What Do Technology Shocks Tell Us about the New Keynesian Paradigm?*

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Abstract

Researchers have used unanticipated changes to monetary policy to identify preference and technology parameters of macroeconomic models. This paper uses changes in technology to identify the same set of parameters. Estimates based on technology shocks differ substantially from those based on monetary policy shocks. In the post World War II United States, a positive technology shock reduces inflation and increases hours worked, significantly and rapidly in both cases. Relative to policy shock identification, technology shock identification implies: (1) long duration durability in preferences instead of short duration habit, (2) built-in inflation inertia disappears and price flexibility increases. In response to technological improvement, consumption durability increases hours worked because households temporarily increase labor supply to accumulate durables towards new, higher steady state levels. Limited nominal rigidities allow inflation to fall because firms are able to immediately cut prices when households' labor supply increases.

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1 Introduction

In the past ten years, several studies have addressed what deep economic parameters (e.g. parameteres concerning preferences and technology) can explain the observed response of macroeconomic variables to unanticipated monetary policy shocks from a structural vector autoregression (SVAR). Our incomplete list of these studies begins with Rotemberg and Woodford (1997). They use the approach to recover the parameters of a three variable sticky price model. Boivin and Giannoni (2006) study changes in the U.S. economy between before and after 1980 using this approach. Christiano, Eichenbaum and Evans (2005, hereafter CEE) use the identified policy shock to estimate the parameters of a much larger economic model matching eleven different impulse responses. Their model is successful in that the economic model's estimated impulse responses closely follow the point estimates from the SVAR estimates for each variable. The economic model's impulse responses nearly always lie within the 95% confidence band from the SVAR. Their model has rightly become the center of empirical work on structural, equilibrium monetary economics.[1],[2]

Two key model ingredients are shared by each of these studies. First, consumption decisions must be made with substantial decision lags or alternatively individuals must have a preference for slow consumption adjustment (i.e. habit persistence). Second, firms must change their prices infrequently and also there must be inertia in the amount by which price changes do occur. This inertia may be built in either by decision lags, backward looking expectations by price setters or by backward-looking price indexation schemes. The different variants on each of the ingredients used by different researchers matters little for fitting these empirical responses. In fact, one ingredient is often isomorphic or near isomorphic to another (e.g. backward looking price setting and backward looking price indexation).

[1] Other studies include DiCecio and Nelson (2007), who apply the approach to U.K. data, Uribe and Yue (2006), who assess an international model with this method. Other examples, including Altig, Christiano, Eichenbaum and Linde (2004) and Edge, Laubach and Williams (2004), are discussed below.

[2] Our discussion of existing research limits itself to studies matching economic model impulse responses to structural VAR impulse responses. Expanding our discussion to include studies using maximum likelihood or Bayesian methods may be treacherous because we have no sense of how these two approaches differ in practice in this application.

The original work on SVARs began with Sims (1980). More recently, Blanchard and Quah (1989) developed an SVAR based approach that allows researchers to identify shocks using long-run restrictions. The application of the Blanchard-Quah technique began on a large scale eighteen years after Sims' paper, with Gali (1999). Given this chronology, it is not surprising that significantly more research has used policy rather than technology shocks to recover 'deep parameters' of business cycle models.

Monetary policy shock identification, however, has detractors. First, monetary policy may have no or a negligible random component. Cochrane (1994, pg. 3) asks:

> But why should a policy-maker deliberately introduce a random component to its decisions? Any maximization objective in a non-strategic environment leads to deterministic rules as for setting controls as a function of state. The Fed always describes its actions as responses to events, not randomized experiments.

Instead, omitted variables from the monetary policy equation may give the appearance of random policy shocks.[3] Second, Rudebusch (1998) examines monetary policy from these SVARs and finds that they are inconsistent with conventional wisdom about monetary policy. Third, there is a great deal of evidence that monetary policy regimes have switched during the past fifty years, e.g. pre-Volcker versus Volcker-Greenspan-Bernanke. This almost certainly implies misspecification when a single time invariant policy rule is used for the entire period. To this point, Boivin and Giannoni (2006) find very different results depending on which time period the estimation is applied to.

A consensus among macroeconomists on the issue of the usefulness of short-run restrictions has not been reached. Long run restrictions provide an alternative or complementary approach to identifying deep parameters of macro models. Gali's long run restriction holds

[3] Friedman and Schwartz (1968) very plausibly identify the monetary expansion from 1897 to 1914 during the Gold Standard era, due to an increase in gold output, as an exogenous policy change. Researchers sometimes cite, in the post-Gold Standard era, changes in central bank leadership personnel as a similar source of independent variation. This latter source is much less plausible. For example, in Chairman Ben Bernanke's confirmation hearing (2005) he states "With respect to monetary policy, I will make continuity with the policies and policy strategies of the Greenspan Fed a top priority."

that non-technology shocks have no long run effect on labor productivity. If valid, the restriction may allow researchers to identify technology shocks, and through them, an economic model's deep parameters. The long run restriction is based on balanced growth assumptions that most business cycle and growth models satisfy. Also, *prima facie*, technology shocks are likely to be large enough to identify an economic model's deep parameters.

Suppose a researcher believes the long-run, but rejects the short-run, identifying assumption. Then, if the two schemes deliver very similar estimates of an economic model's parameters, then the accord between the two alternative approaches would constitute a major success of the New Keynesian paradigm.

This paper estimates an equilibrium economic model's parameters based on technology shocks. We find that both habits and nominal rigidities disappear or are significantly changed when moving from monetary to technology shock based identification. First, there is no habit. Instead, preference for consumption display long duration durability. Second, nominal prices are relatively flexible and there is no built in inflation inertia..

Using technology shock based identification, the SVAR implies that a technological improvement, on impact, raises labor productivity and hours and reduces inflation. What economic machinery can explain this?

Standard preferences[4] imply a negligible effect on equilibrium labor because wealth and substitution effects largely offset each other. The first ingredient, consumption durability, motivates workers to increase labor supply. They work more to buy goods to push their stock of durables towards new, higher levels.[5]

Next, this implied shift out in labor supply depresses the equilibrium wage. Thus, firms wish to cut prices to maintain their desired markup. The downward jump in inflation from the SVAR can then be explained by the economic model so long as firms are able to change their prices. This implies substantial price flexibility and little built in inflation inertia.

A few studies use SVAR identified technology shock to estimate the parameters of a New Keynesian model. Altig, Christiano, Eichenbaum and Linde (2005, hereafter ACEL) estimate an economic model using different combinations of technology and policy shocks.

[4] Time seperable and satisfying the balanced growth assumption.

[5] This mechanism is similar to that in Jaimovich and Rebelo (2006).

Edge, Laubach and Williams (2003) estimate an economic model using both technology and policy shocks simultaneously. We present a detailed comparision of our results to these and several other papers in section 4.

We first estimate an SVAR using now standard identifying assumptions to uncover the dynamic response of hours, labor productivity, inflation and the nominal rate to each of the two shocks: technology and monetary policy.

With these eight impulses (four variables for two shocks each), we present an economic model with optimizing firms and households with resource constraints and market clearing conditions. Second, we estimate the economic model's parameters so that the economic model's impulse responses line up as closely as possible with the impulses responses from the SVAR. Lining up as closely as possible the two sets of impulse responses (SVAR and economic model) is an application of the minimum distance approach. Fitting the policy shock has received the lion's share of attention in existing research; therefore, this paper focuses mainly on technology shock based identification.

Using the impulse responses from four variables, we can strip down the economic model greatly. For example, by excluding investment from our variable list we do not need to estimate the capital depreciation rate or the nature of investment adjustment costs.

Using a small set of variables brings a second benefit. In the above existing studies, with the exception of Rotemberg and Woodford, there are many more impulse responses for real variables than nominal ones. In Edge, Laubach and Williams (2003), for example, seven variables are real and only two are nominal. Using their minimum distance criteria, it is plausible to conjecture that the estimates give up on matching the nominal variable dynamics in order to match a set of seven real (and largely co-moving) variables.

