points, each of which is solved for (g_1, g_2, g_3). Using these solution triples and equations (4.3), (4.4), and (4.5) we generate time series for $\frac{s}{f}, \frac{i}{k}$ and $\frac{qv}{n}$. On these 1000 runs we apply two sets of selection criteria: first, we pick those specifications which imply plausible adjustment cost functions, i.e. positive costs that are not excessive.[8] Out of the specifications that survived the first selection criteria, we computed the fit of the implied $\frac{s}{f}, \frac{i}{k}$ and $\frac{qv}{n}$ with the actual data. The table presents a number of "representative" solutions that display a relatively good fit. The table reports the g_1, g_2, g_3 values, the correlation between actual and "fitted" investment rates $\frac{i}{k}$, hiring rates $\frac{qv}{n}$, and stock prices $\frac{s}{f}$ and the variance of fitted asset values relative to the variance of actual asset values.

Table 3

The different specifications differ mostly with respect to the hiring series fit and the asset value variance fit. From these results and from other, unreported ones, it turns out that the scale

[8]Note that the first part of the calibration – solving for g_1, g_2 and g_3 – was performed on the mean values of $\frac{i}{k}$ and $\frac{qv}{n}$, while the selection criteria pertain to the time series over the entire sample period.

parameters g_1, g_2 and g_3 play two connected roles: the absolute value of these parameters is important for capturing the level of $\frac{s}{f}$ and its variance; the ratios of these parameters one to another, for example $\frac{g_1}{g_3}$, are important for capturing the behavior of $\frac{i}{k}$ and $\frac{qv}{n}$. The specification that exhibits the best performance is the one presented in column .It is better than the others in capturing the behavior of investment and hiring rates, and it is good at fitting asset value volatility (though not the very best). It is noteworthy that its parameter values are close to the results of column 3 in Table 2, the preferred GMM specification.

5.2. Variations on the Benchmark Specification

Table 4 takes up specification 3 from Table 2 (which is similar to column 1 in Table 3) replicated here in column 1 and examines further variations along several dimensions: looking at alternative instrument sets and using alternative definitions of the variables ψ, δ and β,as explained in the table's notes.

Table 4

The common results are the value of 2 as the point estimate for the free power parameter η_2, the estimate of the production function parameter α at around 0.7-0.8 and a fit of almost 0.8 with respect to asset values $\frac{s}{f}$. The differences pertain to the scale parameters, both in terms of magnitude and in terms of the ratios between them. Those specifications that result in relatively low point estimates of g_1, g_2 and g_3 (columns 2, 3 and 6) generate a relatively poor fit of hiring rates and asset value volatility. However, it is not only scale that matters: column 4 that has the biggest estimates in absolute value provides a poor fit of hiring rates and "overfits" asset value volatility. This is so because the ratios between the scale estimates change. Column 1 remains a preferred specification, though column 5 performs well too.

We turn now to examine the implications of the estimates for the adjustment costs function and for the time series behavior of hiring and investment rates and of asset values.

6. Hiring, Investment and Asset Values

In this section we look at the implications of the results, using the preferred specifications – the GMM estimates reported in column 3 of Table 2 and the calibration results reported in column 1 of Table 3. We begin by looking at the implied adjustment costs function (6.1). We then study the joint behavior of hiring and investment (6.2) and the behavior of asset values (6.3). Finally we summarize the main implications of the estimates (6.4).

6.1. Adjustment Costs

The results of Tables 2, 3 and 4 allow us to construct time series for marginal adjustment costs by using the point estimates of the parameters of the g function. As can be seen from equations $(F1)$ and $(F2)$, it is these costs that are key for the determination of hiring and investment behavior. The two first moments for these series in the sample, using the preferred specifications from the tables, are reported in Table 5.

Table 5

The table reports the LHS of the Euler equations (without taxes) and its decomposition. This represents the cost for the firm of hiring or investing at the margin.

Consider hiring first, as reported in the first panel. The first row reports net costs on the marginal gross hire. This is bascially Q^N before taxes, set in terms of average output per worker $(\frac{f}{n})$. The two specifications yield results of 1.7 and 2.6. This is roughly equivalent to three and four quarters of wage payments. We are aware of no study on the aggregate economy to which these numbers can be compared, but it seems a plausible estimate, i.e. that marginal costs are in the order of a few quarters worth of work. Note that gross marginal costs (reported in row (2)) are much higher than net marginal costs, as the gross costs are reduced by the interaction between hiring and investment costs, with the interaction term having a negative sign (reported in row (3)). The volatility of marginal costs, as reported in the standard deviation statistics, is roughly the same for net costs and for each component (gross costs and the interaction term). The two components co-vary negatively.

Consider now the costs on the marginal unit of capital, as reported in the second panel. Here we note that the firm pays a purchase price (p^I) and incurs adjustment costs. We present the data on both in terms relative to output per unit of capital ($\frac{f}{k}$). The first row reports the total capital expenditure on the marginal unit. Looking at its decomposition in rows 2, 3 and 4, it is clear that it is dominated by the purchase price – comparing rows 1 and 2 we see that the purchase price is on average 98% (according to the GMM estimates) or 86% (according to the calibration results) of the total marginal expenditure. This is so because, as in the hiring case, gross adjustment costs are greatly reduced by the interaction term, leaving much smaller net adjustment costs (reported in the next to last row). The adjustment costs terms exhibit higher volatility than the purchase price. The table also reports Tobin's Q^K (before-tax); the estimates are 1.3 on average for the GMM specification and 1.5 on average for the calibration specification.

How reasonable are these magnitudes of capital adjustment costs? There exists a vast literature on the quantitative importance of adjustment costs for investment in physical capital. This literature builds upon the traditional Q-theory of investment discussed above and encompasses time series as well as panel data analyses. Chirinko (1993) provides a comprehensive survey. In what follows, we briefly review the main findings in order to compare to the results of panel b in Table 5. The studies examined typically assume the following quadratic formulation:

$$g\left(\frac{i_t}{k_t}\right) = \frac{g_1}{2}\left(\frac{i_t}{k_t}\right)^2 k_t. \tag{6.1}$$

This functional form implies marginal costs of adjusting investment, g_i, which are linear in the investment rate:

$$g_i = g_1\left(\frac{i_t}{k_t}\right). \tag{6.2}$$

With this marginal adjustment cost function, there is a linear relationship between the investment-to-capital ratio $\frac{i_t}{k_t}$ and Tobin's marginal Q for capital, Q^K as implied by equation (3.20). The results reported below are based on regression estimation of this linear relationship or, alternatively, on

Euler equation estimation of equation $F1$ (omitting the other terms, i.e. without the terms involving $\frac{qv}{n}$). Table 6 offers a summary of some key studies.

