The New Keynesian Phillips Curve: the Role of Hiring and Investment Costs

Preliminary

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Abstract

We embed convex hiring and investment costs and their interaction in a New Keynesian DSGE model with Nash wage bargaining. We explore the implications with respect to inflation dynamics in the New Keynesian Phillips curve. We use two structural estimation methods (GMM and Bayesian estimation) and two aggregate data sets (the U.S. and the U.K. economies). Our results indicate that :

(i) one-step ahead inflation rate predictions are much closer to the data in the model with hiring and investment costs than in the standard New-Keynesian model without these costs.

(ii) The model provides new estimates for hiring and investment frictions, price adjustment costs, wage bargaining power and the disutility of labor.

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1 Introduction

New Keynesian models (see Woodford (2003) and Gali (2008) and Christiano et al (2010) for surveys and discussions) posit that inflation dynamics are driven by expected future real marginal costs. In this paper we allow for convex hiring and investment costs and their interaction to play a substantial role in marginal costs and explore the implications with respect to inflation dynamics. We embed these frictions in a New Keynesian DSGE model with Nash wage bargaining and estimate the model using two structural estimation methods (GMM and Bayesian estimation) and two aggregate data sets (the U.S. and the U.K. economies). In doing so the paper follows work that has structurally estimated the New Keynesian Phillips Curve, such as that of Gali and Gertler (1999), Sbordone (2005) and Krause, Lopez-Salido and Lubik (2008), to name just a number of key papers in this literature. It follows work by Merz and Yashiv (2007) and Yashiv (2011) in formulating convex hiring and investment costs and structurally estimating their functional form and time series behavior.

At this point our key results are that:

(i) one-step ahead inflation rate predictions are much closer to the data in the model with hiring and investment costs than in the standard New-Keynesian model without these costs.

(ii) The model provides new estimates for hiring and investment frictions, price adjustment costs, wage bargaining power and the disutility of labor.

In what follows Section 2 presents the model, Section 3 the data and the estimation methodology, Section 4 the results, and Section 5 concludes. Technical matters are relegated to appendices.

2 The Model

The model is a New Keynesian one with hiring and investment frictions. It combines several approaches: the basic New Keynesian part of it is in the spirit of the models discussed in Gali (2008); in its considerations of labor market frictions and Nash wage bargaining it follows the same route as the work of Krause, Lopez-Salido and Lubik (2008); and investment costs in this setting have been modelled by Woodford (2003, see Section 5.3). In what follows we look in detail at households, three types of firms, the monetary authority and the aggregate economy. The model features three sources of frictions: price adjustment costs, costs of hiring workers and costs of installing capital. It has three shocks: a preference shock, a neutral technology shock and a monetary policy shock.

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2.1 Households

The representative household comprises a unit measure of workers searching for jobs in a frictional labour market. At the end of each time period workers can be either employed or unemployed. The household enjoys utility from the aggregate consumption index C_t and disutility from employment, N_t. Employed workers earn the nominal wage W_t and hold nominal bonds denoted by B_t. Both variables are expressed in units of consumption, which is the numeraire. The budget constraint is:

$$P_t^C C_t + \frac{B_{t+1}}{R_t} = W_t N_t + B_t + \Upsilon_t, \tag{1}$$

where $R_t = (1 + i_t)$ is the gross nominal interest rate, P_t^C is the price of the consumption good and Υ_t is a lump sum component of income which includes dividends from ownership of firms and government transfers.

The labour market is frictional and workers who are unemployed at the beginning of each period t are denoted by U_t^0. It is assumed that these unemployed workers can start working in the same period if they find a job with probability $x_t = \frac{H_t}{U_t^0}$, where H_t denotes the total number of matches. It follows that the workers who remain unemployed for the rest of the period, denoted by U_t, is $U_t = (1 - x_t)U_t^0$. At the end of each period t employed workers lose their job with probability $\delta_{N,t}$. Consequently, the evolution of aggregate employment N_t is:

$$N_t = (1 - \delta_{N,t})N_{t-1} + x_t U_t^0. \tag{2}$$

The intertemporal problem of the households is to maximise the discounted present value of current and future utility:

$$\max E_t \sum_{j=0}^{\infty} \beta^j \vartheta_{t+j} \left(\ln C_{t+j} - \frac{\chi}{1+\varphi} N_{t+j}^{1+\varphi} \right),$$

subject to the budget constraint (1) and the law of motion of employment (2). The parameter $\beta \in (0,1)$ denotes the discount factor, φ is the inverse Frisch elasticity of labour supply, $\chi > 0$ is a scale parameter and ϑ_t denotes a preference shock, which is assumed to follow the process $ln\vartheta_t = \rho_\vartheta ln\vartheta_{t-1} + e_t^\vartheta$, with $e_t^\vartheta \sim N(0, \sigma_\vartheta)$.

The Lagrangean is:

$$\begin{aligned}
\max \mathcal{L} =& E_t \sum_{j=0}^{\infty} \beta^j \vartheta_{t+j} \Bigg\{ \ln C_{t+j} - \frac{\chi}{1+\varphi} N_{t+j}^{1+\varphi} \\
& -\lambda_{t+j} P_{t+j}^C \mathcal{V}_{t+j}^N \left\{ N_{t+j} - (1 - \delta_{N,t+j}) N_{t+j-1} - x_{t+j} U_{t+j}^0 \right\} \\
& -\lambda_{t+j} \left[P_{t+j}^C C_{t+j} + \frac{B_{t+j+1}}{R_{t+j}} - W_{t+j} N_{t+j} - B_{t+j} \right] \Bigg\}
\end{aligned}$$

The FOCs with respect to C_t, B_{t+1}, and N_t are:

$$\lambda_t = \frac{1}{P_t^C C_t}, \tag{3}$$

$$\frac{1}{R_t} = \beta E_t \frac{P_t^C C_t}{P_{t+1}^C C_{t+1}} \frac{\vartheta_{t+1}}{\vartheta_t}, \tag{4}$$

$$\mathcal{V}_t^N = \frac{W_t}{P_t^C} - \chi N_t^{\varphi} C_t + \beta \left(1 - \delta_{N,t+1}\right) E_t \frac{C_t}{C_{t+1}} \mathcal{V}_{t+1}^N. \tag{5}$$

In the competitive benchmark the marginal rate of substitution equals the real wage: $\frac{W_t}{P_t^C} = \chi N_t^{\varphi} C_t$, which determines labour supply.

2.2 Firms

We assume three types of firms: intermediate good producers, final good producers and retailers. Intermediate producers hire labour and invest in capital to produce a homogeneous product, which is then sold to final producers in perfect competition. Final producers transform each unit of the homogeneous product into a unit of a differentiated product facing price rigidities a la Calvo. This separation between intermediate and final firms is often assumed to get around the difficulties that arise whenever the bargaining problem and the price setting decisions are concentrated in the same firm.

We also assume that retailers buy a bundle of differentiated goods from the final producers and transform it into homogeneous consumption and investment goods. In turn, these goods are sold in perfect competition to consumers and intermediate firms, respectively. A key assumption is that the transformation technology may differ in the consumption and in the investment sector, which generates a relative price for investment goods.

Retailers

We assume that there is a continuum of retailers that buy the final output good and converts it into consumption and investment. The final good is a Dixit-Stiglitz aggregator of a bundle of differentiated goods:

$$Y_t = \left(\int_0^1 Y_t(i)^{(\epsilon-1)/\epsilon} di \right)^{\epsilon/(\epsilon-1)},$$

where ϵ denotes the elasticity of substitution across varieties. Denoting by $P_t^Y(i)$ the price of a variety produced by a monopolistic competitor i, the expenditure minimising price index associated with the output index Y_t is:

$$P_t^Y = \left(\int_0^1 P_t^Y(i)^{1-\epsilon} di \right)^{1/(1-\epsilon)}.$$

The retailers, which are defined on the zero to one interval in each sector, are assumed to operate under perfect competition. The transformation technology in the consumption sector is $C_t = Y_t^C$, where Y_t^C denotes the amount of final good that is used in the production of the consumption good. The maximisation problem of the representative consumption retailer is:

$$\max_{Y_t^C} P_t^C Y_t^C - P_t^Y Y_t^C, \tag{6}$$

which implies that

$$P_t^C = P_t^Y. \tag{7}$$

The transformation technology in the investment sector is $I_t = q_t Y_t^I$, where Y_t^I denotes the amount of final good that is used in the production of the investment good and q_t follows the stochastic process $lnq_{t+1} = \rho_q \ln q_t + e_q$, and $e_q \sim N(0, \sigma_q)$, where e_q is an investment specific technology shock. The maximisation problem reads:

$$\max_{Y_t^I} P_t^I q_t Y_t^I - P_t^Y Y_t^I, \tag{8}$$

which, together with equation (7) implies that $\frac{P_t^I}{P_t^Y} = \frac{P_t^I}{P_t^C} = \frac{1}{q_t}$.

Intermediate producers

A unit measure of intermediate producers sell homogeneous goods to final producers in perfect competition. Intermediate firms combine physical capital, K, and labour, N, in order to produce intermediate output goods, Z. The constant returns to scale production function is $A_t f(N_t, K_{t-1}) = A_t N_t^\alpha K_{t-1}^{1-\alpha}$, where A_t is a stochastic variable capturing neutral technology shocks and is assumed to follow the process $lnA_t = \rho_a lnA_{t-1} + e_t^a$, with $e_t^a \sim N(0, \sigma_a)$. It is assumed that hiring and investment are expensive activities. Hiring costs include advertising, screening and training. Investment costs include installation costs, learning the use of new equipment, etc. All these activities, which imply some disruption in the production process, are captured by the adjustment cost function $g(I_t, K_{t-1}, H_t, N_t)$, where I denotes investment, and H denotes hires. These adjustment costs are thought of as forgone output. Following Merz and Yashiv (2007) and Yashiv (2011) we assume that this function is constant returns to scale and is increasing in each of the firm's decision variables. We also allow for the interaction of investment and hiring adjustment costs. In particular, we assume the following explicit functional form:

$$g(I_t, K_{t-1}, H_t, N_t) = \left[f_1 \frac{I_t}{K_{t-1}} + f_2 \frac{H_t}{N_t} + \frac{e_1}{\eta_1} \left(\frac{I_t}{K_{t-1}} \right)^{\eta_1} + \frac{e_2}{\eta_2} \left(\frac{H_t}{N_t} \right)^{\eta_2} + \frac{e_3}{\eta_3} \left(\frac{I_t}{K_{t-1}} \frac{H_t}{N_t} \right)^{\eta_3} \right] A_t N_t^\alpha K_{t-1}^{1-\alpha} \tag{9}$$

The net output of a representative firm at time t is:

$$Z_t = A_t f(N_t, K_{t-1}) - g(I_t, K_{t-1}, H_t, N_t).$$

In every period t, the existing capital stock depreciates at the rate $\delta_{K,t}$ and is augmented by new investment:

$$K_t = (1-\delta_{K,t})K_{t-1} + I_t, \quad 0 \leq \delta_{K,t} \leq 1. \tag{10}$$

Similarly, the number of a firm's employees decreases at the rate $\delta_{N,t}$ and it is augmented by new hires H_t. The law of motion for employment reads:

$$N_t = (1-\delta_{N,t})N_{t-1} + H_t, \quad 0 \leq \delta_{N,t} \leq 1. \tag{11}$$

Notice that we have assumed that new hires are immediately productive. If this were not the case, then output would be predetermined.

