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Factor adjustment costs: a structural investigation

Haroon Mumtaz and Francesco Zanetti

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Abstract

This paper assesses various capital and labour adjustment costs functions estimating a general equilibrium framework with Bayesian methods using US aggregate data. The estimation reveals that the adjustment costs are convex in both capital and labour and allowing for their joint interaction is important. The structural model enables us to identify the response of factor adjustment costs to exogenous disturbances, and to establish that shocks to technology and the job separation rate are key drivers of adjustment costs. However, the analysis shows that factor adjustment costs are unable to explain large fluctuations in the firm's market value in the data.

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Summary

The costs associated with changes in capital and labour inputs are important factors affecting firms' decisions to expand or contract production. These ultimately affect the levels of economic activity and the patterns of business cycle activity that an economy experiences over long periods, and understanding the process is consequently important to macroeconomic policy makers. This paper investigates what theory and data tell us about the precise nature of adjustment costs, thus enabling us to build macroeconomic models better to describe business cycle fluctuations.

We conduct the analysis by estimating a 'dynamic stochastic general equilibrium' model that accounts for several important features of the economy. Dynamic, because it emphasises how the economy evolves over time; stochastic, because in the model as in the world agents are continually buffeted by random shocks of various kind; and general equilibrium, because all parts of the economy are connected and affect each other. We examine several competing adjustment costs functions using US aggregate data. This approach has two main advantages. First, the model is derived by solving the optimal decision of each agent in the economy, thus enriching our theoretical understanding of how adjustment costs affect production. Second, rather than estimating adjustment costs functions using single equations, we pursue a multivariate approach by estimating the entire structural model, enabling more accurate estimates, aided by the fact that the independent variables are uncorrelated with the error terms (shocks) in the model.

We also find that the empirically acceptable adjustment costs function is non-linear, is increasing in both labour and capital, and also accounts for joint interactions between the two production inputs. Alternative specifications, with only capital or labour adjustment costs are not powerful.

We find that adjustment costs are small for both input factors. According to the theoretical framework, total adjustment costs represent 1.98 % of total output per quarter. In addition, the cost of hiring an additional worker amounts to fourteen weeks of wages, whereas the cost of an extra unit of investment equals 0.21 % of average output per unit of capital. Such estimates are within the range of values estimated using disaggregated data.

The analysis suggests that the reaction of factor adjustment costs to shocks is generally

procyclical, except to shocks to the rate at which jobs and capital are dismissed. Finally, technology shocks are a major influence on fluctuations in factor adjustment costs in the short run, whereas shocks to the job dismissal rate compete with technology shocks to explain the bulk of fluctuations of factor adjustment costs in the long run.

1 Introduction

An extensive literature finds that capital and labour inputs are costly to adjust. Factor adjustment costs make the asset values of capital and labour fluctuate according to their underlying marginal adjustment costs, whereas otherwise they would be constant. Moreover, when demand rises unexpectedly, adjustment costs generate rents, whose movements, in principle, may explain large fluctuations in the market value of the firm relative to the underlying factor input costs. In this respect, a structural investigation on the size and dynamics of factor adjustment costs is important in order to understand aggregate fluctuations in the prices of capital and labour inputs, and the firm's market value.

The contribution of this paper is to assess the importance of factor adjustment costs by estimating a dynamic stochastic general equilibrium (DSGE) model for several competing adjustment costs functions using US aggregate data. Our approach has several advantages. First, the theoretical setting is microfounded and based on a prototype production-based model enriched with labour market frictions and factor adjustment costs. Second, rather than estimating asset price functions in a univariate setting, we pursue a multivariate approach by estimating the entire structural model. The system approach optimally adjusts the estimation of the asset price equation's coefficients for the endogeneity of the right hand side variables. Moreover, we are able to exploit cross-equation restrictions that link agent's decision rules with the coefficients in the asset price equations. To conduct the estimation we assign prior distributions to the parameters of the adjustment costs function and exogenous disturbances and use Bayesian inference. Posterior distributions are used to determine the functional form of the adjustment costs functions and posterior odds ratio to assess their empirical adequacy. To the best of our knowledge, this is the first time that such a methodology has been applied to investigate the issue of factor adjustment costs.

To establish the empirically suitable adjustment costs function, the theoretical model allows, but does not require, capital and labour adjustment costs to include linear and convex cost components, and to let adjustment costs interact. This formulation encompasses a broad range of possibilities. In this way, the theoretical model allows for both investment and hiring decisions to simultaneously affect the asset prices of capital and labour, and consequently the firm's market value. The posterior odds ratio shows that the data prefer the adjustment costs function that includes both linear and convex cost components, and that also accounts for the joint interaction between capital and labour costs. Specifications with capital adjustment costs only—as in the investment literature—or with labour adjustment costs only—as in the labour demand literature—are rejected by the data. The econometric estimation finds that adjustment costs are small for both input factors. According to the theoretical framework, total adjustment costs represent 1.98% of total output per quarter. In addition, the cost of hiring an additional worker amounts to 14 weeks of wages, whereas the cost of an extra unit of investment equals 0.21% of average output per unit of capital. Such estimates are within the range of values estimated using disaggregated data.

The use of a structural approach enables additional interesting results. We identify structural disturbances in the data based on the dynamic effects that they have on the model's observable variables. The model's reduced form enables us to extend the identification of shocks to the model's unobservable variables, and we are therefore able to map the response of key macroeconomic variables and factor adjustment costs to the exogenous disturbances to technology, labour supply, job and capital destruction rates and tax changes. We find that total factor adjustment costs are procyclical for all the shocks, except for those to the job and capital destruction rates. We also find that the asset prices of capital and labour mirror one-for-one the reaction of the marginal costs of investing and hiring, which in turn determine the firm's market value. Forecast error variance decompositions show that technology shocks are a major influence on output, factor adjustment costs and the firm's market value in the short run, whereas shocks to the job separation rate compete with technology shocks to explain the bulk of fluctuations of factor adjustment costs in the long run.

In addition, the structural model allows us to estimate the unobservable shocks using a Kalman smoothing algorithm that uses the information contained in the full sample of the data. By feeding the estimated shocks into the theoretical model we generate time series for the unobservable variables that can be compared against the actual series in the data. In contrast to studies based on single-equation estimations, we find that the fully defined general equilibrium model is unable to replicate the large fluctuations in the firm's market value in the data.

Before proceeding, we discuss the context provided by related studies. As mentioned, one contribution of the paper is to estimate the adjustment costs function that fits aggregate data. In general, estimates of factor adjustment costs are based on disaggregated firm-level data, as surveyed by Bond and Van Reenen (2007), and only a few studies focus on aggregate data. Of these, the majority estimates either capital adjustment costs, or labour adjustment costs individually, assuming the other factor is flexible. In particular, Christiano, Eichenbaum and Evans (2005), Ireland (2003) and Smets and Wouters (2007) use DSGE models to estimate capital adjustment costs in a frictionless labour market. On the other hand, Cogley and Nason (1995), Chang, Doh and Schorfheide (2007) and Janko (2008) estimate labour adjustment costs in the absence of capital adjustment costs. Our paper uses a similar methodology but it assesses the adequacy of various adjustment costs functions that allow for both capital and labour adjustment costs.