Table 6

The cited studies, relating to different data sets and time periods, indicate that average investment rate ($\frac{i}{k}$) per annum differs for aggregate data, where it is typically around 0.10, and the widely-used Compustat firm panel data, where it is around 0.20. The estimates of g_i exhibit large variation within and across studies. This variation may be described as follows: the early studies [Summers (1981) and Hayashi (1982)] tended to show large values of adjustment costs, implying very slow adjustment of capital. This finding led researchers to refine the data used and the econometric specification and so later studies typically yield estimates of g_i in a lower range, typically between 0.2 and 1.2. This variation is found both across and within studies and reflects differences in the sample of firms, in the specification (variables included, measurement issues) and econometric methodology. Note that even for the five papers dealing with Compustat data the estimates vary widely in the cited range.[9]

How do these results compare to those reported in panel b of Table 5? First, note that the estimates reported in Table 6 do not refer to purchase costs and that the cited studies do not consider an interaction between capital adjustment costs and hiring costs. Next, note that our specification has $\eta_1 = 3$ based on estimation, while the reported literature assumes $\eta_1 = 2$. These differences notwithstanding, the net estimates reported in the last row of Table 5 are consistent with the cited range: the mean GMM estimate (0.17) is at the low end of this range, while the mean calibration result (1.20) is at the high end of this range. More importantly, the results of Table 5 shed light on two issues with respect to this literature: first, judging marginal costs as high or low requires consideration of the purchase price, which is clearly dominant in our results, and

[9]The study of Abel and Eberly (2002), using Compustat data and both OLS and IV estimation, suggests a different, higher range: $1.2 - 22.9$. These high estimates are described by the authors as excessive and lead them to adopt a different specification with fixed costs and capital heterogeneity. The latter yields much lower estimates.

the interaction with hiring costs, that greatly reduce costs. Second, it is clear from Table 5 that omitting the hiring-investment interaction, one obtains very high estimates – 11.5 in the GMM case and 11 in the calibration case. This finding can explain the tendency of studies with such omission to yield high estimates.

6.2. Hiring and Investment

Table 7 presents statistics on the actual and fitted investment $\frac{i}{k}$ and hiring $\frac{qv}{n}$ rates series. These include the contemporaneous correlation of the fitted (denoted by tildes) and actual series, the best cross-correlation of the series, the ratio between the mean and the variance of the series, and the auto-correlation. It also reports the correlation between the hiring and investment series.

Table 7

Figure 1 shows the actual and fitted values of hiring and investment rates. Panels (a) and (c) present the fitted values according to the calibration results (column 1 of Table 3). The GMM-based results are similar but do not fit the data as well (see Table 7). For reasons to be discussed below, panels b and d present exponentially smoothed versions of the fitted values according to the GMM specification (column 3 in Table 2).[10] In panel (e) we plot the actual investment rate series and two fitted series: one is the above GMM estimate and the other is the conventional quadratic formulation without hiring costs. The latter fitted series is implied by the point estimates of Column 5 of Table 2.

Figure 1

Several implications stand out from the table and the figure:

[10] Gaps in the fitted investment series indicate that there were no real roots for the relevant third order polynomial that is solved to generate the fitted series.

First, each fitted series captures the mean well but overstates the volatility and understates the autocorrelation; thus the actual series look like a filter of the fitted series. When we exponentially smooth the fitted series these problems are greatly reduced. This may be due to the fact that the Euler equations posit that investment and hiring in a given quarter are functions of expected values in the adjacent, subsequent quarter. While the latter do contain elements of expected values into the infinite future, it may be true that some investment starts to produce only in subsequent quarters. Thus the formulations used above may suffer from being too "high frequency," generating volatile fitted series, that exhibit a lot of short term movements. This is further evidenced by the fact that cross correlations one quarter ahead for the fitted series are higher than the contemporaneous correlations. Actual rates may thus be capturing expected future values that are more distant than the subsequent quarter value.

Second, the fitted series capture the interesting and somewhat counter-intuitive phenomenon of a negative correlation between investment rates, which went up, particularly in the 1990s, and hiring rates, which declined over the same period. The correlation between the actual series is -0.27 while the fitted series correlation is -0.24 according to the GMM estimates and -0.21 according to the calibration results.

Third, the table and the figure show that the conventional quadratic specification with no hiring costs does poorly. It generates a highly volatile investment rate series – its variance is almost 20 times as big as the actual – that is not well correlated with the actual series (correlation of 0.23) and that has very low autocorrelation (0.12 compared to 0.92 of the actual series).

6.3. Asset Values

Table 8 takes up the preferred specifications and presents their implications for asset values $\frac{s}{f}$.

Table 8

Panels (b) and (c) of the table rely on the following decomposition:

$$
\begin{aligned}
\frac{s}{f} &= \frac{s_t^1}{f_t} + \frac{s_t^2}{f_t} + \frac{s_t^3}{f_t} \\
\frac{s_t^1}{f_t} &= \frac{f_{t+1}}{f_t}\beta_{t+1}(1-\tau_{t+1})\left[(1-\alpha) + (1-\delta_{t+1})\frac{p_{t+1}^I}{\frac{f_{t+1}}{k_{t+1}}}\right] \\
\frac{s_t^2}{f_t} &= \frac{f_{t+1}}{f_t}\beta_{t+1}(1-\tau_{t+1})\left[-\frac{g_{k_{t+1}}}{\frac{f_{t+1}}{k_{t+1}}} + (1-\delta_{t+1})\frac{g_{i_{t+1}}}{\frac{f_{t+1}}{k_{t+1}}}\right] \\
\frac{s_t^3}{f_t} &= \frac{f_{t+1}}{f_t}\beta_{t+1}(1-\tau_{t+1})\left(\alpha - \frac{w_{t+1}n_{t+1}}{f_{t+1}} - \frac{g_{n_{t+1}}}{\frac{f_{t+1}}{n_{t+1}}} + \frac{(1-\psi_{t+1})g_{v_{t+1}}}{q_{t+1}\frac{f_{t+1}}{n_{t+1}}}\right)
\end{aligned}
$$

The first term, $\frac{s_t^1}{f_t}$, represents the asset value in the absence of any adjustment costs (note that in this case $\alpha = \frac{wn}{f}$). The second term, $\frac{s_t^2}{f_t}$, represent the value of capital adjustment and the third term, $\frac{s_t^3}{f_t}$, represents the value of hiring.

Figure 2 plots in two panels the actual $\frac{s}{f}$ series, the fitted values (according to the GMM estimates of Table 2 column 3), and their decomposition into the above three components.

Figure 2

We examine the results reported in Table 8 and Figure 2 along four dimensions:

Fit. Panel (a) of the table indicates that the fit of the chosen specifications is relatively good, at almost 0.8.

Mean. In terms of the mean, the fitted value is somewhat higher than the actual value. Its decomposition (in panel (b)) according to the GMM estimates shows that 79% comes from the first term, which is the value without any adjustment costs, 17% from the hiring cost term and the remaining 4% from the capital adjustment cost term. The calibration results indicate that 65% comes from the first term, 21% from the hiring cost term and 14% from the capital adjustment cost term.

Volatility. As shown in panel (a), the preferred specifications capture a big part of the variance of the actual series. Panel (c) shows the decomposition of the fitted variance, where each term is divided by the total fitted variance so the elements of the matrix sum to 1. The two specifications are almost identical here. By far the biggest role is played by the second term, i.e. by capital adjustment costs. Two other noteworthy results are the negative co-variation between the first and second terms and between the second and the third terms. The former means that the "classic" part of the asset value is negatively correlated with the part due to capital adjustment costs. The latter means that capital adjustment costs and hiring costs co-vary negatively. Note that hiring costs contribute as much as the "classic" part of the asset value to overall variance.

Decomposition of the fitted series. Figure 2b shows that the traditional component of asset values, as captured by $\frac{s_t^1}{f_t}$, is in fact negatively correlated (-0.30) with the actual asset values. Note in particular that it falls, rather than rises, in the 1990s. This has to do with the fact that p^I fell during this period. It is the capital adjustment part, captured by $\frac{s_t^2}{f_t}$, that generates the fit. The hiring costs part, captured by $\frac{s_t^3}{f_t}$, is also negatively correlated with actual asset values. This is so because hiring rates fell in the 1990s. Recall, however, that the results reported in Table 2 column 5 indicate that capital adjustment costs alone, with no hiring costs, do not account for asset value behavior (the fitted asset value series in the latter case has a -0.05 correlation with the actual one).

