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Abstract

Barro and King (1984) conjecture that shocks other than those to total factor productivity will have difficulty generating key business cycle comovements between output, consumption, investment and hours worked. Recent years have seen the emergence of a class of DSGE models in which aggregate fluctuations are driven by several shocks, making them particularly vulnerable to the "Barro-King Curse". These models emphasize monopolistically competitive goods and labor markets, nominal rigidities and real frictions. We show that the standard medium-scale New Keynesian model is vulnerable to the curse predicting anomalous contemporaneous correlations between key variables and wrong profiles of cross-correlations. With the realistic additions of roundabout production and real per capita output growth, the New Keynesian model can survive the curse despite standard preferences and positive trend inflation.

JEL classification: E31, E32.

Keywords: Monopolistic competition; Nominal wage and price rigidities; Firms networking; Trend output growth; Trend inflation; Business cycle comovements.

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1 Introduction

In the wake of the seminal contributions of Lucas (1977) and Kydland and Prescott (1982), a litmus test of general equilibrium macroeconomic models has been their ability to account for the cyclical comovements between output, consumption, investment and hours worked. Barro and King (1984) conjecture that shocks other than those to total factor productivity (TFP) will have difficulty generating business cycle comovements. We refer to this theoretical prediction as the "Barro-King curse".

Recent years have witnessed the emergence of a class of dynamic stochastic general equilibrium (DSGE) models driven by several disturbances other than TFP shocks. These models emphasize imperfectly competitive goods and labor markets, nominal rigidities and real adjustment frictions (Erceg et al., 2000; Christiano et al., 2005; Smets and Wouters, 2007) and are commonly known as Medium-Scale New Keynesian (MSNK) models. They are now widely used in central banks and for academic research.

A main purpose of this class of models has been to identify the sources of business cycle fluctuations and assess their relative contributions to aggregate fluctuation. The fact that it is often found that non-TFP shocks explain the bulk of business cycle fluctuations in these models make them vulnerable to the curse. Thus, our primary goal in this paper is to examine whether this is in fact the case.

Our analysis focuses on the *contemporaneous comovements* between the growth rates of output, consumption and investment and the level of hours (hours being stationary in our model), and on the *profiles of their cross-correlations*. We argue that these moments are particularly useful when judging whether a specific model is prone to the curse.

In a first step, we look at a four-shock version of the model proposed by Christiano et al. (2005), which also incorporates non-zero trend inflation. Aggregate fluctuations are driven by shocks to TFP, intertemporal preference, monetary policy and marginal efficiency of investment (MEI). Consistent with the approach laid out in Justiniano et al. (2011), MEI shocks are orthogonal to trend reductions in the price of investment relative to consumption. MEI shocks may proxy for more fundamental disturbances to the intermediation ability of the financial system.

Based on model simulations assigning different percentage contributions of TFP and MEI shocks to output fluctuations, we compare theoretical volatility and comovement statistics to those observed in the data. We find that the standard MSNK model is indeed vulnerable to the curse for a plausible calibration of the model.

A first set of substantive findings pertains to the inability of the standard model to account for the main business cycle comovements. With MEI shocks explaining 50% of business cycles, as often found in the broader literature, we show the standard model implies a negative contemporaneous correlation between the growth rates of consumption and investment at -0.05, compared to the positive correlation found in the data at 0.44. It also generates the wrong profile of cross-correlations. That is, while the profiles of cross-correlations between consumption growth and investment growth are substantially positive and decreasing both at leads and lags in the data, the standard model predicts they are more or less flat around zero.

The standard MSNK model also implies anomalous comovements between consumption growth and output growth. While in the data the contemporaneous correlation between these variables is 0.75 and the cross-correlations are very positive and declining, we find that the standard model predicts a contemporaneous correlation of 0.39 between consumption and output growth. The standard model also systematically understates the cross-correlations between these variables.

Looking at the comovements between consumption growth and the level of hours (hours being stationary in the models we study), we find that the standard model predicts a weakly positive contemporaneous correlation as in the data, but generates the wrong profiles of cross-correlations.

To provide some intuition as to why the standard MSNK model is vulnerable to the curse, we use the "Hicksian" decomposition proposed by King (1991) for general equilibrium models.[1] We decompose the response of consumption to a MEI shock – which is the main source of the wrong comovements in the model – into wealth and substitution effects. We show that the standard model generates a weakly positive income effect and a strongly negative short-run substitution effect on consumption. On balance, the substitution effect dominates over the income effect, so the response of consumption is negative on impact of a positive MEI shock and remains negative for about six quarters.

A significant strand of the literature has paid a particular attention to this "comovement problem", or the fact that consumption typically falls following a positive investment shock. To solve this problem, Greenwood et al. (1997) focus on variable capacity utilization for capital in the neoclassical model. Another avenue explored by Jaimovich and Rebelo (2009) posits non-standard preferences that restrict the strength of short-run wealth effects on the labor supply.[2] Khan and Tsoukalas (2011) specify the cost of capital utilization in terms of increased depreciation of capital as a possible solution. By contrast, when the cost of capital utilization is specified in terms of foregone consumption, as in Christiano et al. (2005) and in our model, they find that solving the

[1] See also Guerrieri et al. (2014).

[2] Papanikolaou (2011) and Eusepi and Preston (2015) also emphasize departures from utility functions that are additively separable in consumption and leisure.

comovement problem requires the complete absence of a wealth effect on labor supply. Schmitt-Grohé and Uribe (2011) have pointed to cointegration between TFP and MEI shocks. Furlanetto and Seneca (2014) suggest combining sticky prices with Edgeworth complementarity between consumption and hours worked. Guerrieri et al. (2014) propose a two-sector model where expansionary productivity shocks to an investment-producing sector boost consumption in every period.

As our Hicksian decomposition for the standard MSNK model suggests, a potential solution would be to strengthen the positive income effect on consumption conditioned on a MEI shock, while weakening the negative short-run substitution effect. Therefore, in a second step, we consider adding to the standard model two structural ingredients that can potentially do this. One is to modify the production structure to account for input-output linkages between firms along the lines of Basu (1995). The other is to account for real per capita output growth. We refer to this particular model as our *benchmark MSNK model*. We deliberately omit non-standard preferences to emphasize the generality of the solution we propose.

We show that these two ingredients have the potential to boost the positive income effect on consumption while weakening the negative short-run substitution effect. Of the two, roundabout production has the stronger income effect. But taken separately, neither roundabout production nor economic growth is sufficient to generate the desired income and substitution effects that would help to generate a positive response of consumption on impact of a positive MEI shock. It is only by combining the two that the response of consumption turns positive. Note that contrary to Khan and Tsoukalas (2011), our benchmark model is able to solve the comovement problem despite a standard specification of preferences and that the cost of capital utilization is measured in terms of foregone consumption.[3]

Our benchmark MSNK model is immune from the curse. With the MEI shock contributing from between 40% and 60% to output fluctuations, the model generates a contemporaneous correlation between consumption growth and investment growth ranging between 0.4 to 0.3. Meanwhile, the contemporaneous correlation between consumption growth and output growth ranges from 0.76 to 0.65. Our benchmark model also matches the profiles of cross-correlations between output, consumption, investment and hours quite well. Overall, our benchmark model improves significantly over the standard model.

The paper looks at one final question: a potentially pervasive effect of the interaction between trend inflation and the *persistence* of the MEI shock on business cycle comovements. Ascari et al. (2018) show that a moderate level of trend inflation may alter the impulse responses of output,

[3] Measuring the cost of capital utilization in terms of increased capital depreciation would boost the income effect on consumption even more in our model.

consumption and investment following a MEI shock relative to the responses obtained under zero trend inflation. This means that even a moderate rate of trend inflation can possibly alter some key business cycle comovements depending on the persistence of the MEI shock, something that has thus far been overlooked in the literature.

Estimates of the AR(1) parameter of the MEI shock process typically range from 0.7 to 0.85. For an AR(1) parameter of the MEI shock varying between 0.7 and 0.9 and a MEI shock explaining 50% of output fluctuations, we show that the contemporaneous correlation between consumption growth and investment growth predicted by the standard MSNK model will vary from 0.12 to −0.43, compared to 0.44 in the data. Meanwhile, the contemporaneous correlation between output growth and consumption growth will range from 0.51 to 0.09, compared to 0.75 in the data. In comparison, our benchmark MSNK model predicts that the contemporaneous correlation between consumption growth and investment growth will lie between 0.4 and 0.09 for different levels of trend inflation and persistence of the MEI shock. It also implies that the contemporaneous correlation between output growth and consumption growth will range from 0.73 to 0.53, hence making our benchmark model less vulnerable to potential pitfalls.

The remainder of the paper is organized as follows. Section 2 lays out our medium-scale DSGE model and discusses some issues related to calibration. Section 3 measures how the standard MSNK model squares with the Barro-King curse. Section 4 adds roundabout production and trend output growth to the standard model. Section 5 examines the robustness of our results. Section 6 adds concluding remarks.

2 Model and Calibration

2.1 The Model

The baseline MSNK model embeds a number of features found in similar models in the literature – such as standard additively separable preferences, nominal rigidities as Calvo (1983) wage and price contracts, habit formation in consumption, investment adjustment costs, variable capital utilization and a Taylor rule. It also allows for non-zero trend inflation.

Our benchmark MSNK model adds to the standard model roundabout production, recently referred to as "firms networking" (FN) (e.g., Christiano, 2015). Evidence supporting this production structure is discussed in Basu (1995), Huang et al. (2004) and Nakamura and Steinsson (2010). It is also confirmed by a recent dataset gathered through the joints efforts of the NBER and the U.S. Census Bureau's CES that covers 473 six-digit 1997 NAICS industries for the years 1959-2009. These data reveal that the share of materials in final sales in the manufacturing sector exceeds

50 percent. For simplicity, we will refer to models incorporating this feature as *FN-models*. Our model also allows for real per capita output growth stemming from trend growth in neutral and investment-specific technologies (G). We will refer to models incorporating this particular feature as *G-models*. Appendix A contains a detailed description of the model equations, together with the full set of equilibrium conditions re-written in stationary terms.