Similarly to our approach, Dib (2003) estimates a DSGE model using maximum likelihood methods that allows for simultaneous capital and labour adjustment costs. However, the model abstracts from the joint interaction between capital and labour costs, and the analysis neither focuses on the size of adjustment costs, nor on their implication for the model's dynamics. Bloom (2009), Merz and Yashiv (2007) and Yashiv (2010) develop partial equilibrium models to study the interaction of capital and labour adjustment costs. They estimate asset pricing equations in a univariate setting, using the generalized method of moments and instrumental variables. Instead, we use a fully defined DSGE model that uses the same asset price equations and also exploits the cross-equation restrictions of the entire structural model, thereby overcoming the identification issues encountered in single-equation estimates.

The remainder of the paper is organized as follows. Section 2 lays out the model. Section 3 presents the econometric methodology and the data. Section 4 presents the estimation results, assesses the empirical fit of alternative adjustment costs functions, illustrates the steady-state and dynamics properties of the model and relates the analysis to existing studies. Section 5 concludes.

2 The model

This section lays out the theoretical model. The standard production-based model by Cochrane (1991) is enriched with labour market frictions as in Blanchard and Gali (2010) and a factor adjustment costs function as in Merz and Yashiv (2007) and Bloom (2009). This framework relies on the assumption that the process of job search and recruitment is costly for both the firm and the worker. Job creation takes place when a firm and a searching worker meet and agree to form a match at a negotiated wage, which depends on the parties' bargaining power. The match continues until the parties exogenously terminate the relationship. When this occurs, job destruction takes place and the worker moves from employment to unemployment, and the firm can either withdraw from the market or hire a new worker. The wage splits the surplus from working between the firm and the household.

The model economy consists of a representative firm and household. The rest of this section describes the agents' preferences, technologies and the structure of the labour market.

2.1 The Representative Firm

During each period $t = 0, 1, 2, ...$, the representative firm employs n_t units of labour and k_t units of capital from the representative household, in order to manufacture y_t units of good according to the constant returns to scale production technology

$$y_t = f(a_t, k_t, n_t), \tag{1}$$

where a_t is the neutral technology process $a_t = \Gamma(a_{t-1}, \varepsilon_{at})$, and ε_{at} is an i.i.d. shock. The firm's real profits, π_t, equal the difference between revenues net of factor adjustment costs, $g(i_t, k_t, h_t, n_t)$, which depend on the firm's new investment i_t, the installed capital k_t, the number of new hires h_t, the stock of labour n_t, and total labour compensation, $w_t n_t$:

$$\pi_t = f(a_t, k_t, n_t) - g(i_t, k_t, h_t, n_t) - w_t n_t, \tag{2}$$

where w_t is the real wage. The problem for the firm is to maximize its total real market value, v_t, given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t d_t, \tag{3}$$

where d_t is the firm's real cash-flow payments (defined below), and $\beta^t \lambda_t$ measures the marginal utility value (defined below) to the representative household of an additional dollar in value during period t. The firm's real cash-flow payments, d_t, equals profits minus purchases of investment goods

$$d_t = (1 - \tau_t)\pi_t - i_t, \tag{4}$$

where τ_t is the corporate income tax rate $\tau_t = \Gamma(\tau_{t-1}, \varepsilon_{\tau t})$, and $\varepsilon_{\tau t}$ is an i.i.d. shock. During each period $t = 0, 1, 2, ...$, by investing i_t units of output during period t, the firm increases the capital stock k_{t+1} available during period $t+1$ according to

$$k_{t+1} = (1-\delta_t)k_t + i_t, \quad \textbf{(5)}$$

where δ_t is the capital depreciation rate $\delta_t = \Gamma(\delta_{t-1}, \varepsilon_{\delta t})$, and $\varepsilon_{\delta t}$ is an i.i.d. shock. Similarly, by hiring h_t new workers during period t, the firm increases the employment stock n_{t+1} available during period $t+1$ according to

$$n_{t+1} = (1-\psi_t)n_t + h_t, \quad \textbf{(6)}$$

where ψ_t is the exogenous separation rate $\psi_t = \Gamma(\psi_{t-1}, \varepsilon_{\psi t})$, and $\varepsilon_{\psi t}$ is an i.i.d. shock. Thus the firm chooses $\{n_{t+1}, k_{t+1}, h_t, i_t\}_{t=0}^{\infty}$ to maximize its market value **(3)** subject to the law of capital and employment accumulation **(5)** and **(6)** for all $t = 0, 1, 2, ...$ By letting q_t^k and q_t^n denote the non-negative Lagrange multiplier on the law of capital accumulation **(5)** and the law of employment accumulation **(6)**, the first-order conditions for this problem are

$$q_t^k = E_t\beta_{t,t+1}\left[(1-\tau_t)\left(f_{k,t+1} - g_{k,t+1}\right) + q_{t+1}^k(1-\delta_{t+1})\right], \quad \textbf{(7)}$$

$$q_t^n = E_t\beta_{t,t+1}\left[(1-\tau_t)\left(f_{n,t+1} - g_{n,t+1} - w_{t+1}\right) + q_{t+1}^n(1-\psi_{t+1})\right], \quad \textbf{(8)}$$

$$q_t^k = 1 + g_{i,t}, \quad \textbf{(9)}$$

and

$$q_t^n = g_{h,t}, \quad \textbf{(10)}$$

where E_t is the expectation conditional on information available in period t, $\beta_{t,t+1} = \beta\lambda_{t+1}/\lambda_t$ is the stochastic discount factor, $f_{x,t+1}$ denotes the marginal product of factor x at time $t+1$, $g_{x,t+1}$ denotes the marginal cost of changing variable x at time $t+1$, and w_{t+1} the real wage at time $t+1$. Equation **(7)** equates the contribution of an additional unit of investment to the firm's market value (left-hand side, LHS) to the expected marginal productivity of capital net of adjustment costs, plus the expected marginal contribution of investment during period $t+1$ (right-hand side, RHS). Equation **(8)** equates the contribution of an additional hired worker to the firm's market value (LHS) to the expected marginal product of labour, net of total labour compensation, plus the expected future saving if the worker is retained during period $t+1$ (RHS). Finally, equations **(9)** and **(10)** are the standard marginal q equations for investment and hiring respectively, which equate the contribution of an additional unit of investment or worker (LHS) to the firm's costs generated by the additional unit of investment or the cost of recruiting (RHS).

To conclude the description of the representative firm, we specify the firm's market value. The firm's ex dividend market value in period t is defined as

$$s_t = E_t \beta_{t,t+1} (s_{t+1} + d_{t+1}). \quad \textbf{(11)}$$

As shown in Merz and Yashiv (2007), the firm's market value can be decomposed into the sum of the value due to physical capital and the stock of employment, such that equation **(11)** can be written as

$$s_t = k_{t+1} q_t^k + n_{t+1} q_t^n \quad \textbf{(12)}$$

Equation **(12)** shows that the market value of the firm depends on the present expected value of capital as well as the present expected value of labour.