We detail the economic model's estimates fitting solely the technology shock identified SVAR. The paper's punchline is that the implications for preferences and nominal rigidities depend on whether these mechanisms are identified by technology or policy shocks. The next section presents the equilibrium economic model. Section 3 describes the estimation procedure and then reports and discusses our estimates. Section 4 discusses existing research in the context of our results. The final section concludes.

2 An Equilibrium Model with Technology and Monetary Shocks

Monetary Policy and Technology Shocks

The first of the model's two random shocks affects the central bank interest rate policy. In each period, it stands willing to trade currency for nominal bonds at its desired rate.[6] It determines this rate R_t according to the following rule:

$$R_t = (R_{t-1})^{\rho_r} (\pi_t)^{\phi_\pi(1-\rho_r)} (n_t)^{\phi_n(1-\rho_r)} \exp(-qg_t) \exp(\varepsilon_{r,t}) \tag{1}$$

where $1 > \rho_r > 0$. The central bank sets the interest rate based on inflation π_t, hours worked n_t and last period's interest rate. It also has a systematic response to technology shocks, g_t. For example, if q is positive, then the central bank lowers the interest rate, ceterius paribus, when there is a positive innovation to the technology growth rate. Finally, $\varepsilon_{r,t}$ represents the random, exogenous component of monetary policy. We assume $\varepsilon_{r,t}$ is iid normal with mean zero and standard deviation σ_r.

The second shock affects the economy's production possibility frontier. Let the level and gross growth rate of total factor productivity be denoted A_t and G_t. The law of motion for the technology growth rate is:

$$G_t = (\mu_z)^{1-\rho} (G_{t-1})^{\rho} \exp(\varepsilon_{a,t}) \tag{2}$$

where (A_0, G_0) are exogenously given and $1 > \rho > 0$. μ_z is the steady state growth rate of technology. Assume that $\varepsilon_{a,t}$ is iid normal with mean zero and standard deviation σ_a. Further, we denote g_t as the growth rate of G_t.

Household Problem

A representative household maximizes its utility by choice of consumption $\tilde{C}_t$, nominal bonds B_t and money holding M_t to maximize:

$$\sum_{t=0}^{\infty} \beta^t E_t[\log\left(\tilde{C}_t - \kappa \tilde{X}_t\right) - \varphi_L N_t + b \log\left(\frac{M_t}{P_t}\right)] \tag{3}$$

[6] It finances this rule through lump sum taxes and transfers and we may, therefore, suppress the government budget constraint.

subject to:

$$P_t\tilde{C}_t + M_t + \frac{B_t}{R_t} = \tilde{W}_t N_t + B_{t-1} + M_{t-1} + \Pi_t + T_t$$

Here, $P_t, \tilde{W}_t, \Pi_t, T_t$ are nominal variables representing the price of consumption, the nominal wage level, profits paid by firms and a lump sum transfer from the government.

The term $\tilde{X}_t$ corresponds to the level of habit/durables accumulated by the household. It evolves according to:

$$\tilde{X}_t = \tilde{C}_{t-1} + (1-\delta)\,\tilde{X}_{t-1}$$

In the above problem, let $b, \varphi_L > 0$ and $\delta \in (0,1)$. We set $\beta = 0.99$ throughout the paper.

Our preference specification is general. It allows for habits ($\kappa > 0$) that accumulate very slowly, i.e. if δ is small, or standard 'lagged consumption' habits, i.e. if $\delta = 1$. It also allows for time separability, i.e. no habits, $\kappa = 0$. When $\kappa < 0$, consumption is durable.

An important aspect of the above problem is a timing restriction. We assume that B_t, M_t, N_t may be chosen after the period t technology and policy shocks $(\varepsilon_{a,t}, \varepsilon_{r,t})$ have been realized; however, $\tilde{C}_t$ is chosen after the technology shock's realization but before the policy shock's realization.

For the sake of conciseness, we present only the log-linearized versions of the household Euler equations. Also, because technology is non-stationary, we transform several variables: $C_t = \tilde{C}_t/A_t, W_t = \tilde{W}_t/A_t$ and $X_t = \tilde{X}_t/A_{t-1}$. Then,

$$-\frac{1}{(\bar{c} - \frac{\kappa}{\mu_z}\bar{x})^2}[\bar{c}c_t - \frac{\kappa}{\mu_z}\bar{x}(x_t - g_t)] - \bar{\lambda}\lambda_t + \bar{\mu}\mu_t = 0 \tag{4}$$

$$\frac{1}{(\mu_z\bar{c} - \kappa\bar{x})^2}\left[\mu_z\bar{c}\,(g_{t+1} + c_{t+1}) - \kappa\bar{x}x_{t+1}\right] - \bar{\mu}\mu_t + \beta\,(1-\delta)\,\frac{\bar{\mu}}{\mu_z}(\mu_{t+1} - g_{t+1}) = 0 \tag{5}$$

$$\lambda_t + w_t = n_t \tag{6}$$

Optimal bond holdings imply that:

$$\lambda_t - E_t\,(\lambda_{t+1} + g_{t+1}) = r_t - E_t\,(\pi_{t+1}) \tag{7}$$

The log-linearized law of motion for habit/durability is:

$$\bar{x}x_{t+1} = \bar{c}c_t + \frac{(1-\delta)}{\mu_z}\bar{x}(x_t - g_{t-1}) \tag{8}$$

The market clearing condition implies that

$$c_t = n_t \tag{9}$$

A lower case letters denotes the log-deviation (from the steady-state) of its upper case counterpart. Also, λ_t is the shadow value of income and μ_t is the shadow value of x_t.

Firm Problem

There is a continuum of firms on the unit interval $i \in [0,1]$. Firm i is the monopolist producer of a final good that is differentiated from the goods of all other firms. Household demand for good i, $\tilde{Y}_t(i)$, is given by:

$$\tilde{Y}_t \left(\frac{P_t(i)}{P_t} \right)^{-\theta} = \tilde{Y}_t(i) \tag{10}$$

where $\tilde{Y}_t$ is the total demand in the economy and θ is the demand elasticity of differentiated goods. Let $\theta > 1$. The production function for good i is:

$$\tilde{Y}_t(i) = A_t N_t(i) \tag{11}$$

where A_t is the technology level and $N_t(i)$ is the firm i choice of labor. For simplicity, we assume the production function is linear in labor input. It is also a reasonable assumption due to some factors outside our model, such as capital utilization. In the short run, firms cannot adjust the capital stock but they can adjust the utilization rate such that the labor-capital in use ratio, $\left(\frac{N_t}{u_t K_t} \right)$ stays at the optimal level, thus the marginal product labor will be a constant.[7]

In addition, the firm must also pay workers one period in advance of their production. The firm borrows to do so; therefore, the wage bill is $(R_t)^d \tilde{W}_t N_t(i)$, where d measures the effect of the interest rate on each firm's cost. This setting represents an extra channel for monetary policy to affect the private sector. CEE (2005) and ACEL (2004) assume that the entire wage bill is borrowed, i.e. $d = 1$.

The firm optimally resets its price with probability $1 - \nu$ in each period. When the firm does optimally set its price, we assume that it can observe the current technology shock but not the current monetary policy shock.

[7] Altig, Christiano, Eichenbaum and Linde (2004) shows that there could be increasing return to scale for labor in the short run due to changes in capital utilization.

Let the optimally chosen price at t be denoted P_t^*. If the firm last re-optimized its price at t, then its time $t+j$ price is:

$$P_{t,j}^* = P_t^* (\frac{P_{t+j-1}}{P_{t-1}})^\gamma \tag{12}$$

Here, γ represents the degree of price indexation and we assume it lies between 0 and 1.

The firm i with the opportunity to re-optimize its price at t maximizes the expected discounted value of real profits

$$\max_{P_t^*, N_{t+j}} \sum_{j=0}^{\infty} (\nu\beta)^t E_{t-1} \left[\frac{\tilde{\Lambda}_{t+j}}{P_{t+j}} \left(P_{t,j}^* Y_{t+j}(i) - (R_{t+j})^d \tilde{W}_{t+j} N_{t+j}(i) \right) \right]$$

subject to the demand curve (10), the production function (11), and the evolution of the firm's price (12). Here, $\tilde{\Lambda}_t$ is the household's marginal utility of income.