Unlike Christiano et al. (2005) and Smets and Wouters (2007), both the standard and benchmark models abstract from the automatic indexation of non-reset wages and prices to past inflation and/or steady-state inflation. Combined with Calvo contracts, either form of indexation implies that all nominal wages and prices change every quarter. This is inconsistent with evidence that many wages and prices remain fixed for relatively long periods of time (e.g., Eichenbaum et al., 2011; Klenow and Malin, 2011; Barattieri et al., 2014). Indexation is also criticized for a lack of microeconomic foundations (Chari et al., 2009). Moreover, Cogley and Sbordone (2008) find no evidence of price indexation to the previous period's rate of inflation when combining sticky prices with time-varying trend inflation. Therefore, indexation has been omitted from many recent New Keynesian models such as Christiano et al. (2010), Christiano et al. (2015, 2016) and Ascari et al. (2018). The presence of FN is able to generate realistic inertia in inflation, without the unrealistic assumption of backward-looking indexation.

The production function for a typical producer j is given by:

$$X_t(j) = \max\left\{ A_t \Gamma_t(j)^{\phi} \left(\widehat{K}_t(j)^{\alpha} L_t(j)^{1-\alpha} \right)^{1-\phi} - \Upsilon_t F, 0 \right\}, \tag{1}$$

where A_t is neutral productivity, $\Gamma_t(j)$ denotes intermediate inputs, F is a fixed cost, Υ_t is a growth factor (see below) and production is required to be non-negative. $\phi \in (0,1)$ is the intermediate input share. Intermediate inputs come from aggregate gross output, X_t. $\widehat{K}_t(j)$ represents capital services or the product of utilization (Z_t) and physical capital (K_t), while $L_t(j)$ is labor input.

The cost minimization problem of a typical firm yields the following expression for real marginal cost, v_t, which is common across firms:

$$v_t = \overline{\phi} A_t^{-1} \left(r_t^k \right)^{\alpha(1-\phi)} w_t^{(1-\alpha)(1-\phi)}, \tag{2}$$

where $\overline{\phi}$ is a constant, r_t^k is the common real rental price on capital services and w_t is the real wage index. This expression for real marginal cost shows that relative to the basic case in the literature, FN reduces the sensitivity of real marginal cost to factor prices by a factor of $1-\phi$. Hence, FN flattens the New Keynesian Phillips Curve, amplifying the stickiness in the economy caused by nominal rigidities.

The second important feature of our model is real per capita output growth stemming from two distinct sources: trend growth in neutral technology and in investment-specific technology (IST). Greenwood et al. (1997) show that investment-specific technological change has been a major source of U.S. economic growth during the postwar period. In the context of our model, trend growth in IST realistically captures the downward secular movement in the relative price of investment observed during the postwar period. First, neutral productivity obeys a process with both a trending and stationary component.

$$A_t = A_t^{\tau} \widetilde{A}_t, \tag{3}$$

A_t^{τ} is the deterministic trend component that grows at a constant gross rate g_A, while $\widetilde{A}_t$ is the stationary component. The initial level in period 0 is normalized to 1: $A_0^{\tau} = 1$. The stationary component follows an AR(1) process. To introduce IST, we specify the physical capital accumulation process as follows:

$$K_{t+1} = \varepsilon_t^{I,\tau} \vartheta_t \left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right) I_t + (1-\delta)K_t, \tag{4}$$

where K_t is the physical capital stock and I_t is investment measured in units of consumption. $S\left(\frac{I_t}{I_{t-1}}\right)$ is an investment adjustment cost that satisfies $S\left(g_I\right) = 0$, $S'\left(g_I\right) = 0$, and $S''\left(g_I\right) > 0$, where $g_I \geq 1$ is the steady state (gross) growth rate of investment. $0 < \delta < 1$ is the depreciation rate. $\varepsilon_t^{I,\tau}$ measures the level of IST and it enters the capital accumulation equation by multiplying investment.[4] $\varepsilon_t^{I,\tau}$ follows a deterministic trend with no stochastic component, where g_{ε^I} is the gross growth rate. ϑ_t is a shock to the marginal efficiency of investment.

Most variables in the model inherit trend growth from the deterministic trends in neutral and investment-specific productivity.[5] Suppose that this trend factor is Υ_t. Output, consumption, investment (measured in units of consumption), intermediate inputs, and the real wage all grow at the rate of this trend factor on a balanced growth path: $g_Y = g_I = g_\Gamma = g_w = g_\Upsilon$. The capital stock grows faster due to growth in investment-specific productivity, with $\widetilde{K}_t \equiv \frac{K_t}{\Upsilon_t \varepsilon_t^{I,\tau}}$ being stationary. The trend factor inducing stationarity among transformed variables is:

$$\Upsilon_t = \left(A_t^{\tau}\right)^{\frac{1}{(1-\phi)(1-\alpha)}} \left(\varepsilon_t^{I,\tau}\right)^{\frac{\alpha}{1-\alpha}}. \tag{5}$$

[4] $\varepsilon_t^{I,\tau}$ also enters the budget constraint in terms of the resource cost of capital utilization, see Appendix A.2.

[5] Given our specification of preferences, labor hours are stationary.

Note the interaction between FN and growth in this expression. When there are no intermediate inputs, this expression reverts to the conventional trend growth factor in a model with growth in neutral and investment-specific productivity. (5) implies that a higher value of the share of intermediate inputs ϕ amplifies the effects of trend growth in neutral productivity on output and its components. For a given level of trend growth in neutral productivity, the economy will grow faster the larger is the share of intermediates in production.

ϑ_t in (4) is a stochastic MEI shock. Justiniano et al. (2011) distinguish between IST and MEI, showing that IST growth maps one-to-one into the relative price of investment goods, while MEI shocks have no impact on the relative price of investment. Their evidence suggests that the MEI shock is the main disturbance explaining business cycle fluctuations, while the stochastic shock to IST virtually has no impact on output at business cycle frequencies. Hence, we assume that the MEI component is stochastic while the IST term affects trend growth only.

Our model includes four shocks: MEI, neutral productivity, intertemporal preference and monetary policy. In Christiano et al. (2005), aggregate fluctuations are driven solely by monetary policy shocks. In Smets and Wouters (2007) they are driven by seven shocks. Chari et al. (2009), however, criticize multi-shock New Keynesian models, arguing that of the several shocks used in these models, only three can be viewed as truly "structural" in the sense of having a clear economic interpretation: investment, neutral technology, and monetary policy. So, we keep these three shocks in the model. We also keep the intertemporal preference shock since Justiniano et al. (2011) find that this shock explains 55 percent of consumption fluctuations. The MEI shock follows a stationary AR(1) process, with innovation u_t^I drawn from a mean zero normal distribution with standard deviation s_I:

$$\vartheta_t = (\vartheta_{t-1})^{\rho_I} \exp(s_I u_t^I), \quad 0 \le \rho_I < 1. \tag{6}$$

The stationary component of neutral productivity, $\widetilde{A}_t$, follows an AR(1) process in the log, with the non-stochastic mean level normalized to unity, and innovation, u_t^A, drawn from a mean zero normal distribution with known standard deviation equal to s_A:

$$\widetilde{A}_t = \left(\widetilde{A}_{t-1}\right)^{\rho_A} \exp\left(s_A u_t^A\right), \quad 0 \le \rho_A < 1. \tag{7}$$

The intertemporal preference shock ε_t^b follows a stationary AR(1) process:

$$\varepsilon_t^b = (\varepsilon_{t-1}^b)^{\rho_b} \exp(s_b u_t^b), \tag{8}$$

with innovation u_t^b drawn from a mean zero normal distribution with standard deviation s_b.

The monetary policy shock represents a random deviation from the following Taylor rule:

$$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_i} \left[\left(\frac{\pi_t}{\pi}\right)^{\alpha_\pi} \left(\frac{Y_t}{Y_{t-1}} g_Y^{-1}\right)^{\alpha_y}\right]^{1-\rho_i} \varepsilon_t^r. \tag{9}$$

The central bank adjusts the nominal interest rate, i_t, in response to deviations of inflation from an exogenous steady-state inflation target, and to deviations of output growth from its steady-state level. ε_t^r is the exogenous shock to the policy rule and it is assumed to be white noise. ρ_i is a smoothing parameter while α_π and α_y are two policy parameters. The above rule does not include a response to the level of the output gap. The reason for this is that Khan et al. (2019) show that when trend inflation interacts with sticky wages and trend growth, achieving determinacy when the Taylor rule includes the output gap calls for a response to inflation that significantly exceeds the original Taylor Principle ($\alpha_\pi \geq 1$) and the estimates found in the literature. This is true even levels of inflation as low as 2% or 3%. By contrast, a rule reacting to output growth, but not to the output gap, increases the central bank's ability to ensure determinacy for a wider array of policy responses to inflation. See also Coibion and Gorodnichenko (2011).

2.2 Calibration

Tables 1 and 2 summarize the calibration of the model, which is rather standard and in line with the literature (e.g., Christiano, Eichenbaum, and Evans, 2005; Justiniano, Primiceri, and Tambalotti, 2010, 2011). Appendix B discusses it in further detail. In the text, we focus on the central ingredients of our model: FN, trend growth, and the shocks.

The share of intermediate inputs, ϕ, is set to 0.61. The values of ϕ used in the comparable literature typically range from 0.5 to 0.8. Ours is obtained as follows. Following Nakamura and Steinsson (2010), we take the weighted average revenue share of intermediate inputs in the U.S. private sector using Consumer Price Index (CPI) expenditure weights to be roughly 51 percent in 2002. The cost share of intermediate inputs is equal to the revenue share times the price markup. Since our calibration implies a steady state markup of 1.2, our estimate of the weighted average cost share of intermediate inputs is roughly 0.61.

