Labor Market Frictions, Capital Adjustment Costs and Stock Prices

Preliminary

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Abstract

The aim of this paper is twofold: to explain the joint behavior of hiring and investment and to explore the links between the latter and the behavior of stock prices. The model includes labor market frictions and capital adjustment costs as key ingredients and the connection between the asset value of the firm-worker match and the asset value of the firm as a key relationship. The model's quantitative implications are explored using structural estimation and calibration, employing aggregate time-series data for the U.S. economy. The results provide for (i) better understanding of the stochastic behavior of investment and stock prices and the relations between them, and (ii) the formulation and quantification of the linkages between labor market variables and both investment (in physical capital) and stock prices. One of these relations models market value as a fraction of GDP as a function of GDP growth, the discount rate, the corporate tax rate, and (convex functions of) the investment rate and the hiring rate.

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The paper connects three strands of literature: the search and matching model of the labor market, the Q-theory of investment, and production-based asset pricing. It provides a possible explanation for the previous empirical failure of Q models, demonstrates the usefulness of the Q approach when labor market frictions are embedded in the model, and lends substantive new support to the production-based model.

Key words: investment, hiring, stock prices, q-theory, search and matching, 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. economy. The estimates yield time series of capital adjustment costs and firms' search costs as well as predicted investment rates, hiring rates, and stock prices. A calibration exercise then reinforces the validity of estimation.

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 investment patterns. Third, while the idea that labor market frictions may be useful to enhance our understanding of cyclical fluctuations is gaining acceptance, little empirical work has been undertaken to quantify their effects, particularly in conjunction with capital adjustment costs. The results of the empirical work reported here produce the following contributions: better understanding of the stochastic behavior of investment and stock prices (and the relations between them), and the formulation and quantification of the relationships between labor market variables and both investment (in physical capital) and stock prices. One of these

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relations formulates market value as a fraction of GDP as a function of GDP growth, discount rates, the corporate tax rate, and convex functions of the investment rate and the hiring rate.

The 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 worker in the rent is the wage. 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. The latter is also made up of the value of capital and of the value of the technology for adjusting the stock of capital. Hence, fluctuations in labor market frictions engender fluctuations in rents, in the asset value of matches and consequently in firm values. The paper studies the role played by labor market frictions and the associated rents in the behavior of firm asset values.

The innovation of this approach is to allow for the labor market frictions and their interaction with capital adjustment costs to be a determinant of stock prices and to use labor market data in conjunction with stock market and physical capital data to examine this idea empirically. The data set used has some distinctive features: it makes use of gross worker flow data; physical investment and capital data 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 functions and structural estimation allow for a more general framework than the quadratic cost formulation that is prevalent in the literature.

The main 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. 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 estimation methodology. Section 5 presents the results, discussing alternative specifications. Section 6 derives the results' implications with respect to hiring and investment behavior and Section 7 does so with respect to asset prices. Section 8 concludes. Technical derivations and data definitions are elaborated in appendices.

2. Related Literature

As noted, the paper refers to several strands of literature. In this section we 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 [see Mortensen and Pissarides (1999) for a recent survey] centers around the idea that trade frictions exist in the labor market. 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; following Diamond (1982), 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) which quantified and validated 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 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. The relationship between investment and Q is a first-order condition equating the marginal cost of investment, including costs of adjustment, with the appropriate shadow price Q (of installed capital) . Hayashi (1982) presented conditions under which the appropriate but unobservable shadow price of capital, sometimes known as marginal Q, is identically equal to Tobin's Q, the ratio of the market value of a firm's capital stock to its replacement value, which is observable and is sometimes known as average Q. This demonstration justified the use of securities market valuation of an entire firm for the purpose of assessing the marginal valuation 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, however, the model has been partially rehabilitated using several modifications: Cochrane (1991, 1996) and Lettau and Ludvigson (2002) have shown that it can account for the behavior of asset prices, provided time-varying discount rates are applied to future streams; Erickson and Whited (2000) have shown that the model works well if measurement error in firms' value is properly accounted for; Cooper and Haltwianger (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; Christiano and Fisher (1998) show that when used as a component of a DGSE model it accounts relatively well for moments that connect the stock market and the business cycle.

The current paper uses the Q framework with a number of essential modifications. First, it allows for the interaction of capital adjustment costs with firms' search and 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) 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

[2] 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, while in Shapiro (and other work) they pertain to net costs and relate to changes in the employment stock; (ii) the current paper uses the asset values of firms in estimation while no such restriction 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.

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 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.

Lettau and Ludvigson (2002) consider the relationships between discount rates, stock prices, stock returns and investment returns. The authors propose the following logic: if expected stock returns fall, then the dividend price ratio falls; this implies that the future growth rate of Q falls; as investment is positively dependent on Q, future investment growth falls. Hence there is a positive co-variance between future investment growth and expected returns. The paper then examines the ability of predictor variables of expected stock returns to predict future investment growth. Their main finding is that a good predictor variable is the log consumption-wealth ratio.

The current paper lends much stronger support to this view. The literature has assumed, rather than estimated, particular adjustment cost processes and examined reduced form relationships. 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.

2.4. Asset Values and Intangible Capital

A number of recent papers claimed that asset values (and in particular stock prices) reflect not only the value of physical capital but also the value of intangible capital. Hall (2000, 2001a,b) uses a Q-model and finds that a large amount of intangible capital has been formed in the U.S. in the post-war period, particularly in the 1990s. This capital, labeled 'e-capital,' is the firm's body of technical knowledge and organizational know-how. Hall's calculations are based on a model of calibrated, asymmetric quadratic adjustment costs. Fed Flow of Funds data are used to build a series of firms' value in the non-farm, non-financial U.S. corporate sector. Intangible capital is the difference between firms' value and the value accounted for by physical capital. In the 1960s, and more so in the 1990s, it is found to have had positive value. The current paper shows to what extent asset values can be accounted for by tangible capital and by labor. Hence what is left unexplained may potentially correspond to any intangible capital.[3]

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.[4]

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:

$$M_t = \mu U_t^{\lambda} V_t^{1-\lambda},\ 0 \leq \lambda \leq 1,\ M_t \leq \min\left(U_t, V_t\right), \tag{3.1}$$

where μ is the matching technology parameter. 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. The

[3]Related contributions by McGrattan and Prescott (2000) and Atkeson and Kehoe (2002) use other ways to compute the value of intangible capital, not dependent upon the valuation of the contribution of adjustment costs.