6.4. Main Implications

Summing up the implications of both the estimation and the calibration results, we get the following picture: first, the formulation of the adjustment costs function needs to allow for greater convexity than the quadratic with respect to physical investment rates, and for an interaction between investment and hiring costs. Omission of the interaction term results in a serious upward bias of the marginal cost estimates for capital adjustment. Second, the g function scale parameters need to be sufficiently high to capture the mean and the variance of asset values; they need to satisfy certain ratios between them to fit hiring and investment rates. Third, the fitted hiring and investment series display the negative correlation observed in the data but overstate the volatility of each series, possibly because of the relatively high frequency nature of the Euler equations.

Fourth, the asset value series $\frac{s}{f}$ is well captured by the estimates. Asset values went up in the 1990s as investment rates increased. Adjustment costs explain up to 35% of the mean asset value, with hiring costs accounting for about 120%. Most of the volatility in asset value is due to capital adjustment costs volatility. The role of hiring costs in volatility is relatively small but is as big as that of the "classic" part of the asset value.

A key finding throughout is the important role played by the interaction term. This term is estimated to be negative, implying that for given levels of investment (hiring) rates, costs decline as hiring (investment) increases. One interpretation of the this result is that simultaneous hiring and investment is less costly than sequential hiring and investment of the same magnitude. This may be due to the fact that simultaneous action by the firm is less disruptive to production than sequential action.

7. Conclusions

The key message of this paper is that one needs to examine investment and hiring jointly and that both are essential for the determination of asset values. The estimated convex adjustment cost function is able to replicate the negative correlation between investment and hiring rate over the sample period and track the rise in asset values. The key findings are that hiring costs account for about 17% of mean asset values and that capital adjustment costs account for most of asset value volatility. The results imply two rejections of conventional models: first, quadratic adjustment costs for capital with no hiring costs perform very poorly both with respect to investment and with respect to asset values. Second, the traditional element of asset values (that does not depend on adjustment costs) accounts for roughly 70% of mean values and plays the same small role as hiring costs in asset value volatility.

The results also suggest some reasons for the empirical failures of previous model: lack of consideration of the interaction between capital and labor adjustment costs (or the use of net rather than gross labor adjustment costs), the use of fixed or otherwise inappropriate discount factors, and insufficient convexity of the adjustment cost function. Possibly the use of aggregate data which is too broad or econometric techniques that did not sufficiently cater for non-linearities were pitfalls too.

In further work to be reported in future versions of this paper, we intend to test alternative timing assumptions w.r.t the realization of investment and hiring, to see if we can improve the fit w.r.t hiring and investment volatility. Also we would like to examine the effects of using alternative discount factors (β) and asset value (s) variables.

It would appear that a panel study of firms or plants may be insightful. Such a study could allow for heterogeneity and the examination of issues such as fixed costs. However, a serious empirical difficulty is likely to be the (non) existence of appropriate gross flows worker data in conjunction with matching data on investment flows and stock prices. Given the results indicating a key role played by the interaction of hiring and investment rates, this data problem needs to be resolved before any further exploration is accomplished.

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A. Derivation of the Firms Asset Value Equation

The following derivations are based on Hayashi (1982). First we multiply throughout the FONC with respect to investment (3.12) by i_t, the FONC with respect to capital (3.11) by k_{t+1}, the FONC with respect to vacancies (3.14) by v_t, and the one with respect to employment (3.13) by n_{t+1} to get

$$
\begin{aligned}
0 &= -(1-\tau_t)\left(p_t^I + g_{i_t}\right) i_t + i_t Q_t^K && \text{(A.1)}\\
0 &= -(1-\tau_t)\, g_{v_t} v_t + v_t q_t Q_t^N && \text{(A.2)}\\
k_{t+1} Q_t^K &= k_{t+1} E_t\left\{\beta_{t+1}[(1-\tau_{t+1})\left(f_{k_{t+1}} - g_{k_{t+1}}\right) + (1-\delta_{t+1}) Q_{t+1}^K]\right\} && \text{(A.3)}\\
n_{t+1} Q_t^N &= n_{t+1} E_t\left\{\beta_{t+1}\left[(1-\tau_{t+1})\left(f_{n_{t+1}} - g_{n_{t+1}} - w_{t+1}\right) + (1-\psi_{t+1}) Q_{t+1}^N\right]\right\} && \text{(A.4)}
\end{aligned}
$$

Then we insert the law of motion for capital (3.3) into equation (A.1), roll forward all expressions one period, multiply both sides by β_{t+1} and take conditional expectations on both sides:

$$E_t\left[\beta_{t+1}(1-\tau_{t+1})\left(p_{t+1}^I + g_{i_{t+1}}\right) i_{t+1}\right] = E_t\left\{\beta_{t+1}\left[k_{t+2} - (1-\delta_{t+1}) k_{t+1}\right] Q_{t+1}^K\right\}. \qquad \text{(A.5)}$$

and

$$(1-\delta_{t+1}) E_t\left[\beta_{t+1}\left(k_{t+1} Q_{t+1}^K\right)\right] = E_t\left\{\beta_{t+1}\left[\left(k_{t+2} Q_{t+1}^K - (1-\tau_{t+1})\left(p_{t+1}^I + g_{i_{t+1}}\right) i_{t+1}\right)\right]\right\}$$

Combining this expression with equation (A.3) we get

$$k_{t+1} Q_t^K = E_t\left(\beta_{t+1} c f_{t+1}^k + k_{t+2} Q_{t+1}^K\right) \qquad \text{(A.6)}$$

or

$$E_t\left(\beta_{t+1} c f_{t+1}^k\right) = k_{t+1} Q_t^K - E_t\left(\beta_{t+1} k_{t+2} Q_{t+1}^K\right). \qquad \text{(A.7)}$$

It follows from the definition of the firm's market value in equation (3.24) that

$$\vartheta_t^k - E_t\left(\beta_{t+1}\vartheta_{t+1}^k\right) = E_t\left(\beta_{t+1}cf_{t+1}^k\right). \tag{A.8}$$

Thus,

$$\vartheta_t^k - E_t\left(\beta_{t+1}\vartheta_{t+1}^k\right) = k_{t+1}Q_t^K - E_t\left(\beta_{t+1}k_{t+2}Q_{t+1}^K\right), \tag{A.9}$$

which implies

$$\vartheta_t^k = k_{t+1}Q_t^K.$$

We derive a similar expression for the case of labor. Inserting the law of motion for labor from equation (3.4) into equation (A.2), multiplying both sides by β_t, rolling forward all expressions by one period and taking conditional expectations yields

$$E_t\left[\beta_{t+1}\left(1-\tau_{t+1}\right)g_{v_{t+1}}v_{t+1}\right] = E_t\left\{\beta_{t+1}\left[n_{t+2} - (1-\psi_{t+1})n_{t+1}\right]Q_{t+1}^N\right\} = 0, \tag{A.10}$$

and therefore

$$(1-\psi_{t+1})E_t\left(\beta_{t+1}n_{t+1}Q_{t+1}^N\right) = E_t\left\{\beta_{t+1}\left[n_{t+2}Q_{t+1}^N - \left(1-\tau_{t+1}\right)g_{v_{t+1}}v_{t+1}\right]\right\}$$

When combining this equation with equation (A.4) we get

$$n_{t+1}Q_t^N = E_t\left(\beta_{t+1}cf_{t+1}^n + \beta_{t+1}n_{t+2}Q_{t+1}^N\right), \tag{A.11}$$

or

$$E_t\left(\beta_{t+1}cf_{t+1}^n\right) = n_{t+1}Q_t^N - E_t\left(\beta_{t+1}n_{t+2}Q_{t+1}^N\right). \tag{A.12}$$

The definition of the firm's value in equation (3.7) implies that

$$\vartheta_t^n - E_t\left(\beta_{t+1}\vartheta_{t+1}^n\right) = E_t\left(\beta_{t+1}cf_{t+1}^n\right). \tag{A.13}$$

Thus,

$$\vartheta_t^n - E_t\left(\beta_{t+1}\vartheta_{t+1}^n\right) = n_{t+1}Q_t^N - E_t\left(\beta_{t+1}n_{t+2}Q_{t+1}^N\right). \tag{A.14}$$

This implies the following expression for the asset value of a job-match:

$$\vartheta_t^n = n_{t+1} Q_t^N.$$

Hence, the total market value of a firm, s_t, equals:

$$s_t = \vartheta_t^k + \vartheta_t^n = k_{t+1} Q_t^K + n_{t+1} Q_t^N. \tag{A.15}$$

where Q_t^K and Q_t^N are defined in equations (3.17) and (3.18), respectively.