The first-order condition to the firm problem is:

$$P_t^* \sum_{j=0}^{\infty} (\nu\beta)^j E_t \left[\Lambda_{t+j} Y_{t+j} \left(\frac{(\frac{P_{t+jt-1}}{P_{t-1}})^\gamma}{P_t} \right)^{1-\theta} \right] = \frac{\theta}{\theta - 1} \sum_{j=0}^{\infty} (\nu\beta)^j E_t \left[\Xi_{t+j} Y_{t+j} \left(\frac{(\frac{P_{t+t-1}}{P_{t-1}})^\gamma}{P_t} \right)^{-\theta} \right] \tag{13}$$

where $\Xi_t = (R_t)^d \Lambda_t W_t / P_t$. Note that $\Lambda_t = \tilde{\Lambda}_t A_t$, $W_t = \tilde{W}_t / A_t$ and $Y_t = \tilde{Y}_t / A_t$.

Next, the law of motion for the overall price index takes the form:

$$P_t = \{(1-\nu) P_t^{*1-\theta} + v[P_{t-1}(P_{t-1}/P_{t-2})^\gamma]^{1-\theta}\}^{\frac{1}{1-\theta}} \tag{14}$$

From (13) and (14), one can show that the log-linearized inflation equation is:

$$\pi_t - \gamma\pi_{t-1} = E_{t-1} \left[\frac{(1-v)(1-\beta v)}{v} (\xi_t - \lambda_t) + \beta (\pi_{t+1} - \gamma\pi_t) \right]$$

Given our definition of Ξ_t and the household labor demand relationship (6), the inflation Euler equation becomes:

$$\pi_t - \gamma\pi_{t-1} = E_{t-1} \left[\beta (\pi_{t+1} - \gamma\pi_t) + \frac{(1-v)(1-\beta v)}{v} (r_t d - \lambda_t) \right] \tag{15}$$

Equilibria Close to the Steady-State Growth Path

An equilibrium consists of six endogenous variables $\{\pi_t, r_t, n_t, x_t, \lambda_t, \mu_t\}$, one exogenous state variable g_t, and two shocks $\{\varepsilon_{r,t}, \varepsilon_{a,t}\}$. The relationships between these variables are

governed by: three equations expressing consumer demand (4),(5) and (8), the Fisher equation (7), the inflation Euler equation (15), as well as the log-linearized interest rate rule and technology evolution equation:

$$r_t = \rho_r r_{t-1} + (1-\rho_r)\left(\phi_\pi \pi_t + \phi_n n_t\right) - q g_t + \varepsilon_{r,t}$$

$$g_t = \rho g_{t-1} + \varepsilon_{a,t}$$

We assume $\phi_\pi \geq 1$ in estimation.

The entire system is governed by twelve parameters. Two relate to household preferences (κ, δ). Three are due to price setting (γ, v, d). Four concern monetary policy $(\rho_r, \phi_\pi, \phi_n, q)$.[8] There are two shock standard deviations (σ_r, σ_a) and ρ measures the persistence of technology growth shocks.

3 Preferences & Frictions Identified from a Technology Shock

3.1 Identification of Shocks

Technology Shock

The first ingredient in our statistical model is a set of ten macroeconomic variables Y_t. These consist of

$$\begin{aligned} Y_t &= \left[\begin{array}{ccc} z_t & \cdots & r_t \end{array}\right]' \\ &= \left[\begin{array}{ccccccc} \Delta\,(\text{labor productivity}) & \text{inflation} & \text{hours} & \text{utilization} & \Delta\,(\text{investment price}) & \cdots \\ \cdots & \text{consumption share} & \text{investment share} & \text{velocity of money} & \text{markup} & \text{Federal Funds rate} \end{array}\right]' \end{aligned}$$

Details related to the data and computations appear in the appendix.

We consider in turn two distinct identification schemes, one for each shock. We base our identification of the technology shocks on a long run restriction. To this end, we partition

[8] Additional parameters described above are unrelated to the system dynamics and we set $\beta = 0.99$.

the vector Y_t into $\left[\begin{array}{cc} z_t & \hat{Y}_t' \end{array} \right]'$. It will be more convenient to express the technology shock identified VAR in its MA form

$$\left[\begin{array}{c} z_t \\ \hat{Y}_t \end{array} \right] = \left[\begin{array}{cc} C^{11}(L) & C^{12}(L) \\ C^{21}(L) & C^{22}(L) \end{array} \right] \left[\begin{array}{c} u_t^z \\ u_t^{\hat{Y}_t} \end{array} \right]$$

We seek the economy's response to a technology shock u_t^z. We normalize the covariance matrix of the MA shocks to be the identity matrix. Our identifying assumption is that only the technology shock has a long run effect on labor productivity. Thus the cumulative effect of $u_t^{\hat{Y}_t}$ on z_t must be zero, or $C^{12}(1) = 0$. The resulting estimates of the response of (z_t, π_t, n_t, r_t) to an innovation to u_t^z are used in the minimum distance estimation that follows.

Monetary Policy Shock

Let the monetary policy shock be denoted u_t^r. Our identification scheme is to partition the vector Y_t into $\left[\begin{array}{cc} \bar{Y}_t' & r_t \end{array} \right]'$. Then we assume $\bar{Y}_t$ responds only with a lag to changes in the interest rate r_t, whereas r_t can respond to contemporaneous changes in $\bar{Y}_t$. The short-run identified VAR can be expressed as:

$$\bar{Y}_t = \sum_{i=1}^{b} B_i^{\bar{Y}} \bar{Y}_{t-i} + \sum_{i=1}^{b} B_i^r r_{t-i} + u_t^{\bar{Y}} \tag{16}$$

$$r_t = \sum_{i=0}^{b} C_i^{\bar{Y}} \bar{Y}_{t-i} + \sum_{i=1}^{b} C_i^r r_{t-i} + u_t^r \tag{17}$$

We use standard methods to estimate this system. The resulting estimates of the response of (z_t, π_t, n_t, r_t) to an innovation to u_t^r are used in the minimum distance estimation that follows.

Implementation by the Minimum Distance Method

The economic model parameters are estimated by the minimum distance method, used in the papers described in the introduction. We minimize a measure of distance between the impulse responses generated by the economic model and those generated, in turn, by each of the two statistical models. Our objective function is defined as

$$D = \min_{\theta} [\Upsilon(\theta) - \Upsilon^s]' \Omega^{-1} [\Upsilon(\theta) - \Upsilon^s]$$

where $\theta = \{...\}$ is our "deep" parameter vector. $\Upsilon(\theta)$ represents the impulse response function from the theoretical model and Υ^s is the impulse response function from the VAR model (either using policy or technology shocks). Ω is the weighting matrix. Following CEE (2005), let Ω be a a diagonal matrix with the sample variance of Υ^s on the main diagonal. The estimator, $\hat{\theta}$, is picked to minimize the above objective function.

3.2 The Statistical Model and Its Results

The dash-dotted lines in Figure 1 report the responses of the labor productivity growth rate, hours as well as the APR inflation and Federal Funds rates to a positive, one-standard deviation innovation, $\sigma_a = 0.32$, to the growth rate of technology. The shock leads to a short-run increase in labor input and short run reductions in the inflation and the Federal Funds rates. The dotted lines are the outer envelope of the 90% confidence interval.

Inflation has its largest response on impact. It jumps down 60 basis points. Then, it asymptotes monotonically towards the steady-state, although it remains ten basis points below the steady-state five years following the shock. The zero response lies above the confidence interval in all but one quarter.

Labor jumps up on impact and then rises, reaching its maximal impact at quarter three. This maximal response of approximately 25 basis points is maintained throughout the plotted response. The zero response of labor lies below the confidence interval until quarter ten.

The Federal Funds rate falls approximately five basis points on impact. It remains below the steady-state for the entire five year horizon. The zero response lies inside the confidence interval in every quarter before year four.

3.3 Implications for the Economic Model

The impulse responses implied by the technology shock each respectively tell different stories for the economy's underlying structure regarding (i) preferences and (ii) nominal rigidity. Since the model's estimated parameters using the monetary policy shock are well known from previous studies, we organize each point under a heading that summarizes how the technology shock identified parameters differ from the monetary shock identified ones.