At the beginning of each period, firms hire new workers and invest in capital. Next, wages are negotiated following a standard Nash bargaining criterion. When maximising its market value, defined as the present discounted value of future cash flows, the representative producer anticipates the impact of its hiring and investment policy on the bargained wage. The intertemporal maximisation problem of the firm reads as follows:

$$\max E_t \sum_{j=0}^{\infty} \Lambda_{t,t+j} \left\{ (1-\tau) \left[mc_{t+j} \left(A_{t+j} f(N_{t+j}, K_{t+j-1}) - g(I_{t+j}, K_{t+j-1}, H_{t+j}, N_{t+j}) \right) \right. \right. ,$$

$$\left. \left. - \frac{W_{t+j}(I_{t+j}, K_{t+j-1}, H_{t+j}, N_{t+j})}{P^C_{t+j}} N_{t+j} - \frac{P^I_{t+j}}{P^C_{t+j}} I_{t+j} \right] \right\},$$

subject to the laws of motion for capital (10) and labour (11), where $\Lambda_{t,t+j} = \beta^j \frac{C_t}{C_{t+j}} \frac{\vartheta_{t+j}}{\vartheta_t}$ is the real discount factor of the households who own the firms and $mc_t \equiv P^Z_t / P^C_t$ is the relative price of the intermediate firm's good. This relative price will equal the real marginal cost for a final goods producer since, as we describe later, such producers transform one unit of intermediate good into one unit of final good that, in equilibrium, they will sell at $P^Y_t = P^C_t$.

The first-order conditions for dynamic optimality are:

$$\mathcal{Q}^K_t = E_t \Lambda_{t,t+1} \left[(1-\tau_{t+1}) \left(mc_{t+1}(A_{t+1} f_{K,t+1} - g_{K,t+1}) - \frac{W_{K,t+1}}{P_{t+1}} N_{t+1} \right) + (1-\delta_{K,t+1}) \mathcal{Q}^K_{t+1} \right] \tag{12}$$

$$\mathcal{Q}^K_t = (1-\tau_t) \left(mc_t g_{I,t} + \frac{W_{I,t}}{P^C_t} N_t + \frac{P^I_t}{P^C_t} \right), \tag{13}$$

$$\mathcal{Q}^N_t = (1-\tau_t) \left[mc_t \left(A_t f_{N,t} - g_{N,t} \right) - \frac{W_t}{P^C_t} - \frac{W_{N,t}}{P^C_t} N_t \right] + (1-\delta^{t+1}_N) E_t \Lambda_{t,t+1} \mathcal{Q}^N_{t+1} \tag{14}$$

$$\mathcal{Q}^N_t = (1-\tau_t) \left(mc_t g_{H,t} + \frac{W_{H,t}}{P^C_t} N_t \right), \tag{15}$$

where $\mathcal{Q}_t^K$ and $\mathcal{Q}_t^N$ are the Lagrange multipliers associated with the capital and the employment laws of motion, respectively.

Substituting for $\mathcal{Q}_t^K$ and $\mathcal{Q}_t^N$, the four equations above can be rewritten:

$$\left(mc_t g_{I,t} + \frac{W_{I,t}}{P_t^C} N_t + \frac{P_t^I}{P_t^C}\right) = E_t \Lambda_{t,t+1} \frac{(1-\tau_{t+1})}{(1-\tau_t)} \left\{ mc_{t+1}(A_{t+1} f_{K,t+1} - g_{K,t+1}) - \frac{W_{K,t+1}}{P_{t+1}} N_{t+1} \right.$$

$$\left. + (1-\delta_{K,t+1})(mc_{t+1} g_{I,t+1} + \frac{W_{I,t+1}}{P_{t+1}^C} N_{t+1} + \frac{P_{t+1}^I}{P_{t+1}^C}) \right\} \tag{16}$$

$$mc_t g_{H,t} + \frac{W_{H,t}}{P_t^C} N_t = mc_t \left(A_t f_{N,t} - g_{N,t}\right) - \frac{W_t}{P_t^C} - \frac{W_{N,t}}{P_t^C} N_t$$

$$+ (1-\delta_{N,t+1}) E_t \Lambda_{t,t+1} \frac{(1-\tau_{t+1})}{(1-\tau_t)} \left(mc_{t+1} g_{H,t+1} + \frac{W_{H,t+1}}{P_{t+1}^C} N_{t+1} \right), \tag{17}$$

which offer two dynamic equations for the final goods producers' real marginal cost.

In the competitive benchmark we assume that there are no adjustment costs. This implies that the marginal rate of substitution equals the marginal revenue product of employment: $W_t/P_t^C = mc_t A_t f_{n,t}$. It also implies that the user cost of capital equals the marginal revenue product of capital: $E_t \frac{1-\tau_t}{1-\tau_{t+1}} \frac{P_t^I}{P_t^C} R_t/\pi_{t+1} = E_t mc_{t+1} A_{t+1} f_{k,t+1} + (1-\delta_{K,t+1}) \frac{P_{t+1}^I}{P_{t+1}^C}$.

Final good producers

There is a unit measure of monopolistically competitive final good firms indexed by $i \in [0,1]$. Each firm i transforms $Z(i)$ units of the intermediate good into $Y(i)$ units of a differentiated good, where $Z(i)$ denotes the amount of intermediate input used in the production of good i. Monopolistic competition implies that each final firm i faces the following demand for its own product:

$$Y_t(i) = \left(\frac{P_t^Y(i)}{P_t^Y}\right)^{-\epsilon} Y_t, \tag{18}$$

where Y_t denotes aggregate demand from the retailers.

We assume price stickiness à la Rotemberg, meaning firms maximise current and expected discounted profits subject to quadratic price adjustment costs.

Final good firms maximise the following expression:

$$\max E_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \frac{P_t^Y}{P_{t+s}^Y} \left[\left(P_{t+s}^Y(i) - P_{t+s}^Y mc_{t+s}\right) Y_{t+s}(i) - \frac{\zeta}{2} \left(\frac{P_{t+s}^Y(i)}{P_{t+s-1}^Y(i)} - 1 \right)^2 P_{t+s}^Y Y_{t+s} \right],$$

subject to the demand function (18). The first order conditions with respect to $P_t^Y(i)$ and $Y_t(i)$

read as follows:

$$Y_t(i) - \zeta \left(\frac{P_t^Y(i)}{P_{t-1}^Y(i)} - 1 \right) \frac{1}{P_{t-1}^Y(i)} P_t^Y Y_t = \eta_t \varepsilon \frac{Y_t}{P_t^Y} \left(\frac{P_t^Y(i)}{P_t^Y} \right)^{-\varepsilon-1}$$

$$-\Lambda_{t,t+1} \frac{P_t^Y}{P_{t+1}^Y} \zeta \left(\frac{P_{t+1}^Y(i)}{P_t^Y(i)^2} \right) \left(\frac{P_{t+1}^Y(i)}{P_t^Y(i)} - 1 \right) P_{t+1}^Y Y_{t+1}, \tag{19}$$

and

$$\eta_t = P_t^Y(i) - P_t^Y \cdot mc_t, \tag{20}$$

where η_t is the Lagrange multiplier associated with eq. (18).

Since all firms set the same price and therefore produce the same output at equilibrium, equations (19) and (20) can be combined to obtain the following law of motion for inflation:

$$\pi_t(1+\pi_t) = \frac{1-\varepsilon}{\zeta} + \frac{\varepsilon}{\zeta} mc_t + E_t \frac{1}{1+r_t} (1+\pi_{t+1}) \pi_{t+1} \frac{y_{t+1}}{y_t}, \tag{21}$$

where r_t denotes the real interest rate and we have used $E_t \Lambda_{t,t+1} = \frac{1}{(1+i_t)/(1+\pi_{t+1})} = \frac{1}{1+r_t}$. Equation (21) specifies that inflation depends on marginal costs as well as expected future inflation. Solving forward equation (21), it is possible to show that inflation depends on current and expected future real marginal costs.

In order to understand the driving forces of inflation in this model, it is worth solving the FOCs for employment and capital in equations (12) and (14) for real marginal cost. Rearranging equation (14) we get the following expression:

$$mc_t = \frac{\frac{W_t}{P_t^C}}{A_t f_{N,t} - g_{N,t}} + \frac{\frac{W_{N,t}}{P_t^C} N_t}{A_t f_{N,t} - g_{N,t}} + \frac{1}{1-\tau} \frac{\mathcal{Q}_t^N - (1-\delta_N) E_t \Lambda_{t,t+1} \mathcal{Q}_{t+1}^N}{A_t f_{N,t} - g_{N,t}}. \tag{22}$$

The first term in the above equation is real unit labour cost, expressed as the ratio of real wages to the net marginal product of labour. The second term is a correction for intra-firm bargaining. Since the marginal product of labour is decreasing with the size of the firm, the marginal worker will decrease the marginal product of labour and the wage bargained by all workers. Having assumed strategic hiring behaviour, the impact of the marginal hire on the negotiated wage bill will affect the marginal cost. The third term shows that with frictions in the labour market, marginal costs depend on expected changes in the marginal value of employment, a point already made by Krause, Lopez Salido and Lubik (2008). In this model the marginal value of employment equals the sum of the marginal hiring cost and the impact of the marginal hire on the negotiated wage bill (equation 15).

Having assumed that capital generates rents, marginal costs will also be related to the dynamics of capital. Rearranging equation (12) to solve for expected real marginal cost next period one gets the following expression:

$$E_t mc_{t+1} = E_t \frac{\frac{W_{K,t+1}}{P_{t+1}} N_{t+1}}{A_{t+1} f_{K,t+1} - g_{K,t+1}} + \frac{1}{\Lambda_{t,t+1}(1-\tau)} E_t \frac{\mathcal{Q}_t^K - \Lambda_{t,t+1}(1-\delta_K)\mathcal{Q}_{t+1}^K}{A_{t+1} f_{K,t+1} - g_{K,t+1}}. \tag{23}$$

The first term in equation (23) is a correction term for intrafirm bargaining. Higher capital makes workers more productive, thereby increasing the expected marginal product of labour and the bargained wage. Strategic wage bargaining implies that the impact of marginal capital on the negotiated wage bill will affect real marginal cost. The second term shows that whenever capital generates rents, expected changes in Tobin's Q will affect real marginal cost. It is worth noting that the marginal cost of investment in this model will also depend on the impact of investment on the negotiated wage bill (equation 13).