B. Data

The data are quarterly and cover the period 1976:1-1997:4. They pertain to the U.S. non-financial corporate sector unless noted otherwise.

B.1. Output and Price Deflator

Output, f_t and its price deflator p_t^f pertain to the non-financial corporate business (NFCB) sector. They originate from the NIPA accounts published by the BEA of the Department of Commerce.[11]

B.2. Investment, Capital, Depreciation and the Price of Investment

These are new data series on the non-financial corporate sector made available in 2001:Q1 by the BEA of the Department of Commerce. See Herman (2000)[12] for definitions.

The capital stock k_t series is measured as the sum of non-residential equipment, software and structures of the non-financial corporate sector. In 1998, for example, total private k was 18,643 billion dollars; total private non-residential k totalled 9,450 billion dollars; 6,402 billion dollars were non-financial corporate. Thus the latter was 34% of private k and 68% of the non-residential part.

B.2.1. Computations

Both k and i are reported at an annual frequency.

The Capital Stock We construct the quarterly capital stock data by interpolating the annual series according to the following formula:

$$\ln(k_{t+1,i}) = \ln(k_t) + \frac{i}{4}[\ln(k_{t+1}) - \ln(k_t)]$$

[11] See web page http://www.bea.doc.gov/bea/dn/st-tabs.htm

[12] See www.bea.doc.gov/bea/ARTICLES/NATIONAL/NIPAREL/2000/0400fxacdg.pdf

$i = 1, 2, 3, 4$, k_t denotes the capital stock at the end of year t and $k_{t+1,i}$ denotes the capital stock in the i-th quarter of year $t + 1$.

The Investment Flow We construct the quarterly investment series using the following three alternative interpolation schemes:

(i) distributing i according to the weights of the private sector investment series which is available quarterly

b) dividing i evenly to 4 quarters

c) taking the annual growth rate in logs, denoting it by g^a, defining $g = (1 + g^a)^{0.25} - 1$ and then computing

$i^1 = \frac{i}{1+g+g^2+g^3}$; $i^2 = i^1(1 + g)$; $i^3 = i^2(1 + g)$; $i^4 = i^3(1 + g)$

It turns out that there is little difference between these series. Thus in the tables we focus on the last measure.

The Rate of Depreciation We have two sets of measures:

(i) $\delta 1$ the depreciation series computed by the BEA; this is available in annual frequency and we convert it to quarterly using $\delta_t = (1 + \delta_t^a)^{0.25} - 1$

(ii) $\delta 2$ we solve for δ_t using the equation

$$\delta_t = \frac{i_t}{k_t} + 1 - \frac{k_{t+1}}{k_t}$$

and the three measures for i_t computed above

The Price of Investment In order to compute the real price of capital, p^I, we determine the price indices for output and for investment goods. The price index for output, p^f, equals the ratio of nominal to real GDP. Similarly, the price index for a particular type of investment good, PSE equals the ratio of nominal to real investment. We let τ denote the statutory corporate income tax rate, ITC the investment credit on equipment and public utility structures, $ZPDE$ the present discounted value of capital depreciation allowances, and χ the percentage of the cost of equipment that cannot be depreciated if the firm takes the investment tax credit. Furthermore, S denotes structures, Eq denotes equipment, and s_{Eq} denotes the fraction of equipment in business fixed investment.

The real price of business fixed capital, p^I, then equals

$$p^I = p^I_{Eq} \frac{(1-\tau\ ZPDE)}{1-\tau} s_{Eq} + p^I_S \frac{1-ITC-\tau ZPDE\,(1-\chi ITC)}{1-\tau}\,(1-s_{Eq})\,, \qquad \text{(B.1)}$$

where $p^I_{Eq} = PSE_{Eq}/p^f$, and $p^I_S = PSE_S/p^f$.

We use two methods of transforming annual values into quarterly values:

method A

$$\ln(PSE_{t+1,i}) = \ln(PSE_t) + \frac{i}{4}[\ln(PSE_{t+1}) - \ln(PSE_t)]$$

$i = 1, 2, 3, 4$, PSE_t denotes the price level at the end of year t and $PSE_{t+1,i}$ denotes the price level in the i-th quarter of year $t+1$.

method B

1) interpolate the annual i into quarterly using the growth method (method c above)

2) compute the quarterly PSE by dividing the nominal by the real

B.3. Employment, Matches and Separations

Employment We use two alternative measures of employment from Bureau of Labor Statistics Household Survey data.

One measure, covers wage and salary workers in non-agricultural industries less government workers less workers in private households less self-employed workers less unpaid family workers. We use this series in conjunction with the NFCB GDP f described above. The other measure is civilian employment used in conjunction with the employment inflow qv (see below).

Matches (qv) We use data on worker flows as computed by Bleakely et al (1999). These data are adjusted CPS data and pertain to flows to employment from unemployment and from out of the labor force to employment.

The separation rate Solving the employment dynamics equation

$$n_{t+1}^m = n_t^m(1-\psi^m) + (qv)^m$$

we get (in monthly terms):

$$\psi^m = \frac{(qv)^m}{n_t^m} + 1 - \frac{n_{t+1}^m}{n_t^m}$$

We then transform to quarterly:

$$\psi^Q = \psi^1 + (1-\psi^1)\psi^2 + (1-\psi^1)(1-\psi^2)\psi^3 \tag{B.2}$$

B.4. The Labor Share

For the labor share of income $\frac{wn}{f}$ we use the sum of wages and salaries as part of national income (from NIPA). This is deflated using the implicit price deflator for national income.

B.5. Asset Value Data

We use the market value of non-farm, non-financial business. The data are taken from Hall (2001)[13] based on the Fed Flow of Funds accounts and are defined as follows:

Source: Flow of Funds data and interest rate data from www.federalreserve.gov/releases. The data are for non-farm, non-financial business. Stock data were taken from ltabs.zip.[14]

[13]See http://www.stanford.edu/~rehall/Procedure.htm for a full description and http://www.stanford.edu/~rehall/page3.html

[14]Downloaded at http://www.federalreserve.gov/releases/z1/Current/data.htm.

Definition: The value of all securities is the sum of financial liabilities and equity less financial assets, adjusted for the difference between market and book values for bonds. The subcategories unidentified miscellaneous assets and liabilities were omitted from all of the calculations. These are residual values that do not correspond to any financial assets or liabilities.

B.6. Discount Rate and Discount Factor

We use three alternatives for the firms' discount rate r_t, which generates the discount factor given by $\beta_t = [1/(1+r_t)]$:

a. The main series used, following the weighted average cost of capital approach in corporate finance, is a weighted average of the returns to debt, r_t^b, and equity, r_t^e:

$$r_t = \omega r_t^b + (1-\omega) r_t^e, \tag{B.3}$$

with

$$r_t^b = (1-\tau_t) i_t^{CP} - \pi_t \tag{B.4}$$

$$r_t^e = \frac{\widetilde{cf}_t}{\widetilde{s}_t} + \widehat{\widetilde{s}}_t - \pi_t \tag{B.5}$$

where:

(i) ω is the share of debt finance. We set this share equal to 0.4, consistent with the data reported in Fama and French (1999).