Mapping the model to the data, the trend growth rate of the IST term, g_{ε^I}, equals the negative of the growth rate of the relative price of investment goods. To measure this in the data, we define investment as expenditures on new durables plus private fixed investment, and consumption as consumer expenditures of nondurables and services. These series are from the BEA and cover the period 1960:I-2007:III, to leave out the financial crisis.[6] The relative price of investment is the ratio

[6] A detailed explanation of how these data are constructed can be found in Ascari et al. (2018).

of the implied price index for investment goods to the price index for consumption goods. The average growth rate of the relative price from the period 1960:I-2007:III is -0.00472, so that $g_{\varepsilon^I} = 1.00472$. Real per capita GDP is computed by subtracting the log civilian non-institutionalized population from the log-level of real GDP. The average growth rate of the resulting output per capita series over the period is 0.005712, so that $g_Y = 1.005712$ or 2.28 percent a year. Given the calibrated growth of IST, we then use (5) to set $g_A^{1-\phi}$ to generate the appropriate average growth rate of output. This implies $g_A^{1-\phi} = 1.0022$ or a measured growth rate of TFP of about 1 percent per year.[7]

Regarding the calibration of the shocks, we set the autoregressive parameter of the neutral productivity shock at 0.95. Based on the estimate in Justiniano et al. (2011), we set the baseline value of the autoregressive parameter of the MEI process at 0.8 and that of the intertemporal preference shock at 0.6. In the robustness Section 5, we also look at the effects of lowering the persistence of the MEI shock to 0.7 and increasing it to 0.9.

Our procedure to pin down the standard deviations of the four shocks in our model is to target the size of shocks s_A, s_I, s_b and s_r, for which the model exactly matches the actual standard deviation of output growth observed in our data (0.0078) assuming an average growth rate of the price index equal to that in the data over the period 1960:I-2007:III. This implies a positive steady-state inflation of 3.52 percent annualized ($\pi^* = 1.0088$).[8]

We then assign to each shock a target percentage contribution to the unconditional variance decomposition of output growth. Our targets for the contribution of the shocks to the variance of output growth are based on empirical consensus from the recent literature. In this literature, investment shocks are the main driver behind business-cycle fluctuations, followed by neutral technology shocks. In the estimates from Justiniano et al. (2010), the investment shock explains about 50 percent of the variance decomposition of output growth at business cycle frequencies, followed by the neutral technology shock with 25 percent, the intertemporal preference shock with 7 percent and the monetary policy shock with 5 percent. This leaves only 13 percent to be explained by other shocks, which in their model are government-spending, price-markup, and wage-markup shocks.

Justiniano et al. (2011) distinguish between an investment-specific technology (IST) shock and a shock to the marginal efficiency of investment (MEI). The MEI shock explains 60 percent of fluctuations in output growth, the neutral technology 25 percent, the intertemporal preference shock 5 percent and the monetary policy shock 4 percent. This leaves only 6 percent of output

[7]Note that this is a lower average growth rate of TFP than would obtain under traditional growth accounting exercises. This is due to the fact that our model includes FN, which would mean that a traditional growth accounting exercise ought to overstate the growth rate of true TFP.

[8]Ascari et al. (2018) study the welfare and cyclical implications of moderate trend inflation.

fluctuations to be explained by other types of shocks. Other studies in which investment shocks explain a larger fraction of output fluctuations than TFP shocks include Fisher (2006), Justiniano and Primiceri (2008), Altig et al. (2011) and Khan and Tsoukalas (2011).[9]

To determine the exact numerical values for s_A, s_I, s_b and s_r, our baseline calibration assigns 50 percent of the variance of output growth to the MEI shock, 35 percent to the TFP shock, 8 percent to the intertemporal preference shock, and 7 percent to the monetary policy shock. In the robustness Section 5, we also consider two other different splits for the target contribution of shocks to the variance decomposition of output growth. That is, we will also assess the sensitivity of our results to increasing the contribution of the MEI shock to 60 percent while lowering that of the neutral technology shock to 25 percent, and to increasing the contribution of the neutral technology shock to 45 percent while lowering that of the MEI shock to 40 percent.

Thus, according to our baseline calibration, the MEI shock is the key disturbance driving the business cycle, but the TFP shock remains quite important. Table 3 displays the values of the standard deviations of the shocks generated through this procedure for four different versions of our model. The first column refers to a model with no FN and no growth, that we name for simplicity "standard New Keynesian model" in the text. The second column refers to our benchmark model with FN and growth. The last two columns refer to versions of the model where one of the two additional features is switched off.

What is striking about these numbers is that, with intermediate inputs and trend output growth, the standard deviations of the TFP and MEI shocks needed to match the actual volatility of output growth are much smaller. The neutral technology shock is nearly 61 percent smaller with these features added to the model. FN is the key factor behind the magnifying effects of a neutral technology shock. With only FN added to the model, the neutral technology shock is nearly 58 percent smaller. This is not surprising since relative to the standard model, the productivity shock in essence affects output "twice" with roundabout production, first via its direct effect on output in the production function and then indirectly through its effect on intermediate inputs. The standard deviation of the MEI shock is 32 percent smaller than in the standard model, and both FN and growth contribute to this reduction in roughly equal proportions. The model with FN and trend growth also magnifies the effects of monetary policy shocks on output, with a standard

[9]One exception, however, is Smets and Wouters (2007), who report that investment shocks account for less than 25 percent of the forecast error variance of GDP at any horizon. Justiniano et al. (2010) explore the reasons for these differences, showing that the smaller contribution of investment shocks in Smets and Wouters (2007) results from their definition of consumption and investment which includes durable expenditures in consumption while excluding the change in inventories from investment, although not from output. With the more standard definition of consumption and investment found in the business-cycle literature (e.g., Cooley and Prescott, 1995; Christiano et al., 2005; Del Negro et al., 2007), they find that investment shocks explain more than 50 percent of business-cycle fluctuations.

deviation of the shock which is 21 percent smaller than in the standard model. FN and growth have comparably little effect on the standard deviation of the intertemporal preference shock in our calibration exercise.

3 The Barro-King Curse in the Standard MSNK Model

This section addresses the following questions. How does the standard MSNK model (abstracting from FN and trend output growth) square with the stylized facts under our baseline calibration? Is it prone to the curse? If the answer proves to be affirmative, what are some potential reasons for this problem?

3.1 Business Cycle Moments

We focus on moments that will help assessing whether the standard MSNK model is vulnerable to the Barro-King curse. They include volatility and comovement business cycle statistics. The sample period is 1960:II-2007:III. The variables of interest are output, consumption, investment and hours.

The first row in Table 4 displays moments in the data. Recall that we require from a model that it matches the actual volatility of output growth, so that there is no need to report it in the table. Consumption growth is 40 percent less volatile than output growth. Investment growth is 2.6 times more volatile than output growth. First-differenced hours are about as volatile as output growth. These relative volatilities are well known stylized facts in the business cycle literature.

The contemporaneous correlation between investment growth and output growth is positive and high at 0.92. Consumption growth is also quite procyclical, but less than investment growth, with a contemporaneous correlation of 0.75. The contemporaneous correlation between the growth rates of consumption and investment is positive and mild in the data at 0.44. The contemporaneous correlation between output growth and hours in levels is weakly positive at 0.11, and so is the correlation between consumption growth and the level of hours at 0.075.

Figure 1 displays the cross-correlograms between the growth rates of output, consumption and investment and the level of hours. The cross-correlations in the data are represented by the lines with circles. The cross-correlograms involving output growth and consumption growth, output growth and investment growth, and consumption growth and investment growth are positive and decreasing in the data, both at lags and leads. The profiles of cross-correlations involving hours in levels are not so uniform at lags and leads. That is, the patterns of cross-correlations $(L_t, dY_{t-k}), (L_t, dC_{t-k}), (L_t, dI_{t-k}),\ k = 0, ..., 4,$ are all positive and increasing. By contrast, the patterns of cross-correlations $(dY_t, L_{t-k}), (dC_t, L_{t-k}), (dI_t, L_{t-k}),\ k = 0, ..., 4$, are positive contemporaneously, but then turn negative for $k \geq 1$.

3.2 The Standard MSNK Model: Vulnerable to the Curse

The second row of Table 4 reports the business cycle statistics predicted by the standard MSNK model (i.e., No FN/No G) for our baseline calibration.[10] The standard model nearly matches the volatility of consumption growth in the data, but significantly overstates the volatility of investment growth by 23 percent and the volatility of hours by 25 percent.

It fails to match key business cycle comovements. One failure is its prediction of a negative contemporaneous correlation between the growth rates of consumption and investment at -0.05. The standard model also implies incorrect patterns of cross-correlations. That is, the cross-correlations at lags and leads of 1 to 4 quarters implied by the standard model and denoted by the solid lines in Figure 1 are more or less flat around zero, which contrasts sharply with the substantially positive and decreasing pattern of cross-correlations in the data.

Another anomaly of the standard model is that it generates a contemporaneous correlation between consumption growth and output growth which is mildly positive at 0.39. Furthermore, the cross-correlations between consumption growth and output growth implied by the standard model are systematically lower than those found in the data (see Figure 1). As we will later show, these anomalies are even more severe when the MEI shock is more persistent.

A third anomaly of the standard model pertains to the cross-correlations between consumption growth and the level of hours. While the contemporaneous correlation between consumption growth and the level of hours is somewhat understated by the standard model, it is not too far from the low and positive value observed in the data. The problem is with the profile of cross-correlations. That is, $(dC_t, L_{t-k}),\ k = 0, ..., 4$, is mildly increasing in the model and weakly decreasing in the data, while $(dC_{t-k}, L_t),\ k = 0, ..., 4$, is increasing in the model but much less than in the data.

The most important anomalies of the standard model are related to consumption. What are the reasons for these anomalies? As shown by the dotted line in the second panel of the first row of Figure 2, a key factor is the negative short-run response of consumption following a positive MEI shock. The MEI shock can be seen as an aggregate demand shock that raises the current demand for (investment) goods relative to supply, pushing output and inflation in the same direction. Moreover, following a positive MEI shock, investment is more profitable, so agents substitute consumption for investment. The impulse-response function is hump-shaped, so consumption drops on impact,

[10] When comparing moments predicted by alternative models to the data, the models are solved via second order perturbation about the non-stochastic steady state.

keeps decreasing for two quarters, and then starts increasing, only turning above steady state after six quarters. A more persistent MEI shock would make things worse and the anomalies would be more severe.