Several of the parameters are calibrated rather than estimated. These are: the time discount factor, $\beta = 0.99$; the disutility weight on labor, $\psi_L = 4$; the growth rate of technology, $\mu_z = 1.005$; the parameter governing substitutability between goods, $\theta = 21$, making the steady state markup equal 1.05. These are values typically used in existing research.

3.3.1 Long Duration Durability Replaces Short Duration Habit

A permanent technology improvement induces a jump down in inflation and a jump up in hours in the SVAR. In the economic model, in order for inflation to fall, firms must see a reduction in w_t, the technology scaled marginal cost, as in equation (15). This reduction gives each firm an incentive to lower its price. Based on technology shock identification, consumption is durable, with $\kappa = -0.005$. The parameter is statistically, significantly negative at conventional confidence levels. Also, consumption is extremely durable. The estimated depreciation rate δ is 0.0004. Slow depreciation of durability keeps hours above the steady state for many periods following the shock, as seen in Figure 1. Slow depreciation helps generate the large fall of inflation on impact, because inflation is forward looking.

Together with the SVAR's increase in hours, a reduction in w_t implies that the increase in labor demand (due to a higher marginal product of labor) must be outpaced by a decrease in labor supply. Because our preferences imply that steady-state labor does not depend on the technology level, the labor supply and demand effects must exactly offset in the long run.

In the short run, however, consumption durability mitigates the labor supply reduction. This, in turn, tempers the increase in the real wage (and reduces the technology scaled real wage w_t).

To compare the dynamic responses of hours worked under two different cases, habits versus durability, consider a simple planning problem. To focus on the main factor driving hours worked after a technology shock, ignore all nominal rigidities. The production function is linear in labor multiplied by the technology level and all output is consumed. Assume the technology level is fixed.

As in the section 2, we scale consumption and the stock of habit/durability by the

technology level. The stationary representation of the planning problem is:

$$\max_{N_t, X_t} \int_0^\infty e^{-\rho t} \left[\log\left(N_t - \kappa X_t\right) - N_t\right] dt \tag{18}$$

subject to

$$\dot{X}_t = N_t - (1-\delta) X_t \tag{19}$$

Again, X_t is the stock of habit/durables scaled by the technology level.

The solution to the problem satisfies:

$$\dot{N}_t = \kappa \left[2N_t - (\delta + \kappa) X_t\right] + (\rho + \delta) \left[\left(N - \kappa X_t\right)^2 - \left(N - \kappa X_t\right)\right]$$

equation (19), a transversality condition and an initial condition for X.

To study the effect of technology shocks, we express the phase diagram around the steady state.[9] Fig 2a and Fig 2b are two local phase diagrams corresponding to the case of habits and consumption durability respectively. Suppose the economy is at its steady-state level. It then experiences, at time zero, a one-time, permanent, unanticipated technology improvement. The (non-scaled) habit/durables stock is a state variable that does not jump. Since the technology level jumps up, then there is an immediate decrease the scaled habit/durables stock falls on impact to X_0.

The implications for hours in the two cases are very different. With habits, i.e. Figure 2a, the decrease in the technology scaled habit stock requires labor hours to jump below its steady state at time zero to put the system on the stable manifold. Intuitively, if the agent were to hold labor fixed, then his consumption would jump because productivity increases. However, habits encourage agents to smooth changes (more specifically, partial changes) in consumption. To make consumption *growth* increase more smoothly, the agent will cut labor immediately and then have it asymptote to the steady-state.

With durability, i.e. Figure 2b, hours must rise to put the system on the stable manifold. The intuition for the role of consumption durability on labor supply follows. A household receives two benefits from supplying labor. First, the earned labor income buys consumption, which increases utility directly. Second, the additional consumption from supplying labor raises the quantity of the durable good, which increases utility in future periods.

[9] There are two steady-states, however, one is economically irrelevant.

A permanent increase in technology raises the long run level of consumption and durable goods. Whereas the adjustment of consumption to the new steady state can occur quickly, the adjustment of the durable good quantity to the steady-state takes many periods. The agent has incentive to increase labor supply to expedite the transition to the new steady-state.

Figure 3 sketches out (roughly) the role of durability by looking at the labor supply and demand relationships in the decentralized model. The market is initially at the hours, wage pair (n, w), corresponding to the intersection of curves n_d and n_s. An increase in technology leads to a shift out in the firms' labor demand curve from n_d to n_d^* .

The labor supply change under time separability causes labor supply to shift from n_s to n_s^*. Then, hours worked is unchanged $n = n^*$. The wage increases by exactly the same amount as technology increases. Because the technology-scaled wage in unchanged, firms have no incentive to change prices.

Durability, on the other hand, induces the shift in labor supply curve from n_s to n_s^{**}. This is because each household increases its labor supply to push its durable stock up towards a new higher steady-state. As such, equilibrium labor increases $n^{**} > n$. The wage increases by less than technology increases, which puts a downward pressure on firms prices.

Figure 4 plots the impulse responses of inflation and labor when durability is replaced, in turn, by: (a) time separable preferences, (b) short duration habits. Each remaining parameter is fixed at its estimated value in Table 1. In case (a), i.e. $\kappa = 0$, increased labor demand almost exactly offsets the decreased labor supply. Equilibrium labor does not change with the technology level. While the real wage rises, the technology scaled wage w_t is unchanged. As such, no firm has incentive to change its price; therefore, the inflation response is zero. As Figure 4 demonstrates, neither inflation nor labor respond in this case.

The New Keynesian paradigm depends heavily upon short-duration habits. These habits help match the hump shaped response of consumption to an expansionary monetary shock. Application of the New Keynesian paradigm typically use $\delta = 1$. Then, the first term in (3) becomes

$$\log\left(\tilde{C}_t - \kappa \tilde{C}_{t-1}\right)$$

Typical estimates of κ from monetary shock based studies are: 0.64 (Edge, Laubach and

Williams 2003), 0.77 (DiCecio and Nelson 2007) and 0.50 (Boivin and Giannoni 2005). When based on the monetary shock, we estimate $\kappa = 0.65$ and $\delta = 1$.

The two lower panels of Figure 4 show the impulse responses for $\kappa = 0.6$ and $\delta = 1$.[10] Hours falls on impact following a technology improvement. The labor response under habits is *even more counterfactual* than with time separability.

3.3.2 Sticky Prices Abate and Price Indexation Disappears

As explained above, long duration durability gives firms incentive to lower prices in response to a technological improvement. For inflation to fall, firms must have not only the *desire* to change prices but also the *ability* to do so. Our point estimate implies that fifty-seven percent of all firms reoptimize their prices in each period. We estimate $\upsilon = 0.4302$ with a standard error of 0.05. Allowing many firms to adjust their prices immediately is necessary to match the sharp decline in inflation following a positive technology shock (see Figure 1).

In contrast, price rigidity estimated using policy shock SVARs (in existing work) is much larger. Comparing the degree of price fixity across studies is difficult because of differences in modelling details. Several studies, as well as ours, do share a similar partially reduced form equation for inflation:[11]

$$\pi_t - \gamma\pi_{t-1} = \beta E_t \left(\pi_{t+1} - \gamma\pi_t\right) + \alpha c_t$$

where γ has the same meaning as above and c_t equals marginal cost. In our model, $\alpha = (1-\upsilon)(1-\beta\upsilon)/\upsilon$ and is estimated, based on technology shocks, to be 0.32. Boivin and Giannoni (2006) find $\alpha = 0.011$ (pre-1980 data) and $\alpha = 0.008$ (post-1980 data). Rotemberg and Woodford (1997) find $\alpha = 0.02$. On the other hand, monetary policy shock identification implies $\alpha = 0.012$, with $\upsilon = 0.9047$. One exception to this disconnect is Altig, et.al. (2004) who find a value of α (based on policy shocks) closer to ours (based on technology shocks). When estimated using only the monetary shock, they find $\alpha = 0.18$.

Another hallmark of the New Keynesian paradigm is a built-in inflation inertia mechanism. The mechanism is required to make inflation have a hump shaped response to a

[10] Again, each remaining parameters is set equal to its value from Table 1.