2.2 The Representative Household

During each period $t = 0, 1, 2, \ldots$, the representative household maximizes the expected utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\ln c_t - \chi_t n_t^{1+\phi} / (1+\phi) \right], \quad \textbf{(13)}$$

where the variable c_t is consumption, n_t is units of labour, β is the discount factor $0 < \beta < 1$, ϕ is the inverse of the Frisch elasticity of labour supply $\phi > 0$, and χ_t is the degree of disutility of labour $\chi_t > 0$ and $\chi_t = \Gamma(\chi_{t-1}, \varepsilon_{\chi t})$. The representative household enters period t with the firm's cash-flow payments d_t. The household supplies n_t units of labour at the real wage rate w_t to the firm during period t. The household uses its income for consumption, c_t, subject to the budget constraint

$$c_t = w_t n_t + d_t, \quad \textbf{(14)}$$

for all $t = 0, 1, 2, ...$ Thus, the household chooses $\{c_t\}_{t=0}^{\infty}$ to maximize its utility **(13)** subject to the budget constraint **(14)** for all $t = 0, 1, 2, ...$ Letting λ_t denote the non-negative Lagrange multiplier on the budget constraint **(14)**, the first-order condition for c_t is

$$\lambda_t = 1/c_t. \quad \textbf{(15)}$$

According to equation **(15)**, the Lagrange multiplier equals the household's marginal utility of consumption.

The wage splits the total surplus from working. As in Pissarides (2000), the wage is set according to the Nash bargaining solution. In what follows we describe the structure of the labour market to explicitly derive the wage-setting equation.

At the beginning of each period t there is a pool of unemployed household members who are available for hire, and whose size we denote by u_t. As in Blanchard and Gali (2010), we refer to the latter variable as the beginning of period unemployment. The pool of household's members unemployed and available to work before hiring takes place is

$$u_t = 1 - (1 - \psi_{t-1})n_{t-1}. \tag{16}$$

It is convenient to represent the job creation rate, x_t, by the ratio of new hires over the number of unemployed workers such that:

$$x_t = h_t / u_t, \tag{17}$$

with $0 < x_t < 1$, given that all new hires represent a fraction of the pool of unemployed workers.

Let $\mathcal{W}_t^n$, and $\mathcal{W}_t^u$, denote the marginal value of the expected income of an employed, and unemployed worker respectively. The employed worker earns a wage, suffers disutility from work, and might lose their job with probability ψ_t. Hence, the marginal value of a new match is:

$$\mathcal{W}_t^n = w_t - \frac{\chi n_t^{\phi}}{\lambda_t} + \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left\{ \left[1 - \psi_{t+1} \left(1 - x_{t+1} \right) \right] \mathcal{W}_{t+1}^n + \psi_{t+1} \left(1 - x_{t+1} \right) \mathcal{W}_{t+1}^u \right\}. \tag{18}$$

This equation states that the marginal value of a job for a worker is given by the wage less the marginal disutility that the job produces to the worker, plus the expected-discounted net gain from being either employed or unemployed in period $t + 1$.

The unemployed worker expects to move into employment with probability x_t. Hence, the marginal value of unemployment is:

$$\mathcal{W}_t^u = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left[x_{t+1} \mathcal{W}_{t+1}^n + \left(1 - x_{t+1} \right) \mathcal{W}_{t+1}^u \right]. \tag{19}$$

This equation states that the marginal value of unemployment is made up of the expected-discounted capital gain from being either employed or unemployed in period $t + 1$.

As mentioned, the share of the surplus from establishing a job match is determined by the wage level, which is set according to the Nash bargaining solution. The worker and the firm split the surplus of their matches with the absolute share $0 < \eta < 1$. The difference between equations **(18)** and **(19)** determines the worker's economic surplus. The firm's surplus is simply given by the real cost per additional hire, $g_{h,t}$, as in Blanchard and Gali (2010). Hence, the total surplus from a match is the sum of the worker's and firm's surpluses. The Nash wage bargaining rule for a match is

$$\eta g_{h,t} = (1-\eta)(\mathcal{W}_t^n - \mathcal{W}_t^u).$$

Substituting equations **(18)** and **(19)** into this last equation produces the agreed wage:

$$w_t = \chi n_t^{\phi}/\lambda_t + \zeta g_{h,t} - \beta\left(1-\psi_{t+1}\right) E_t\left(\lambda_{t+1}/\lambda_t\right)\left(1-x_{t+1}\right)\zeta g_{h,t+1}, \qquad \textbf{(20)}$$

where $\zeta = \eta/\left(1-\eta\right)$ is the relative bargaining power of the worker. Equation **(20)** shows that the wage equals the marginal rate of substitution between consumption and leisure (first term on the RHS) plus current hiring costs (second term on the RHS), minus the expected savings in terms of the future hiring costs if the match continues in period $t+1$ (third term on the RHS). Equation **(20)** is the standard wage equation with Nash bargaining.

2.3 Aggregate Constraint and Model Solution

The aggregation of the firm's real cash-flow payments **(4)** and the household's budget constraint **(14)** produces the aggregate resource constraint

$$y_t = c_t + i_t + g(i_t, k_t, h_t, n_t). \qquad \textbf{(21)}$$

In order to produce a quantitative assessment of the system we need to parameterize the production technology, the adjustment costs function and the exogenous disturbances. To parameterize the production technology, we use the standard Cobb-Douglas function:

$$y_t = a_t k_t^{1-\alpha} n_t^{\alpha}, \qquad \textbf{(22)}$$

where $0 < \alpha < 1$ represents the labour share of production. For the adjustment costs, as in Merz and Yashiv (2007), we use the convex function

$$g(i_t, k_t, h_t, n_t) = \left[f_1 \frac{i_t}{k_t} + f_2 \frac{h_t}{n_t} + \frac{e_1}{\eta_1}\left(\frac{i_t}{k_t}\right)^{\eta_1} + \frac{e_2}{\eta_2}\left(\frac{h_t}{n_t}\right)^{\eta_2} + \frac{e_3}{\eta_3}\left(\frac{i_t}{k_t}\frac{h_t}{n_t}\right)^{\eta_3} \right] f(a_t, k_t, n_t), \qquad \textbf{(23)}$$

where parameters f_1, f_2, e_1, e_2, e_3, express scale, and η_1, η_2, η_3, express the elasticity of adjustment costs with respect to the different arguments. Equation **(23)** expresses the idea that the disruption in the production process increases with the size of the factor adjustment relative to the size of production, and adjustment costs increase in the investment and hiring rates. Importantly, the sign of the interaction term, e_3, determines the complementarity between investment and hiring. A positive value induces an increase in the asset value of capital (labour), which triggers an increase in the hiring (investment) rate, whereas the effect is the opposite for a negative estimate. As detailed below, this term is important for the model's dynamics. It is worth noting that equation **(23)** encompasses a wide range of convex adjustment costs functions.