3.3 Hicksian Decomposition

Another way to look at the failure of the standard MSNK model to produce comovements is by considering a "Hicksian" decomposition proposed by King (1991) for general equilibrium models. Figure 3 decomposes the response of consumption (hours) to a MEI shock into wealth and substitution effects. Following King (1991), the wealth effect on consumption is defined as the log change in steady-state consumption (hours) that would yield the same change in intertemporal utility as that generated by the MEI shock keeping prices, wages and the real interest rate constant at their steady state levels. The substitution effect is the path of consumption that would induce no change in utility in reaction to price, wage and interest rate changes induced by the MEI shock.

The wealth and substitution effects implied by the standard MSNK model are displayed as dotted lines in the four panels of Figure 3. The standard model implies a weakly positive income effect on consumption. Meanwhile, it generates a strong, negative short-run substitution effect on consumption, with the substitution effect starting to turn positive only after six quarters. On balance, the short-run negative substitution effect dominates the positive wealth effect on consumption, implying that the response of consumption to a positive MEI shock is initially negative.

4 Surviving the Curse in the MSNK Model

Here, we examine how the addition of firms networking (FN) and economic growth (G) impacts moments vis-à-vis the standard model. The moments from our model are shown in Table 4. The contemporaneous correlation between the growth rates of consumption and investment is now positive and close to the one observed in the data at 0.36. The contemporaneous correlation between consumption growth and output growth also improves substantially, being equal to 0.70. The contemporaneous correlation between investment growth and output growth implied by the FN/G model is nearly 0.9. With respect to hours, our model does as well as the standard model, with the contemporaneous correlation between output growth and the level of hours marginally worsening, while the one between consumption growth and hours marginally improves. Finally, Table 4 shows that our benchmark model with firms networking and trend output growth almost exactly matches the volatilities of consumption growth, investment growth, and the log first difference in hours worked.

Another dimension along which our benchmark model improves over the standard MSNK model is its ability to broadly reproduce the profiles of all the cross-correlograms which are denoted by the dashed lines in Figure 1. Note in particular how well it reproduces the positive and decreasing cross-correlations (dC_t, dI_{t-k}) compared to the pattern predicted by the standard model which is more or less flat around zero. As for the cross-correlations (dC_{t-k}, dI_t), the benchmark model also captures the positive and decreasing profile.

The benchmark model also closely matches the positive and decreasing cross-correlations between consumption growth and output growth at both leads and lags. It is also broadly consistent with the cross-correlations (dC_t, L_{t-k}) and (dC_{t-k}, L_t) found in the data, while the standard model performs less well along this particular dimension. All in all, the benchmark model outperforms the standard MSNK model on almost all the cross-correlograms. Its ability to reproduce all the cross-correlations is quite striking.

The key to these improved results is the short-run response of consumption after a positive MEI shock. Compared to the baseline MSNK model, this response is markedly different in the benchmark model with FN and trend output growth, as shown by the solid line in the second panel of the first row of Figure 2. Here, consumption rises on impact of a positive MEI shock and it continues to increase over time.

Why does our model generate a positive response of consumption to a MEI shock? Because of a stronger income effect. Figure 2 shows that the response of output is more persistent in our benchmark model. The output path is very close to the one of the standard model for the first two quarters, but our benchmark model creates a larger hump from period three and onward. Output keeps increasing in our model because the response of the marginal costs, and also of inflation, is more muted in presence of FN. The MEI shock is ultimately a demand shock whereby investment increases. FN flattens the Phillips curve, making marginal costs less responsive and the boom more long-lasting. Moreover, trend growth also contributes to a lower response to inflation because price-setters are more forward-looking and less sensitive to current conditions.

The higher path of output creates a stronger income effect in our model. This can be seen from Figure 3 where we use the Hicksian decomposition proposed by King (1991). There, we can see that the income effect on consumption induced by the MEI shock in our model is twice the income effect in the standard model ($6.9\text{x}10^{-4}$ vs. $3.4\text{x}10^{-4}$). While the income effect generated by the standard MSNK model is too low to turn the response of consumption from negative (due to the substitution effect) to positive, the one generated by our benchmark model is able to overturn the negative substitution effect on consumption. The income effect on hours has the same absolute value and the opposite sign.[11] It follows that households consume more and work less. Hence, the response of investment is lower on impact, but more persistent in our model.

To conclude, a MSNK model with FN and growth makes the key macroeconomic variables (i.e., output, consumption, investment and hours) positively comove after a MEI shock, which is not the case after a positive TFP shock since output, consumption and investment then increase while hours decline in the short run. As such, this model breaks the Barro-King's curse formulated in a neoclassical framework that only TFP shocks are able to generate the typical positive comovements between these variables. It actually goes further than surviving the Barro-King curse, because it reproduces strikingly well business cycle moments between key macroeconomic variables beyond relative volatilities and contemporaneous correlations. As we have found, it also quite closely matches the cross-correlograms between the key macroeconomic variables (i.e., output, consumption, investment and hours) in the data.

4.1 Disentangling the effects of FN and Trend Growth

Next, we disentangle the effect of FN vs. trend output growth on our findings. Table 4 shows the unconditional moments implied by the following two versions of the model: one with growth but no FN (No FN/ Growth) and the other with FN but no trend growth (FN/No Growth).[12] The Table shows that both trend output growth and FN lead to some improvements in business cycle comovements with respect to the standard MSNK model. For instance, the contemporaneous correlation between the growth rates of consumption and investment becomes positive when one of the two features is added to the model. However, it is much lower than in the data at 0.12 and 0.19, respectively. Each of these two features represents a step in the right direction, but the presence of only one of the two is not enough to overcome the anomaly. This also applies to the correlation between the growth rates of consumption and output.

Figure 2 highlights the relative role of these two features in breaking the Barro-King curse. Trend growth affects mainly the persistence of the IRFs of the variables to a MEI shock with respect to the standard model. In this case, the initial responses (see dashed lines) of output and hours are similar to the standard model, but the IRFs are more persistent. According to the previous intuition, trend growth makes price-setting more forward-looking and less sensitive to current conditions, thereby flattening the Phillips curve. Indeed, the response of inflation is slightly more muted. This generates a stronger wealth effect relative to the standard model, such

[11] This is because preferences are time separable and the instantaneous utility when $\chi = 1$ implies unit elastic demand, as noted by King (1991).

[12] Recall that for each version, we rescale the size of shocks so the model exactly matches that the volatility of output growth in the data, see Table 3.

that there is less substitution between consumption and investment: consumption decreases less and investment increase less with respect to the standard model. FN instead lowers the response of inflation to a MEI shock by making the response of marginal cost more muted. Hence, FN affects the initial response of output and other variables, rather than their persistence. As a result, the consumption response is higher initially with FN rather than with economic growth, but six quarters after the shock it is the opposite, because trend growth makes the IRFs more persistent.

So while FN and trend output growth each contributes in their own way to fix the anomalies of the standard MSNK model, it is really the interaction between these two ingredients in the FN/G model that contributes to break the Barro-King curse within this class of models.

Previously, we have argued that most of the action is due to a muted response of inflation. Hence, to further illustrate the usefulness of combining FN and economic growth to avoid the short-run decline in consumption following a positive MEI shock, we now ask what the Calvo probabilities of wage and price non-reoptimization would need to be in the standard MSNK model to generate the same increase in consumption on impact in response to a positive investment shock as in the FN/G model. Here, we consider three different scenarios. In the first scenario, the Calvo probability of wage non-reoptimization ξ_w is kept at 2/3, while we search for the appropriate Calvo probability of price non-reoptimization ξ_p. The second scenario is a similar exercise, except that this time we keep ξ_p at 2/3 while searching for ξ_w. Lastly, we set $\xi_w = 0.76$ following the microeconomic evidence found in Barattieri et al. (2014) and search for ξ_p.[13]

The results are presented in Figure 4. Panel A of the Figure shows the results for the first scenario. Here we report the response of consumption with $\xi_p = 0.88$ and $\xi_w = 2/3$.[14] For $\xi_p = 0.88$, which represents an average waiting time between price adjustments of 25 months, we find that the increase in consumption is smaller on impact after a MEI shock and is also smaller at all horizons than in our benchmark model under our baseline calibration. Of course, having prices adjust once every 25 months on average is empirically implausible. Panel B shows the results corresponding to the second scenario. With ξ_p kept at 2/3, ξ_w would need to be 0.82 to match the rise in consumption on impact of a positive investment shock in the benchmark model. This represents an average frequency of nominal wage adjustment of once every 17 months, which is significantly higher than assumed in the benchmark model under our baseline calibration. Panel C sets ξ_w at 0.76, so ξ_p needs to be 0.86, meaning that prices adjust once every 21.5 months on average to match the initial rise in consumption in the benchmark model.

[13] As before, we rescale the size of shocks so that our model matches the postwar volatility of output growth also for these exercises.

[14] The model does not have a determinate solution for ξ_p higher than 0.88 because of a positive trend inflation rate of 3.52 annually (see Ascari and Ropele, 2009; Coibion and Gorodnichenko, 2011).

What do we conclude from these three exercises? We conclude that it takes implausibly high Calvo probabilities of wage and price non-reoptimization in the standard MSNK model to avoid the short-run decline in consumption following a positive investment shock.

5 Robustness

We look in this Section at the robustness of our results with respect to: (i) the relative contributions of the shocks to the variance decomposition of output growth; (ii) the autoregressive coefficient of the MEI shock.