[11] Here we set $d = 0$ for the sake of comparison.

monetary policy shock. It may arise from backward looking firms (e.g. Gali and Gertler 1999), sticky information (e.g. Mankiw and Reis 2002), or indexing prices to lagged inflation (e.g. Christiano Eichenbaum and Evans 2005). We follow the latter's approach and allow prices that are not reoptimized in a period to be indexed γ percent to lagged inflation. If $\gamma = 0$, there is no indexation. If $\gamma = 1$, there is full indexation.

Technology shock identification finds $\gamma = 0.0091$. with a standard error equal to 0.0405. That is, there is no built in inflation mechanism. In contrast, using policy shock identification, Boivin and Giannoni (2006) estimate γ equals one based on policy shock identification. Using policy shock identification, we also find $\gamma = 1$.

To see the importance of reduced nominal rigidities for fitting the technology shocks, figure 5 plots the inflation impulse response when our estimated parameters (γ, η) are replaced with those typically found using monetary shock SVARs. In particular, we set these as $(1, 0.8)$. This corresponds to full indexation and 80% of firms not reoptimizing their prices. Making prices less flexible and making inflation more inertial substantially degrades the economic model's fit. The economic model's inflation exhibits an upside down hump. Inflation begins close to the steady-state. It declines and reaches a minimum at quarter five before asymptoting to the steady-state. In addition, hours falls instead of rises when nominal rigidities are present. Both impulse responses lie outside the SVAR's 90% confidence interval in some quarters.

3.3.3 Additional Results

Using technology shock based identification, the point estimate of the interest rate policy is:

$$r_t = 0.87 \times (1.61\pi_t + 0.09n_t) + (1 - 0.87) \times r_{t-1} - 0.016g_t$$

With the exception of the final term, the policy is consistent with previous studies: there is substantial interest rate smoothing; the nominal rate responds positively to economic activity n_t.; the nominal rate responds in a greater than one-for-one manner to an increases in inflation.

The final term represents how much the nominal rate responds to the technology shock g_t directly. The point estimate is -0.016; however, the standard error is 0.063; therefore, we

cannot reject the hypothesis that the Federal Reserve does not respond directly to technological growth. Instead, any accommodation or leaning against the wind towards technology shocks is done indirectly by responding to π_t or n_t.

Next, technology shock identification implies a working capital channel. Firms must pay 70.9% of the wage bill in advance. This helps fit the inflation drop in the SVAR. Real marginal cost increases with the nominal rate. Since the nominal rate falls on impact, this works to reduce real marginal cost and givens firms incentive to lower prices. In contrast, policy shock based identification finds a neglible working capital channel; a negligible fraction of the wage bill must be paid in advance.

The final two parameters estimated using technology shock identification are σ_a and ρ_a, the standard deviation of a technology shock innovation and the persistence of that innovation. First, ρ_a is estimated at zero with great precision. Thus, technology is a random walk with drift. The standard error is 0.329.

Table 2 reports parameter estimates, based on the long run restriction when a subset of the parameters are fixed at certain values (columns three through five) and using SVAR impulse responses based on different data (six column). The 'Standard Habit' column restricts the model to have short duration habits, a standard component in the New Keynesian paradigm.[12] This restriction results in a substantially worse fit of the model. The objective function increases over six hundred percent relative to the benchmark. This is consistent with Figure 5. Short-duration habits make hours fall and inflation be unchanged following a positive techology shock.

The 'Nominal Rigidity' column of Table 2 reestimates the model assuming full price indexation and only twenty percent of firms update their prices in each quarter. The fit of the model worsens somewhat. The objective function increases XXX relative to the benchmark.

The 'Bare Bones' column of Table 2 examines the minimum set of parameters required to get good fit of the model. We shut down price indexation, the working capital channel and accomodation of monetary policy, $\gamma = d = q = 0$. The estimated parameters change little from their benchmark values.

[12] In the standard habit, nominal rigidity and bare bones columns, we set $\sigma_a = 0.3109$.

Finally, the 'ACEL' column reports the parameter estimates if when we replace our SVAR technology identified impulse responses from those in ACEL (which can be generated using code available on Larry Christiano's website). This exercise demonstrates that the results of our paper do not depend upon particular data selection or estimation procedure we use. The point estimate and standard error for every parameter map nearly identically across the 'Benchmark' and 'ACEL' columns.

4 Technology Shock Identification & New Keynesianism: Existing Research

This section discusses, contextually with respect to our findings, existing work that matches long run identified impulse responses and those from economic models.[13] Cogley and Nason (1994) compare the output and inflation impulse responses from a long-run identified SVAR to those from a limited participation model.[14] They find a downward jump in inflation on impact in the SVAR. The limited participation model reasonably matches the SVAR nominal responses but misses the output responses. Thus, Cogley and Nason recognized early on that a simple flexible price monetary model can explain the SVAR inflation response to a technology shock.

Gali and Rabanal (2005) estimate the parameters of a small scale equilibrium model similar to ours; however, they do not allow for durability of consumption.[15] Rather than using an SVAR, they estimate parameters using Bayesian methods and five shocks (including shocks to technology growth and monetary policy). Their findings are similar on several dimensions. First, built-in inflation inertia disappears. The fraction of backward looking firms falls from approximately one-third (prior) to zero (posterior). Second, the average

[13] Important papers not discussed here because of space constraints are: Del Negro, Schorfieder, Smets and Wouters (2007); Gali (1992); Smets and Wouters (2003).

[14] Their paper differs from the others in this section in two ways. Their identification assumptions differ somewhat from Gali's (described in the introduction) and they calibrate rather than estimate their economic model.

[15] Their model also restricts technology to follow a random walk, allows for sticky wages and does not have a working capital channel.

duration of a price remains at approximately two quarters, from prior to posterior. We also estimate this value at two quarters. Third, while our model assumes flexible wages, they allow for sticky wages. They soundly reject wage stickiness. The average duration of a wage falls from two quarters (prior) to one quarter (posterior).

One important difference relative to our findings is that Gali and Rabanal estimate significant short-duration habit. The weight on lagged consumption in the utility function, κ, moves from 0.50 (prior) to 0.42 (posterior). The disparity arises because of detrending. Before estimation, Gali and Rabanal detrend the hours series, whereas we do not. Their detrending implies that hours falls following a positive technology shock, according to Figure 7 in their paper. This response is consistent with our explanation in section 3 and simulation in Figure 4.b. Habits imply that hours falls in response to a positive technology shock. Households with habit preferences cut labor supply to smooth consumption growth.

ACEL (2005) estimate the parameters of an equilibrium model using the minimum distance SVAR approach. Their benchmark case fits three identified shocks simultaneously: a neutral technology shock, a monetary policy shock and an investment-specific technology shock.

ACEL show that while the economic model fits most of the impulse responses well, it is unable to match the inflation response to a technology shock. In part, this is because relatively infrequent price adjustment is needed to match the inflation response to a monetary shock. They also estimate the model based on solely the neutral technology shock, i.e. the shock we consider. They report point estimates with substantial price flexibility. Specifically, firms update prices once every quarter on average.

Our paper builds on this finding. While ACEL explain that their model cannot explain the inflation response to a technology shock, unlike our paper, they do not report impulse responses that can match this finding.

With respect to our other findings, the ACEL model does not allow for: (i) variation in the degree of price indexation, i.e. γ is fixed at one; (ii) durability in consumption, i.e. κ is required to be non-negative; (iii) long-duration time non-seperability, i.e. δ is fixed at one. Because of flexibility along these dimensions, we are able to recover the important role of long-duration durability and the absence of built-in inflation inertia.

Finally, ACEL does not explore the degree of tension between real and nominal rigidities that are identified by the policy versus technology shocks. We demonstrate a great deal of tension by reporting standard errors on point estimates as well as the counterfactual analysis in Figures 4 and 5. This difference arises because of the different focus of ACEL relative to our paper.

Edge, Laubach and Williams (2003) estimate a nine variable equilibrium model using an SVAR with both a neutral technology and monetary policy shock. The model can match the jump down in inflation following a technological improvement; however, it cannot also match the inertial inflation response to a monetary shock. This latter model impulse response lies outside the SVARs confidence interval for ten of the twenty quarters reported.