(ii) The definition of r_t^b reflects the fact that nominal interest payments on debt are tax deductible. i_t^{CP} is Moody's seasoned Aaa commercial paper rate. The commercial paper rate for the first month of each quarter represents the entire quarter. The tax rate is τ as discussed above.

(iii) π_t denotes the GDP-deflator inflation of p^f discussed above.

(iv) For equity return we use the CRSP Value Weighted NYSE, Nasdaq and Amex nominal returns ($\frac{\widetilde{cf}_t}{\widetilde{s}_t} + \widehat{\widetilde{s}}_t$ in terms of the model, using tildes to indicate nominal variables) deflated by the same GDP-deflator inflation π.

We experiment with two other series to see their effect:

b. The rate of change of the SP500 index computed as follows:

$$r_t^Q = \frac{\left[\frac{S_3}{S_0}\frac{S_4}{S_1}\frac{S_5}{S_2}\right]^{\frac{1}{3}}}{1+\pi} - 1$$

where S_j is the level of the stock index at the end of month j, the current quarter has months 4 and 5, the preceding quarter has months $1, 2, 3$ and the quarter preceding that has month 0.

c. Non-durable consumption growth, which corresponds to the discount rate in a DSGE model with log utility. If utility is given by:

$$U(c_t) = \ln c_t$$

Then in general equilibrium:

$$\begin{aligned} U'(c_t) &= U'(c_{t+1})\,(1 + r_{t,t+1}) \\ \frac{1}{1+r_{t,t+1}} &= \frac{U'(c_{t+1})}{U'(c_t)} \\ \frac{1}{1+r_{t,t+1}} &= \frac{c_t}{c_{t+1}} \end{aligned}$$

Hence:

$$r_{t,t+1} = \frac{c_{t+1}}{c_t} - 1$$

Table 1

Data Summary Statistics

quarterly

	76:1-97:4	n=88
variable	mean	std.
$\frac{i}{k}$	0.025	0.002
p^I	1.29	0.07
τ	0.41	0.06
δ	0.018	0.001
$\frac{qv}{n}$	0.089	0.008
$\frac{wn}{f}$	0.648	0.010
ψ	0.085	0.008
$\frac{s}{f}$	5.3	1.4
r (bonds+equity)	0.023	0.045
r (sp500)	0.013	0.049
r (consumption)	0.006	0.006

Note:

For data definitions see Appendix B.

Table 2

GMM Estimates of F1, F2 and the Asset Pricing Equation

alternative specifications, 1976-1997, $n = 88$.

	1	2	3	4	5	6
$\{\eta_1, \eta_2, \eta_3\}$	free	η_1, η_2 free	η_2 free	{3,2,2}	$\eta_1 = 2$	{2,2,1}
η_1	3.06 (0.14)	3.07 (0.07)	$\eta_2 + 1$	3 imposed	2 imposed	2 imposed
η_2	2.01 (0.02)	2.01 (0.01)	1.99 (0.01)	2 imposed	–	2 imposed
η_3	1.95 (0.18)	η_2	η_2	2 imposed	–	1 imposed
g_1	27,071 (25,580)	27,936 (13,767)	18,427 (750)	6,679 (583)	57 (2)	917 (33)
g_2	37 (13)	54 (5)	53 (5)	16 (2)	0 imposed	52 (2)
g_3	-67,921 (38,271)	-71, 829 (16, 029)	-55,769 (7,680)	-18,260 (2,156)	0 imposed	-229 (9)
α	0.69 (0.06)	0.74 (0.03)	0.78 (0.03)	0.69 (0.01)	0.66 (0.001)	0.63 (0.01)
J-Statistic	53.1	52.2	57.5	54.8	61.2	50.0
p-Value	0.02	0.03	0.01	0.03	0.01	0.08
$\rho_{\frac{i}{k}}(fitted, actual)$	0.62	0.59	0.57	0.44	0.23	0.91
$\rho_{\frac{qv}{n}}(fitted, actual)$	0.03	0.17	0.53	0.57	–	0.84
$\rho_{\frac{s}{f}}(fitted, actual)$	0.77	0.78	0.77	0.58	-0.05	0.67
$\frac{var \frac{s}{f} \text{fitted}}{var \frac{s}{f} \text{actual}}$	1.13	1.13	0.85	0.12	0.05	0.76

Notes:

1. Standard errors are given in parantheses.

2. Instruments used are a constant and in F1 2 lags of $\{\frac{i}{k}, p^I, \tau, \frac{f}{k}, \beta, \frac{s}{f}\}$, in F2 2 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \tau, \beta, \frac{s}{f}\}$, and in the asset pricing equation 2 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \frac{i}{k}, p^I, \tau, \frac{f}{k}, \beta, \frac{s}{f}\}$.

Table 3

Calibration Results

	1	2	3	4	5	6
g_1	18,000	20,104	17,424	14,700	18,500	19,500
g_2	59	55	42	39	44	53
g_3	-50,000	-56,453	-46,564	-36,700	-47,700	-53000
$\rho \frac{i}{k}(fitted, actual)$	0.63	0.63	0.59	0.61	0.63	0.60
$\rho \frac{qv}{n}(fitted, actual)$	0.70	0.52	0.39	0.64	0.44	0.57
$\rho \frac{s}{f}(fitted, actual)$	0.76	0.81	0.81	0.81	0.81	0.81
$\frac{var \frac{s}{f} \text{fitted}}{var \frac{s}{f} \text{actual}}$	0.83	0.97	0.71	0.50	0.79	0.89

Table 4

GMM Estimates of F1, F2 and the Asset Pricing Equation

Alternative specifications with η_2 free

	1	2	3	4	5	6
η_2	1.99	1.99	2.00	2.06	2.00	2.02
	(0.01)	(0.01)	(0.02)	(0.00)	(0.17)	(0.04)
g_1	18,427	12,580	11,889	25,428	19,800	11,232
	(750)	(407)	(594)	(962)	(13,158)	(931)
g_2	53	30	36	58	44	25
	(5)	(1)	(2)	(4)	(15)	(3)
g_3	-55,769	-36,559	-36,988	-90,768	-35,700	-36,593
	(7,680)	(3,066)	(6,142)	(5,812)	(63,742)	(12,559)
α	0.78	0.74	0.74	0.78	0.68	0.68
	(0.03)	(0.00)	(0.00)	(0.02)	(0.02)	(0.01)
J-Statistic	57.5	74.9	62.3	53.7	79.6	53.1
p-Value	0.01	0.32	0.08	0.03	0.00	0.03
$\rho\frac{i}{k}(fitted, actual)$	0.57	0.58	0.54	0.48	0.75	0.16
$\rho\frac{qv}{n}(fitted, actual)$	0.53	0.35	0.59	0.32	0.67	0.25
$\rho\frac{s}{f}(fitted, actual)$	0.77	0.75	0.74	0.78	0.68	0.79
$\frac{var\frac{s}{f}\text{fitted}}{var\frac{s}{f}\text{actual}}$	0.85	0.37	0.33	1.05	0.71	0.28

Notes:

1. Column 1 repeats column 3 from Table 2. It uses the following instrument sets (a constant is always included too). F1 2 lags of $\{\frac{i}{k}, p^I, \tau, \frac{f}{k}, \beta, \frac{s}{f}\}$, in F2 2 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \tau, \beta, \frac{s}{f}\}$, and in the asset pricing equation 2 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \frac{i}{k}, p^I, \tau, \frac{f}{k}, \beta, \frac{s}{f}\}$.