The processes for a_t and χ_t evolve according to

$$\ln(a_t) = \rho_a \ln(a_{t-1}) + \varepsilon_{at}, \tag{24}$$

and

$$\ln(\chi_t) = \rho_\chi \ln(\chi_{t-1}) + \varepsilon_{\chi t}, \tag{25}$$

with $0 < \left(\rho_a, \rho_\chi\right) < 1$, and where the zero-mean, serially uncorrelated innovations ε_{at} and $\varepsilon_{\chi t}$ are normally distributed with standard deviation σ_a and σ_χ respectively. Finally, the processes for τ_t, δ_t, and ψ_t evolve according to

$$\ln(\tau_t) = (1 - \rho_\tau) \ln(\tau) + \rho_\tau \ln(\tau_{t-1}) + \varepsilon_{\tau t}, \tag{26}$$

$$\ln(\delta_t) = (1 - \rho_\delta) \ln(\delta) + \rho_\delta \ln(\delta_{t-1}) + \varepsilon_{\delta t}, \tag{27}$$

and

$$\ln(\psi_t) = (1 - \rho_\psi) \ln(\psi) + \rho_\psi \ln(\psi_{t-1}) + \varepsilon_{\psi t}, \tag{28}$$

where τ, δ, and ψ are the steady-state levels of the corporate tax rate, the capital depreciation rate and the separation rate respectively, with $0 < \left(\rho_\tau, \rho_\delta, \rho_\psi\right) < 1$, and where the zero-mean, serially uncorrelated innovations $\varepsilon_{\tau t}$, $\varepsilon_{\delta t}$ and $\varepsilon_{\psi t}$ are normally distributed with standard deviation σ_τ, σ_δ and σ_ψ respectively.

Hence, equations **(1)-(10)**, **(15)-(17)**, **(20)**, **(21)** and **(24)-(28)** describe the behaviour of the 19 endogenous variables $\{y_t, c_t, k_t, i_t, n_t, h_t, x_t, u_t, w_t, s_t, d_t, q_t^k, q_t^n, \lambda_t, a_t, \tau_t, \delta_t, \psi_t, \chi_t\}$. The equilibrium conditions do not have an analytical solution. Consequently, the system is approximated by loglinearizing its equations around the stationary steady state. In this way, a linear dynamic system describes the path of the endogenous variables' relative deviations from their steady-state value, accounting for the exogenous disturbances. The solution to this system is derived using Klein (2000).

3 Econometric Methodology, Data and Prior Distributions

In this section we first present the econometric methodology and then we describe the data and the prior distributions for the Bayesian analysis.

We estimate the model using Bayesian methods. To describe the estimation procedure, define Θ as the parameter space of the DSGE model, and $Z^T = \{z_t\}_{t=1}^T$ as the data observed. According to Bayes' Theorem the posterior distribution of the parameter is of the form $P(\Theta|Z^T) \propto P(Z^T|\Theta)P(\Theta)$. This method updates the *a priori* distribution using the likelihood contained in the data to obtain the conditional posterior distribution of the structural parameters. In order to approximate the posterior distribution, we employ the random walk Metropolis-Hastings algorithm. We use 50,000 replications and discard the first 25,000 as burn-in. We save every 25th remaining draw. The sequence of retained draws is stable, providing evidence on convergence.[1] The posterior density $P(\Theta|Z^T)$ is used to draw statistical inference on the parameter space Θ. An and Schorfheide (2007) provides a detailed description of Bayesian simulation techniques applied to the DSGE models.

The econometric estimation uses US quarterly data for the period 1976:1-2002:4. We use data for output, y, gross investment rate, i/k, gross hiring rate, h/n, the labour share of income, wn/y, and the gross depreciation rate of capital, δ. The series are from the NIPA data, except those on gross worker flows, which are from the BLS data. We demean the stationary series for i/k, h/n and wn/y, while we detrend the non-stationary series for y and δ using a HP filter with a smoothing parameter of 1600 prior the estimation.[2] A detailed description of the data sources and construction is in the appendix.

Our empirical strategy consists in estimating the parameters related to the adjustment costs function and the exogenous disturbances, fixing the remaining parameters. The values of the fixed parameters are described below and reported in Table 1. We set the discount factor, β, equal

[1] An appendix that details evidence on convergence is available upon request from the authors.

[2] As a robustness check, we have also estimated the model by detrending the series for i/k, h/n and wn/y using a HP filter and established that the results hold.

to 0.99 to generate an annual real interest rate of 4%, as in the data. We calibrate the inverse of the Frisch intertemporal elasticity of substitution in labour supply, ϕ, equal to 1, which is in line with micro- and macro-evidence as detailed in Card (1994) and King and Rebelo (1999). We set the production labour share, α, equal to 0.66, a value commonly used in the literature. We set the steady-state capital destruction rate, δ, and the job destruction rate, ψ, to match the NIPA data as described in Merz and Yashiv (2007), and therefore set them equal to 0.015 and 0.086 respectively.[3] Similarly, we set the steady-state corporate tax rate, τ, equal to 0.39. The wage bargaining parameter, η, is set to 0.5, as standard in the search and matching literature. The steady-state values of the technological progress, a, and of the disutility of labour, χ, are conveniently set equal to 1.

We estimate the remaining parameters pertaining to the adjustment costs function and the exogenous disturbances $\{f_1, f_2, e_1, e_2, e_3, \eta^1, \eta^2, \eta^3, \rho_a, \rho_\chi, \rho_\delta, \rho_\psi, \rho_\tau, \sigma_a, \sigma_\chi, \sigma_\delta, \sigma_\psi, \sigma_\tau\}$. Table 2 reports the prior distributional forms, means, standard deviations and 90% confidence intervals, for the complete set of parameters. Naturally, each constrained model would use a subset of these priors. We choose priors for these parameters based on several considerations. The priors for the parameters of the adjustment costs functions allow for a wide range of values. The linear parameters f_1 and f_2 are gamma distributed with a prior mean of 1 and a prior standard deviation of 0.3. The priors for the coefficients in front of the convex terms e_1,e_2, and e_3 are assumed to be normal around a mean of 0 with a sizeable standard error of 15, so to allow for a wide range of values. The priors for η^1,η^2, and η^3 are assumed to be gamma distributed with a prior mean of 2 and a standard deviation of 2.

The priors on the stochastic processes are harmonized across different shocks. We assume that the persistence parameters $\{\rho_a, \rho_\chi, \rho_\delta, \rho_\psi, \rho_\tau\}$ are beta distributed, with a prior mean equal to 0.8 and a prior standard deviation equal to 0.1. The standard errors of the innovations $\{\sigma_a, \sigma_\chi, \sigma_\delta, \sigma_\psi, \sigma_\tau\}$ follow an inverse-gamma distribution with prior mean 0.1 and a prior standard deviation of 10, which corresponds to a rather loose prior.