2.3 Wage Bargaining

Wages are assumed to maximise a geometric average of the household's and the firm's surplus weighted by the parameter γ, which denotes the bargaining power of the households:

$$W_t = \arg\max \left\{ \left(\mathcal{V}_t^N\right)^{\gamma} \left(\mathcal{Q}_t^N\right)^{1-\gamma} \right\}, \tag{24}$$

The first order condition to this problem leads to the Nash sharing rule:

$$(1-\gamma)\mathcal{V}_t^N = \frac{\gamma \mathcal{Q}_t^N}{1-\tau}. \tag{25}$$

Substituting (5) and (14) into the above equation and using the sharing rule (25) to eliminate the terms in $\mathcal{Q}_{t+1}^N$ and $\mathcal{V}_{t+1}^N$ one gets the following expression for the real wage:

$$\frac{W_t}{P_t^C} = \gamma mc_t \left(A_t f_{N,t} - g_{N,t}\right) - \gamma \frac{W_{N,t}}{P_t^C} N_t + (1-\gamma)\chi C_t N_t^{\varphi}. \tag{26}$$

Assuming a Cobb-Douglas production function and the functional form for the adjustment cost function in (9) the solution to the differential equation in (26) reads as follows:

$$\begin{aligned} \frac{W_t}{P_t^C} = \gamma mc_t A_t K_t^{1-\alpha} \Bigg\{ & \alpha \left[1 - f_1 \frac{I_t}{K_t} - \frac{e_1}{\eta_1} \left(\frac{I_t}{K_t}\right)^{\eta_1} \right] A_1 N_t^{\alpha-1} + \left(1 - \frac{\alpha}{\eta_2}\right) e_2 H_t^{\eta_2} A_2 N_t^{\alpha-1-\eta_2} \\ & + \left(1 - \frac{\alpha}{\eta_3}\right) e_3 \left(\frac{H_t I_t}{K_t}\right)^{\eta_3} A_3 N_t^{\alpha-1-\eta_3} + (1-\alpha) f_2 H_t A_4 N_t^{\alpha-2} \Bigg\} + (1-\gamma)\chi C_t N_t^{\varphi}, \end{aligned} \tag{27}$$

where A_1, A_2, A_1, A_1 are parameters, which are reported in the Appendix A.2 together with the full derivation.

Notice that in the special case in which workers have no bargaining power, i.e., $\gamma = 0$, the real wage equals the marginal rate of substitution between consumption and leisure, as in the standard New-Keynesian model with a perfectly competitive labour market.

2.4 The Monetary Authority

The monetary authority sets the nominal interest rate following the Taylor rule:

$$\frac{R_t}{R^*} = \left(\frac{R_{t-1}}{R^*}\right)^{\rho_r} \left[\left(\frac{1+\pi_t}{1+\pi^*}\right)^{r_\pi} \left(\frac{y_t}{y^*}\right)^{r_y}\right]^{1-\rho_r} \xi_t,$$

where an asterisk superscript denotes the steady-state values of the associated variables and π_t measures the rate of inflation of the consumption good. The parameter ρ_r represents interest rate smoothing, and r_y and r_π govern the response of the monetary authority to deviations of output and inflation from their steady-state values. The term ξ_t captures a monetary policy shock, which is assumed to follow the process $ln\xi_t = \rho_\xi ln\xi_{t-1} + e_t^\xi$, with $e_t^\xi \sim N(0, \sigma_\xi)$.

2.5 Aggregation

Aggregating output demand in units of the consumption good implies the following relationship between the consumption and investment demand from the representative retailer and aggregate supply of the final good:

$$C_t + \frac{P_t^I}{P_t^C} I_t = Y_t = \left(\int_0^1 Y_t(i)^{(\epsilon-1)/\epsilon} di\right)^{\epsilon/(\epsilon-1)}. \tag{28}$$

Aggregating on the supply side of the economy implies the following relationship between final goods and intermediate inputs:

$$Z_t = A_t f(N_t, K_{t-1}) - g(I_t, K_{t-1}, H_t, N_t) = \int_0^1 Y_t(i)\, di = Y_t \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} di = Y_t, \tag{29}$$

where $\int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} di = 1$ since with Rotemberg pricing there is no price dispersion in equilibrium.

Combining the expressions in (28) and (29) implies that:

$$C_t + \frac{P_t^I}{P_t^C} I_t = A_t f(N_t, K_{t-1}) - g(I_t, K_{t-1}, H_t, N_t). \tag{30}$$

3 Data and Estimation Methodology

We employ two structural estimation methodologies, GMM and Bayesian estimation and consider two aggregate data sets, on the U.S. and on the U.K. economies. We present the data and then discuss each methodology in turn.

3.1 The Data

The model is estimated on US data over the period 1985 Q1 to 2007 Q4 and on UK data over the period 1997 Q2 to 2010 Q4.

3.1.1 US Data

The data are quarterly, pertain to the private sector of the US economy, and cover the period 1985-2007. Although information on all the time series we need is available from 1976 onward, we restrict the sample to concentrate on a time period which is characterized by a single monetary policy regime in which Paul Volcker and Alan Greenspan were Federal Reserve Chairmen. The data include NIPA data on GDP and its deflator, capital, investment, the price of investment goods and depreciation, BLS CPS data on employment and on worker flows, and Fed data on the constituents of the discount factor and on tax and depreciation allowances (Fed computations). Appendix B elaborates on the sources and on data construction. These data have the following features:

(i) The data pertain to the U.S. private sector, thus not confounding the analysis with government hiring and investment.

(ii) Both hiring h and investment i refer to gross flows. Likewise, separation of workers δ_N and depreciation for capital δ_K are gross flows.

(iii) The estimating equations take into account taxes and depreciation allowances.

Points (ii) and (iii) require a substantial amount of computation, which is contained in Appendix B.

3.1.2 UK Data

Again the UK data are quarterly, range from 1997 Q2 to 2010 Q4, and cover only the private sector. Although we would like to go back further, unfortunately we only have data on hiring and job separations since 1997 Q2. That said, this does mean that the monetary policy framework was stable over the entire period. Private-sector output is defined as GDP less expenditure on actual and imputed rents and general government final consumption and investment expenditure plus total general government procurement of private-sector goods and services and its construction is described in Harrison *et al.* (2005). We use the deflator associated with this variable as our price index. For consumption, we used the *National Accounts* measure of consumption less expenditure on actual and imputed rents. We use data on business investment from the Office for National Statistics together with a measure of business-sector capital and its associated deflator, whose construction is described in Oulton and Srinivasan (2003). For business taxes we use the headline rate of corporation tax. For the interest rate facing investors, we used a measure of the weighted average cost of capital, weighting together the rates of interest on corporate bonds and corporate loans from banks with the cost of capital implied by equity prices. The labour share is measured as total compensation of private-sector workers (including self-employed) divided by nominal private-sector output. (Again, see Harrison *et al.* (2005) for more description.) We use data on the total flow into employment and private-sector employment including self-employed from the *Labour Force Survey* as our measures of hiring and employment, respectively. The separation rate is calculated as the total flow out of employment divided by private-sector employment including self-employed, again from the *Labour Force Survey*.

3.2 GMM Estimation

We use Hansen's (1982) GMM methodology. To estimate the model we need to parameterize the relevant functions. For the *production function* we use a standard Cobb-Douglas formulation:

$$F_t(N_t, K_{t-1}) = A_t N_t^{\alpha} K_{t-1}^{1-\alpha} \tag{31}$$

The *cost function* g, capturing the different frictions in the hiring and investment processes, is at the focus of the estimation work and merits discussion. It is meant to capture all the frictions involved, and not, say, just adjustment costs or vacancy costs. One should keep in mind that it is formulated as the cost function for the representative intermediate firm within a macroeconomic model, and not one for a single firm in a heterogenous firms micro set-up.

Functional Form. The parametric form we use is the following, generalized convex function.

$$g(I_t, K_{t-1}, H_t, N_t) = \underbrace{\left[\begin{array}{c} f_1 \frac{I_t}{K_{t-1}} + f_2 \frac{H_t}{N_t} \\ + \frac{e_1}{\eta_1}\left(\frac{I_t}{K_{t-1}}\right)^{\eta_1} + \frac{e_2}{\eta_2}\left(\frac{H_t}{N_t}\right)^{\eta_2} + \frac{e_3}{\eta_3}\left(\frac{I_t}{K_{t-1}}\frac{H_t}{N_t}\right)^{\eta_3} \end{array} \right]}_{\widetilde{g}} A_t N_t^{\alpha} K_{t-1}^{1-\alpha} \tag{32}$$

This function is linearly homogenous in its arguments I, K, H, and N. The parameters f_1, f_2, e_l, $l = 1, 2, 3$ express scale, and the parameters η_1, η_2, η_3 express the elasticity of costs with respect to the different arguments. This form is rationalized in Yashiv (2011).

We use GMM to estimate equations (16), (17) and (21). The specific form is spelled out in Appendix C. The parameters estimated are the following:

Table 1

3.3 Bayesian Estimation

Subsequently we estimate the model with Bayesian methods (see An and Schorfheide (2007) for a discussion). First, we take a first-order (log) approximation of the system of equations around a deterministic steady-state with zero inflation. We then solve the model and apply the Kalman filter to evaluate the likelihood function of the observable variables. The likelihood function and the prior distribution of the parameters are combined to obtain the posterior distributions. The posterior kernel is simulated numerically using the Metropolis-Hasting algorithm.[2] In what follows we discuss the calibrated values and the priors. The model is estimated on US data over the period 1985 Q1 to 2007 Q4 and UK data over the period 1997 Q2 to 2010 Q4. We treated three of the variables in our model: output, inflation and the interest rate facing investors. In our estimation we used the series for private-sector output, quarterly private-sector output inflation and the quarterly interest rate facing investors that we described earlier. The inflation and interest rate series are demeaned, while output is detrended using a HP-filter with smoothing parameter 1600. Within the model, we considered three shocks: the preference shock, the productivity shock and the monetary policy shock described earlier. All shocks are assumed to follow a first-order autoregressive process with i.i.d. normal errors.

The model contains 20 structural parameters, excluding the shock parameters. Some of these parameters were kept fixed during the estimation, either because they were not identified, or because they made the estimation unstable. In order to select the prior mean of the estimated parameters or to assign values to the fixed parameters we follow a standard calibration exercise. We rely on two sources of information. Some parameters are set using *a priori* information, while others are normalised. The remaining ones are set so as to match the US and UK data.

We start by discussing the parameters that affect the stationary equilibrium and are either normalized or set using *a priori* information. These are summarized in Table 2.

Table 2

The discount factor β equals 0.99 implying a quarterly interest rate of 4%. The elasticity of output to the labour input α is set to 0.66. The job separation rate δ_N and the capital depreciation rate δ_K are set to match their respective values in the data, which are 0.126 and 0.0187 for the United States and 0.0322 and 0.0086 for the United Kingdom. The inverse Frisch elasticity φ is set equal to 5, as in Gali (2010). The elasticity of demand is set to 11, implying a steady-state markup of 10% as in Krause, Lopez Salido and Lubik (2008). The parameters of the adjustment cost function f_1 and f_2 are normalized to zero while the exponential terms η_1, η_2 and η_3 are set to equal 2, 2 and 1, respectively. The parameter χ in the utility function is normalised to equal 1. The workers' bargaining power is calibrated to match a US job finding rate of 0.7 as in Gali (2010), which implies a value for γ of 0.35. The US unemployment rate implied by this calibration is 5.6%,

[2] We use five blocks of 250,000 draws. The sequence of draws is stable, providing evidence on convergence.

which is the average value observed over the period 1985-2007. For the UK economy we adopt the same value of γ, which in turn implies a job finding rate of 0.4, broadly in line with the observed data.