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

matching probability for a given vacancy, q, or for an unemployed worker, p, respectively, depends on the degree of labor market tightness θ—the ratio of job-vacancies to total unemployment:

$$\begin{aligned} p_t &= \frac{M_t}{U_t} = \mu\theta_t^{1-\lambda}, \\ q_t &= \frac{M_t}{V_t} = \mu\theta_t^{-\lambda}. \end{aligned} \tag{3.2}$$

With an increase in job-vacancies, the matching probability for unemployed workers rises while that for vacancies declines. The opposite is true when the total number of unemployed workers increases. 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. Firms

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. 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 input in order to produce output goods y according to a constant-returns-to-scale production function f:

$$y_t = f(n_t, k_t), \tag{3.3}$$

Investment and hiring 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 labor 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:

$$k_{t+1} = (1 - \delta_t)k_t + i_t, \quad 0 \leq \delta_t \leq 1. \tag{3.4}$$

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

$$n_{t+1} = (1 - \psi_t)n_t + q_t v_t, \quad 0 \leq \psi_t \leq 1. \tag{3.5}$$

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

$$\pi_t = [f(n_t, k_t) - g(i_t, k_t, q_t v_t, n_t)] - w_t n_t \,. \tag{3.6}$$

By assumption, firms finance new investment projects through retained earnings. Every period, firms make unlevered 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:

$$cf_t = (1 - \tau_t)\pi_t - (1 - \chi_t - \tau_t D_t)\, \widetilde{p}_t^I\, i_t \,, \tag{3.7}$$

where τ is the corporate income tax rate, χ the investment tax credit, D the present discounted value of capital depreciation allowances, and $\widetilde{p}^I$ 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:

$$s_t = E_t\left[\beta_{t+1}\left(s_{t+1} + cf_{t+1}\right)\right], \tag{3.8}$$

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 weighted average cost of capital between periods $t + j - 1$ and $t + j$. Appendix B contains a detailed description of how the weighted average cost of capital

r is 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.

$$s_t = E_t \left\{ \sum_{j=1}^{\infty} \left(\prod_{i=1}^{j} \beta_{t+i} \right) cf_{t+j} \right\} \tag{3.9}$$

The representative firm chooses sequences of k_{t+1}, i_t, n_{t+1} and v_t in order to maximize its *cum dividend* market value $cf_t + s_t$:

$$\max_{\{k_{t+1+j}, i_{t+j}, n_{t+1+j}, v_{t+j}\}} E_t \left\{ \sum_{j=0}^{\infty} \left(\prod_{i=0}^{j} \beta_{t+i} \right) cf_{t+j} \right\} \tag{3.10}$$

subject to the definition of cf_{t+j} in equation (3.7) and the following constraints:

$$\begin{aligned} k_{t+1+j} &= (1 - \delta_{t+j}) k_{t+j} + i_{t+j} \\ n_{t+1+j} &= (1 - \psi_{t+j}) n_{t+j} + q_{t+j} v_{t+j} \end{aligned} \tag{3.11}$$

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 real after-tax price of investment goods equals

$$p^I_{t+j} = \frac{1 - \chi_{t+j} - \tau_{t+j} D_{t+j}}{1 - \tau_{t+j}} \widetilde{p}^I_{t+j}. \tag{3.12}$$

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:

$$Q^K_t = E_t \beta_{t+1} \left\{ (1 - \tau_{t+1}) \left[f_{k_{t+1}} - g_{k_{t+1}} \right] + Q^K_{t+1} (1 - \delta_{t+1}) \right\} \tag{3.13}$$

$$Q^K_t = (1 - \tau_t) \left(g_{i_t} + p^I_t \right) \tag{3.14}$$

$$Q^N_t = E_t \beta_{t+1} \left\{ (1 - \tau_{t+1}) \left[f_{n_{t+1}} - g_{n_{t+1}} - w_{t+1} \right] + \left(1 - \psi_{t+1} \right) Q^N_{t+1} \right\} \tag{3.15}$$

$$Q^N_t = (1 - \tau_t) \frac{g_{v_t}}{q_t} \tag{3.16}$$

Dynamic optimality requires the following two transversality conditions to be fulfilled

$$\begin{aligned} \lim_{T\to\infty} \beta_T \, Q_T^K \, k_{T+1} &= 0 \\ \lim_{T\to\infty} \beta_T \, Q_T^N \, n_{T+1} &= 0. \end{aligned} \tag{3.17}$$

We can summarize the firm's first-order necessary conditions from equations (3.13)-(3.16) by the following two expressions:

$$\begin{aligned} F1 &: (1-\tau_t)\left(g_{i_t} + p_t^I\right) = E_t\beta_{t+1}(1-\tau_{t+1})\left[f_{k_{t+1}} - g_{k_{t+1}} + (1-\delta_{t+1})(g_{i_{t+1}} + p_{t+1}^I)\right] \\ F2 &: (1-\tau_t)\frac{g_{v_t}}{q_t} = E_t\beta_{t+1}(1-\tau_{t+1})\left[f_{n_{t+1}} - g_{n_{t+1}} - w_{t+1} + (1-\psi_{t+1})\frac{g_{v_{t+1}}}{q_{t+1}}\right]. \end{aligned}$$

Solving equation (3.13) 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:

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

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 (3.15) 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:

$$Q_t^N = E_t\left\{\sum_{j=0}^{\infty}\left(\prod_{i=0}^{j}\beta_{t+1+i}\right)\left(\prod_{i=0}^{j}(1-\psi_{t+1+i})\right)(1-\tau_{t+1+j})\left(f_{n_{t+1+j}} - g_{n_{t+1+j}} - w_{t+1+j}\right)\right\}. \tag{3.19}$$

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

Given that adjusting investment and vacancies is 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 vacancy-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

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

A simple rearrangement yields

$$\frac{i}{k} = (g_i)^{-1}\left(\frac{f_k - g_k - p^I(r+\delta)}{r+\delta}\right) \equiv I\left(Q^K - 1\right), \tag{3.21}$$

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 (3.21) states that the investment-to-capital ratio increases with an increase in the difference between the marginal product of capital net of capital adjustment costs and the effective cost of capital. Q^K equals one if the marginal adjustment costs of capital are 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 vacancy-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:

$$\frac{g_v\left(\frac{v}{n}\right)}{q}(r+\psi) = f_n - g_n - w. \tag{3.22}$$

Rearranging this equation yields

$$\frac{v}{n} = (g_v)^{-1}\left[\frac{f_n - g_n - w}{r+\psi}q\right] \equiv H\left[\left(Q^N - 1\right)q\right], \tag{3.23}$$

where $Q^N = [f_n - g_n - (w - r - \psi)] / (r + \psi)$, and $H' \left[\left(Q^N - 1 \right) q \right] > 0$. According to equation (3.23), labor demand relative to the level of employment co-varies positively with the difference between the marginal product of labor net of employment adjustment costs and the labor compensation rate. Labor demand also co-varies positively with the probability of a vacancy leading to a new job-match, q. Q^N equals one if the marginal adjustment costs of employment are zero and labor is paid its marginal product.