5.1 Relative Size of Shocks

Here we consider two other different splits of the relative importance of shocks in determining the variance of output growth. A first split (Split 1) increases the relative importance of MEI shocks, by setting the target contribution of the MEI shock and TFP shock to 60 and 25 percent, respectively. This split is broadly consistent with the evidence reported in Justiniano et al. (2011) where the MEI shock is by far the most important disturbance driving business cycle fluctuations. A second split (Split 2) increases the importance of TFP shocks relative to our benchmark case, assigning 45 percent to the TFP shock and 40 percent to the MEI shock, so that the TFP shock becomes the main disturbance driving the business cycle. In both splits, the percentage contributions of the other two shocks are kept constant. The numerical values for the shock standard deviations for these two splits for the alternative models are reported in Table 5. As expected, no matter what the split of shocks is, the standard deviation of the MEI shock is by far the largest, followed by the standard deviation of the intertemporal preference shock, then of the neutral technology shock, and last of the monetary policy shock.

Table 6 replicates Table 4 showing selected business cycle moments for the two splits. As foreseen by Barro and King (1984), the less important the TFP shock is (or the more important the MEI shock is), the farther away from the data are the correlations between consumption growth and investment growth and between consumption growth and output growth. However, when the percentage contribution of the neutral technology shock decreases from 35 to 25 percent, these two contemporaneous correlations deteriorate more in the standard model (from -0.05 to -0.16 for $\rho(\Delta C, \Delta I)$ and from 0.39 to 0.26 for $\rho(\Delta Y, \Delta C)$) than in the benchmark model (from 0.36 to 0.30 for $\rho(\Delta C, \Delta I)$ and from 0.7 to 0.65 for $\rho(\Delta Y, \Delta C)$). In contrast, with a less important TFP shock, either model better replicates the contemporaneous correlations related to hours.

Whatever the split of the shocks: (i) the standard MSNK model remains far off in replicating two key correlations in the business cycle: the one between consumption growth and investment growth and the one between consumption growth and output growth; (ii) in comparison, our benchmark model gets quite close in replicating the data. Moreover, similarly to Figure 1, Figure 5 shows the cross-correlograms for our benchmark calibration for the two alternative splits. It demonstrates that the results from our model are quite robust to the changes in the relative importance of the shocks. Intuitively, the cross-correlograms from our benchmark calibration are between the ones generated from Splits 1 and 2. The alternative splits have some effects on these cross-correlograms, but these effects are quite small.

5.2 Persistence of MEI shock

The results are sensitive to the degree of persistence of the MEI shock. Table 7 shows how selected business cycle moments change when ρ_I takes on a lower (0.7) or a higher value (0.9). When the MEI shock is less persistent, the key correlations we have focused on so far improve in both models, at the expenses of a worse fit of the correlations relative to hours. When the MEI shock is more persistent, in contrast, the opposite occurs and the performance of the models deteriorates. This is particularly true for the correlation between consumption growth and investment growth. In the standard model this correlation becomes quite negative at -0.43, while in our benchmark model it remains positive. This suggests that a value of ρ_I as high as 0.9 would have undesirable business cycle implications for MSNK models.

Why do the anomalies in business cycle comovements become more severe when the MEI shock is more persistent? A high level of persistence for the MEI shock generates a stronger contractionary effect on consumption. To see this, Figure 6 compares the impulse responses of consumption and inflation for different value of the persistence of the MEI shock. The intuition is straightforward: a higher persistence of the MEI shock triggers a stronger and more persistent response of investment. Moreover, forward-looking price setters anticipate it and, when they can, they will reset a higher price generating a stronger and more persistent response of inflation. As a result, the response of consumption is lower the higher the persistence of the shock. When the degree of persistence of the MEI shock is 0.9, the impact response of inflation is about two times the one under our baseline calibration, and still is positive after 15 quarters. Thus consumption drops on impact.[15]

[15] Ascari et al. (2018) show that the effect of a more persistent MEI shock on the response of inflation is amplified by positive trend inflation, as we have in the model. In the textbook New Keynesian model with sticky prices only, trend inflation makes current inflation more sensitive to expected inflation (Ascari, 2004). A higher persistence of the MEI shock generates higher expected future inflation, that feeds into current inflation, the higher trend inflation is.

On the one hand, this explains why some business cycle comovements deteriorate with a high level of persistence of the MEI shock. On the other hand, it takes very high value of persistence of the MEI shock to generate a drop in consumption: the response of consumption is still positive when $\rho_I = 0.85$. Moreover, again, our main result still holds. Whatever the degree of persistence of the MEI shock, our benchmark model helps surviving the Barro-King curse.

6 Conclusion

The recent literature shows that medium-scale New Keynesian models, with monopolistic competition in the goods and labor markets, sticky wages and sticky prices have been empirically successful. In several multi-shock New Keynesian models, investment shocks are typically identified as the main driving force behind business cycle fluctuations. But we show that these models are vulnerable to the Barro-King curse with several anomalous business cycle comovements, especially where consumption is involved, because an improvement in the marginal efficiency of investment typically triggers a short-run contractionary effect on consumption.

We have proposed a way for the MSNK model to survive the curse. Our alternative approach is based on two empirically relevant features: roundabout production and trend output growth stemming from trend growth in neutral technology and investment-specific technology. We think our approach is more general in that it does not require non-standard preferences that restrict the strength of short-run wealth effects on the labor supply. It is also general enough to escape the curse whether the cost of capital utilization is measured in terms of increased depreciation of capital or foregone consumption. We view these refinements as increasing the empirical plausibility of this class of models and their usefulness for policy analysis.

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Appendix

A The Model

This section lays out our medium-scale New Keynesian model. As other similar models, ours embeds standard preferences, nominal rigidities in the form of Calvo (1983) wage and price contracts, habit formation in consumption, investment adjustment costs, variable capital utilization and a Taylor rule.

However, relative to the models of Christiano et al. (2005) and Smets and Wouters (2007), ours adds the following features. The first feature is the use of intermediate inputs in a so-called "roundabout production" structure (Basu 1995; Huang et al. 2004) or "firms networking". The second feature is real per capita output growth stemming from two distinct sources: trend growth in investment-specific technology (IST) and neutral technology. In the context of our model, trend growth in IST realistically captures the downward secular movement in the relative price of investment observed during the postwar period. The third feature is non-zero trend inflation. We account for positive steady-state inflation because actual inflation has averaged 4 percent (annualized) more or less during the postwar period. A major difference with previous New Keynesian models, however, is that ours omits wage and price indexation either to past or steady-state inflation. The subsections below lay out the decision problems, while the optimality conditions of the relevant model agents are kept for an Appendix.

A.1 Good and Labor Composites

A continuum of firms, indexed by $j \in [0, 1]$, produce differentiated goods with the use of a composite labor input. The composite labor input is aggregated from differentiated labor supplied by a continuum of households, indexed by $i \in [0, 1]$. The differentiated goods are bundled into a gross output good, X_t. Some of this gross output good can be used as a factor of production by firms. Net output is measured as gross output less intermediates, Γ_t. The households can either consume or invest the final net output good. The composite gross output and labor input respectively are:

$$X_t = \left(\int_0^1 X_t(j)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}}, \tag{10}$$

$$L_t = \left(\int_0^1 L_t(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}. \tag{11}$$

The parameters $\theta > 1$ and $\sigma > 1$ are the elasticities of substitution between goods and labor. The demand curves for goods and labor are:

$$X_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\theta} X_t, \quad \forall j, \tag{12}$$

$$L_t(i) = \left(\frac{W_t(i)}{W_t}\right)^{-\sigma} L_t, \quad \forall i. \tag{13}$$

The aggregate price and wage indexes are:

$$P_t^{1-\theta} = \int_0^1 P_t(j)^{1-\theta} dj, \tag{14}$$

$$W_t^{1-\sigma} = \int_0^1 W_t(i)^{1-\sigma} di. \tag{15}$$

A.2 Households

A continuum of households, indexed by $i \in [0, 1]$, are monopoly suppliers of labor. They face a downward-sloping demand curve for their particular type of labor given in (13). Each period households face a fixed probability, $(1 - \xi_w)$, that they can adjust their nominal wage. The utility is separable in consumption and labor, and state-contingent securities insure households against idiosyncratic wage risk arising from staggered wage-setting (Erceg et al. 2000). With this setup, households are identical along all dimensions other than labor supply and wages.

A typical household solves the following problem, omitting dependence on i except for these two dimensions:

$$\max_{C_t, L_t(i), K_{t+1}, B_{t+1}, I_t, Z_t} \quad E_0 \sum_{t=0}^{\infty} \beta^t \varepsilon_t^b \left(\ln\left(C_t - bC_{t-1}\right) - \eta \frac{L_t(i)^{1+\chi}}{1+\chi} \right), \tag{16}$$

subject to the following budget constraint,

$$P_t \left(C_t + I_t + \frac{a(Z_t)K_t}{\varepsilon_t^{I,\tau}} \right) + \frac{B_{t+1}}{1+i_t} \leq W_t(i)L_t(i) + R_t^k Z_t K_t + \Pi_t + B_t + T_t, \tag{17}$$

and the physical capital accumulation process,

$$K_{t+1} = \varepsilon_t^{I,\tau} \vartheta_t \left(1 - S\left(\frac{I_t}{I_{t-1}} \right) \right) I_t + (1-\delta)K_t. \tag{18}$$

P_t is the nominal price of goods, C_t is consumption, I_t is investment measured in units of consumption, K_t is the physical capital stock, and Z_t is the level of capital utilization. $W_t(i)$ is the nominal wage paid to labor of type i, and R_t^k is the common rental price on capital services (the product of utilization and physical capital). Π_t and T_t are the distributed dividends from firms and the lump sum taxes from the government, both of which households take as given. B_t is a stock of nominal bonds that the household enters the period with. $a(Z_t)$ is a resource cost of utilization that satisfies $a(1) = 0$, $a'(1) = 0$, and $a''(1) > 0$. This resource cost is measured in units of physical capital. $S\left(\frac{I_t}{I_{t-1}}\right)$ is an investment adjustment cost that satisfies $S(g_I) = 0$, $S'(g_I) = 0$, and $S''(g_I) > 0$, where $g_I \geq 1$ is the steady state (gross) growth rate of investment. i_t is the nominal interest rate. $0 < \beta < 1$ is the discount factor, $0 < \delta < 1$ is the depreciation rate, and $0 \leq b < 1$ is the parameter for internal habit formation. χ is the inverse Frisch labor supply elasticity.