In terms of our priors for the parameters that we estimate, we first set the prior means of our coefficients in the adjustment cost function e_1, e_2, and e_3 to the values estimated by Yashiv (2011). At the calibrated equilibrium for the US these coefficients would imply: marginal hiring costs equal to 0.4 (approximately equivalent to five weeks of wages), marginal investment cost of 1 and total adjustment costs equal to 2% of output. For the UK economy, these coefficients imply much smaller adjustment costs: a marginal hiring cost of 0.1 (approximately one week of output), marginal investment costs of 0.8 and total investment costs equal to 0.2% of output. We have experimented with prior coefficients implying much lower marginal and total adjustment costs for the US and found very similar results. In terms of the remaining parameters, which have no impact on the stationary equilibrium, we set the prior means for the coefficients on the Taylor rule to standard values in the literature – that is, responses to inflation and output of 1.5 and 0.125, respectively – while the degree of interest rate smoothing captured by the parameter ρ_r is set to equal 0.75. The prior mean for the parameter governing price stickiness is set to equal 20, as in Krause Lubik and Lopez-Salido (2008) and the prior mean for the elasticity of substitution, ε, is set to equal 11, which would imply a steady-state mark-up of 1.1.

In terms of distributions for our priors, we use the beta distribution for priors that take values between zero and one, the gamma distribution for parameters restricted to be positive, the normal distribution for parameters whose sign is left unrestricted and the inverse gamma distribution for the standard deviation of the shocks. Table 3 fully characterises the priors used for the estimation.

Table 3

4 Results

4.1 GMM Structural Estimation (preliminary)

The following table summarizes estimation results.

Table 4

Standard errors are mostly very high and consequently J statistics are relatively high with low p values. Two parameters are estimated within a tight range across specifications: α the production function parameter at around 0.68-0.69 and the bargaining power γ at $0.76-0.77$. When estimated we get φ at 1 .5 which means a Frisch elasticity of 0.67.The scale parameters χ (of the labor part of the utility function) and ζ (of the price adjustment function) are estimated at a relatively narrow range. The scale parameters of the adjustment costs function are estimated within wide ranges and huge standard errors. e_3 is negative implying complementarity between hiring and investment.

4.2 Bayesian Estimation (preliminary)

In order to evaluate whether a model with hiring and investment costs affects marginal costs in a way that is useful to explain and predict inflation, we proceed using the following steps. First, we estimate, using Bayesian methods, the full model described in Section 2 using the priors and the shocks discussed above. Next, using the same shocks, the same observables and the same priors, we estimate a restricted version of the same model, which imposes that there are no hiring and investment costs. We refer to this latter model as the "New Keynesian" model. We gauge how costs help predict inflation by computing one-step ahead inflation rate predictions for both models and compute the root mean squared error as the sum of squared deviations of the one-step ahead predictions from the actual values. In order to understand what drives the different behaviour of inflation in the two models we then compare and investigate the determinants of the estimated marginal costs series. We begin to illustrate our findings by presenting our results on the US economy in Figures 1a and 2a.

Figures 1 and 2

The main result is that the one-step ahead inflation rate predictions are much closer to the data in the model with hiring and investment costs than in the standard New-Keynesian model without these costs. The root mean squared error in the model with costs is 0.058 and compares to a figure of 0.106 in the model without costs. We illustrate this result in Figure 1a. Inflation is less volatile in the model with adjustment costs because the estimated marginal costs series is much smoother than in the model without adjustment costs. In order to gain intuition on what is driving the smooth behaviour of marginal costs, we decompose the marginal cost series in equation (22) into its three estimated components: unit labour costs, intrafirm bargaining and search frictions. As we illustrate in the following figure, search frictions have an offsetting effect on unit labour costs, which in turn produces a dampening effect on real marginal costs and inflation.

Results are less stark on UK data (see Figures 1b and 2b). Labor frictions still offset the unit labor costs, but the predicted inflation series in the models with and without adjustment costs are very similar. The root mean squared error is still smaller in the model with adjustment costs, but quantitatively less so (0.049 against 0.050). The UK series appears to be bouncing around the mean, and exhibits no autocorrelation. Most of these quarterly fluctuations do not seem to be picked-up by the determinants of our model.

An alternative way to compare how well the two models are able to fit inflation is to look at the conditional marginal data densities (MDD) of inflation. Before discussing the computation of the conditional MDD, we introduce the following notation. Let's denote the set of observables excluding inflation as D_T and the inflation series as Π_T. Let's also denote the benchmark New Keynesian model without adjustment costs as $\mathcal{M}_{NK}$, and the New-Keynesian model augmented with adjustment costs as $\mathcal{M}_{AC}$. It is possible to show that the conditional MDD of inflation for the model with adjustment costs is:

$$p(\Pi_T \mid D_T, \mathcal{M}_{AC}) = \frac{p(D_T, \Pi_T \mid \mathcal{M}_{AC})}{p(D_T \mid \mathcal{M}_{AC})},$$

where the numerator of the ratio on the right hand side is the MDD of the adjustment cost model estimated on the full sample, and the denominator is the MDD of the same model estimated on the restricted sample (the full sample less inflation). We compute the MDD of each model using the modified harmonic mean estimator introduced by Geweke (1999). Similarly, the conditional MDD of inflation in the benchmark New-Keynesian model is:

$$p(\Pi_T \mid D_T, \mathcal{M}_{NK}) = \frac{p(D_T, \Pi_T \mid \mathcal{M}_{NK})}{p(D_T \mid \mathcal{M}_{NK})}.$$

The conditional MDD can be written as:

$$p(\Pi_T \mid D_T, \mathcal{M}_{AC}) = \int p(\Pi_T \mid \Theta, D_T, \mathcal{M}_{AC})\, p(\Theta \mid D_T, \mathcal{M}_{AC})\, d\Theta,$$

where $p(\Pi_T \mid \Theta, D_T, \mathcal{M}_{AC})$ is the conditional likelihood and $p(\Theta \mid D_T, \mathcal{M}_{AC})$ is the conditional distribution of the parameters Θ.

Using US data, the conditional MDD of inflation for the AC model with adjustment costs is 286.06, and compares with a value of 258.42 in the NK model. The difference, 28 log points, is substantial and can be interpreted as strong evidence in favour of the AC model.

To provide some intuition on how large is such a difference in log-points we proceed following Melosi (2011). We perform a Bayesian test of the null hypothesis that the AC model is at odds with the behavior of inflation by comparing the conditional MDD associated with the AC and the NK models. As shown by Shorfheide (2000), under a 0-1 loss function the null is rejected if the AC model has a larger posterior probability than the NK model. The posterior probability of the model with adjustment costs denoted by $p(\mathcal{M}_{AC}|\Pi_T)$ is:

$$p(\mathcal{M}_{AC}|\Pi_T) = \frac{p(\Pi_T|D_T, \mathcal{M}_{AC})\, p_0(\mathcal{M}_{AC})}{p(\Pi_T|D_T, \mathcal{M}_{AC})\, p_0(\mathcal{M}_{AC}) + p(\Pi_T|D_T, \mathcal{M}_{NK})\, p_0(\mathcal{M}_{NK})},$$

where $p(\Pi_T|D_T, \mathcal{M}_{AC})$ and $p(\Pi_T|D_T, \mathcal{M}_{NK})$ are the conditional MDD defined above, while $p_0(\mathcal{M}_{AC})$ and $p_0(\mathcal{M}_{NK}) = 1 - p_0(\mathcal{M}_{AC})$ are the prior probabilities in favor of the two models. The null can be rejected so long as the prior probability in favour of the AC model is not less than 1E-12. So, one can conclude that the null cannot be rejected only if her prior against the AC model is extremely strong.

5 Conclusions

At this stage we can conclude that the model has the potential to explain inflation better than the standard NK model, all while providing new estimates for hiring and investment frictions, price adjustment costs, wage bargaining power and the disutility of labor. The next versions will enlarge the set of estimates and use GMM estimates to inform the Bayesian estimation.

References

[1] An, S. and Frank Schorfheide. 2007. "Bayesian Analysis of DSGE Models," **Econometric Reviews** 26, nos. 2-4 (April): 113-72.

[2] Christiano, Lawrence J., Mathias Trabandt and Karl Walentin, 2010. " DSGE Models for Monetary Policy Analysis," Chapter 7 in Benjamin M. Friedman and Michael Woodford (eds.) **Handbook of Monetary Economics Vol 3A**, 285-367, Elsevier, Amsterdam.

[3] Faccini, Rentao, Stephen P. Millard, and Francesco Zanetti, 2011. "Wage rigidities in an estimated DSGE model of the UK labour market, " Bank of England Working Paper No. 408.

[4] Hansen, Lars P., 1982. "Large sample properties of generalized method of moments estimators," **Econometrica**, 50, 1,029-54.

[5] Harrison, Richard, Kalin Nikolov, Meghan Quinn, Gareth Ramsay, Alasdair Scott and Ryland Thomas, 2005. **The Bank of England Quarterly Model**, Bank of England, London.

[6] Krause, Michael U., David Lopez-Salido and Thomas A. Lubik, 2008. "Inflation dynamics with search frictions: A structural econometric analysis," **Journal of Monetary Economics** 55, 892– 916

[7] Gali, Jordi, 2008. **Monetary Policy, Inflation and the Business Cycle: An Introduction to the New Keynesian Framework.** Princeton University Press, Princeton.

[8] Gali, Jordi, 2010. Chapter 10 in Benjamin M. Friedman and Michael Woodford (eds.) "Monetary policy and unemployment" **Handbook of Monetary Economics Vol. 3A**, 487-546, Elsevier, Amsterdam.

[9] Gali, Jordi and Mark Gertler, 1999. "Inflation dynamics: a structural econometric analysis." **Journal of Monetary Economics** 44, 195–222.

[10] Gertler, Mark, Luca Sala and Antonella Trigari, 2008. "An estimated monetary DSGE model with unemployment and staggered nominal wage bargaining." **Journal of Money, Credit and Banking**, 40, 1,713-64.

[11] Geweke, John, 1999, "Using simulation methods for bayesian econometric models: inference, development,and communication," **Econometric Reviews**, 18, 1, 1-73.

[12] Melosi, Leonardo, 2011, "Public's inflation expectations and monetary policy", London Business School, mimeo.

[13] Merz, Monika and Eran Yashiv, 2007. "Labor and the market value of the firm,"' **American Economic Review**, 97, 1,419-31.

[14] Oulton, Nicholas and Sylaja Srinivasan, 2003. "Capital stocks, capital services and depreciation: An integrated framework", Bank of England Working Paper No. 192.