[3] To ensure that the results hold for different values of the job destruction rate we have estimated the model with alternative values for this parameter and established that the results in the paper are robust.

4 Estimation Results

In this section we present the estimation results. We first estimate several adjustment costs functions, assess their empirical fit, and evaluate their plausibility using the general equilibrium model. We then investigate the dynamics properties of the model by using impulse response functions and forecasting variance decompositions. Finally, we use the estimated model to provide some additional insights into the model's dynamics and compare the simulated series with their empirical counterparts.

Using the priors we estimate several versions of the model, whose posterior mean estimates and standard errors (in parenthesis) are reported in each column of Table 3. The first column shows the adjustment costs function that allows for both linear and convex capital and labour adjustment costs, and that also allows for their joint interaction, as in equation **(23)**. The second column shows the adjustment costs function that allows for capital adjustment costs only, assuming labour costs are absent, as typical in the investment literature. The third column shows the adjustment costs function that allows for labour adjustment costs only, assuming capital costs are absent, as typical in the labour demand literature. The fourth column shows the adjustment costs function that allows for quadratic costs only and no interaction between capital and labour adjustment costs, as typical in the convex adjustment costs models. The fifth column shows the adjustment costs function that allows for quadratic costs only and it also allows for interaction between capital and labour adjustment costs, as typical in convex adjustment costs models.

Before looking into the parameters' estimates we assess the overall fit of the models. In order to establish which theoretical framework fits the data more closely, we use the marginal log-likelihood. The marginal or the integrated log-likelihood represents the posterior distribution, with the uncertainty associated with parameters integrated out, and therefore it also reflects the models prediction performance. The marginal log-likelihood is approximated using the modified harmonic mean, as detailed in Geweke (1999). Considering that this criterion penalizes overparametrization, the model with the unrestricted adjustment costs function does not necessarily rank better if the extra parameters are not informative in explaining the data. As from the last row of Table 3, the marginal log-likelihood associated with the model that allows for all types of adjustment costs is the highest among the constrained alternatives and equal to 849.09. To econometrically test the extent to which the model with the highest log-likelihood improves the fit of the data over and above the alternative models, we use the posterior odds ratio. Table 4 reports the posterior odds ratios, computed as the difference between the marginal log-likelihood of the model that allows for the broader set of parameters and each of the marginal log-likelihoods of the alternative specifications. The posterior odds ratio ranges from $e^{89.24}$ to $e^{17.22}$, which provides very strong evidence in favour of the model that includes both linear and convex cost components, and that also accounts for the joint interaction between capital and labour costs. The rest of the analysis focuses on the unconstrained model, unless otherwise stated.

Table 3 displays the value of the posterior mean of the parameters together with their standard errors in parenthesis. Column 1 reports the model that allows for all types of adjustment costs and the other columns report the alternative models. The posterior mean estimates are remarkably close among models, indicating that parameter estimates are consistently and robustly estimated across the two different settings. The posterior means of the linear parameters f_1 and f_2 equal 0.003 and 0.001 respectively, showing that the linear components of both labour and capital adjustment costs are small, similarly to Bloom (2009). The convex components of the adjustment costs function are more sizeable, as the posterior means of e_1, and e_2 equal 0.949 and 4.799 respectively. Also, it is interesting to note that the estimation reveals cubic capital adjustment costs, as the posterior mean of η^1 equals 3.501, whereas the degree of convexity of labour adjustment costs component η^2 is lower and equal to 1.964. Interestingly, the posterior mean of the term that allows for the interaction between capital and labour adjustment costs, e_3, equals 1.756 and the posterior mean of η^3 equals 2.623, the latter showing an almost quadratic degree of convexity. Note that a positive posterior mean of the interaction parameter between capital and labour, e_3, implies that total and marginal costs of investment increase with hiring. As detailed below, this relation is important in establishing the dynamic response of the adjustment costs function to exogenous disturbances to the job and capital destruction rates. The posterior means of the stochastic processes show that shocks to technology, preferences and the job separation rate are more persistent than shocks to the capital destruction and tax rates. In addition, the posterior means of the volatilities of the stochastic processes show that shocks to the job separation rate are more volatile, whereas the volatility of the other shocks is of similar magnitude.

These estimates have important implications for the steady-state and the dynamics properties of the model, as we detail below, and they differ from those obtained using a single equation model, as in Merz and Yashiv (2007). In particular, the estimates of the linear terms f_1 and f_2 are close to zero and significant in our analysis, whereas they are approximately 2 and -2 with very large standard errors in the mentioned study. The estimates of the scale parameters e_1, e_2 and e_3 are also different, as our estimates are close to zero with smaller standard errors compared to Merz and Yashiv (2007) and, importantly for the model's dynamics, as detailed below, the parameter e_3 is small and positive (equal to 1.7559), whereas it is large and negative (equal to -103.85) in the mentioned study. Finally, we find that the estimates of the elasticity of adjustment costs with respect to the different arguments η^1, η^2, and η^3 show that nonlinearities characterize adjustment costs. However, our estimates suggest that η^2 is quadratic and η^1 and η^3 are cubic, whereas Merz and Yashiv (2007) find that η^1 and η^2 are quadratic and η^3 is cubic. Our general equilibrium approach entails a few important differences compared to the partial equilibrium analysis in Merz and Yashiv (2007). First, the stochastic discount factor is the discounted growth of real consumption, whereas it is the real interest rate in the partial equilibrium setting. Second, the wage rate becomes endogenous, as defined in equation **(20)**, whereas it is assumed exogenous in the single equation estimation. Third, the model satisfies the aggregate resource constraint, as in equation **(21)**. Finally, the general equilibrium approach provides tight estimation restrictions that link the agent's decision rules with the coefficients in the asset price equation. Such restrictions are absent in the partial equilibrium analysis and therefore the model has higher degrees of freedom to match the data. Importantly, the estimates from the general equilibrium model are consistent with the rest of the model and generate a plausible steady state, whereas this is not the case in the partial equilibrium analysis. This is immediately apparent if we compare the implied steady-state share of total adjustment costs with respect to output, g/y. From equation **(23)**, we can easily derive $g/y = \left[f_1\delta + f_2\psi + \frac{e_1}{\eta_1}\delta^{\eta_1} + \frac{e_2}{\eta_2}\psi^{\eta_2} + \frac{e_3}{\eta_3}(\delta\psi)^{\eta_3}\right]$, since $i/k = \delta$, $i/k = \psi$ from equations **(5)** and **(6)** respectively. If we calibrate the parameters of this equation with our estimated values, g/y equals approximately 1.98%, whereas it equals approximately -14% if calibrated with the estimates in Merz and Yashiv (2007). This shows that accounting for general equilibrium effects in the estimation has two important advantages: first, it improves the accuracy of the estimates and, second, it delivers a plausible steady state for the endogenous variables.[4]

We now evaluate the plausibility of these adjustment costs estimates exploiting the long-run