ε_t^b is an intertemporal preference shock. $\varepsilon_t^{I,\tau}$ enters the capital accumulation equation by multiplying investment and the budget constraint in terms of the resource cost of capital utilization; it measures the level of IST and follows a deterministic trend with no stochastic component. The deterministic trend is necessary to match the actual downward trend in the relative price of investment goods in the data.[16] ϑ_t is a stochastic MEI shock.

A household given the opportunity to adjust its wage in period t chooses a "reset wage" that maximizes the expected value of the discounted flow utility, where discounting in period $t+s$ is $(\beta\xi_w)^s$, ξ_w^s being the probability that a wage chosen in period t will still be in effect in period $t+s$. Given our assumption on preferences and wage-setting, all updating households choose the same reset wage, denoted in real terms by w_t^*. The optimal reset wage is given by:

$$w_t^* = \frac{\sigma}{\sigma - 1} \frac{f_{1,t}}{f_{2,t}}, \tag{19}$$

where the terms $f_{1,t}$ and $f_{2,t}$ can be written recursively as:

$$f_{1,t} = \eta \left(\frac{w_t}{w_t^*}\right)^{\sigma(1+\chi)} L_t^{1+\chi} + \beta\xi_w E_t(\pi_{t+1})^{\sigma(1+\chi)} \left(\frac{w_{t+1}^*}{w_t^*}\right)^{\sigma(1+\chi)} f_{1,t+1}, \tag{20}$$

and

$$f_{2,t} = \lambda_t^r \left(\frac{w_t}{w_t^*}\right)^{\sigma} L_t + \beta\xi_w E_t(\pi_{t+1})^{\sigma-1} \left(\frac{w_{t+1}^*}{w_t^*}\right)^{\sigma} f_{2,t+1}. \tag{21}$$

A.3 Firms

The production function for a typical producer j is:

[16] In the model, the relative price of investment goods is $\frac{1}{\varepsilon_t^{I,\tau}}$. Thus, the division by $\varepsilon_t^{I,\tau}$ in the resource cost of utilization is required so that capital is priced in terms of consumption goods.

$$X_t(j) = \max\left\{A_t\Gamma_t(j)^{\phi}\left(\widehat{K}_t(j)^{\alpha}L_t(j)^{1-\alpha}\right)^{1-\phi} - \Upsilon_t F, 0\right\}, \tag{22}$$

where F is a fixed cost, and production is required to be non-negative. Υ_t is a growth factor. Given Υ_t, F is chosen to ensure zero profits along a balanced growth path, so the entry and exit of firms can be ignored. $\Gamma_t(j)$ is the amount of intermediate inputs, and $\phi \in (0,1)$ is the intermediate input share. Intermediate inputs come from aggregate gross output, X_t. $\widehat{K}_t(j)$ is capital services or the product of utilization and physical capital, while $L_t(j)$ is labor input. This production function differs from the standard specification in the New Keynesian DSGE literature by adding intermediate inputs, $\Gamma_t(j)$, allowing for roundaboutness in the production structure or firms networking.

The firm gets to choose its price, $P_t(j)$, as well as quantities of intermediates, capital services, and labor input. Each period firms face a probability $(1-\xi_p)$ that they can adjust their price. Regardless of whether a firm is given the opportunity to adjust its price, it will choose inputs to minimize total cost, subject to the constraint of producing enough to meet demand. The cost minimization problem of a typical firm is:

$$\min_{\Gamma_t,\widehat{K}_t,L_t} \quad P_t\Gamma_t + R_t^k\widehat{K}_t + W_tL_t \tag{23}$$

s.t.

$$A_t\Gamma_t^{\phi}\left(\widehat{K}_t^{\alpha}L_t^{1-\alpha}\right)^{1-\phi} - \Upsilon_t F \geq \left(\frac{P_t(j)}{P_t}\right)^{-\theta} X_t$$

Applying some algebraic manipulations to the first order conditions for cost-minimization yields the following expression for real marginal cost, v_t, which is common across firms:

$$v_t = \overline{\phi}A_t^{-1}\left(r_t^k\right)^{\alpha(1-\phi)} w_t^{(1-\alpha)(1-\phi)}, \tag{24}$$

where $\overline{\phi}$ is a constant. This expression for real marginal cost can be compared to the expression we get in the standard model that abstracts from intermediate inputs ($\phi = 0$):

$$v_t = \overline{\alpha}A_t^{-1}(r_t^k)^{\alpha}(w_t)^{1-\alpha}, \tag{25}$$

where $\overline{\alpha}$ is a constant.

A firm given the opportunity to adjust its price maximizes the expected discounted value of profits, where discounting in period $t+s$ is by the stochastic discount factor as well as ξ_p^s, ξ_p^s being the probability that a price chosen in period t will still be in effect in period $t+s$. All updating firms choose the same reset price. Let $p_t^* \equiv \frac{P_t^*}{P_t}$ be the optimal reset price relative to the aggregate price index. The optimal pricing condition can be written:

$$p_t^* = \frac{\theta}{\theta - 1} \frac{x_{1,t}}{x_{2,t}}, \tag{26}$$

where the auxiliary variables $x_{1,t}$ and $x_{2,t}$ can be written recursively:

$$x_{1,t} = \lambda_t^r v_t X_t + \beta \xi_p E_t (\pi_{t+1})^{\theta} x_{1,t+1}, \tag{27}$$

$$x_{2,t} = \lambda_t^r X_t + \beta \xi_p E_t (\pi_{t+1})^{\theta - 1} x_{1,t+1}, \tag{28}$$

where λ_t^r is the marginal utility of an additional unit of real income received by the household.

A.4 Monetary Policy

Monetary policy is described by the following Taylor rule:

$$\frac{1+i_t}{1+i} = \left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_i} \left[\left(\frac{\pi_t}{\pi}\right)^{\alpha_\pi} \left(\frac{Y_t}{Y_{t-1}} g_Y^{-1}\right)^{\alpha_y}\right]^{1-\rho_i} \varepsilon_t^r. \tag{29}$$

According to this specification, the FED adjusts the nominal interest rate in response to deviations of inflation from an exogenous steady-state inflation target, π, and to deviations of output growth from its steady-state level, g_Y. ε_t^r is a white-noise exogenous shock to the policy rule. ρ_i is a smoothing parameter while α_π and α_y are two control parameters.

A.5 Shock Processes

The intertemporal preference shock ε_t^b follows a stationary AR(1) process:

$$\varepsilon_t^b = (\varepsilon_{t-1}^b)^{\rho_b} \exp(s_b u_t^b), \tag{30}$$

with innovation u_t^b drawn from a mean zero normal distribution with standard deviation s_b.

Neutral productivity obeys a process with both a trending and stationary component. A_t^τ is the deterministic trend component, where g_A is the gross growth rate:

$$A_t = A_t^\tau \widetilde{A}_t, \tag{31}$$

$$A_t^\tau = g_A A_{t-1}^\tau. \tag{32}$$

The initial level in period 0 is normalized to 1: $A_0^\tau = 1$. The stationary component of neutral productivity follows an AR(1) process in the log, with the non-stochastic mean level normalized to unity, and innovation, u_t^A, drawn from a mean zero normal distribution with known standard deviation equal to s_A:

$$\widetilde{A}_t = \left(\widetilde{A}_{t-1}\right)^{\rho_A} \exp\left(s_A u_t^A\right), \quad 0 \leq \rho_A < 1, \tag{33}$$

The IST term obeys the following deterministic trend, where g_{ε^I} is the gross growth rate and the initial level in period 0 is normalized to unity:

$$\varepsilon_t^{I,\tau} = g_{\varepsilon^I} \varepsilon_{t-1}^{I,\tau} \tag{34}$$

The MEI shock follows a stationary AR(1) process, with innovation u_t^I drawn from a mean zero normal distribution with standard deviation s_I:

$$\vartheta_t = (\vartheta_{t-1})^{\rho_I} \exp(s_I u_t^I), \quad 0 \leq \rho_I < 1 \tag{35}$$

The only remaining shock in the model is the monetary policy shock, ε_t^r. We assume that is drawn from a mean zero normal distribution with known standard deviation s_r.

A.6 Functional Forms

The resource cost of utilization and the investment adjustment cost function have the functional forms:

$$a(Z_t) = \gamma_1(Z_t - 1) + \frac{\gamma_2}{2}(Z_t - 1)^2, \tag{36}$$

$$S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - g_I\right)^2, \tag{37}$$

where $\gamma_2 > 0$ is a free parameter; as $\gamma_2 \to \infty$ utilization is fixed at unity. γ_1 must be restricted so that the optimality conditions are consistent with the normalization of steady state utilization of 1. $\kappa \geq 0$ is a free parameter. The functional form for the investment adjustment cost is standard in the literature (e.g., Christiano et al., 2005).

A.7 Growth

Most variables in the model inherit trend growth from the deterministic trends in neutral and investment-specific productivity. Suppose that this trend factor is Υ_t. Output, consumption, investment, intermediate inputs, and the real wage all grow at the rate of this trend factor on a balanced growth path: $g_Y = g_I = g_\Gamma = g_w = g_\Upsilon$. The capital stock grows faster due to growth in investment-specific productivity, with $\widetilde{K}_t \equiv \frac{K_t}{\Upsilon_t \varepsilon_t^{I,\tau}}$ being stationary. Given our specification of preferences, labor hours are stationary.