2. Column 2 is the same as column 1 but increasing the number of lags in the instrument

set to 4.

3. Column 3 uses the following instrument sets (a constant is always included too). F1 4 lags of $\{\frac{i}{k}, p^I, \tau, \frac{f}{k}\}$, in F2 4 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \tau\}$, and in the asset pricing equation 4 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \frac{i}{k}, p^I, \tau, \frac{f}{k}, \frac{s}{f}\}$.

4. Column 4 uses fixed rates of depreciation and separation equal to the sample means ($\delta = 0.018$ and $\psi = 0.08$).

5. Column 5 uses a discount factor β based on the SP500 rate of change (see Appendix B).

6. Column 6 uses a discount factor β based on on the growth rate of non-durable consumption (see Appendix B).

Table 5

Sample Moments of Marginal Hiring and Investment Costs

a. Gross Hiring

	specification	GMM	calibration
		Table 2 Column 3	Table 3 column 1
	net marginal hiring costs	1.65	2.55
(1)	$\frac{\partial g/\partial v}{f/n} = \left[g_2(\frac{q_t v_t}{n_t})^{\eta_2 - 1} + g_3(\frac{i_t}{k_t}\frac{q_t v_t}{n_t})^{\eta_{3-1}}\frac{i_t}{k_t}\right]$	(0.49)	(0.49)
(2)	gross marginal hiring costs	4.76	5.24
	$g_2(\frac{q_t v_t}{n_t})^{\eta_2 - 1}$	(0.41)	(0.47)
(3)	interaction labor-capital	-3.12	-2.70
	$g_3(\frac{i_t}{k_t}\frac{q_t v_t}{n_t})^{\eta_{3-1}}\frac{i_t}{k_t}$	(0.44)	(0.38)

b. Investment

	specification	GMM	calibration
		Table 2 Column 3	Table 3 column 1
(1)	marginal capital adjustment+purchase costs	7.69	8.72
	$\frac{p^I}{f/k} + \frac{\partial g/\partial i}{f/k} = \left[\frac{p_t^I}{\frac{f_t}{k_t}} + \left[g_1(\frac{i_t}{k_t})^{\eta_1 - 1} + g_3(\frac{i_t}{k_t}\frac{q_t v_t}{n_t})^{\eta_3 - 1}\frac{q_t v_t}{n_t} \right] \right]$	(1.87)	(1.67)
(2)	$\frac{p_t^I}{\frac{f_t}{k_t}}$	7.52	7.52
		(0.82)	(0.82)
(3)	gross marginal adjustment costs	11.50	10.97
	$g_1(\frac{i_t}{k_t})^{\eta_1 - 1}$	(1.63)	(2.20)
(4)	interaction capital-labor	-11.33	-9.76
	$g_3(\frac{i_t q_t v_t}{k_t n_t})^{\eta_3 - 1}\frac{q_t v_t}{n_t}$	(1.93)	(1.67)
(3) + (4)	net marginal adjustment costs $\left[g_1(\frac{i_t}{k_t})^{\eta_1 - 1} + g_3(\frac{i_t}{k_t}\frac{q_t v_t}{n_t})^{\eta_3 - 1}\frac{q_t v_t}{n_t} \right]$	0.17	1.20
	before tax $Q_t^K = (g_{i_t} + p_t^I)$	1.34	1.52
		(0.38)	(0.35)

Notes:

The table reports sample means with standard deviations in parantheses.

Table 6

Estimates of Marginal Adjustment Costs for Capital

Summary of studies for the U.S. economy

study	sample	mean $\frac{i}{k}$	mean g_i
Summers (1981)	BEA, 1932-1978	0.13	$2.5 - 60.5$
Hayashi (1982)	corporate sector, 1953-1976	0.14	3.2
Shapiro (1986)	Manufacturing, 1955-1980	0.08	0.43
Hubbard, Kayshap and Whited (1995)	Compustat, 1976-1987	$0.20 - 0.23$	$0.15 - 0.45$
Gilchrist and Himmelberg (1995)	Compustat, 1985-1989	$0.17 - 0.18$	$0.50 - 0.98$
Gilchrist and Himmelberg (1998)	Compustat, 1980-1993	0.23	$0.15 - 0.21$
	split sample		$0.13 - 1.1$
Barnett and Sakellaris (1999)	Compustat, 1960-1987	0.20	0.27
Cooper and Haltiwanger (2002)	LRD panel, 1972-1988	0.12	$0.04, 0.26$
Hall (2002)	35 industry panel, 1959-1999	0.10(?)	0.15
Abel and Eberly (2002)	Compustat 1974-1993	0.15	$1.2 - 22.9$

Notes:

1. Investment rates $\frac{i}{k}$ are expressed in annual terms.

2. All studies pertain to annual data except Shapiro (1986) which is based on quarterly data.

Table 7

Implications of the Estimates for Investment and Hiring Rates

a. Investment Rates

specification	GMM	calibration	GMM, smoothed	GMM, quadratic
	Table 2 Col. 3	Table 3 Col. 1	smoothed Table 2 Col. 3	Table 2 Col. 5
$\rho(\frac{i_t}{k_t}, \widetilde{\frac{i_t}{k_t}})$	0.57	0.65	0.58	0.23
$\rho(\frac{i_t}{k_t}, \widetilde{\frac{i_{t+j}}{k_{t+j}}})$	$0.63(j=1)$	$0.66(j=1)$	$0.73(j=4)$	$0.28(j=-2)$
$\frac{\text{mean fitted}}{\text{mean actual}}$	0.999	0.995	0.998	1.026
$\frac{\text{variance fitted}}{\text{variance actual}}$	2.4	2.2	1.3	19.7
$\rho(\widetilde{\frac{i_t}{k_t}}, \widetilde{\frac{i_{t-1}}{k_{t-1}}})$	0.28	0.37	0.88	0.12

Notes:

1. Fitted values are denoted by tildes.
2. The actual autocorrelation is given by $\rho(\frac{i_t}{k_t}, \frac{i_{t-1}}{k_{t-1}}) = 0.92$

b. Hiring Rates

specification	GMM	Calibration	GMM, smoothed
	Table 2 Col. 3	Table 3 Col. 1	smoothed Table 2 Col. 3
$\rho(\frac{qv_t}{n_t}, \widetilde{\frac{qv_t}{n_t}})$	0.53	0.71	0.70
$\rho(\frac{qv_t}{n_t}, \widetilde{\frac{qv_{t+j}}{n_{t+j}}})$	$0.59(j=1)$	$0.77(j=1)$	$0.70(j=0)$
$\frac{\text{mean fitted}}{\text{mean actual}}$	1.048	1.06	1.044
$\frac{\text{variance fitted}}{\text{variance actual}}$	1.8	1.3	1.2
$\rho(\widetilde{\frac{qv_t}{n_t}}, \widetilde{\frac{qv_{t-1}}{n_{t-1}}})$	0.45	0.60	0.92

Notes:

1. Fitted values are denoted by tildes.
2. The actual autocorrelation is given by $\rho(\frac{qv_t}{n_t}, \frac{qv_{t-1}}{n_{t-1}}) = 0.89$

c. Co-movement of Investment and Hiring Rates

specification	GMM	calibration	GMM, smoothed
	Table 2 Col. 3	Table 3 Col. 1	smoothed Table 2 Col. 3
$\rho(\widetilde{\frac{qv_t}{n_t}}, \widetilde{\frac{i_t}{k_t}})$	−0.24	−0.21	−0.13

Note:

1. Fitted values are denoted by tildes.
2. The actual correlation is given by $\rho(\frac{qv_t}{n_t}, \frac{i_t}{k_t}) = -0.27$.