Their estimates imply no built-in inflation inertia and a 2.5 quarter average price duration. This further evidence the tension between the two identification schemes. Edge, et.al do not estimate the model solely using the technology shock. Therefore, there are no results directly comparable to ours. Also, only short-duration habit is permitted in estimation.

5 Final Remarks

The parameter estimates of a standard New Keynesian model change greatly when monetary policy shock identification is replaced with technology shock identification. Future work will proceed along two dimensions. First, one drawback of long run identification is that it often implies large confidence tunnels around structural impulse point estimates,[16] especially relative to short-run identification. Improving SVAR procedures, in particular those using long run restrictions, should increase the precision of inference.[17]

This is currently an active and fruitful research area. Christiano, Eichenbaum and Vigfussion (2006) use spectral density methods to reduce the potential bias associated with the conventional SVAR approach. Hall, Inoue, Nason and Rossi (2007) develop a new Infor-

[16] See Chari, Kehoe and McGrattan (2005). Faust and Leeper (1997) discuss theoretical issues underlying to this problem.

[17] In addition, there are additional long run restrictions that have been employed. Fisher (2002) develops an identification restriction to isolate investment specific technology shocks. Kim (2007) develops an identification restriction to isolate markup shocks.

mation Criterion to improve estimating economic model parameters via matching impulse response functions. The method chooses the lag number optimally and excludes redundant impulse response coefficients. Jorda (2005) estimates MA processes using local projections, which can be applied to long run restrictions. Dupor and Kiefer (2007) modify Jorda's approach, apply it to the labor productivity identification scheme, and report promising results.

Second, researchers should understand what generates the tension in the New Keynesian paradigm depending on whether parameters are technology versus policy shock identified. We conjecture three potential explanations for this change. First, one of the identification schemes or data detrending may be incorrect. For example, there is an ongoing debate on technology shock based identification. Christiano, Eichenbaum and Vigfusson (2005) state that treating hours as trend stationary leads hours to rise in response to a positive technology shock, whereas treating hours as difference stationary, as in Gali (1999), leads hours to fall. Chari, Kehoe and McGrattan (2005) argue that the technology shock identified VAR is not useful because it is overly sensitive to detrending methods and VAR length specification.[18]

Second, our economic model may be insufficiently rich to capture the VAR dynamics. For example, it has only twelve parameters. More sophisticated models, including, e.g. capital utilization, sticky wages, longer decision lags, may be capable of matching impulse responses for both shocks simultaneously. We are not optimistic about this approach. An ingredient that helps fit the SVAR impulses from one shock can easily make the fit from the other shock worse. As an example, adding sticky information will make inflation respond more slowly to the monetary shock; however, it will also reduce the ability of inflation to jump in response to a technology shock.

The third possible explanation is that the standard sticky price model is deficient in an important way. A limited participation component may be one solution. Technology shocks affect firms and households directly. As such, we may see relatively rapid adjustment of prices. With limited participation, monetary shocks may take time to work themselves from the financial sector to goods producing firms. Because of this, we may see slow changes in prices and real quantities.

[18] See also Ravenna (2007) for a less pessimistic establishment of the same problem.

Our bet is on the third explanation.

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6 Appendix: Data Computation and Details

A. Data is quarterly, from the U.S. and covers 1959:1-2001:4. Inflation π_t is the quarter-on-quarter change in the log GDP deflator. Labor productivity growth z_t is the quarter-on-quarter change in log productivity, where productivity is the ratio between real gross output and non-farm business hours worked to U.S. population (P.16). Hours n_t is the non-farm business hours (LBMNU). Utilization u_t is the Federal Reserve Board's manufacturing industry's capacity utilization index (IPXMCA). The interest rate r_t is the Federal Funds Rate. The other auxiliary variables include the growth rate of real investment price (p_t^I), which is calculated by Fisher (2006) based on the GCV annual data; the share of nominal consumption and investment in nominal output; the velocity of money circulation, where the money stock is measured by MZMSL (M2 less small-denomination time deposits plus institutional money funds) calculated by Federal Reserve Bank, St. Louis; and the markup level (μ_t), calculated as the ratio between nominal output per hour and the average hourly compensation in non-farm business sector (LBCPU).

B. SVAR estimates are computed using MATLAB with bootstrap generated standard errors. The economic model is simulated using code based on the solution algorithm in Christiano (2001) with the linearized equilibrium conditions presented in section 2. Point estimates of the economic model (EM) parameters are found using Matlab's minimization routine to close the distance between the (first sixteen quarters of) SVAR and economic model impulse responses. Throughout minimization, a EM parameter vector that did not imply a unique equilibrium was assigned a high penalty—ensuring the estimated parameter vectors delivered a unique equilibrium.

C. The estimation of the standard errors of structural parameters is done with the delta method. The value function or the objective function in estimation is defined as

$$V = \min_{\theta}(\Psi(\Theta) - \Psi^{VAR})' W^{-1} (\Psi(\Theta) - \Psi^{VAR}) \tag{20}$$

The estimator $\hat{\Theta}$ is the minimizer of V, thus we have $g(\hat{\Theta}, \Psi^{VAR}) = \frac{\partial V}{\partial \hat{\Theta}} = 0$. $g(\hat{\Theta}, \Psi^{VAR}) = 0$ defines $\hat{\Theta}$ as an implicit function of Ψ^{VAR}, and we have

$$\frac{\partial g}{\partial \hat{\Theta}} d\hat{\Theta} + \frac{\partial g}{\partial \Psi^{VAR}} d(\Psi^{VAR}) = 0$$

By the consistency of estimator $\hat{\Theta}$, the asymptotic distribution of $\hat{\Theta}$ satisfies

$$\sqrt{T}(\hat{\Theta} - \Theta_0) \underrightarrow{d} N(0, \Omega)$$

Ω can be calculated ad $(-(\frac{\partial g}{\partial \hat{\Theta}})^{-1} \frac{\partial g}{\partial \Psi^{VAR}})' \tilde{W} (-(\frac{\partial g}{\partial \hat{\Theta}})^{-1} \frac{\partial g}{\partial \Psi^{VAR}})$. $\tilde{W}$ is the variance-covariance matrix of Ψ^{VAR}, which can be obtained in the process of estimating the VAR model. Both $\frac{\partial g}{\partial \hat{\Theta}}$ and $\frac{\partial g}{\partial \Psi^{VAR}}$ are calculated numerically.

Table 1: Parameter Estimates from Economic Model			
Parameter	**Technology** (Benchmark)	**Monetary Policy***	**Meaning of Parameters**
$\mathbf{d}$	0.7085 (0.0399)	0.0100 (0.0011)	Share of wage bill borrowed
$\boldsymbol{\phi}_{\pi}$	1.6067 (0.0260)	1.0101 (0.0200)	Policy reaction to deviation in inflation
$\boldsymbol{\phi}_{n}$	0.0906 (0.0034)	0.9999 (0.1089)	Policy reaction to deviation in labor
$\boldsymbol{\rho}_{r}$	0.8675 (0.0010)	0.9308 (0.0002)	Interest rate smoothing
$\boldsymbol{\gamma}$	0.0091 (0.0405)	1.0000 (0.0019)	Price indexation
$\boldsymbol{\nu}$	0.4302 (0.0120)	0.9047 (0.0044)	Share of firms cannot re-optimize prices
$\boldsymbol{\kappa}$	−0.0050 (0.0000)	0.6501 (0.2063)	Habit persistence
$\mathbf{q}$	−0.0164 (0.0630)	$n.a.$ $(n.a.)$	Policy reaction to technology shocks
$\boldsymbol{\delta}$	0.0004 (0.0001)	1.0000 (0.0434)	Depreciation rate of habit/durable stock
$\boldsymbol{\rho}_{a}$	0.0000 (0.0000)	$n.a$ $(n.a.)$	Persistence of technology shock
$\boldsymbol{\sigma}_{a}$	0.3290 (0.0048)	$n.a$ $(n.a.)$	Std. dev. of technology shock
$\boldsymbol{\sigma}_{r}$	$n.a$ $(n.a.)$	0.1230 (0.0049)	Std. dev. of monetary policy shock
** The impulse responses to monetary policy shocks are estimated based on ACEL setting, in the other word, imposing both short run and long run restriction simultaneously.*			