3.4. Wage Determination Scheme

Once an unemployed agent is matched with a vacancy, the agent and the firm decide upon the time path for the agent's wage. In each period for which the match remains in existence, the wage is assumed to be determined by the Nash bargaining solution. Hiring an additional worker generates a surplus for the firm $\left\{ \left[f_{n_t} - g_{n_t} + (1 - \psi_t) \frac{g_h h_{v_t}}{q_t} \right] (1 - \tau_t) - w_t \right\}$. The expression $f_{n_t} - g_{n_t}$ denotes the increase in the marginal product of labor net of employment adjustment costs, and $(1 - \psi_t) \frac{g_h h_{v_t}}{q_t}$ captures further hiring costs saved because of the match-creation. Finally, w_t denotes the period t wage which the firm pays the worker. The worker's period t surplus from entering the job-match equals $(w_t - b_t)$. The worker earns the wage w_t and forgoes unemployment income b_t (benefits plus any non-pecuniary income) when making the transition from unemployment to employment. Hence, the Nash bargaining solution for the wage rate w_t solves

$$w_t = \arg\max_{w_t} \left(\left[f_{n_t} - g_{n_t} + (1 - \psi_t) \frac{g_{v_t}}{q_t} \right] (1 - \tau_t) - w_t \right)^{\phi} (w_t - b_t)^{1-\phi} \tag{3.24}$$

where the parameter $\phi \in (0, 1)$ is the firm's bargaining weight.

The first-order necessary condition corresponding to the Nash bargaining problem implies the following optimal wage rate w_t:

$$w_t = (1 - \phi) \left(f_{n_t} - g_{n_t} + p_t \frac{g_{v_t}}{q_t} \right) (1 - \tau_t) + \phi b_t. \tag{3.25}$$

3.5. Implications For Asset Values

We use standard asset-pricing theory when deriving 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 (3.8), the firm's period t market value is defined as the expected discounted *pre-dividend* market value of the following period:

$$s_t = E_t \left[\beta_{t+1} \left(s_{t+1} + cf_{t+1} \right) \right]. \tag{3.26}$$

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

$$s_t = \vartheta_t^k + \vartheta_t^n = E_t \left[\beta_{t+1} \left(\vartheta_{t+1}^k + cf_{t+1}^k \right) \right] + E_t \left[\beta_{t+1} \left(\vartheta_{t+1}^n + cf_{t+1}^n \right) \right], \tag{3.27}$$

where

$$cf_t = (1 - \tau_t) \left[f(n_t, k_t) - g\left[i_t, k_t, h(v_t, q_t v_t), n_t \right] - w_t n_t - p_t^I i_t \right]. \tag{3.28}$$

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

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

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):

$$s_t = \vartheta_t^k + \vartheta_t^n = k_{t+1} Q_t^K + n_{t+1} Q_t^N. \tag{3.29}$$

where Q_t^K and Q_t^N are defined in equations (3.18) and (3.19), respectively.

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

$$\begin{aligned} s_t &= k_{t+1}E_t\left[\beta_{t+1}\left(1-\tau_{t+1}\right)\left[f_{k_{t+1}}-g_{k_{t+1}}+(1-\delta_{t+1})(p^I_{t+1}+g_{i_{t+1}})\right]\right] \\ &\quad +n_{t+1}E_t\left[\beta_{t+1}\left(1-\tau_{t+1}\right)\left(f_{n_{t+1}}-g_{n_{t+1}}-w_{t+1}+\frac{(1-\psi_{t+1})g_{v_{t+1}}}{q_{t+1}}\right)\right] \end{aligned} \tag{3.30}$$

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 hiring and investment behavior jointly and to relate this behavior to the asset value of the firm. We begin by presenting the methodology and delineating the key relations to be studied empirically. We then discuss the data and the alternative specifications used in the empirical work.

4.1. Methodology

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

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

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}.

We structurally estimate stationary versions of the firms' first-order necessary conditions summarized in equations $(F1)$ and $(F2)$, and the asset pricing equation (3.30) 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. $E(j \otimes Z) = 0$. As a further check on the validity of estimation , we compare the estimates to the results of a calibration exercise. The latter uses reasonable values of total and marginal adjustment costs to derive the parameters and study the performance of the equations. We further elaborate below.

4.2. The Data

Our data sample is quarterly, private sector data for the U.S. economy in the period 1976:1-1997:4. We also experiment with a larger set, beginning in 1968:1, but that entails the cost of some inaccuracy involved in chaining two series for worker flows. In what follows we briefly describe the data; 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] For employment (n) we use two alternative employment CPS measures. For worker flows (qv) we use adjusted CPS data as computed by Bleakely et al (1999). As an alternative we look at a longer series which is obtained by chaining the latter series to another adjusted CPS series computed by Blanchard and Diamond (1989). We derive the depreciation rate (δ_t) and the separation rate (ψ_t) by solving the dynamic equations (of capital and labor) for these variables; alternatively we use the sample average of these

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

variables as fixed values or use a BEA/NFCB computed series for δ_t. For the labor share of income $\frac{wn}{f}$ we use the sum of wages and salaries as part of national income (from NIPA) divided by the product of civilian employment and the implicit price deflator for national income. For s we use the market value of non-farm, non-financial business. The data are taken from Hall (2001a) based on the Fed Flow of Funds accounts. For the discount rate (r) we use two alternatives: a weighted average of the returns to debt and to equity or the rate of non-durable consumption growth, which serves as the discount rate in a DGSE model with log utility. Table 1 presents summary statistics for both sample periods noted above.

Table 1

4.3. Alternative Specifications

We formulate equations ($F1$) and ($F2$), and the asset pricing equation (3.30) in stationary terms.[6] We explore several alternative specifications:

(i) *The degree of convexity.* While the literature has for the most part assumed the quadratic form, we test for alternative values of the powers (η_1, η_2, η_3) or let them be determined by estimation.

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

(iii) *Variables' formulation.* We check the effect of using alternative time series for some of the variables, which have multiple time series representations. These include $\frac{qv}{n}, \delta, \psi$ and β.

(iv) *Sample period.* By looking at the two alternative $\frac{qv}{n}$ series cited above, we are in fact looking at two sample periods: 1976-1997 (n=88) and 1968-1997 (n=120).

[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.

5. Results

We begin by presenting the results of alternative specifications pertaining to the functional form of the adjustment costs function g. Table 2 reports the results of joint estimation of equations ($F1$) and ($F2$), and the asset pricing equation (3.30). We examine different values for the powers, including the classic quadratic formulation, and free powers (i.e. estimating η_1, η_2 and η_3). The table presents the parameter estimates and their standard errors, and several test statistics – Hansen's J-statistic and its p-value, and the correlations between actual and "fitted" investment rates $\frac{i}{k}$, hiring rates $\frac{qv}{n}$, and stock prices $\frac{s}{f}$.[7]

Table 2

The specification that is clearly the least fitting is the most prevalent one, i.e. the quadratic with respect to investment, where $\eta_1 = 2$ and $g_2 = g_3 = 0$ (as reported in column 4). The correlation of fitted values with the actual investment rate is essentially zero and it also fits the asset data $\frac{s}{f}$ less well than all other specifications (correlation of 0.4 as compared to 0.6 and over). Moreover, the estimate of $g_1 = 101$ implies very high marginal adjustment costs (for further discussion, see Section 6 below). The other quadratic specification, reported in column 3, allows for quadratic hiring costs and linear interaction, and its statistics imply a relatively good fit. However, its implications with respect to the g function and its derivatives are implausible: it implies high adjustment costs (the sample average is almost 11% of output), very high marginal hiring costs (in the order of more than 3 quarters of the average wage) and high volatility of marginal adjustment costs of capital (implying negative marginal costs in parts of the sample). The specification of column 5 allows the powers to be estimated. The GMM procedure has difficulties in converging in this case and the specification reported is rejected by the J-statistic test. Moreover, its implications for the g function are worse