[15] Sbordone, Argia, 2005. "Do expected future marginal costs drive inflation dynamics?" **Journal of Monetary Economics,** 49, 1,183-97.

[16] Smets, Frank, and Rafael Wouters, 2007. "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," **American Economic Review**, 97, 3, 586-606.

[17] Woodford, Michael, 2003. **Interest and Prices: Foundations of a Theory of Monetary Policy.** Princeton University Press, Princeton.

[18] Yashiv, Eran, 2011. "The joint behaviour of hiring and investment, " CEPR Discussion Paper No. 8,237, available at www.cepr.org/pubs/dps/DP8237.asp.

Appendix A1
The Stationary Equilibrium

Normalisation of labour force participation

$$1 = N + U \tag{33}$$

Using (2):

$$\delta_N N = \frac{x}{1-x} U \tag{34}$$

Using (17):

$$[1 - (1 - \delta_N)\,\beta] \left(mcg_H + \frac{W_H}{P} N \right) = mc(f_N - g_N) - \frac{W_N}{P} N - W^r, \tag{35}$$

where W^r denotes the real wage W/P.

Using (16):

$$[1 - (1 - \delta_K)\,\beta] \left(1 + mcg_I + \frac{W_I}{P} N \right) \delta_K = \beta \left[mc\,(f_K - g_K) - \frac{W_K}{P} N \right] \tag{36}$$

Using (26):

$$W^r = \gamma mc\,(f_N - g_N) - \gamma \frac{W_N}{P^C} N + (1-\gamma)\,\chi C N^{\varphi} \tag{37}$$

Using (30):

$$f(K, N) = C + I + g \tag{38}$$

Using (10):

$$K = \frac{I}{\delta_K} \tag{39}$$

by definition of job finding rate:

$$x = \frac{H_t}{U_t^0/\,(1-x)} \tag{40}$$

and using (21)

$$mc = \frac{\varepsilon - 1}{\varepsilon}. \tag{41}$$

This system solves for $N, U, H, I, W^r, C, K, x, mc$ once the derivatives of the wage function with respect to H, I, N, and K are substituted using equation (27).

Appendix A2
Solving for the Wage Function with Intrafirm Bargaining

We rewrite below for convenience the wage sharing rule consistent with Nash bargaining as derived in equation (25):

$$(1-\gamma)\mathcal{V}_t^N = \frac{\gamma \mathcal{Q}_t^N}{1-\tau}. \tag{42}$$

Substituting (5) and (14) into the above equation one gets:

$$\gamma \left\{ \left[mc_t \left(A_t f_{N,t} - g_{N,t} \right) - \frac{W_t}{P_t^C} - \frac{W_{N,t}}{P_t^C} N_t \right] + \beta(1-\delta_N) E_t \frac{C_t}{C_{t+1}} \frac{\mathcal{Q}_{t+1}^N}{1-\tau} \right\} =$$

$$(1-\gamma) \left[\frac{W_t}{P_t^C} - \chi N_t^{\varphi} C_t + \beta \left(1-\delta_N\right) E_t \frac{C_t}{C_{t+1}} \mathcal{V}_{t+1}^N \right].$$

Using the sharing rule in (42) to cancel out the terms in $\mathcal{Q}_{t+1}^N$ and $\mathcal{V}_{t+1}^N$ we obtain the following expression for the real wage:

$$\frac{W_t}{P_t^C} = \gamma mc_t \left(A_t f_{N,t} - g_{N,t} \right) - \gamma \frac{W_{N,t}}{P_t^C} N_t + \left(1-\gamma\right) \chi C_t N_t^{\varphi}. \tag{43}$$

Ignoring the term $\left(1-\gamma\right) \chi C_t N_t^{\varphi}$, which is independent of N_t, and dropping the time subscript with no risk of ambiguity, we can rewrite the above equation as follows:

$$W_N + \frac{1}{\gamma N} W - P^C mc \left(\frac{A f_N}{N} - \frac{g_N}{N} \right) = 0 \tag{44}$$

The solution of the homogeneous equation:

$$W_N + \frac{1}{\gamma N} W = 0, \tag{45}$$

is

$$W(N) = C N^{-\frac{1}{\gamma}}, \tag{46}$$

where C is a constant of integration of the homogeneous equation. Assuming that C is a function of N and deriving (46) w.r.t. N, yields:

$$W_N = C_N N^{-\frac{1}{\gamma}} - \frac{1}{\gamma} C N^{-1-\frac{1}{\gamma}}. \tag{47}$$

Substituting (46) and (47) into (44) one gets:

$$C_N = N^{\frac{1-\gamma}{\gamma}} P^C mc(A f_N - g_N). \tag{48}$$

Integrating (48) yields:

$$C = P^C mc \int_0^N z^{\frac{1-\gamma}{\gamma}} (Af_z - g_z) dz + D, \tag{49}$$

where D is a constant of integration. Let's solve for the two integrals in Af_z and g_z, one at a time. Assuming that $f(z, K) = z^\alpha K^{1-\alpha}$, we can write:

$$P^C mc \int_0^N z^{\frac{1-\gamma}{\gamma}} Af_z dz = P^C mc\alpha \frac{\gamma}{1-\gamma(1-\alpha)} AN^{\frac{1-\gamma(1-\alpha)}{\gamma}} K^{1-\alpha}. \tag{50}$$

Given our assumptions on the functional form of g as in (9), the function g_N can be rearranged as follows:

$$g_N = -AK^{1-\alpha}\left[e_2 H^{\eta_2} N^{\alpha-1-\eta_2} + e_3 \left(\frac{HI}{K}\right)^{\eta_3} N^{\alpha-1-\eta_3} + f_2 H N^{\alpha-2}\right].$$

$$+\alpha AK^{1-\alpha}\left[f_1 \frac{I}{K} N^{\alpha-1} + f_2 H N^{\alpha-2} + \frac{e_1}{\eta_1}\left(\frac{I}{K}\right)^{\eta_1} N^{\alpha-1} + \frac{e_2}{\eta_2} H^{\eta_2} N^{\alpha-1-\eta_2} + \frac{e_3}{\eta_3}\left(\frac{HI}{K}\right)^{\eta_3} N^{\alpha-1-\eta_3}\right] \tag{51}$$

Integrating separately the three additive terms in the first row of the above equation yields:

$$P^C mc \int_0^N z^{\frac{1-\gamma}{\gamma}} AK^{1-\alpha} e_2 H^{\eta_2} z^{\alpha-1-\eta_2} dz = P^C mc e_2 H^{\eta_2} AK^{1-\alpha} \frac{\gamma}{1-\gamma+\gamma(\alpha-\eta_2)} N^{\frac{1-\gamma+\gamma(\alpha-\eta_2)}{\gamma}}, \tag{52}$$

$$P^C mc \int_0^N z^{\frac{1-\gamma}{\gamma}} AK^{1-\alpha} e_3 \left(\frac{HI}{K}\right)^{\eta_3} z^{\alpha-1-\eta_3} dz = P^C mc e_3 \left(\frac{HI}{K}\right)^{\eta_3} AK^{1-\alpha} \frac{\gamma}{1-\gamma+\gamma(\alpha-\eta_3)} N^{\frac{1-\gamma+\gamma(\alpha-\eta_3)}{\gamma}}, \tag{53}$$

$$P^C mc \int_0^N z^{\frac{1-\gamma}{\gamma}} AK^{1-\alpha} f_2 H z^{\alpha-2} dz = P^C mc f_2 HAK^{1-\alpha} \frac{\gamma}{1-\gamma+\gamma(\alpha-1)} N^{\frac{1-\gamma+\gamma(\alpha-1)}{\gamma}}. \tag{54}$$

Integrating separately the five terms on the second row of equation (51) yields:

$$-P^C mc \int_0^N z^{\frac{1-\gamma}{\gamma}} \alpha AK^{1-\alpha} f_1 \frac{I}{K} z^{\alpha-1} dz = -P^C mc f_1 \frac{I}{K} \alpha AK^{1-\alpha} \frac{\gamma}{1-\gamma(1-\alpha)} N^{\frac{1-\gamma(1-\alpha)}{\gamma}}, \tag{55}$$

$$-P^C mc \int_0^N z^{\frac{1-\gamma}{\gamma}} \alpha AK^{1-\alpha} f_2 H z^{\alpha-2} dz = -P^C mc f_2 H \alpha AK^{1-\alpha} \frac{\gamma}{1-\gamma+\gamma(\alpha-1)} N^{\frac{1-\gamma+\gamma(\alpha-1)}{\gamma}}, \tag{56}$$

$$-P^C mc\int_0^N z^{\frac{1-\gamma}{\gamma}}\alpha AK^{1-\alpha}\frac{e_1}{\eta_1}\left(\frac{I}{K}\right)^{\eta_1}z^{\alpha-1}dz=-P^C mc\frac{e_1}{\eta_1}\left(\frac{I}{K}\right)^{\eta_1}\alpha AK^{1-\alpha}\frac{\gamma}{1-\gamma\left(1-\alpha\right)}N^{\frac{1-\gamma(1-\alpha)}{\gamma}},\tag{57}$$

$$-P^C mc\int_0^N z^{\frac{1-\gamma}{\gamma}}\alpha AK^{1-\alpha}\frac{e_2}{\eta_2}H^{\eta_2}z^{\alpha-1-\eta_2}dz=-P^C mc\frac{e_2}{\eta_2}H^{\eta_2}\alpha AK^{1-\alpha}\frac{\gamma}{1-\gamma+\gamma(\alpha-\eta_2)}N^{\frac{1-\gamma+\gamma(\alpha-\eta_2)}{\gamma}},\tag{58}$$

$$-P^C mc\int_0^N z^{\frac{1-\gamma}{\gamma}}\alpha AK^{1-\alpha}\frac{e_3}{\eta_3}\left(\frac{HI}{K}\right)^{\eta_3}z^{\alpha-1-\eta_3}dz=-P^C mc\frac{e_3}{\eta_3}\left(\frac{HI}{K}\right)^{\eta_3}\alpha AK^{1-\alpha}\frac{\gamma}{1-\gamma+\gamma(\alpha-\eta_3)}N^{\frac{1-\gamma+\gamma(\alpha-\eta_3)}{\gamma}}.\tag{59}$$

Denoting $A_1\equiv\frac{\gamma}{1-\gamma(1-\alpha)}$, $A_2\equiv\frac{\gamma}{1-\gamma+\gamma(\alpha-\eta_2)}$ $A_3\equiv\frac{\gamma}{1-\gamma+\gamma(\alpha-\eta_3)}$, $A_4\equiv\frac{\gamma}{1-\gamma+\gamma(\alpha-1)}$, we can now rewrite (49) as follows:

$$C=D+P^C mcAK^{1-\alpha}\left\{\alpha A_1N^{1/A_1}+e_2H^{\eta_2}A_2N^{1/A_2}+e_3\left(\frac{HI}{K}\right)^{\eta_3}A_3N^{1/A_3}+f_2HA_4N^{1/A_4}\right.$$
$$\left.-\alpha\left[f_1\frac{I}{K}+\frac{e_1}{\eta_1}\left(\frac{I}{K}\right)^{\eta_1}\right]A_1N^{1/A_1}-\alpha f_2HA_4N^{1/A_4}-\alpha\frac{e_2}{\eta_2}H^{\eta_2}A_2N^{1/A_2}-\alpha\frac{e_3}{\eta_3}\left(\frac{HI}{K}\right)^{\eta_3}A_3N^{1/A_3}\right\}.\tag{60}$$