[4]To investigate the implication of using the estimates for the adjustment costs function (i.e. f_1,f_2,e_1,e_2,e_3,η^1,η^2,η^3) from the partial equilibrium model in Merz and Yashiv (2007), we have imposed their values in our general equilibrium model and established that they generates indeterminacy.

properties of the general equilibrium model. The steady state of the model's variables depends on the preferences and technologies as well as the parameters' estimates of the adjustment costs function. These estimates generate total adjustment costs of approximately 1.98% of total output per quarter (g/y) in the model, which is in line with the estimates based on disaggregate data reported in Bloom (2009). It is also interesting to gauge the plausibility of the marginal cost of hiring in terms of average output per worker ($g_h/(y/n)$). This value is equal to 0.45% in the model, which is equivalent to approximately 1.1 times the quarterly wage, implying that the firm pays about 14 weeks of wages to hire a marginal worker. The marginal cost of investing in terms of average output per unit of capital ($g_i/(y/k)$) is equal to 0.21. Such a value is within the range of estimates in the literature that vary between 0.04 and 0.26, as reported in Cooper and Haltiwanger (2006). Hence, overall the parameters' estimates of the adjustment costs function generate plausible adjustment costs, whose magnitude is in line with estimates based on disaggregate data.

To investigate how adjustment costs and other key variables of the model react to each exogenous disturbance, Figures 1 plots the impulse responses of selected variables to one standard deviation of each of the shocks. A few interesting results stand out. First, for shocks to technology, disutility of labour and tax rate, the reaction of the total adjustment costs, g, is driven by movements in output, which affects the overall costs of adjusting capital and labour by changing the size of production. For instance, in reaction to the technology shock, output rises, expanding production, thereby increasing the total costs of investing and hiring, whereas the effect is the opposite for shocks to the preference in the disutility of labour and the tax rate. Second, for shocks to capital depreciation and job separation rates, the reaction of the total adjustment costs is driven by movements in gross investment and hiring rates, i/k and h/n respectively. For instance, in reaction to an increase in the job separation rate the gross hiring rate rises, pushing total adjustment costs upwards, despite the fall in the size of production. Third, across all shocks the reaction of the marginal costs of investing and hiring, g_i and g_h, determine the response of the asset prices for capital and labour, q^k and q^n, as from equations **(9)** and **(10)**. Moreover, movements in the firm's market value, s, mirror closely the dynamics of the asset prices for capital and labour. For instance, in reaction to the technology shock both g_i and g_h increase, thereby triggering similar movements in the asset values of capital and labour, which in turn increase the firm's market value.

To understand the extent to which each shock explains movements in the variables, Table 5 reports the asymptotic forecast error variance decompositions. The entries show that technology shocks explain short-run movements in output and in the marginal cost of investing, while they compete with preference shocks to explain fluctuation in the firm's market value. Shocks to the preference and the job separation rate explain most of the short-run fluctuations in the total adjustment costs and the marginal cost of hiring. In the long run, technology shocks continue to play a prime role on output and the firm's market value, and they explain a sizeable portion of the marginal cost of hiring and investing. Shocks to the job separation rate primarily drive total adjustment costs and contribute to fluctuations in the marginal cost of hiring, whereas shocks to technology explain together with tax rate shocks the bulk of the fluctuations in the marginal cost of investing.

The advantage of conducting the analysis in a general equilibrium framework is that we can use the model to recover estimates of the individual shocks using a Kalman smoothing algorithm, which relies on information contained in the full sample of data. By feeding the recovered shocks into the theoretical model we are able to generate estimated time series for the model's variables, which we use to provide some additional insights on the model's dynamics and evaluate the model's performance to replicate the firm's market value in the data.

One key finding in Merz and Yashiv (2007) is that factor adjustment costs enable a partial equilibrium model estimated on aggregated data to closely replicate movements in the firm's market value. Would this result hold in a general equilibrium framework? Figure 2 shows the firm's market value from the data[5] (dashed line) against the equivalent series from the theoretical model (solid line). It clearly emerges that the fully defined model is unable to replicate accurately the firm's market value in the data. In particular, movements in the model's series are of small magnitude compared to the large fluctuations in actual data. The standard deviation of the firm's market value is equal to 0.09 in the data, whereas it is equal to 0.04 in the simulated series. Moreover, the two series are weakly correlated, with a correlation coefficient of -0.06. Overall, the analysis shows that the theoretical model fails to replicate movements in the firm's market value in the data, contrary to partial equilibrium studies. Hence, despite the economic estimation finds that factor adjustment costs in both capital and labour increase the empirical

[5]The series for the firms' market value, s, are from Merz and Yashiv (2007), which are based on Hall (2001). To make the series consistent with those in the theoretical model, we detrend them using a HP filter with a smoothing parameter of 1600.

performance of the model, they are unable to explain large movements in the firm's market value once evaluated in a general equilibrium framework. This finding echoes the results in Hall (2004) based on disaggregated data.

5 Conclusion

This paper has studied the importance of factor adjustment costs in a general equilibrium model, estimated using Bayesian methods on US aggregate data. The theoretical framework is a standard production-based model enriched with labour market frictions and factor adjustment costs. Estimation reveals that adjustment costs are convex in both capital and labour costs, and it is important to allow for the joint interaction of capital and labour in the adjustment costs function. We also found that adjustment costs are small, as they represent 1.98% of total output, in line with estimates based on disaggregated data.

Using the fully defined general equilibrium model we uncovered some interesting results. We identify the effect of exogenous disturbances to technology, labour supply, job separation and capital destruction rates and tax changes. In this respect, we found that factor adjustment costs are procyclical for all shocks, except for shocks to job separation and capital destruction rates. Forecast error variance decompositions show that technology shocks drive output and factor adjustment costs in the short run, whereas shocks to the job separation rate compete with technology shocks to explain factor adjustment costs in the long run. Finally, by simulating the system over the sample period we find that it is unable to replicate the large fluctuations in the firm's market value evident in the data.

Our system approach presents several advantages compared to single equation approaches, as detailed in the paper. However, the results have to be qualified with respect to the specific structural model employed. Despite the fact that the underlying theoretical model is a prototype production-based model, its setting may be misspecified. In particular, to keep the analysis simple we made the standard assumption of period-by-period Nash bargaining over wages, whereas a staggered multiperiod wage contracting may provide a more detailed description of the labour market, as suggested in Gertler and Trigari (2009). Also, as noted above, the model is unable to replicate the large fluctuations in the firm's market value in the data, in contrast to the findings based on a partial equilibrium analysis. Beaudry and Portier (2006) show that future expectations of technological changes are key drivers of the firm's market value, whereas Hall (2001) and Hall (2004) suggest that a large stock of intangibles may explain fluctuations in the firm's market value. To enrich the model with these additional features and evaluate their interaction with factor adjustment costs and the firm's market value would certainly be an interesting task for future research.