[7] The "fitted" series are obtained by solving equations ($F1$) and ($F2$) period by period for the value of $\left(\frac{i}{k}\right)_{t+1}$ and $\left(\frac{qv}{n}\right)_{t+1}$ given actual values of all other variables and the point estimates of the parameters. The fitted value of $\frac{s}{f}$ is simply the RHS of equation (3.30).

than in the previous case, including a negative point estimate for g_2. We therefore take up a search for values of the powers and look at all permutations involving $\eta_1 \in \{2, 3, 4\}$, $\eta_2 \in \{2, 3, 4\}$, $\eta_3 \in \{1, 2, 3\}$. It turns out that the specifications that work best are the ones reported in columns 1 and 2. Moreover, their values – {3,2,2} and {4,2,2} – correspond to the free estimates of the power parameters reported in column 5 (see note 3 to the table). It is difficult to single out one of the two, using just the fit statistics, as column 2 fits the investment rate $\frac{i}{k}$ badly but fits the hiring rate $\frac{qv}{n}$ and the asset value $\frac{s}{f}$ better than column 1.

Tables 3 and 4 take up specifications (1) and (2) from Table 2 and examine further variations along several dimensions: looking at alternative instrument sets, as explained in the table's notes, and using alternative definitions of the variables $\frac{qv}{n}, \psi, \delta$ and β.

Tables 3 and 4

All parameters are precisely estimated and there is only one rejection – column 4 of both tables, when the longer sample is used with the chained $\frac{qv}{n}$ series.

In Table 3, the production function labor parameter α is estimated at conventional levels around 0.67. There is some variation across specifications in the point estimates of the scale parameters g_1, g_2, g_3, which was also the case in the structural estimation of the search and matching model using Israeli data reported in Yashiv (2000a,b). This variation in the point estimates is less pronounced when computing the implied values of the g function and its derivatives. The reason is that typically when the point estimate of g_1 or g_2 is high so is the absolute value of the estimate of g_3, which is negative, offsetting the former. Omitting the rejected column 4, the fit of the equation shows a correlation of 0.2–0.5 between the predicted and actual investment rate series, 0.1–0.8 between predicted and actual hiring rate series and 0.4–0.8 for the asset values case. Based on this fit criteria, in what follows we shall report the implications of columns 2 and 3, which feature the highest correlations as well as good J-statistics.

In Table 4 there is less stability: the production function parameter is estimated in a wider range, 0.65–0.78, and there are bigger variations than previously in the g function parameters (across specifications). Moreover, looking at the implied values of costs, all columns but column 6 need to be discarded as they imply negative marginal costs on average or in part of the sample. In what follows we shall report the implications of column 6 only from this table.

6. Implications for Hiring and Investment

The results of Tables 3 and 4 allow us to construct time series for adjustment costs, total as well as marginal, by using the point estimates of the parameters of the g function. The two first moments for these series in the sample, using the preferred specifications from these tables, are reported in Table 5.

Table 5

The table indicates that across specifications total adjustment costs on both investment and hiring range between 2% and 4% of output (f). Looking at investment in physical capital, net marginal adjustment costs range between 0.4 and 0.9 of average output per unit of capital $(\frac{f}{k})$, or 5% to 12% of total marginal costs, including p^I. As to labor, net marginal hiring costs range between 0.1 and 0.2 of average output per worker $(\frac{f}{n})$, or in other words 15% to 30% of quarterly wages. Note that gross marginal costs are much higher and are reduced by the interaction between hiring and investment costs. The interaction term has the expected negative sign; this is the condition needed to have both positive investment and hiring at the same time.

How reasonable are the magnitudes of costs reported above? There is 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 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 (3.21). 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 ($\frac{i}{k}$) 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. 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. Interestingly, the study of Erickson and Whited (2000), using panel data and GMM estimation and correcting for measurement error, suggests a different, higher range – 0.72 to 2.68.

The results reported in Table 5 are well within the 0.2–1 range (see the row of implied $\frac{\partial g/\partial i}{f/k}$). Moreover, they help reconcile the findings of high marginal adjustment costs for capital when using asset value data. As shown in Table 5[8], such high estimates are obtained when the interaction with hiring costs is omitted.

Another way to go about the explanation of hiring and investment behavior and the quantification of adjustment costs is a "calibration" type exercise. The rationale is this: given calibration of the g function, we can compute the solution for $\frac{i}{k}$, $\frac{qv}{n}$ and $\frac{s}{f}$ period by period as implied by the three equations $(F1)$, $(F2)$ and (3.30). We can then compare these solutions to the actual values. This procedure by-passes the GMM estimation procedure and generates the same fit statistics as reported in Tables 2–4. To calibrate we shall continue to assume a power functional form as in equation (4.2). We then postulate a range of reasonable values for $\frac{g}{f}$, $\frac{\partial g/\partial i}{f/k}$, $\frac{\partial g/\partial v}{f/n}$ and solve for the value of g_1, g_2 and g_3 that generate these values, using sample averages of $\frac{i}{k}$ and $\frac{qv}{n}$. The results are reported in Table 7.

Table 7

Note that the table continues to rely on the three equations $(F1)$, $(F2)$ and (3.30) and on the power form for g but does not rely on any estimation. The table, as well as other calibration results not reported here, implies that to explain investment rates $(\frac{i}{k})$ better, a relatively high value of the adjustment cost function $\frac{g}{f}$ is needed (compare columns 4 and 5 to 1–3). This better fit is coupled with a better fit of the asset value $\frac{s}{f}$ but is achieved at the expense of a worse fit for hiring rates $\frac{qv}{n}$. Moreover the results of columns 4 and 5 are problematic for an additional reason: not only is the mean of the series $\frac{g}{f}$ high, but the standard deviation of the marginal adjustment costs series are high, implying negative marginal costs in some parts of the sample. The other specifications do not suffer from these features. The picture that emerges from these specifications is that a reasonable g function yields a 0.41-0.46 correlation of predicted and actual investment rates and a 0.62-0.77 correlation of predicted and actual hiring rates. Comparing columns 1 and 3 in Tables 5 and 7, it can be seen that the estimation and calibration methodologies yield similar values.

[8] See the row with gross marginal costs of capital $g_1\left(\frac{i}{k}\right)^2$ or $g_1\left(\frac{i}{k}\right)^3$

Figure 1 shows the fitted values according to column 1 of Table 5 as compared to the actual values of hiring and investment rates.

Figure 1

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.

Summing up both the estimation and the calibration results, we get the following picture regarding adjustment costs and the resulting investment and hiring behavior: 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. Second, the formulation with relatively low adjustment costs ($\frac{g}{f}$ = 2%) results in a correlation of about 0.5 between predicted and actual investment rates and a correlation of about 0.8 between predicted and actual hiring rates. Third, omission of the interaction term results in a serious upward bias of the cost estimates.

7. Implications for Asset Pricing

Table 8 takes up the preferred specifications from Tables 3 and 4 and two calibration specifications from Table 7 and presents their implications for asset values $\frac{s}{f}$.