Plugging (60) into (46) one gets:

$$W(N)=DN^{-\frac{1}{\gamma}}+P^C mcAK^{1-\alpha}\left\{\alpha\left[1-f_1\frac{I}{K}-\frac{e_1}{\eta_1}\left(\frac{I}{K}\right)^{\eta_1}\right]A_1N^{\alpha-1}+\left(1-\frac{\alpha}{\eta_2}\right)e_2H^{\eta_2}A_2N^{\alpha-1-\eta_2}\right.$$
$$\left.+\left(1-\frac{\alpha}{\eta_3}\right)e_3\left(\frac{HI}{K}\right)^{\eta_3}A_3N^{\alpha-1-\eta_3}+\left(1-\alpha\right)f_2HA_4N^{\alpha-2}\right\}.\tag{61}$$

In order to eliminate the constant of integration D we assume that $\lim_{N\to 0}NW(N)=0$. The solution to (43) therefore is:

$$\frac{W_t}{P_t^C}=mc_tA_tK_{t-1}^{1-\alpha}\left\{\alpha\left[1-f_1\frac{I_t}{K_{t-1}}-\frac{e_1}{\eta_1}\left(\frac{I_t}{K_{t-1}}\right)^{\eta_1}\right]A_1N_t^{\alpha-1}+\left(1-\frac{\alpha}{\eta_2}\right)e_2H_t^{\eta_2}A_2N_t^{\alpha-1-\eta_2}\right.$$
$$\left.+\left(1-\frac{\alpha}{\eta_3}\right)e_3\left(\frac{H_tI_t}{K_{t-1}}\right)^{\eta_3}A_3N_t^{\alpha-1-\eta_3}+\left(1-\alpha\right)f_2H_tA_4N_t^{\alpha-2}\right\}+\left(1-\gamma\right)\chi C_tN_t^{\varphi}.\tag{62}$$

Appendix B
The Data

a. U.S. Data

1. The discount rate and the discount factor

I use two alternatives for the firms' discount rate r_t and the corresponding discount factor $\beta_t = \frac{1}{1+r_t}$:

a. The discount rate based on a DSGE model with logarithmic utility $U(c_t) = \ln c_t$.

Then in general equilibrium:

$$U'(c_t) = U'(c_{t+1}) \cdot (1 + r_t)$$

Hence:

$$\beta_t = \frac{c_t}{c_{t+1}}$$

b. Following the weighted average cost of capital approach in corporate finance, the discount rate is a weighted average of the returns to debt, r_t^b, and equity, r_t^e:

$$r_t = \omega_t r_t^b + (1 - \omega_t)\, r_t^e,$$

with

$$\begin{aligned} r_t^b &= (1 - \tau_t)\, r_t^{CP} - \theta_t \\ r_t^e &= \frac{\widetilde{cf}_t}{\widetilde{s}_t} + \widehat{\widetilde{s}}_t - \theta_t \end{aligned}$$

where:

(i) ω_t is the share of debt finance. I calculate it on the basis of Level Tables of Flow of Funds accounts (files ltabs.zip). The calculations are as follows:

1. D = Credit market instruments (FL104104005 in the Coded Tables ltabs.zip, table L.102) + Trade payables (FL103170005 in the Coded Tables ltabs.zip, table L.102)

2. E = Market value of equities (FL103164003 in the Coded Tables ltabs.zip, table L.102)

3. Debt share = $D/(D + E)$.

(ii) The definition of r_t^b reflects the fact that nominal interest payments on debt are tax deductible. r_t^{CP} is Moody's seasoned Aaa commercial paper rate (Federal Reserve Board table H15). The tax rate is τ as discussed below.

(iii) θ denotes inflation and is measured by the GDP-deflator of p^f .

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

2. Employment, hiring and separations

As a measure of employment in nonfinancial corporate business sector (n) I take wage and salary workers in non-agricultural industries (series ID LNS12032187) less government workers (series ID LNS12032188), less self-employed workers (series ID LNS12032192), less unpaid family workers (series ID LNS12032193). All series originate from CPS databases. I do not subtract workers in private households (the unadjusted series ID LNU02032190) from the above due to lack of sufficient data on this variable.

To calculate hiring and separation rates for the whole economy I use the series kindly provided by Ofer Cornfeld. This computation first builds the flows between E (employment), U (unemployment) and N (not-in-the-labor-force) that correspond to the E, U, N stocks published by CPS. The methodology of adjusting flows to stocks is taken from BLS, and is given in Frazis et al (2005). This methodology, applied by BLS for the period 1990 onward, produces a dataset that appears in **http://www.bls.gov/cps/cps_flows.htm**. Here the series have been extended back to 1976.

The quarterly separation rate (ψ) and the quarterly hiring rate (h/n) for the whole economy are defined as follows:

$$\begin{aligned} \psi &= \frac{EN + EU}{E} \\ h/n &= \frac{NE + UE}{E} \end{aligned}$$

where the employment (E) is the quarterly average of the original seasonally adjusted total employment series from BLS (LNS12000000).

3. Investment, capital and depreciation

The goal here is to construct the quarterly series for real investment flow i_t , real capital stock k_t , and depreciation rates δ_t. I proceed as follows:

- Construct end-of-year fixed-cost net stock of private nonresidential fixed assets in NFCB sector, K_t . In order to do this I use the quantity index for net stock of fixed assets in NFCB (FAA table 4.2, line 28, BEA).

- Construct annual fixed-cost depreciation of private nonresidential fixed assets in NFCB sector, D_t . The chain-type quantity index for depreciation originates from FAA table 4.5, line 28. The current-cost depreciation estimates are given in FAA table 4.4, line 28.

- Calculate the annual fixed-cost investment flow, I_t:

$$I_t = K_t - K_{t-1} + D_t$$

- Calculate implied annual depreciation rate, δ_a:

$$\delta_a = \frac{I_t - (K_t - K_{t-1})}{K_{t-1} + I_t/2}$$

- Calculate implied quarterly depreciation rate for each year, δ_{qt}:

$$\delta_q + (1-\delta_q)\delta_q + (1-\delta_q)^2\delta_q + (1-\delta_q)^3\delta_q = \delta_a$$

- Take historic-cost quarterly investment in private non-residential fixed assets by NFCB sector from the Flow of Funds accounts, atabs files, series FA105013005).

- Deflate it using the investment price index (the latter is calculated as consumption of fixed capital in domestic NFCB in current dollars (NIPA table 1.14, line 18) divided by consumption of fixed capital in domestic NFCB in chained 2000 dollars (NIPA table 1.14, line 41). This procedure yields the implicit price deflator for depreciation in NFCB. The resulting quarterly series, i_t_unadj, is thus in real terms.

- Perform Denton's procedure to adjust the quarterly series i_t_unadj from Federal Flow of Funds accounts to the implied annual series from BEA I_t, using the depreciation rate δ_{qt} from above. I use the simplest version of the adjustment procedure, when the discrepancies between the two series are equally spread over the quarters of each year. As a result of adjustment I get the fixed–cost quarterly series i_t.

- Simulate the quarterly real capital stock series k_t starting from k_0 (k_0 is actually the fixed-cost net stock of fixed assets in the end of 1975, this value is taken from the series K_t) , using the quarterly depreciation series δ_{qt} and investment series i_t from above:

$$k_{t+1} = k_t \cdot (1-\delta_{qt}) + i_t$$

4. Real price of new capital goods

In order to compute the real price of new capital goods, p^I, I use the price indices for output and for investment goods. Investment in NFCB Inv consists of equipment Eq and structures St. I define the time-t price-indices for good $j = Inv, Eq, St$ as p_t^j and their change between $t-1$ and t by Δp_t^j, $j = Inv, Eq, St$. These price indices are chain-weighted. Thus:

$$\frac{\Delta p_t^{Inv}}{p_{t-1}^{Inv}} = \omega_t \frac{\Delta p_t^{Eq}}{p_{t-1}^{Eq}} + (1-\omega_t)\frac{\Delta p_t^{St}}{p_{t-1}^{St}}$$

where

$$\omega_t = \frac{\begin{array}{c}(\text{nominal expenditure share of } Eq \text{ in } Inv)_{t-1}\\ + (\text{nominal expenditure share of } Eq \text{ in } Inv)_t\end{array}}{2}.$$

The weights ω_t are calculated from the NIPA table 1.1.5, lines 8,10. The price indices p_t^j for $j = Eq, St$ are from NIPA table 1.1.4, lines 9, 10. I divide the series by the price index for output, p_t^f, to obtain the real price of new capital goods, p^I.

Note that the price indices p^{Eq} and p^{St} and therefore p^I are actually adjusted for taxes. The parameter τ denotes the statutory corporate income tax rate as reported by the U.S. Tax Foundation.

Let ITC denote the investment tax 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. Flint Brayton has kindly provided me with the data. Then

$$\begin{aligned} p^{Eq} &= \widetilde{p}^{Eq}\left(1 - \tau_{Eq}\right) \\ p^{St} &= \widetilde{p}^{St}\left(1 - \tau_{St}\right), \end{aligned}$$

$$\begin{aligned} 1 - \tau^{S_t} &= \frac{\left(1 - \tau\ ZPDE^{St}\right)}{1 - \tau} \\ 1 - \tau^{Eq} &= \frac{1 - ITC - \tau ZPDE^{Eq}\left(1 - \chi ITC\right)}{1 - \tau} \end{aligned}$$

b. U.K. Data

TBC

Appendix C
GMM Estimating Equations

We use (16), (17) and (21) to derive three estimating equations as follows.