Finally, it would also be interesting to enrich the model with nominal price rigidities, thus including nominal variables in the analysis, and to investigate the interaction between nominal and real adjustment costs on a broader set of macroeconomic aggregates. This extension also remains a valuable task for future research.

Appendix: Data Sources

The time series used to construct the five observable variables in the estimation are:

1. Real Gross Domestic Product, y: NIPA accounts, table 1.1.6, line 1

2. labour share of income, wn/y: NIPA Table 1.16, lines 19 and 24

3. Employment, n: CPS data, computed as employment level in non-agricultural industries (mnemonics LNS12032187) less government workers (LNS12032188), less self-employed workers (LNS12032192), less unpaid family workers (LNS12032193).

4. Depreciation rate of capital, δ: BEA and Fed Flow of Funds data.

5. Investment, i: BEA and Fed Flow of Funds data.

6. Capital stock, k: BEA and Fed Flow of Funds data.

7. Hiring, h: based on BLS data, adjusted as explained in Bleakley, Ferris and Fuhrer (1999).

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Table 1. Parameters Calibration

Parameter		Value
β	Discount factor	0.99
ϕ	Inverse of the Frisch intertemporal elasticity	1
α	Labour share of production	0.66
δ	Steady-state capital destruction rate	0.015
ψ	Job destruction rate	0.086
τ	Steady-state corporate income tax	0.39
η	Steady-state worker bargaining power	0.5
A	Steady-state level of technology	1
χ	Steady-state disutility of labour	1

Notes: The table shows values of the calibrated parameters.

Table 2. Prior Distribution of Parameters

Parameter	Prior distribution			
	Density	Mean	Standard Deviation	90% Interval
Adjustment cost function				
f_1	Gamma	1	0.3	[0,4.993]
f_2	Gamma	1	0.3	[0,4.993]
e_1	Normal	0	15	[-24.722,24.722]
e_2	Normal	0	15	[-24.722,24.722]
e_3	Normal	0	15	[-24.722,24.722]
η^1	Gamma	2	2	[0.107,6.112]
η^2	Gamma	2	2	[0.107,6.112]
η^3	Gamma	2	2	[0.107,6.112]
Stochastic processes				
ρ_a	Beta	0.8	0.1	[0.615,0.939]
ρ_χ	Beta	0.8	0.1	[0.615,0.939]
ρ_δ	Beta	0.8	0.1	[0.615,0.939]
ρ_ψ	Beta	0.8	0.1	[0.615,0.939]
ρ_τ	Beta	0.8	0.1	[0.615,0.939]
σ_a	Inverse Gamma	0.1	10	[0.021,0.274]
σ_χ	Inverse Gamma	0.1	10	[0.021,0.274]
σ_δ	Inverse Gamma	0.1	10	[0.021,0.274]
σ_ψ	Inverse Gamma	0.1	10	[0.021,0.274]
σ_τ	Inverse Gamma	0.1	10	[0.021,0.274]

Notes: The table shows the prior distributional forms, means, standard deviations and 90% confidence intervals of the model's estimated parameters.

Table 3. Posterior Distributions of Parameters

Parameter	Adjustment Cost Specification				
	(1)	(2)	(3)	(4)	(5)
	All	Capital	Labour	Quad no Int	Quad Int
f_1	0.0021 (0.0002)	0.0021 (0.0006)	-	-	-
f_2	0.0001 (0.0000)	-	0.0003 (0.0013)	-	-
e_1	0.9497 (0.4300)	0.0009 (0.0174	-	3.9655 (2.5785)	4.5129 (2.0493)
e_2	4.7998 (0.2275)	-	3.4818 (0.0233)	0.0040 (0.0123)	2.6546 (0.3653)
e_3	1.7559 (0.2525)	-	-	-	5.8726 (1.7265)
η^1	3.5001 (0.4248)	3.3071 (0.0272)	-	3.8601 (0.3562)	4.3158 (0.4985)
η^2	1.9636 (0.0455)	-	1.8416 (0.0025)	4.5984 (0.5840)	1.6304 (0.0971)
η^3	2.6238 (0.2014)	-	-	-	3.1087 (0.4993)
ρ_a	0.9414 (0.0233)	0.9387 (0.0428	0.9456 (0.0008	0.9467 (0.0361)	0.9636 (0.0199)
ρ_χ	0.9389 (0.0213)	0.5777 (0.0340)	0.9890 (0.0004)	0.5646 (0.0577)	0.9908 (0.0154)
ρ_δ	0.8328 (0.0517)	0.9268 (0.0334)	0.8085 (0.0020)	0.8167 (0.0802)	0.8051 (0.0795)
ρ_ψ	0.9133 (0.0152)	0.7591 (0.0074)	0.8539 (0.0010)	0.8030 (0.0515)	0.9121 (0.0301)
ρ_τ	0.8387 (0.0240)	0.8807 (0.0057)	0.9553 (0.0020)	0.9015 (0.0317)	0.8931 (0.0329)
σ_a	0.0334 (0.0013)	0.0285 (0.0005)	0.0326 (0.0000)	0.0314 (0.0025)	0.0314 (0.0019)
σ_χ	0.0420 (0.0017)	0.0366 (0.0012)	0.0400 (0.0003)	0.0373 (0.0029)	0.0399 (0.0028)
σ_δ	0.0288 (0.0011)	0.0248 (0.0003)	0.0315 (0.0002)	0.0295 (0.0018)	0.0294 (0.0019)
σ_ψ	0.0751 (0.0036)	0.0658 (0.0006)	0.0869 (0.0004)	0.0649 (0.0061)	0.0778 (0.0054)
σ_τ	0.0329 (0.0012)	0.0231 (0.0007)	0.0354 (0.0003)	0.0348 (0.0024)	0.0344 (0.0024)
Marginal Log-Likel	849.09	759.85	829.11	778.96	831.87

Notes: Each entry shows the posterior mean estimate with the standard error in brackets. To approximate the posterior distribution, a random walk Metropolis-Hastings algorithm is used, based on 50,000 replications, whose first 25,000 are discarded as burn-in.