Table 8

Implications of Estimates for Asset Values $\frac{s}{f}$

a. Fit

specification	GMM	calibration
	Table 2 Column 3	Table 3 column 1
correlation fitted, actual	0.77	0.76
$\frac{\text{mean fitted}}{\text{mean actual}}$	1.14	1.31
$\frac{\text{variance fitted}}{\text{variance actual}}$	0.85	0.83

b. Decomposition of the Mean Fitted Series

specification	GMM	calibration
	Table 2 Column 3	Table 3 column 1
fitted total	5.65	6.93
share of $\frac{s_t^1}{f_t}$	79%	65%
share of $\frac{s_t^2}{f_t}$	4%	14%
share of $\frac{s_t^3}{f_t}$	17%	21%

c. Variance-Covaraince Decomposition of the Fitted Series

GMM: Table 2 Column 3

	$\frac{s_t^1}{f_t}$	$\frac{s_t^2}{f_t}$	$\frac{s_t^3}{f_t}$
$\frac{s_t^1}{f_t}$	0.06	−0.10	0.04
$\frac{s_t^2}{f_t}$	−0.10	1.34	−0.16
$\frac{s_t^3}{f_t}$	0.04	−0.16	0.06

Calibration: Table 3 column 1

	$\frac{s_t^1}{f_t}$	$\frac{s_t^2}{f_t}$	$\frac{s_t^3}{f_t}$
$\frac{s_t^1}{f_t}$	0.06	−0.10	0.04
$\frac{s_t^2}{f_t}$	−0.10	1.33	−0.17
$\frac{s_t^3}{f_t}$	0.04	−0.17	0.06

Notes:

The tables use the following definitions:

$$\frac{s_t^1}{f_t} = \frac{f_{t+1}}{f_t}\beta_{t+1}(1-\tau_{t+1})\left[(1-\alpha)+(1-\delta_{t+1})\frac{p_{t+1}^I}{\frac{f_{t+1}}{k_{t+1}}}\right]$$

$$\frac{s_t^2}{f_t} = \frac{f_{t+1}}{f_t}\beta_{t+1}(1-\tau_{t+1})\left[-\frac{g_{k_{t+1}}}{\frac{f_{t+1}}{k_{t+1}}}+(1-\delta_{t+1})\frac{g_{i_{t+1}}}{\frac{f_{t+1}}{k_{t+1}}}\right]$$

$$\frac{s_t^3}{f_t} = \frac{f_{t+1}}{f_t}\beta_{t+1}(1-\tau_{t+1})\left(\alpha-\frac{w_{t+1}n_{t+1}}{f_{t+1}}-\frac{g_{n_{t+1}}}{\frac{f_{t+1}}{n_{t+1}}}+\frac{(1-\psi_{t+1})g_{v_{t+1}}}{q_{t+1}\frac{f_{t+1}}{n_{t+1}}}\right)$$

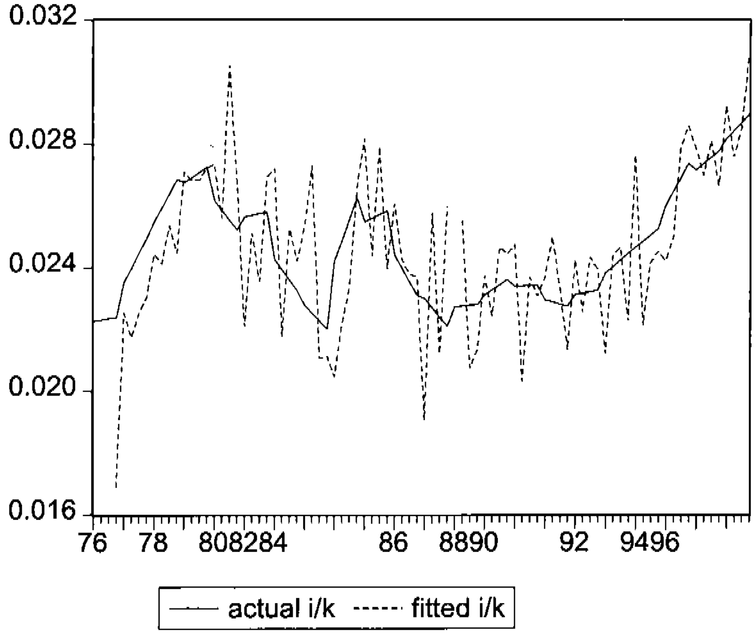

Figure 1a: Actual and fitted (Table 3 col 1) investment rate $\frac{i}{k}$

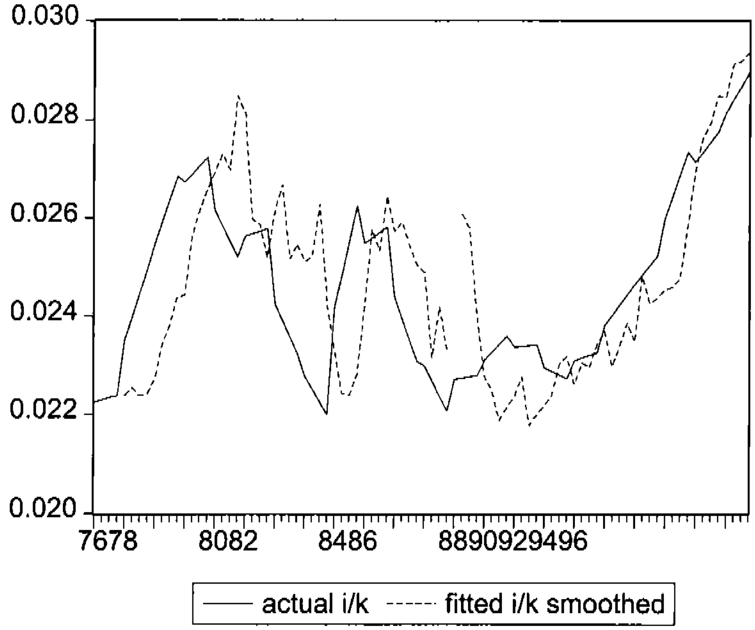

Figure 1b: Actual and fitted (Table 2 col 3, smoothed) investment rate $\frac{i}{k}$