Table 8

Figure 2 plots the fitted values according to specifications 1,2 and 5 from the table and the actual values.

Figure 2

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

$$\frac{s}{f} = \frac{s_t^1}{f_t} + \frac{s_t^2}{f_t} + \frac{s_t^3}{f_t}$$

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

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

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

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.

We examine the results along three dimensions:

Fit. Panel (a) of the table indicates that the fit of the chosen specifications is relatively good, the correlations ranging from 0.4 to 0.8. As tables 3, 4 and 7 indicate, in most cases the fit is 0.5 and higher.

Mean. In terms of the mean, the fitted value is 89% to 98% of the actual value. Its decomposition (in panel (b)) indicates that between 86% to 94% comes from the first term. Most of the rest – 5% to 10% – comes from capital adjustment costs and about 1% to 4% from hiring costs.

Volatility. Most specifications have much lower variance than the actual series. The share in the variance (see panel a) rises with the magnitude of total cost g, reaching 40% in the calibrated specification of column 5, with $\frac{g}{f} = 7\%$. 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. It turns out that, except for specification 1, the biggest role is played by the second term, capital adjustment costs. In fact in specification 5 which has the highest variance, this term has the decisive role in the variance. Note too the negative co-variation between the first and second terms. This means that the "classic" part of the asset value, is negatively correlated with the part due to capital adjustment costs. Hiring costs per se have little part in the variance but a somewhat bigger contribution comes from their negative co-variance with capital adjustment costs.

8. Conclusions

The empirical results suggest that a framework that combines labor market frictions and capital adjustment costs can account for the joint behavior of hiring and investment and for the relationship of this behavior with asset values. The reasons previous results have suggested otherwise are probably related to the 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. The current results do have the drawback of generating insufficient asset value volatility. This may be due to numerous potential reasons, one of which is excess volatility due to "noise" or to "bubbles." This is an issue that remains to be explored.

In terms of the current version further work needs to be done on the effects of using alternative discount factors and asset value variables, on timing issues, on heteroskedasticity issues, on test statistics, on more calibration specifications and on further study of the relationship between asset values and macroeconomic variables.

In the future a cross-sectional study of firms may be insightful, but a serious empirical difficulty is likely to be the (non) existence of appropriate gross flows worker data.

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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 (3.14) by i_t, the FONC with respect to capital (3.13) by k_{t+1}, the FONC with respect to vacancies (3.16) by v_t, and the one with respect to employment (3.15) by n_{t+1} to get

$$0 = -(1-\tau_t)\left(p_t^I + g_{i_t}\right) i_t + i_t Q_t^K \tag{A.1}$$

$$0 = -(1-\tau_t)\, g_{v_t} v_t + v_t q_t Q_t^N \tag{A.2}$$

$$k_{t+1} Q_t^K = k_{t+1} E_t\left\{\left[\beta_{t+1}(1-\tau_{t+1})\left(f_{k_{t+1}} - g_{k_{t+1}}\right) + (1-\delta_{t+1}) Q_{t+1}^K\right]\right\} \tag{A.3}$$

$$n_{t+1} Q_t^N = n_{t+1} E_t\left\{\beta_{t+1}\left[(1-\tau_{t+1})\left(f_{n_{t+1}} - g_{n_{t+1}} - w_{t+1}\right) + (1-\psi_{t+1}) Q_{t+1}^N\right]\right\} \tag{A.4}$$

Then we insert the law of motion for capital (3.4) into equation (A.1), roll forward all expressions one period, multiply both sides by β_{t+1} and take conditional expectations on both sides:

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

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

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

or

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

It follows from the definition of the firm's market value in equation (3.27) 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

$$\vartheta_t^k = k_{t+1}Q_t^K. \tag{A.10}$$

We derive a similar expression for the case of labor. Inserting the law of motion for labor from equation (3.5) into equation (A.2), multiplying both sides by β_t, rolling forward all expressions by one period and taking conditional expectations yields

$$E_t\left[\beta_{t+1}\left(1-\tau_{t+1}\right)g_{v_{t+1}}v_{t+1}\right] = E_t\left\{\beta_{t+1}\left[n_{t+2}-(1-\psi_{t+1})n_{t+1}\right]Q_{t+1}^N\right\} = 0, \tag{A.11}$$

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

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

or

$$E_t\left(\beta_{t+1}cf_{t+1}^n\right) = n_{t+1}Q_t^N - E_t\left(\beta_{t+1}n_{t+2}Q_{t+1}^N\right). \tag{A.13}$$

The definition of the firm's value in equation (3.8) implies that

$$\vartheta_t^n - E_t\left(\beta_{t+1}\vartheta_{t+1}^n\right) = E_t\left(\beta_{t+1}cf_{t+1}^n\right). \tag{A.14}$$

Thus,

$$\vartheta_t^n - E_t\left(\beta_{t+1}\vartheta_{t+1}^n\right) = n_{t+1}Q_t^N - E_t\left(\beta_{t+1}n_{t+2}Q_{t+1}^N\right). \tag{A.15}$$

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

$$\vartheta_t^n = n_{t+1} Q_t^N. \tag{A.16}$$

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

$$s_t = \vartheta_t^k + \vartheta_t^n = k_{t+1} Q_t^K + n_{t+1} Q_t^N. \tag{A.17}$$

where Q_t^K and Q_t^N are defined in equations (3.18) and (3.19), respectively.

B. Data

The data are quarterly and cover the period 1976:1-1997:4 (or with the extended $\frac{qv}{n}$ series for 1968:1-1997:4). 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.[9]

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)[10] 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:

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

$i = 1, 2, 3, 4$, 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 $t+1$.

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

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

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

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

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

$$n^m_{t+1} = n^m_t(1 - \psi^m) + (qv)^m \tag{B.2}$$

we get (in monthly terms):

$$\psi^m = \frac{(qv)^m}{n^m_t} + 1 - \frac{n^m_{t+1}}{n^m_t}$$

We then transform to quarterly:

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

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) divided by the product of civilian employment and 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)[11] 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.[12]

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.

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

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

B.6. Interest Rate and Discount Factor

We use two alternatives:

a. Following the weighted average cost of capital approach in corporate finance, we measure the firms' discount rate r_t as a weighted average of the returns to debt, rd_t, and equity, re_t:

$$r_t = \omega rd_t + (1 - \omega) re_t, \tag{B.4}$$

with

$$rd_t = (1 - \tau_t) i_t^{CP} - \pi_t, \ re_t = \frac{cf_t}{s_t} + \widehat{s}_t - \pi_t \tag{B.5}$$

where ω is the share of debt finance. We set this share equal to 0.4. The definition of rd_t reflects the fact that 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. π_t denotes the GDP-deflator inflation of p^f discussed above. The discount factor β is given by $\beta_t = [1/(1 + r_t)]$.

b. Using non-durable consumption growth as r_t, which corresponds to the discount rate in a DGSE model with log utility.