Equation 1

$$
\begin{aligned}
& mc_t \cdot \frac{\frac{\partial g_t}{\partial I_t}}{\frac{Y_t}{K_{t-1}}} + \frac{\frac{\partial W_t}{\partial I_t} \cdot \frac{N_t}{P_t^C}}{\frac{Y_t}{K_{t-1}}} + \frac{\frac{P_t^I}{P_t^C}}{\frac{Y_t}{K_{t-1}}} \qquad (63) \\
= \; & \beta \cdot \frac{C_t}{C_{t+1}} \cdot \frac{1-\tau_{t+1}}{1-\tau_t} \cdot \frac{\frac{Y_{t+1}}{K_t}}{\frac{Y_t}{K_{t-1}}} \cdot \left[\begin{array}{c} mc_{t+1} \cdot \left(\frac{\frac{\partial F_{t+1}}{\partial K_t}}{\frac{Y_{t+1}}{K_t}} - \frac{\frac{\partial g_{t+1}}{\partial K_t}}{\frac{Y_{t+1}}{K_t}} \right) \\ - \frac{\frac{\partial W_{t+1}}{\partial K_t} \cdot \frac{N_{t+1}}{P_{t+1}^C}}{\frac{Y_{t+1}}{K_t}} \\ + \left(1-\delta_{t+1}^K\right) \cdot \left(\begin{array}{c} mc_{t+1} \cdot \frac{\frac{\partial g_{t+1}}{\partial I_{t+1}}}{\frac{Y_{t+1}}{K_t}} + \\ + \frac{\frac{\partial W_{t+1}}{\partial I_{t+1}} \cdot \frac{N_{t+1}}{P_{t+1}^C}}{\frac{Y_{t+1}}{K_t}} + \frac{\frac{P_{t+1}^I}{P_{t+1}^C}}{\frac{Y_{t+1}}{K_t}} \end{array} \right) \end{array} \right]
\end{aligned}
$$

Equation 2

$$
\begin{aligned}
& mc_t \cdot \left(\frac{\frac{\partial g_t}{\partial H_t}}{\frac{Y_t}{N_t}} - \frac{\frac{\partial F_t}{\partial N_t}}{\frac{Y_t}{N_t}} + \frac{\frac{\partial g_t}{\partial N_t}}{\frac{Y_t}{N_t}} \right) + \qquad (64) \\
& + \frac{\frac{\partial W_t}{\partial H_t} \cdot \frac{N_t}{P_t^C}}{\frac{Y_t}{N_t}} + \frac{\frac{\partial W_t}{\partial N_t} \cdot \frac{N_t}{P_t^C}}{\frac{Y_t}{N_t}} + \frac{\frac{W_t \cdot N_t}{Y_t}}{P_t^C} \\
= \; & \beta \cdot \frac{C_t}{C_{t+1}} \cdot \frac{1-\tau_{t+1}}{1-\tau_t} \cdot \frac{\frac{Y_{t+1}}{N_{t+1}}}{\frac{Y_t}{N_t}} \cdot \left(1-\delta_{t+1}^N\right) \cdot \left[\begin{array}{c} mc_{t+1} \cdot \frac{\frac{\partial g_{t+1}}{\partial H_{t+1}}}{\frac{Y_{t+1}}{N_{t+1}}} + \\ + \frac{\frac{\partial W_{t+1}}{\partial H_{t+1}} \cdot \frac{N_{t+1}}{P_{t+1}^C}}{\frac{Y_{t+1}}{N_{t+1}}} \end{array} \right]
\end{aligned}
$$

Equation 3

$$
\pi_t(1+\pi_t) = \frac{1-\varepsilon}{\zeta} + \frac{\varepsilon}{\zeta} mc_t + \beta \cdot \frac{C_t}{C_{t+1}} \cdot (1+\pi_{t+1})\, \pi_{t+1} \frac{y_{t+1}}{y_t} \qquad (65)
$$

Where:

$$mc_t = \frac{\frac{W_t}{P_t^C} - (1-\gamma)\cdot\chi\cdot C_t\cdot N_t^{\varphi}}{\frac{Y_t}{N_t}\cdot\left[\begin{array}{c}\frac{\alpha\cdot\gamma}{1-\gamma\cdot(1-\alpha)}\cdot\left\{1-f_1\cdot\frac{I_t}{K_{t-1}}-\frac{e_1}{\eta_1}\cdot\left(\frac{I_t}{K_{t-1}}\right)^{\eta_1}\right\}+\frac{(\eta_2-\alpha)\cdot e_2\cdot\gamma}{\eta_2\cdot(1-\gamma\cdot(1-\alpha+\eta_2))}\cdot\left(\frac{H_t}{N_t}\right)^{\eta_2}+\\ +\frac{(\eta_3-\alpha)\cdot e_3\cdot\gamma}{\eta_3\cdot(1-\gamma\cdot(1-\alpha+\eta_3))}\cdot\left(\frac{H_t}{N_t}\frac{I_t}{K_{t-1}}\right)^{\eta_3}+\frac{(1-\alpha)\cdot f_2\cdot\gamma}{1-\gamma\cdot(2-\alpha)}\cdot\frac{H_t}{N_t}\end{array}\right]} \tag{66}$$

$$\frac{\frac{\partial g_t}{\partial I_t}}{\frac{Y_t}{K_{t-1}}} = f_1 + e_1\cdot\left(\frac{I_t}{K_{t-1}}\right)^{\eta_1-1} + e_3\cdot\left(\frac{H_t}{N_t}\frac{I_t}{K_{t-1}}\right)^{\eta_3-1}\cdot\frac{H_t}{N_t} \tag{67}$$

$$\frac{\frac{\partial g_t}{\partial K_{t-1}}}{\frac{Y_t}{K_{t-1}}} = (1-\alpha)\cdot\widetilde{g} - \left(f_1\cdot\frac{I_t}{K_{t-1}} + e_1\cdot\left(\frac{I_t}{K_{t-1}}\right)^{\eta_1} + e_3\cdot\left(\frac{H_t}{N_t}\frac{I_t}{K_{t-1}}\right)^{\eta_3}\right) \tag{68}$$

$$\frac{\frac{\partial g_t}{\partial H_t}}{\frac{Y_t}{N_t}} = f_2 + e_2\cdot\left(\frac{H_t}{N_t}\right)^{\eta_1-1} + e_3\cdot\left(\frac{H_t}{N_t}\frac{I_t}{K_{t-1}}\right)^{\eta_3-1}\cdot\frac{I_t}{K_{t-1}} \tag{69}$$

$$\frac{\frac{\partial g_t}{\partial N_t}}{\frac{Y_t}{N_t}} = \alpha\cdot\widetilde{g} - \left(f_2\cdot\frac{H_t}{N_t} + e_2\cdot\left(\frac{H_t}{N_t}\right)^{\eta_2} + e_3\cdot\left(\frac{H_t}{N_t}\frac{I_t}{K_{t-1}}\right)^{\eta_3}\right) \tag{70}$$

$$\frac{\frac{\partial F_t}{\partial N_t}}{\frac{Y_t}{N_t}} = \alpha \tag{71}$$

$$\frac{\frac{\partial F_t}{\partial K_{t-1}}}{\frac{Y_t}{K_{t-1}}} = 1-\alpha \tag{72}$$

$$\frac{\frac{\partial W_t}{\partial I_t}\cdot\frac{N_t}{P_t^C}}{\frac{Y_t}{K_{t-1}}} = mc_t\cdot\left[\frac{(\eta_3-\alpha)\cdot e_3\cdot\gamma}{1-\gamma\cdot(1-\alpha+\eta_3)}\cdot\left(\frac{H_t}{N_t}\frac{I_t}{K_{t-1}}\right)^{\eta_3-1}\cdot\frac{H_t}{N_t} - \frac{\gamma\cdot\alpha}{1-\gamma\cdot(1-\alpha)}\cdot\left(f_1+e_1\cdot\left(\frac{I_t}{K_{t-1}}\right)^{\eta_1-1}\right)\right] \tag{73}$$

$$\frac{\frac{\partial W_t}{\partial K_{t-1}}\cdot\frac{N_t}{P_t^C}}{\frac{Y_t}{K_{t-1}}} = mc_t\cdot\left[\begin{array}{c}(1-\alpha)\cdot\left\{\begin{array}{c}\frac{\gamma\cdot\alpha}{1-\gamma\cdot(1-\alpha)}\left[1-f_1\cdot\frac{I_t}{K_{t-1}}-\frac{e_1}{\eta_1}\cdot\left(\frac{I_t}{K_{t-1}}\right)^{\eta_1}\right]+\\ +\frac{(\eta_2-\alpha)\cdot e_2\cdot\gamma}{\eta_2\cdot(1-\gamma\cdot(1-\alpha+\eta_2))}\cdot\left(\frac{H_t}{N_t}\right)^{\eta_2}+\frac{(\eta_3-\alpha)\cdot e_3\cdot\gamma}{\eta_3\cdot(1-\gamma\cdot(1-\alpha+\eta_3))}\cdot\left(\frac{H_t}{N_t}\frac{I_t}{K_{t-1}}\right)^{\eta_3}+\\ +\frac{(1-\alpha)\cdot f_2\cdot\gamma}{1-\gamma\cdot(2-\alpha)}\cdot\frac{H_t}{N_t}\end{array}\right\}+\\ +\frac{\gamma\cdot\alpha}{1-\gamma\cdot(1-\alpha)}\cdot\left(f_1\cdot\frac{I_t}{K_{t-1}}+e_1\cdot\left(\frac{I_t}{K_{t-1}}\right)^{\eta_1}\right)-\\ -\frac{(\eta_3-\alpha)\cdot e_3\cdot\gamma}{1-\gamma\cdot(1-\alpha+\eta_3)}\cdot\left(\frac{H_t}{N_t}\frac{I_t}{K_{t-1}}\right)^{\eta_3}\end{array}\right] \tag{74}$$

$$\frac{\frac{\partial W_t}{\partial H_t}\cdot\frac{N_t}{P_t^C}}{\frac{Y_t}{N_t}} = mc_t \cdot \left[\begin{array}{c} \frac{(\eta_2-\alpha)\cdot e_2\cdot\gamma}{1-\gamma\cdot(1-\alpha+\eta_2)}\cdot\left(\frac{H_t}{N_t}\right)^{\eta_2-1} + \frac{(\eta_3-\alpha)\cdot e_3\cdot\gamma}{1-\gamma\cdot(1-\alpha+\eta_3)}\cdot\left(\frac{H_t}{N_t}\frac{I_t}{K_{t-1}}\right)^{\eta_3-1}\cdot\frac{I_t}{K_{t-1}}+ \\ +\frac{(1-\alpha)\cdot f_2\cdot\gamma}{1-\gamma\cdot(2-\alpha)} \end{array} \right] \tag{75}$$

$$\begin{aligned} \frac{\frac{\partial W_t}{\partial N_t}\cdot\frac{N_t}{P_t^C}}{\frac{Y_t}{N_t}} \quad = \quad & -mc_t\cdot(1-\alpha)\cdot\left\{ \begin{array}{c} \frac{\gamma\cdot\alpha}{1-\gamma\cdot(1-\alpha)}\left[1-f_1\cdot\frac{I_t}{K_{t-1}}-\frac{e_1}{\eta_1}\cdot\left(\frac{I_t}{K_{t-1}}\right)^{\eta_1}\right]+ \\ +\frac{(\eta_2-\alpha)\cdot e_2\cdot\gamma}{\eta_2\cdot(1-\gamma\cdot(1-\alpha+\eta_2))}\cdot\left(\frac{H_t}{N_t}\right)^{\eta_2}+\frac{(\eta_3-\alpha)\cdot e_3\cdot\gamma}{\eta_3\cdot(1-\gamma\cdot(1-\alpha+\eta_3))}\cdot\left(\frac{H_t}{N_t}\frac{I_t}{K_{t-1}}\right)^{\eta_3}+ \\ +\frac{(1-\alpha)\cdot f_2\cdot\gamma}{1-\gamma\cdot(2-\alpha)}\cdot\frac{H_t}{N_t} \end{array} \right\} \\ & -mc_t\cdot\left\{ \begin{array}{c} \frac{(\eta_2-\alpha)\cdot e_2\cdot\gamma}{1-\gamma\cdot(1-\alpha+\eta_2)}\cdot\left(\frac{H_t}{N_t}\right)^{\eta_2}+ \\ +\frac{(\eta_3-\alpha)\cdot e_3\cdot\gamma}{1-\gamma\cdot(1-\alpha+\eta_3)}\cdot\left(\frac{H_t}{N_t}\frac{I_t}{K_{t-1}}\right)^{\eta_3}+\frac{(1-\alpha)\cdot f_2\cdot\gamma}{1-\gamma\cdot(2-\alpha)}\cdot\frac{H_t}{N_t} \end{array} \right\}+ \\ & +(1-\gamma)\cdot\chi\cdot\frac{C_t}{Y_t}\cdot\varphi\cdot N_t^{\varphi+1} \end{aligned} \tag{76}$$