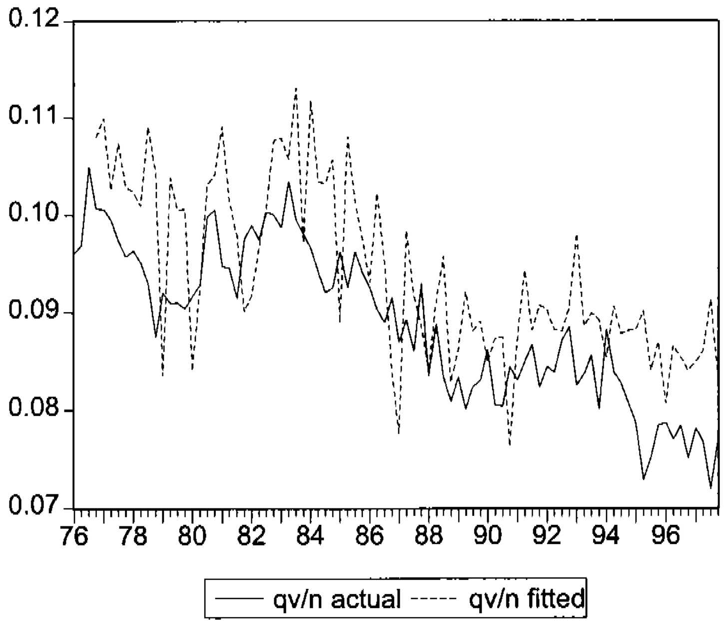

Figure 1c: Actual and fitted (Tabel 3 col 1) hiring rates $\frac{qv}{n}$

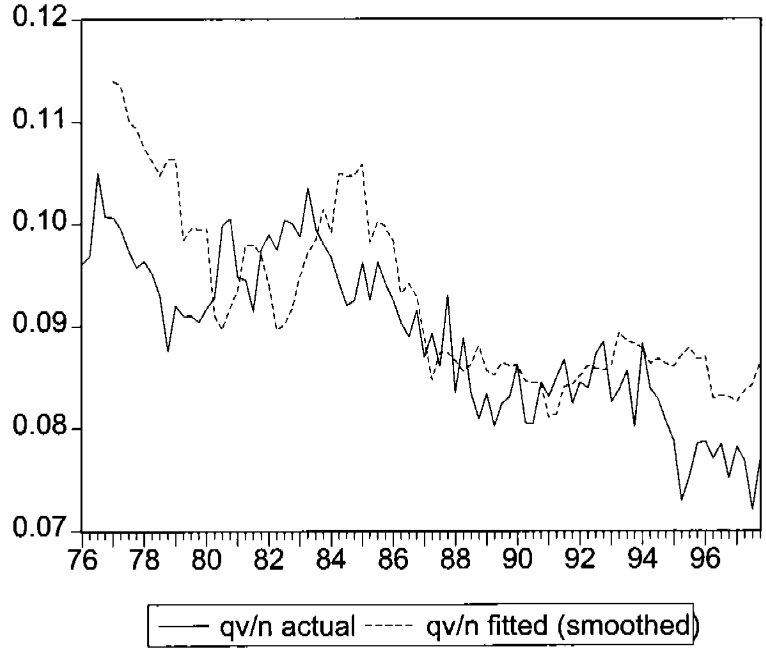

Figure 1d: Actual and fitted (Table 2 col 3, smoothed) hiring rates $\frac{qv}{n}$

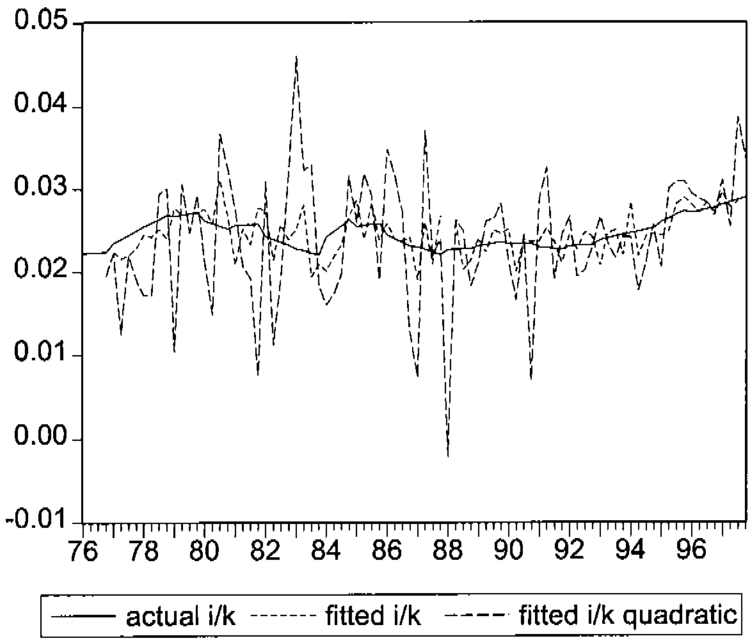

Figure 1e: Actual and two fitted investment rates $\frac{i}{k}$

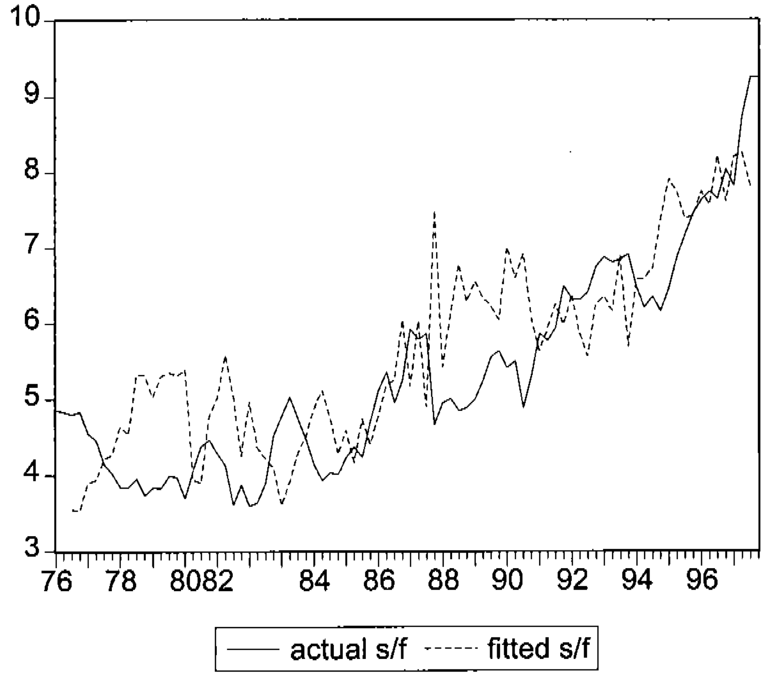

Figure 2a: Actual and fitted asset values $\frac{s}{f}$

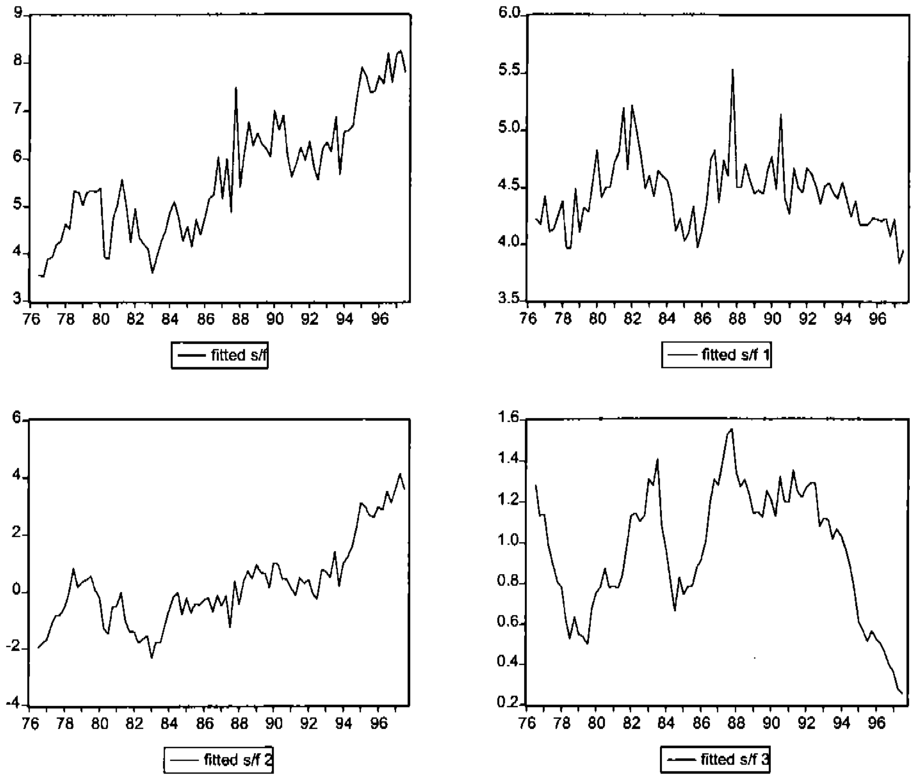

Figure 2b: Fitted asset value decomposition