Table 1

Data Summary Statistics

	76:1-97:4	n=88	68:1-97:4	n=120
variable	mean	std.	mean	std.
$\frac{i}{k}$	0.025	0.002	0.025	0.002
p^I	1.29	0.07	1.30	0.06
τ	0.41	0.06	0.43	0.07
$\delta 1$	0.018	0.001	0.017	0.002
$\delta 2$	0.018	0.002	0.017	0.002
$\frac{qv}{n}$	0.089	0.008	0.091	0.007
$\frac{wn}{f}$	0.648	0.010	0.649	0.010
ψ	0.085	0.008	0.086	0.008
$\frac{s}{f}$	5.3	1.4	5.4	1.3
$r1$	0.023	0.045	0.016	0.052
$r2$	0.006	0.006	0.006	0.007

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
$\{\eta_1, \eta_2, \eta_3\}$	{3,2,2}	{4,2,2}	{2,2,1}	{2}	free[4]
g_1	4,050	145,796	561	101	203,598
	(141)	(9,844)	(25)	(2)	(26,876)
g_2	7.20	16.1	65.4		-145
	(0.36)	(0.86)	(2.94)		(22)
g_3	-9,311	-9,179	-149		-265,769
	(565)	(623)	(8)		(44,518)
α	0.67	0.74	0.80	0.67	1.12
	(0.00)	(0.00)	(0.01)	(0.00)	(0.23)
J-Statistic	64.9	62.6	60.9	68.2	75.9
p-Value	0.17	0.23	0.27	0.15	0.02
$\rho\frac{i}{k}(fitted, actual)$	0.40	0.05	0.36	0.01	-
$\rho\frac{qv}{n}(fitted, actual)$	0.31	0.77	0.74	-	-
$\rho\frac{s}{f}(fitted, actual)$	0.61	0.66	0.76	0.41	0.75

Notes:

1. Standard errors are given in parantheses.

2. Instruments used are a constant and in 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 $\{\frac{qv}{n}, \frac{wn}{f}, \frac{i}{k}, p^I, \tau, \frac{f}{k}, \frac{s}{f}\}$.

3. The powers in column 5 were estimated to be: η_1 = 3.11(0.00), η_2 = 2.14(0.00) and η_3 = 2.15(0.00). In this case we cannot compute fitted values for $\frac{i}{k}$ and $\frac{qv}{n}$.

Table 3

GMM Estimates of F1, F2 and the Asset Pricing Equation

Alternative specifications of $\{\eta_1, \eta_2, \eta_3\} = \{3, 2, 2\}$

	1	2	3	4	5	6	7
g_1	4,050	2,700	6,310	3,925	4,027	3,241	4,461
	(141)	(102)	(154)	(214)	(138)	(76)	(230)
g_2	7.20	4.47	12.1	1.73	7.17	5.10	16.4
	(0.36)	(0.21)	(0.36)	(0.40)	(0.36)	(0.27)	(0.84)
g_3	-9,311	-4,085	-17,561	-4,668	-9,304	-7,023	-16,636
	(565)	(294)	(516)	(629)	(560)	(424)	(883)
α	0.67	0.68	0.70	0.65	0.67	0.67	0.67
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.002)
J-Statistic	64.9	73.0	73.3	80.1	65.0	65.2	68.9
p-Value	0.17	0.18	0.40	0.02	0.17	0.16	0.10
$\rho\frac{i}{k}(fitted, actual)$	0.40	0.49	0.37	0.34	0.25	0.24	0.33
$\rho\frac{qv}{n}(fitted, actual)$	0.31	0.75	0.39	0.36	0.20	0.12	0.66
$\rho\frac{s}{f}(fitted, actual)$	0.61	0.41	0.75	0.13	0.61	0.51	0.66

Notes:

1. Column 1 repeats column 1 from Table 2. It uses the following instrument sets (a constant is always included too). F1: 4 lags of $\{\frac{i}{k}, p^I, \tau, \frac{f}{k}\}$,F2: 4 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \tau\}$, asset pricing equation: 4 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \frac{i}{k}, p^I, \tau, \frac{f}{k}, \frac{s}{f}\}$.

2. Column 2 is the same as column 1 but adds $\frac{s}{f}$ to the instrument sets of equations F1 and F2.

3. Column 3 postulates larger instrument sets: F1: 4 lags of $\{\frac{i}{k}, p^I, \tau, \frac{f}{k}, \frac{s}{f}, \beta\}$,F2: 4 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \tau, \frac{s}{f}\}$, asset pricing equation: 4 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \frac{i}{k}, p^I, \tau, \frac{f}{k}, \frac{s}{f}, \beta\}$.

4. Column 4 uses combined data from Blanchard and Diamond (1989) and Bleakely et al (1999) for the period 1968-1997, hence $n = 120$.

5. Column 5 uses as the depreciation rate the value of δ_t that is the solution of equation (3.4) period by period.

6. Column 6 uses fixed rates of depreciation and separation equal to the sample means ($\delta = 0.018$ and $\psi = 0.08$).

7. Column 7 uses a discount factor β based on the growth rate of non-durable consumption.

Table 4

GMM Estimates of F1, F2 and the Asset Pricing Equation

Alternative specifications of $\{\eta_1, \eta_2, \eta_3\}$ = $\{4, 2, 2\}$

	1	2	3	4	5	6	7
g_1	145,796	171,501	60,942	138,827	132,722	148,942	173,899
	(9,844)	(6,895)	(5,046)	(7,239)	(9,788)	(11,247)	(7,809)
g_2	16.1	20.0	11.3	1.9	15.4	7.7	21.1
	(0.86)	(0.60)	(0.32)	(0.34)	(0.85)	(0.62)	(0.92)
g_3	-9,179	-11,756	-7,080	-4,329	-8,253	-7,040	-17,108
	(623)	(422)	(341)	(507)	(618)	(758)	(789)
α	0.74	0.76	0.69	0.65	0.74	0.68	0.66
	(0.004)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
J-Statistic	62.6	68.1	74.7	80.8	63.0	63.2	68.6
p-Value	0.23	0.31	0.36	0.01	0.21	0.21	0.10
$\rho\frac{i}{k}(fitted, actual)$							
$\rho\frac{qv}{n}(fitted, actual)$	0.78	0.77	0.78	0.18	0.78	0.71	0.78
$\rho\frac{s}{f}(fitted, actual)$	0.66	0.71	0.31	0.19	0.62	0.64	0.73

Notes:

1. Column 1 repeats column 1 from Table 2. It uses the following instrument sets (a constant is always included too). F1: 4 lags of $\{\frac{i}{k}, p^I, \tau, \frac{f}{k}\}$,F2: 4 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \tau\}$, asset pricing equation: 4 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \frac{i}{k}, p^I, \tau, \frac{f}{k}, \frac{s}{f}\}$.

2. Column 2 is the same as column 1 but adds $\frac{s}{f}$ to the instrument sets of equations F1 and F2.

3. Column 3 postulates larger instrument sets: F1: 4 lags of $\{\frac{i}{k}, p^I, \tau, \frac{f}{k}, \frac{s}{f}, \beta\}$,F2: 4 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \tau, \frac{s}{f}\}$, asset pricing equation: 4 lags of $\{\frac{qv}{n}, \frac{wn}{f}, \frac{i}{k}, p^I, \tau, \frac{f}{k}, \frac{s}{f}, \beta\}$.