Table 1

GMM – Estimated Parameters

Parameter	Function	Model Formulation
α	production function of interm. firms	$F_t = A_t N_t^{\alpha} K_{t-1}^{1-\alpha}$
ε	aggregation by retailers	$Y_t = \left(\int_0^1 Y_t(i)^{(\epsilon-1)/\epsilon} di \right)^{\epsilon/(\epsilon-1)}$
ζ	price adjustment costs by final producers	$\frac{\zeta}{2} \left(\frac{P_{t+s}^Y(i)}{P_{t+s-1}^Y(i)} - 1 \right)^2 P_{t+s}^Y Y_{t+s}$
γ	wage bargaining in interm. firms	$W_t = \arg\max \left\{ \left(\mathcal{V}_t^N\right)^{\gamma} \left(\mathcal{Q}_t^N\right)^{1-\gamma} \right\}$
χ	household utility	$E_t \sum_{j=0}^{\infty} \beta^j \left(\ln C_{t+j} - \frac{\chi}{1+\varphi} N_{t+j}^{1+\varphi} \right)$
φ	household utility	$E_t \sum_{j=0}^{\infty} \beta^j \left(\ln C_{t+j} - \frac{\chi}{1+\varphi} N_{t+j}^{1+\varphi} \right)$
$f_1, f_2, e_1, e_2, e_3, \eta_1, \eta_2, \eta_3$	adjustment costs function	see equation 9

Table 2

Parameters Fixed in Bayesian estimation

a. US data

Definition	Parameter	Value	Target/Source
Discount factor	β	0.99	Annual interest rate 4%
Elasticity of output to labour input	α	0.66	
Separation rate	δ_N	0.126	US data 1985-2007
Capital depreciation rate	δ_K	0.0187	US data 1985-2007
Adj. cost function	f_1	0	normalisation
Adj. cost function	f_2	0	normalisation
Adj. cost function	η_1	2	normalisation
Adj. cost function	η_2	2	normalisation
Adj. cost function	η_3	1	normalisation

b. UK Data

Definition	Parameter	Value	Target/Source
Discount factor	β	0.99	Annual interest rate 4%
Elasticity of output to labour input	α	0.66	
Separation rate	δ_N	0.0322	UK data 1997 Q2 - 2010 Q4
Capital depreciation rate	δ_K	0.0086	UK data 1997 Q2 - 2010 Q4
Adj. cost function	f_1	0	normalisation
Adj. cost function	f_2	0	normalisation
Adj. cost function	η_1	2	normalisation
Adj. cost function	η_2	2	normalisation
Adj. cost function	η_3	1	normalisation

Table 3
Prior Distributions for Parameter Values

Definition	**Parameter**	**Density**	**Mean**	**Std.**
Structural parameters				
Adj. Fn capital	e_1	Gamma	50.7	4.0
Adj. Fn labor	e_2	Gamma	2.92	0.5
Adj. Fn interactions	e_3	Normal	-4.87	0.5
Inverse Frisch elasticity	φ	Gamma	5	0.5
Workers' bargaining power	γ	Beta	0.35	0.1
Scale parameter in Utility function	χ	Gamma	1	0.1
Price stickiness	ζ	Gamma	20	5
Elasticity of substitution	ϵ	Gamma	11	1
Taylor response to infl	r_π	Gamma	1.5	0.1
Taylor response to output	r_y	Gamma	0.125	0.5
Interest rate smoothing	ρ_r	Beta	0.75	0.1
Shock parameters				
Autoregressive parameters	$\rho_\vartheta, \rho_a, \rho_\xi$	Beta	0.5	0.2
Standard deviations	$\sigma_\vartheta, \sigma_a, \sigma_\xi$	IGamma	0.1	0.1

Table 4
GMM Estimates
UK Data

	f_1	f_2	e_1	e_2	e_3	χ	ζ	γ	α	φ	$\mathbf{J(p)}$
1	0.08	0.32	56	51	-3.3	0.95	94	0.77	0.69	–	31
	(8.17)	(22.1)	(179)	(232)	(221)	(1.88)	(785)	(0.62)	(0.19)		(0.03)
2	0.12	0.34	29	23	-2.4	0.96	94	0.77	0.68		28
	(6.21)	(19.9)	(176)	(195)	(139)	(1.49)	(797)	(0.53)	(0.18)	–	(0.06)
3	0.80	0.03	54	0.86	-0.2	0.75	81	0.77	0.69	1.5	28
	(14.6)	(1.31)	(200)	(1959)	(7.3)	(0.96)	(779)	(0.0005)	(0.07)	(3.6)	(0.04)

Notes:

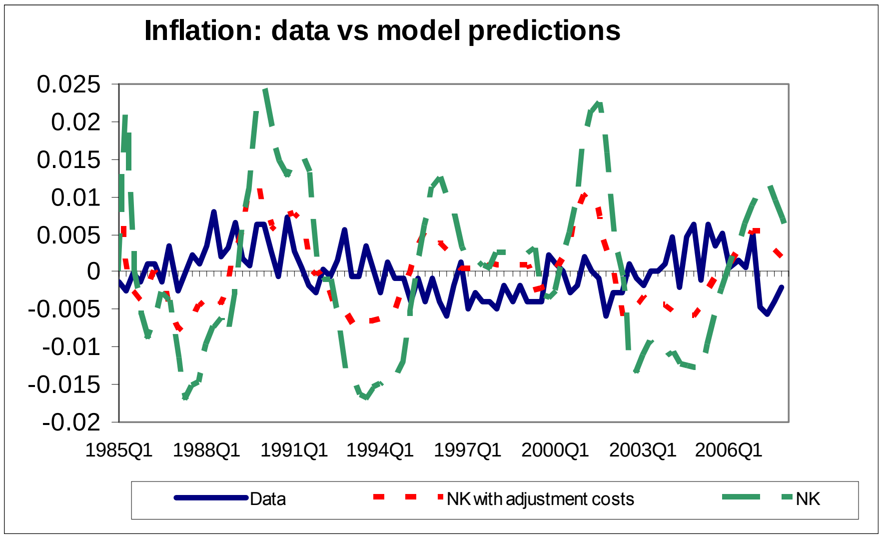
1. Throughout, we fix $\eta_1 = \eta_2 = 2$, $\eta_3 = 1$.In columns 1 and 2 we also fix $\varphi = 1, \epsilon = 10$. In column 3 we set $\epsilon = 10$

2. Standard errors are in parantheses.

3. Last column is the J-statistic with its p-value in paranthases.

4. The instruments are four lags of $\frac{i}{k}$ and $\frac{f}{k}$.

Figure 1
Bayesian Estimation
Inflation Predictions
a. U.S.



b. U.K.

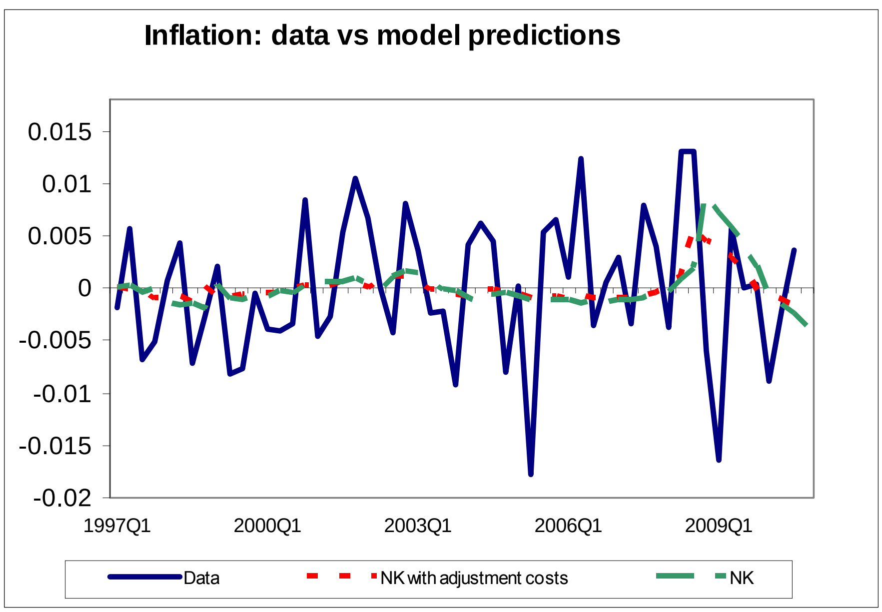
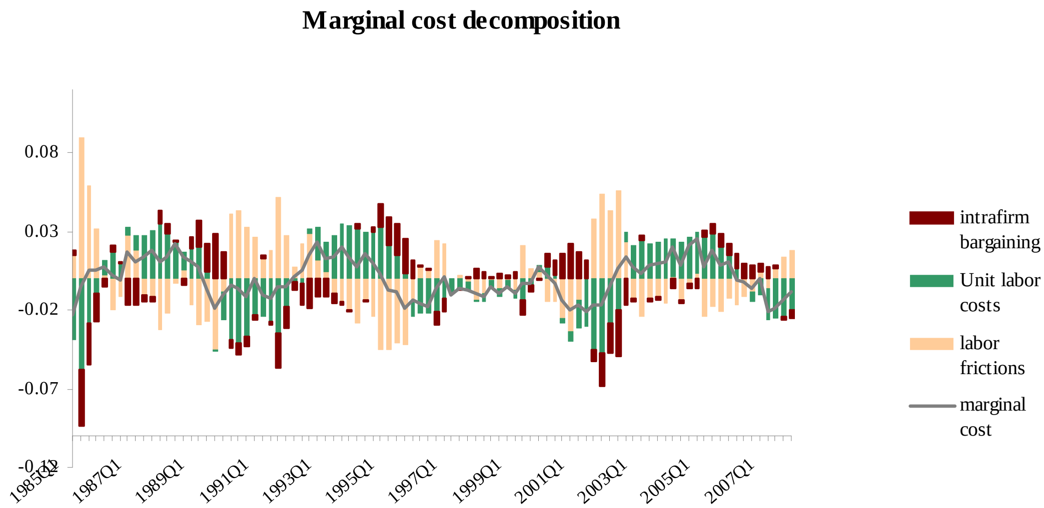


Figure 2
Bayesian Estimation
Marginal Costs Decompsitions

a. U.S.



b. U.K.