Table 2: Robustness Checks					
Parameter	**Benchmark**	**Standard Habit**	**Nominal Rigidity**	**Bare Bones**	**ACEL**
$\mathbf{d}$	0.7085 (0.0399)	0.5230 (23.9625)	0.6978 (0.0239)	0.0000 (*n.a.*)	0.7037 (0.0357)
$\boldsymbol{\phi}_{\pi}$	1.6067 (0.0260)	1.8004 (0.5273)	1.6041 (0.0230)	1.6157 (0.0384)	1.5901 (0.0204)
$\boldsymbol{\phi}_{n}$	0.0906 (0.0034)	0.0018 (0.0590)	0.0939 (0.0032)	0.0980 (0.0054)	0.0905 (0.0028)
$\boldsymbol{\rho}_{r}$	0.8675 (0.0010)	0.9809 (0.0098)	0.8683 (0.0026)	0.8719 (0.0056)	0.8506 (0.0005)
$\boldsymbol{\gamma}$	0.0091 (0.0405)	0.0151 (0.2491)	1.0000 (*n.a.*)	0.0000 (*n.a.*)	0.0086 (0.0575)
$\boldsymbol{\nu}$	0.4302 (0.0120)	0.4491 (0.0994)	0.8000 (*n.a.*)	0.4371 (0.0172)	0.4323 (0.0080)
$\boldsymbol{\kappa}$	−0.0050 (0.0000)	0.6500 (*n.a.*)	−0.0050 (0.0000)	−0.0060 (0.0001)	−0.0052 (0.0000)
$\mathbf{q}$	−0.0164 (0.0630)	−0.0355 (0.0105)	−0.0164 (0.0355)	0.0000 (*n.a.*)	−0.0154 (0.0660)
$\boldsymbol{\delta}$	0.0004 (0.0001)	1.0000 (*n.a.*)	0.0004 (0.0000)	0.0002 (0.0001)	0.0005 (0.0001)
$\boldsymbol{\rho}$	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)
$\boldsymbol{\sigma}_{a}$	0.3290 (0.0048)	0.3290 (*n.a.*)	0.3290 (*n.a.*)	0.3290 (*n.a.*)	0.3040 (0.0044)
Notes:					
Benchmark: 10-variable system with one long run restriction; Standard Habit: Fix $\kappa = 0.65, \delta = 1$ *and re-estimate the model; Nominal Rigidity: Fix* $\nu = 0.8, \gamma = 1$ *and re-estimate the model; Bare Bones: Fix* $d = 0, q = 0, \gamma = 0$ *and re-estimate the model. ACEL: Re-estimate the benchmark model except use VAR of ACEL.*					

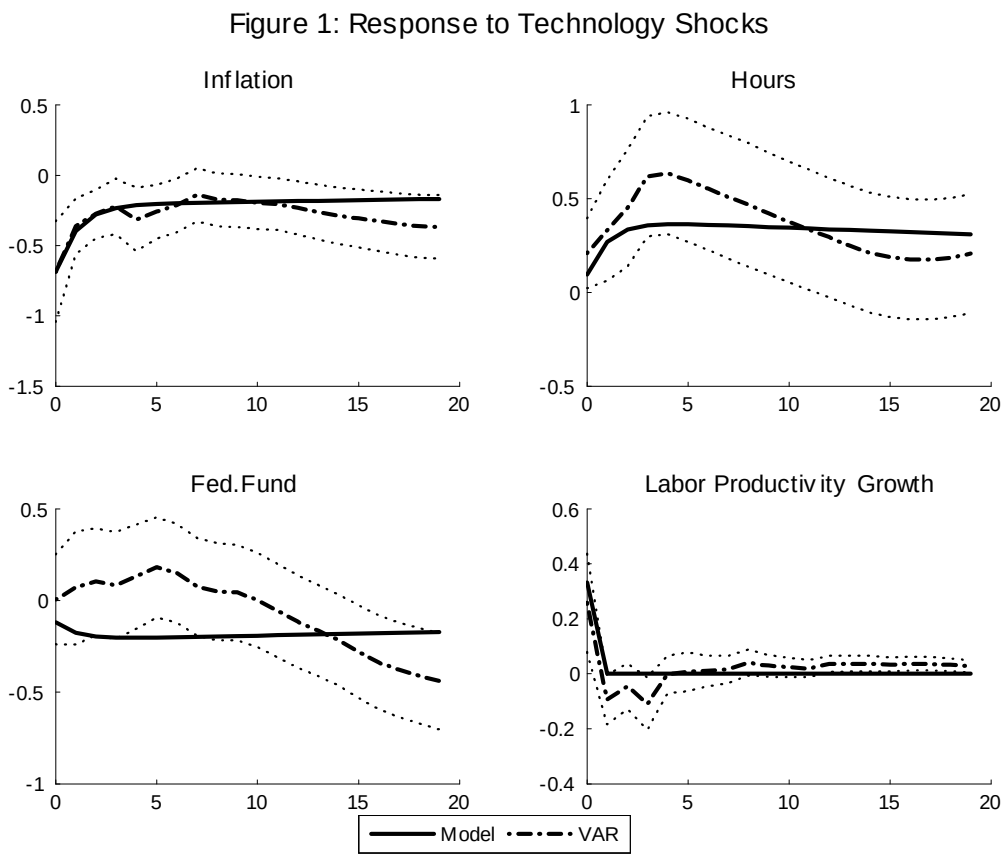
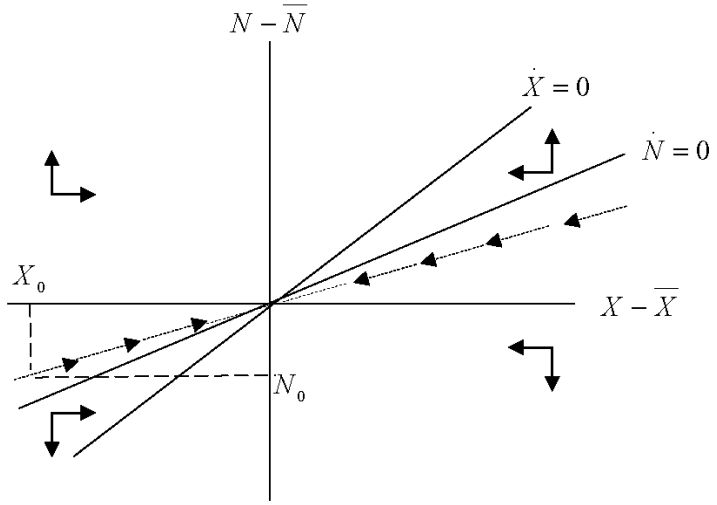
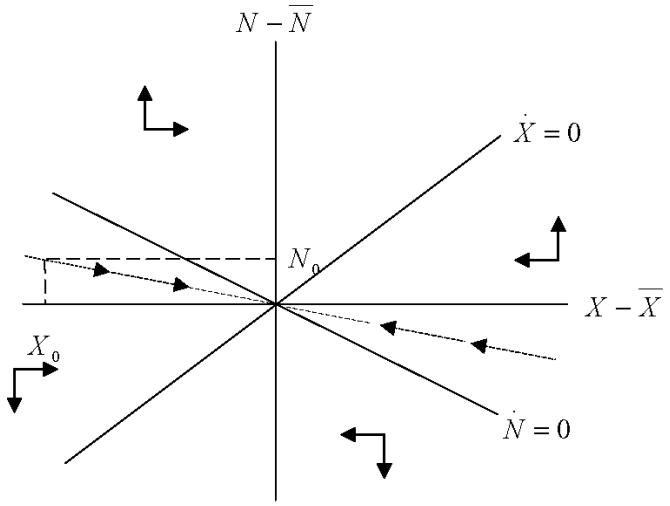


Figure 1. The Benchmark Case. Solid Line: Economic Model; Dash Dotted Line: Point Estimate of VAR; Dotted Line: Upper/Lower Confidence Interval of VAR



(a) Habits. Hours declines after a permanent technology improvement.