The trend factor inducing stationarity among transformed variables is:

$$\Upsilon_t = (A_t^\tau)^{\frac{1}{(1-\phi)(1-\alpha)}} \left(\varepsilon_t^{I,\tau}\right)^{\frac{\alpha}{1-\alpha}}. \tag{38}$$

When there are no intermediate inputs, this expression reverts to the conventional trend growth factor in a model with growth in neutral and investment-specific productivity. The model then reduces to the standard New Keynesian model. Interestingly, from (38), it is evident that a higher value of the share of intermediate inputs ϕ amplifies the effects of trend growth in neutral productivity on output and its components.

A.8 Full Set of Equilibrium Conditions

This Appendix lists the full set of stationarized equations which characterize the equilibrium of our model. Variables with a $\sim$ denote transformed variables which are stationary

$$\widetilde{\lambda}_t^r = \frac{\varepsilon_t^b}{\widetilde{C}_t - b g_\Upsilon^{-1} \widetilde{C}_{t-1}} - E_t \frac{\beta b \varepsilon_{t+1}^b}{g_\Upsilon \widetilde{C}_{t+1} - b\widetilde{C}_t} \tag{A 1}$$

$$\widetilde{r}_t^k = \gamma_1 + \gamma_2(Z_t - 1) \tag{A 2}$$

$$\widetilde{\lambda}_t^r = \widetilde{\mu}_t \vartheta_t \left(1 - \frac{k}{2}\left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Upsilon - g_\Upsilon\right)^2 - \kappa \left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Upsilon - g_\Upsilon\right) \frac{\widetilde{I}_t}{\widetilde{I}_{t-1}} g_\Upsilon\right) + \beta E_t g_\Upsilon^{-1} \widetilde{\mu}_{t+1} \vartheta_{t+1} \kappa \left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_\Upsilon - g_\Upsilon\right)\left(\frac{\widetilde{I}_{t+1}}{\widetilde{I}_t} g_\Upsilon\right)^2 \tag{A 3}$$

$$g_I g_\Upsilon \widetilde{\mu}_t = \beta E_t \widetilde{\lambda}_{t+1}^r \left(\widetilde{r}_{t+1}^k Z_{t+1} - \left(\gamma_1 (Z_{t+1} - 1) + \frac{\gamma_2}{2}(Z_{t+1} - 1)^2\right)\right) + \beta(1-\delta) E_t \widetilde{\mu}_{t+1} \tag{A 4}$$

$$\widetilde{\lambda}_t^r = \beta g_\Upsilon^{-1} E_t (1 + i_t) \pi_{t+1}^{-1} \widetilde{\lambda}_{t+1}^r \tag{A 5}$$

$$\widetilde{w}_t^* = \frac{\sigma}{\sigma - 1} \frac{\widetilde{f}_{1,t}}{\widetilde{f}_{2,t}} \tag{A 6}$$

$$\widetilde{f}_{1,t} = \eta \left(\frac{\widetilde{w}_t}{\widetilde{w}_t^*}\right)^{\sigma(1+\chi)} L_t^{1+\chi} + \beta \xi_w E_t (\pi_{t+1})^{\sigma(1+\chi)} \left(\frac{\widetilde{w}_{t+1}^*}{\widetilde{w}_t^*}\right)^{\sigma(1+\chi)} g_\Upsilon^{\sigma(1+\chi)} \widetilde{f}_{1,t+1} \tag{A 7}$$

$$\widetilde{f}_{2,t} = \widetilde{\lambda}_t^r \left(\frac{\widetilde{w}_t}{\widetilde{w}_t^*}\right)^\sigma L_t + \beta \xi_w E_t (\pi_{t+1})^{\sigma - 1} \left(\frac{\widetilde{w}_{t+1}^*}{\widetilde{w}_t^*}\right)^\sigma g_\Upsilon^{\sigma-1} \widetilde{f}_{2,t+1} \tag{A 8}$$

$$\widetilde{\widetilde{K}}_t = g_I g_\Upsilon \alpha (1 - \phi) \frac{mc_t}{\widetilde{r}_t^k} \left(s_t \widetilde{X}_t + F\right) \tag{A 9}$$

$$L_t = (1-\alpha)(1-\phi)\frac{mc_t}{\widetilde{w}_t}\left(s_t\widetilde{X}_t + F\right) \tag{A 10}$$

$$\widetilde{\Gamma}_t = \phi mc_t \left(s_t\widetilde{X}_t + F\right) \tag{A 11}$$

$$p_t^* = \frac{\theta}{\theta-1}\frac{x_t^1}{x_t^2} \tag{A 12}$$

$$x_t^1 = \widetilde{\lambda}_t^r mc_t\widetilde{X}_t + \xi_p\beta\left(\frac{1}{\pi_{t+1}}\right)^{-\theta} x_{t+1}^1 \tag{A 13}$$

$$x_t^2 = \widetilde{\lambda}_t^r\widetilde{X}_t + \xi_p\beta\left(\frac{1}{\pi_{t+1}}\right)^{1-\theta} x_{t+1}^2 \tag{A 14}$$

$$1 = \xi_p\left(\frac{1}{\pi_t}\right)^{1-\theta} + (1-\xi_p)p_t^{*1-\theta} \tag{A 15}$$

$$\widetilde{w}_t^{1-\sigma} = \xi_w g_\Upsilon^{\sigma-1}\left(\frac{\widetilde{w}_{t-1}}{\pi_t}\right)^{1-\sigma} + (1-\xi_w)\widetilde{w}_t^{*1-\sigma} \tag{A 16}$$

$$\widetilde{Y}_t = \widetilde{X}_t - \widetilde{\Gamma}_t \tag{A 17}$$

$$s_t\widetilde{X}_t = \widetilde{A}_t\widetilde{\Gamma}_t^\phi\widetilde{\widetilde{K}}_t^{\alpha(1-\phi)} L_t^{(1-\alpha)(1-\phi)} g_\Upsilon^{\alpha(\phi-1)} g_I^{\alpha(\phi-1)} - F \tag{A 18}$$

$$\widetilde{Y}_t = \widetilde{C}_t + \widetilde{I}_t + g_\Upsilon^{-1}g_I^{-1}\left(\gamma_1(Z_t-1) + \frac{\gamma_2}{2}(Z_t-1)^2\right)\widetilde{K}_t \tag{A 19}$$

$$\widetilde{K}_{t+1} = \vartheta_t\left(1 - \frac{\kappa}{2}\left(\frac{\widetilde{I}_t}{\widetilde{I}_{t-1}}g_\Upsilon - g_\Upsilon\right)^2\right)\widetilde{I}_t + (1-\delta)g_\Upsilon^{-1}g_I^{-1}\widetilde{K}_t \tag{A 20}$$

$$\frac{1+i_t}{1+i} = \left(\left(\frac{\pi_t}{\pi}\right)^{\alpha_\pi}\left(\frac{\widetilde{Y}_t}{\widetilde{Y}_{t-1}}\right)^{\alpha_y}\right)^{1-\rho_i}\left(\frac{1+i_{t-1}}{1+i}\right)^{\rho_i}\varepsilon_t^r \tag{A 21}$$

$$\widetilde{\widetilde{K}}_t = Z_t\widetilde{K}_t \tag{A 22}$$

$$s_t = (1-\xi_p)p_t^{*-\theta} + \xi_p\left(\frac{1}{\pi_t}\right)^{-\theta} s_{t-1} \tag{A 23}$$

$$v_t^w = (1-\xi_w)\left(\frac{\widetilde{w}_t^*}{\widetilde{w}_t}\right)^{-\sigma(1+\chi)} + \xi_w\left(\frac{\widetilde{w}_{t-1}}{\widetilde{w}_t}g_\Upsilon^{-1}\frac{1}{\pi_t}\right)^{-\sigma(1+\chi)} v_{t-1}^w \tag{A 24}$$

B Calibration

Our baseline calibration of the model's parameters is divided in two groups: non-shock and shock parameters.

B.1 Non-Shock Parameters

The values of non-shock parameters are summarized in Table 1. $\beta = 0.99$ is the discount factor, $b = 0.7$ is the habit formation parameter, $\chi = 1$ is the inverse Frisch elasticity, and $\eta = 6$ is the weight on disutility of labor set so that steady-state labor hours are around 1/3. The parameters in the production function are the share of capital services $\alpha = 1/3$ and the share of intermediate inputs $\phi = 0.61$. The $\phi-$values used in the literature broadly range from 0.5 to 0.8. As explained in the main text, we set the value for ϕ as follows. Following Nakamura and Steinsson (2010), we take the weighted average revenue share of intermediate inputs in the U.S. private sector using Consumer Price Index (CPI) expenditure weights to be roughly 51 percent in 2002. Now, the cost share of intermediate inputs is equal to the revenue share times the price markup. Since the elasticities for goods and labor, θ and σ, are both set equal to 6 (e.g., Rotemberg and Woodford, 1997; Liu and Phaneuf, 2007), our calibration of θ implies a markup of 1.2. Therefore, our estimate of the weighted average cost share of intermediate inputs is roughly 0.61.[17] The depreciation rate on physical capital is $\delta = 0.025$. $\kappa = 3$ is the investment adjustment cost parameter. γ_1 is set so that steady state utilization is 1. The parameter γ_2 is set to 0.05. The parameter values for δ, κ, γ_1 and γ_2 are consistent with the evidence reported in Justiniano, Primiceri, and Tambalotti (2010, 2011).

The Calvo probabilities of wage and price non-adjustments, ξ_w and ξ_p, are both set equal to 2/3, implying an average duration of wage and price contracts of 3 quarters or 9 months. The average frequency of price adjustments in our model is therefore lower than suggested by the evidence in Bils and Klenow (2004) for the years 1995-1997 and Christiano et al. (2005), but can be viewed as conservative in light of the evidence in Eichenbaum et al. (2011) and Klenow and Malin (2011) suggesting that prices remain fixed for relatively long periods of time.[18] The average frequency of wage adjustments is somewhat lower than suggested by the estimates in Christiano et al. (2005), but higher than implied by the estimates in Justiniano, Primiceri, and Tambalotti (2010, 2011) and Barattieri et al. (2014). Overall, we view these values of ξ_w and ξ_p as midway between microeconomic and macroeconomic evidence on the frequency of wages and price changes.