4. Column 4 uses combined data from Blanchard and Diamond (1989) and Bleakely et al (1999) for the period 1968-1997, hence $n = 120$.

5. Column 5 uses as the depreciation rate the value of δ_t that is the solution of equation (3.4) period by period.

6. Column 6 uses fixed rates of depreciation and separation equal to the sample means ($\delta = 0.018$ and $\psi = 0.08$).

7. Column 7 uses a discount factor β based on the growth rate of non-durable consumption.

Table 5

Sample Moments of Total and Marginal Adjustment Costs

	1	2	3
total costs $\frac{g}{f}$	0.022	0.038	0.028
	(0.002)	(0.002)	(0.003)
net marginal costs (i) $\frac{\partial g/\partial i}{f/k}$	0.85	0.42	0.88
	(0.27)	(0.80)	(0.55)
net marginal costs (qv) $\frac{\partial g/\partial v}{f/n}$	0.18	0.13	0.31
	(0.04)	(0.14)	(0.07)
gross marginal costs (i) $g_1\left(\frac{i}{k}\right)^2$ or $g_1\left(\frac{i}{k}\right)^3$	1.64	3.83	2.24
	(0.24)	(0.55)	(0.49)
gross marginal costs (qv) $g_2\frac{qv}{n}$	0.40	1.07	0.69
	(0.04)	(0.10)	(0.06)
interaction capital	-0.80	-3.43	-1.37
	(0.13)	(0.58)	(0.23)
interaction labor	-0.22	-0.95	-0.38
	(0.03)	(0.13)	(0.05)
$\rho\frac{i}{k}(fitted, actual)$	0.49	0.37	
$\rho\frac{qv}{n}(fitted, actual)$	0.75	0.39	0.71

Notes:

1. The table reports sample means with standard deviations in parantheses.
2. Column 1 is derived from column 2 in Table 3.
3. Column 2 is derived from column 3 in Table 3.
4. Column 3 is derived from column 6 in Table 4.

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
Erickson and Whited (2000)	Compustat, 1992-1995	0.12	$0.72 - 2.68$
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

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

Calibration of the g function and its implications

	1	2	3	4	5
implied $\frac{g}{f}$	0.02	0.02	0.03	0.06	0.07
	(0.002)	(0.002)	(0.002)	(0.004)	(0.003)
implied $\frac{\partial g/\partial i}{f/k}$	0.41	0.61	0.83	0.25	0.29
	(0.24)	(0.22)	(0.45)	(0.82)	(1.64)
implied $\frac{\partial g/\partial v}{f/n}$	0.20	0.20	0.20	0.59	0.09
	(0.04)	(0.04)	(0.07)	(0.16)	(0.29)
$\rho\frac{i}{k}(fitted, actual)$	0.41	0.46	0.41	0.60	0.60
$\rho\frac{qv}{n}(fitted, actual)$	0.75	0.77	0.62	0.56	0.17
$\rho\frac{s}{f}(fitted, actual)$	0.34	0.32	0.63	0.79	0.82

Notes:

1. The table reports sample means with standard deviations in parantheses.

Table 8

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

a. Equation Fit

	1	2	3	4	5
correlation fitted, actual	0.41	0.75	0.64	0.63	0.82
$\frac{\text{mean fitted}}{\text{mean actual}}$	0.96	0.91	0.98	0.96	0.89
$\frac{\text{variance fitted}}{\text{variance actual}}$	0.03	0.09	0.05	0.05	0.40

b. Decomposition of the Mean Fitted Series

	1	2	3	4	5
fitted total	5.12	4.86	5.25	5.12	4.76
share of $\frac{s_t^1}{f_t}$	88%	93%	86%	88%	94%
share of $\frac{s_t^2}{f_t}$	10%	5.5%	10%	10%	5%
share of $\frac{s_t^3}{f_t}$	2%	1.5%	4%	2%	1%

c. Variance- Covaraince Decomposition of the Fitted Series

Specification 1

	$\frac{s_t^1}{f_t}$	$\frac{s_t^2}{f_t}$	$\frac{s_t^3}{f_t}$
$\frac{s_t^1}{f_t}$	1.03	-0.33	0.06
$\frac{s_t^2}{f_t}$	-0.33	0.60	-0.05
$\frac{s_t^3}{f_t}$	0.06	-0.05	0.01

Specification 2

	$\frac{s_t^1}{f_t}$	$\frac{s_t^2}{f_t}$	$\frac{s_t^3}{f_t}$
$\frac{s_t^1}{f_t}$	0.33	-0.26	0.07
$\frac{s_t^2}{f_t}$	-0.26	1.29	-0.13
$\frac{s_t^3}{f_t}$	0.07	-0.13	0.04

Specification 3

	$\frac{s_t^1}{f_t}$	$\frac{s_t^2}{f_t}$	$\frac{s_t^3}{f_t}$
$\frac{s_t^1}{f_t}$	0.82	-0.43	0.08
$\frac{s_t^2}{f_t}$	-0.43	1.04	-0.09
$\frac{s_t^3}{f_t}$	0.08	-0.09	0.02

Specification 4

	$\frac{s_t^1}{f_t}$	$\frac{s_t^2}{f_t}$	$\frac{s_t^3}{f_t}$
$\frac{s_t^1}{f_t}$	0.66	-0.34	0.08
$\frac{s_t^2}{f_t}$	-0.34	1.05	-0.10
$\frac{s_t^3}{f_t}$	0.08	-0.10	0.03

Specification 5

	$\frac{s_t^1}{f_t}$	$\frac{s_t^2}{f_t}$	$\frac{s_t^3}{f_t}$
$\frac{s_t^1}{f_t}$	0.08	-0.13	0.03
$\frac{s_t^2}{f_t}$	-0.13	1.35	-0.14
$\frac{s_t^3}{f_t}$	0.03	-0.14	0.04

Notes:

1. The tables use the following definitions:

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

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

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

2. Column 1 is derived from column 2 in Table 3.

3. Column 2 is derived from column 3 in Table 3.

4. Column 3 is derived from column 6 in Table 4.

5. Column 4 is derived from column 3 in Table 7.

7. Column 5 is derived from column 5 in Table 7.

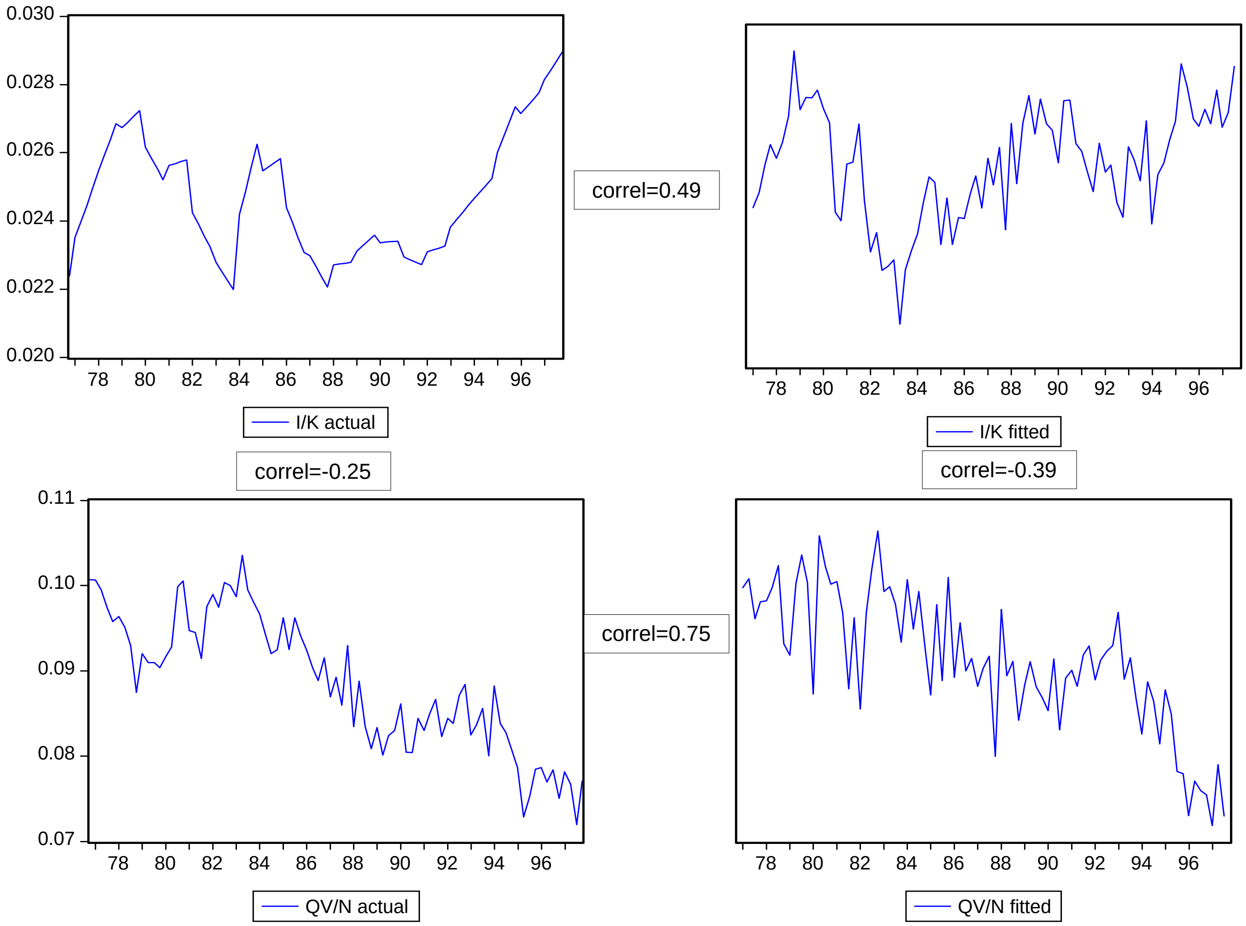

Figure 1: $\frac{i}{k}$ and $\frac{qv}{n}$ correlations (between adjacent graphs)

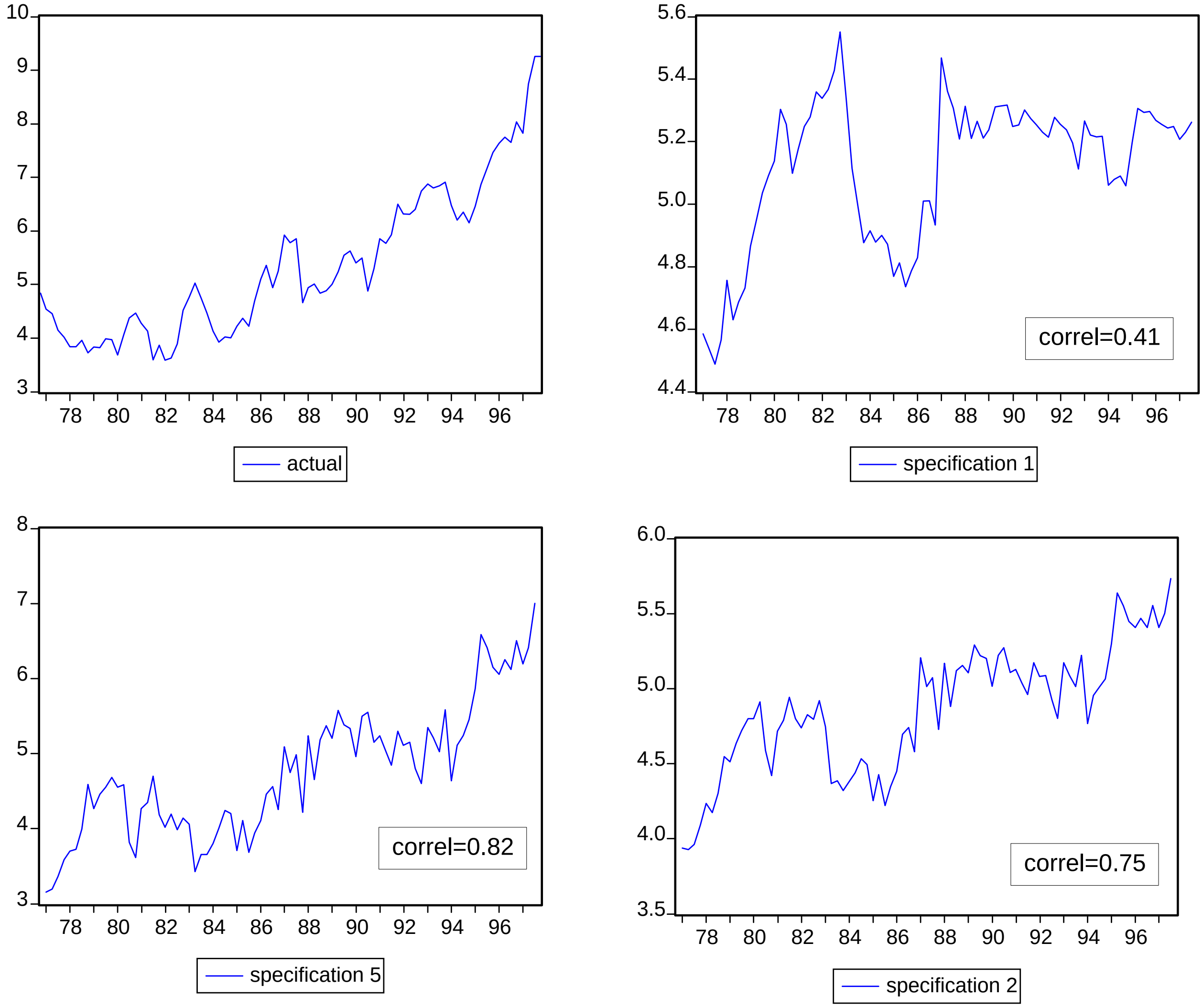

Figure 2: $\frac{s}{f}$ correlations (between fitted and actual)