(b) Durability. Hours increases after a permanent technology improvement.

Figure 2. .

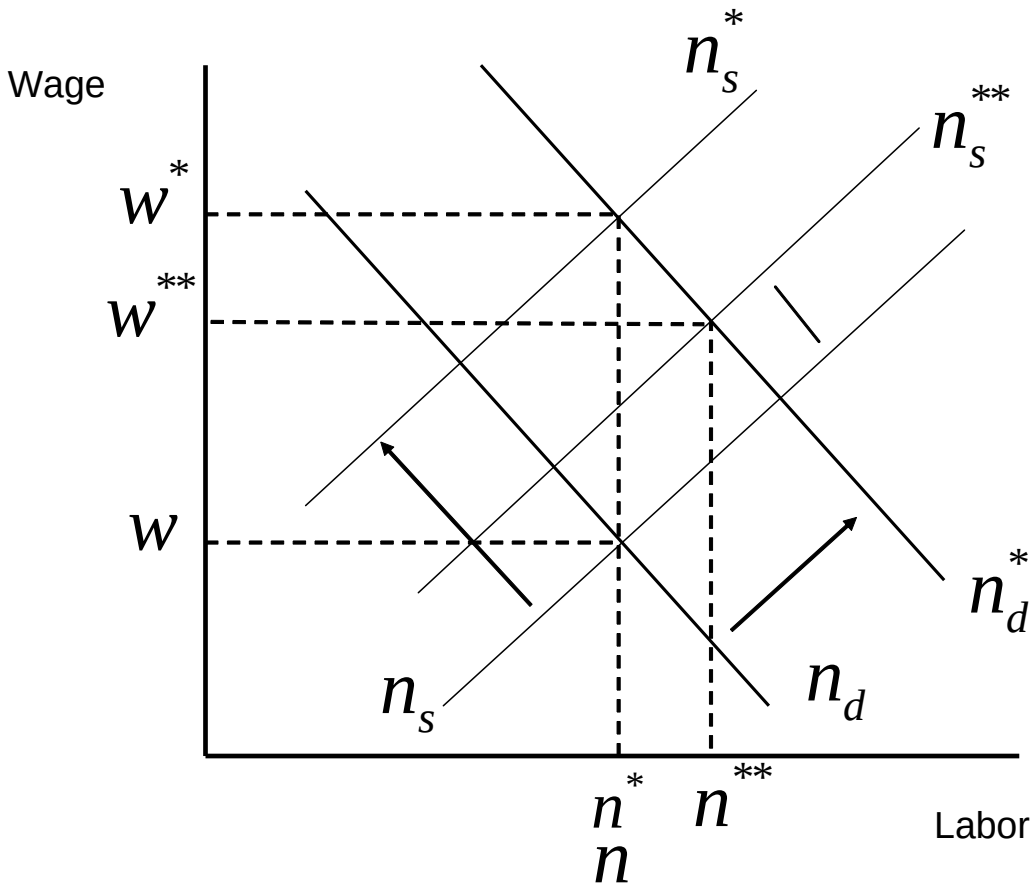


Figure 3. Labor market responses to a technological improvement under time separable preferences and durable consumption preferences.

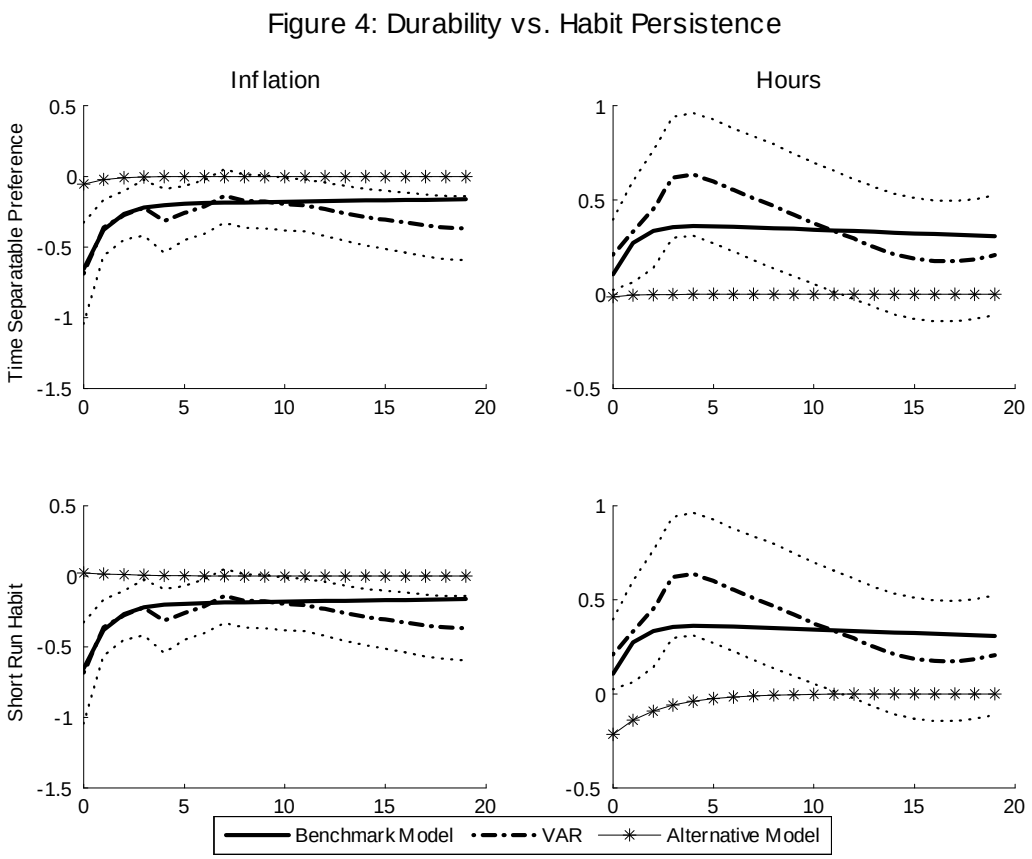


Figure 4. Counterfactural experiment, preferences. Upper panels: time separable preferences; Lower panels: standard short duration habit.

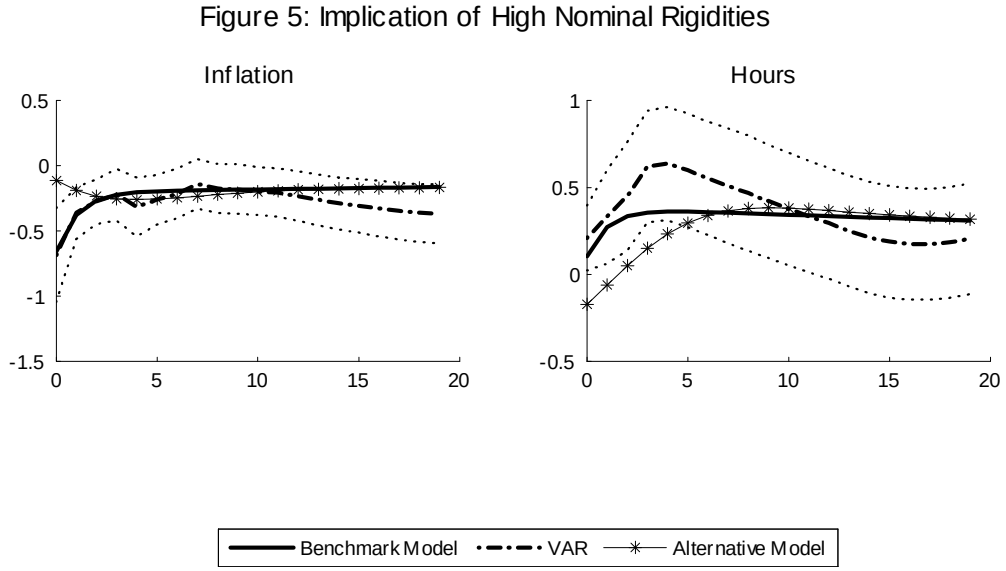


Figure 5. Couterfactual experiment, nominal rigidities. Alternative Model: $\nu = 0.8$, $\gamma = 1$.