Table 4. Posterior Odds Ratios

Adjustment Cost Specification	Posterior Odds Ratio
Capital	$e^{89.24}$
Labour	$e^{19.98}$
Quadratic, no Interaction	$e^{70.13}$
Quadratic, Interaction	$e^{17.22}$

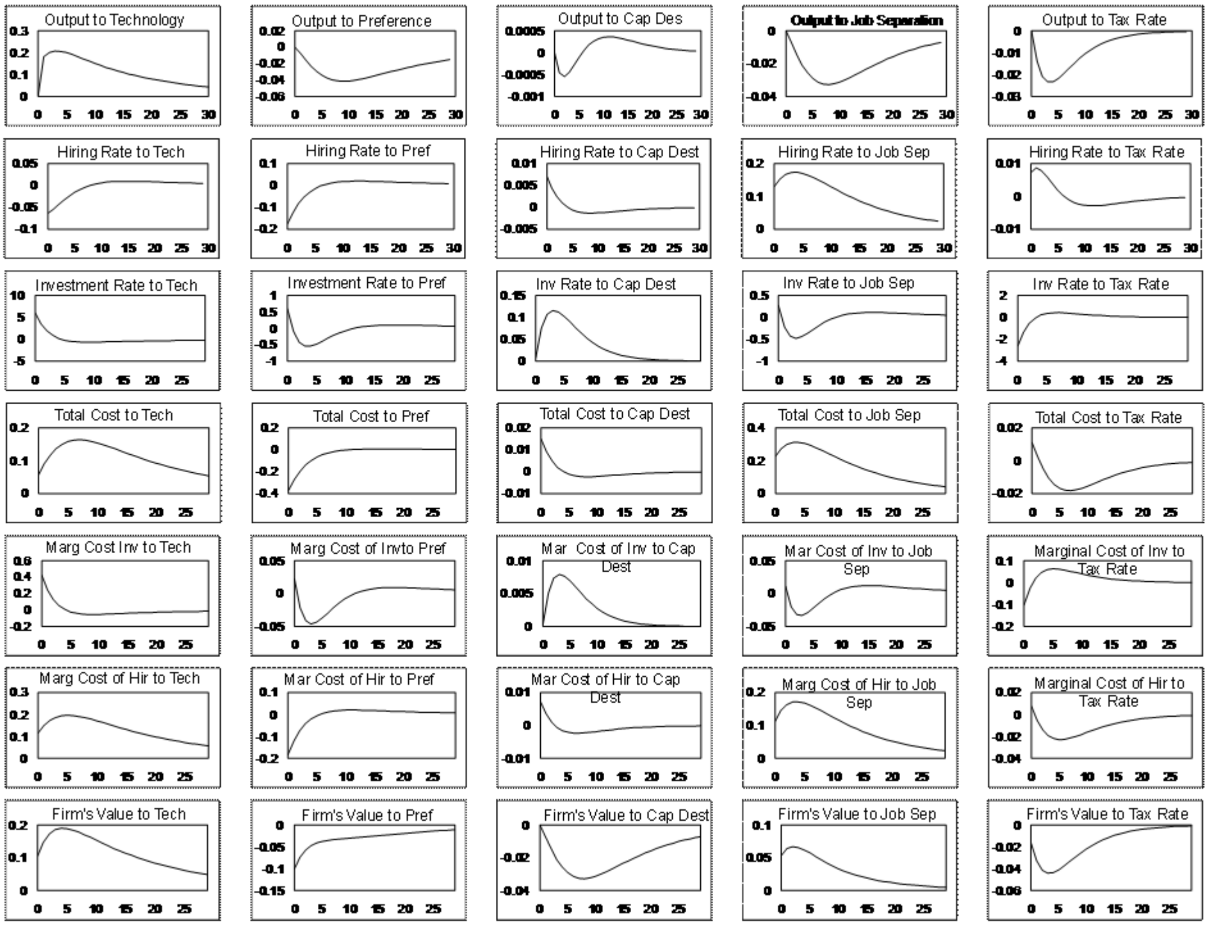
Notes: Each entry shows the posterior odds ratio computed as the difference between the marginal likelihood of the model that allows for the broader set of parameters, reported in the bottom line of column 1 of Table 3, and each of the marginal likelihood of the alternative specification, reported in the bottom line of columns 2-5 of Table 3.

Table 5. Forecast Error Variance Decompositions

Quarters Ahead	Technology	Preference	Capital Destruction Rate	Job Destruction Rate	Tax Rate
Output					
1	100	0	0	0	0
4	97.37	0.63	0	0.98	1.02
8	93.40	2.29	0	3.05	1.26
12	90.72	3.70	0	4.45	1.13
20	88.51	5.14	0	5.40	0.95
36	87.85	5.82	0	5.47	0.86
Firm's Market Value					
1	35.98	42.24	0.02	20.59	1.16
4	58.76	15.81	0.01	21.18	4.25
8	68.07	9.50	0.01	17.94	4.49
12	72.08	8.07	0.01	15.81	4.03
20	75.28	7.46	0.01	13.83	3.42
36	75.84	7.28	0.00	12.77	3.10
Total Adjustment Costs					
1	1.09	60.30	0.07	38.47	0.07
4	4.11	31.43	0.08	64.40	0.04
8	7.36	17.95	0.02	74.57	0.10
12	9.44	13.78	0.01	76.64	0.13
20	11.64	11.48	0.01	76.73	0.14
36	13.06	10.82	0.01	75.97	0.13
Marginal Cost of Investing					
1	91.64	0.36	0.00	0.17	7.83
4	88.77	2.12	0.05	2.14	6.93
8	80.66	3.65	0.09	3.02	12.58
12	78.66	3.52	0.10	2.92	14.80
20	77.83	3.52	0.10	3.45	15.09
36	77.59	3.70	0.10	3.79	14.83
Marginal Cost of Hiring					
1	16.04	51.37	0.06	32.43	0.11
4	27.30	18.94	0.02	53.49	0.26
8	32.93	9.22	0.01	57.35	0.49
12	35.91	6.94	0.01	56.62	0.52
20	39.19	5.80	0.01	54.52	0.47
36	41.48	5.46	0.01	52.62	0.44

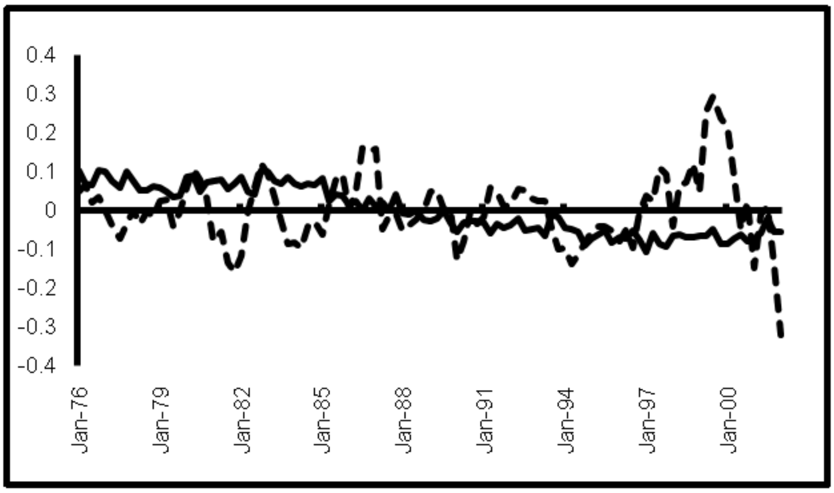
Notes: Forecast error variance decompositions are performed at the mean of the posterior distribution of the estimated parameters.

Figure 1. Variables Responses to Shocks



Notes: Each panel shows the percentage-point response in one of the model's endogenous variables to a one-standard-deviation innovation in one of the model's exogenous shocks. Periods along the horizontal axes correspond to quarter years.

Figure 2. Firm's Market Value, Data and Model



Notes: The figure shows the firm's market value in the data (dashed line) against the equivalent series in the theoretical model (solid line).