The last three parameters are the smoothing parameter which is set at 0.8, the coefficient on the deviations of inflation from the inflation target set at 1.5, and the coefficient on the deviations of output growth from steady state set at 0.2. These values are fairly standard in the literature.

[17] The steady-state price markup is for a trend inflation of zero. We find that this markup is almost insensitive to trend inflation between 0 and 4 percent leaving ϕ unaffected as trend inflation rises.

[18] We do admit, however, that these authors sometimes question the relevance of the Calvo price-setting framework to explain their evidence on nominal price rigidity. We do not address this issue here.

B.2 Trend Inflation and Trend Growth

Next, we turn our attention to the calibration of the parameters governing trend inflation and trend output growth. Table 2 summarizes these parameter values.

The average growth rate of the price index over the period 1960:I-2007:III is 0.008675. This implies $\pi^* = 1.0088$ or 3.52 percent annualized.

As explained in the main text, mapping the model to the data, the trend growth rate of the IST term, g_{ε^I}, equals the negative of the growth rate of the relative price of investment goods. To measure this in the data, we define investment as expenditures on new durables plus private fixed investment, and consumption as consumer expenditures of nondurables and services. These series are from the BEA and cover the period 1960:I-2007:III.[19] The relative price of investment is the ratio of the implied price index for investment goods to the price index for consumption goods. The average growth rate of the relative price from the period 1960:I-2007:III is -0.00472. This implies a calibration of $g_{\varepsilon^I} = 1.00472$. Real per capita GDP is computed by subtracting from the log-level the log civilian non-institutionalized population. The average growth rate of the resulting output per capita series over the period is 0.005712. The standard deviation of output growth over the period is 0.0078. The calculations above imply that $g_Y = 1.005712$ or 2.28 percent a year. Given the calibrated growth of IST from the relative price of investment data ($g_{\varepsilon^I} = 1.00472$), we then pick $g_A^{1-\phi}$ to generate the appropriate average growth rate of output. This implies $g_A^{1-\phi} = 1.0022$ or a measured growth rate of TFP of about 1 percent per year.

[19] A detailed explanation of how these data are constructed can be found in Ascari et al. (2018).

Table 1: Non-Shock Parameters

β	δ	α	η	χ	b	κ	γ_2
0.99	0.025	1/3	6	1	0.7	3	0.005
θ	σ	ξ_p	ξ_w	ϕ	ρ_i	α_π	α_y
6	6	0.66	0.66	0.61	0.8	1.5	0.2

Note: this table gives the baseline values of the parameters unrelated to the stochastic processes used in our quantitative simulations.

Table 2: Standard Values for Shock Parameters

g_A	g_{ε^I}	ρ_b	ρ_I	ρ_A
$1.0022^{1-\phi}$	1.0047	0.6	0.8	0.95

Note: this table gives the baseline values of the parameters of the stochastic processes used in our quantitative simulations. The trend growth rate of the IST process is chosen to match the average growth rate of the relative price of investment goods in the data. The trend growth growth of the neutral productivity process is chosen to match the average growth rate of output observed in the sample conditional on the growth rate of the IST process.

Table 3: The Size of Shocks in Alternative Models - Benchmark Case

	Alternative Models			
Shocks	No FN/No G	FN/G	No FN/G	FN/No G
s_I	0.0287	0.0194	0.0244	0.0234
s_A	0.0069	0.0027	0.0064	0.0029
s_b	0.0086	0.0083	0.0084	0.0084
s_r	0.0019	0.0015	0.0017	0.0016

Note: this table gives the values of the shock standard deviations used in alternative models. Given the assumed values of autoregressive parameters governing the stochastic processes, the shock standard deviations are chosen to match the volatility of output growth in the data with an annualized trend inflation of 3.52 percent. Benchmark case: the MEI shock accounts for 50 percent of the variance of output growth, the neutral technology shock for 35 percent, the monetary policy shock for 7 percent, and the preference shock for 8 percent.

Table 4: Moments in the Benchmark and standard New Keynesian Model

	$\sigma(\Delta C)$	$\sigma(\Delta I)$	$\sigma(\Delta L)$	$\boldsymbol{\rho(\Delta Y, \Delta C)}$
Data	(0.0047)	(0.0202)	(0.0079)	**(0.7542)**
Standard New Keynesian	0.0044	0.0264	0.0105	**0.3889**
Benchmark	0.0048	0.0194	0.0078	**0.7030**
No FN / Growth	0.0045	0.0217	0.0098	0.5262
FN / No Growth	0.0045	0.0240	0.0084	0.5840
	$\rho(\Delta Y, \Delta I)$	$\boldsymbol{\rho(\Delta C, \Delta I)}$	$\rho(\Delta Y, L)$	$\rho(\Delta C, L)$
Data	(0.9192)	**(0.4362)**	(0.1105)	(0.0746)
Standard New Keynesian	0.8892	**-0.0481**	0.0383	0.0147
Benchmark	0.9021	**0.3562**	-0.0001	0.0298
No FN/ Growth	0.8933	0.1256	0.0317	0.0737
FN / No Growth	0.8999	0.1941	0.0166	-0.0048

Note: this table shows selected moments generated from the standard New Keynesian model (i.e., No FN/ no Growth), from our benchmark model with FN and growth, from a model with no FN and growth (i.e., No FN / Growth) and from a model with FN and no growth (i.e., FN / No Growth) . "σ " denotes standard deviation, "Δ " refers to the first difference operator, and ρ is a coefficient of correlation. The variables Y, I, C, and L are the natural logs of these series. Moments in the data are computed for the sample 1960q1-2007q3 and are shown in parentheses.

Table 5: The Size of Shocks in Alternative Models - Split 1 and 2

		Alternative Models			
(a) Shocks Split 1		No FN/No G	FN/G	No FN/G	FN/No G
	s_I	0.0315	0.0212	0.0267	0.0256
	s_A	0.0058	0.0022	0.0054	0.0024
	s_b	0.0086	0.0082	0.0084	0.0083
	s_r	0.0019	0.0015	0.0017	0.0016
(b) Shocks Split 2					
	s_I	0.0257	0.0173	0.0218	0.0210
	s_A	0.0078	0.0030	0.0073	0.0033
	s_b	0.0086	0.0082	0.0084	0.0084
	s_r	0.0019	0.0015	0.0017	0.0016

Note: this table gives the values of the shock standard deviations used in alternative models. The shock standard deviations are chosen to match the volatility of output growth in the data with an annualized trend inflation of 3.52 percent. Split 1: the MEI shock accounts for 60 percent of the variance of output growth, the neutral technology shock for 25 percent, the monetary policy shock for 7 percent, and the preference shock for 8 percent. Split 2: the MEI shock accounts for 40 percent of the variance of output growth, the neutral technology shock for 45 percent, the monetary policy shock for 7 percent, and the preference shock for 8 percent.

Table 6: Moments for alternative Models for different Splits of relative importance of shocks

Panel A: Split 1

	$\sigma(\Delta C)$	$\sigma(\Delta I)$	$\sigma(\Delta L)$	$\rho(\Delta Y, \Delta C)$
Data	(0.0047)	(0.0202)	(0.0079)	(0.7542)
Standard New Keynesian	0.0042	0.0281	0.0100	0.2610
Benchmark	0.0045	0.0205	0.0073	0.6458
No FN / Growth	0.0042	0.0231	0.0093	0.4266
FN / No Growth	0.0042	0.0254	0.0079	0.4957
	$\rho(\Delta Y, \Delta I)$	$\rho(\Delta C, \Delta I)$	$\rho(\Delta Y, L)$	$\rho(\Delta C, L)$
Data	(0.9192)	(0.4362)	(0.1105)	(0.0746)
Standard New Keynesian	0.9003	-0.1628	0.1146	0.0960
Benchmark	0.9117	0.3001	0.0900	0.1551
No FN/ Growth	0.9035	0.0303	0.1051	0.1685
FN / No Growth	0.9098	0.1090	0.1055	0.1071

Panel B: Split 2

	$\sigma(\Delta C)$	$\sigma(\Delta I)$	$\sigma(\Delta L)$	$\rho(\Delta Y, \Delta C)$
Data	(0.0047)	(0.0202)	(0.0079)	(0.7542)
Standard New Keynesian	0.0046	0.0246	0.0111	0.5075
Benchmark	0.0051	0.0181	0.0083	0.7561
No FN / Growth	0.0047	0.0203	0.0103	0.6173
FN / No Growth	0.0048	0.0224	0.0090	0.6641
	$\rho(\Delta Y, \Delta I)$	$\rho(\Delta C, \Delta I)$	$\rho(\Delta Y, L)$	$\rho(\Delta C, L)$
Data	(0.9192)	(0.4362)	(0.1105)	(0.0746)
Standard New Keynesian	0.8806	0.0720	-0.0458	-0.0681
Benchmark	0.8949	0.4176	-0.0987	-0.0898
No FN/ Growth	0.8856	0.2248	-0.0479	-0.0183
FN / No Growth	0.8925	0.2822	-0.0802	-0.1123

Note: this table shows selected moments generated from the standard New Keynesian model (with no FN and no Growth), from our benchmark model with FN and growth, from a model with no FN and growth (i.e., No FN / Growth) and from a model with FN and no growth (i.e., FN / No Growth) . "σ " denotes standard deviation, "Δ " refers to the first difference operator, and ρ is a coefficient of correlation. The variables Y, I, C, and L are the natural logs of these series. Moments in the data are computed for the sample 1960q1-2007q3 and are shown in parentheses. Split 1: the MEI shock accounts for 60 percent of the variance of output growth, the neutral technology shock for 25 percent, the monetary policy shock for 7 percent, and the preference shock for 8 percent. Split 2: the MEI shock accounts for 40 percent of the variance of output growth, the neutral technology shock for 45 percent, the monetary policy shock for 7 percent, and the preference shock for 8 percent.

Table 7: Moments for alternative Models for different degree of persistence of the MEI shock

Panel A: $\rho_I = 0.7$

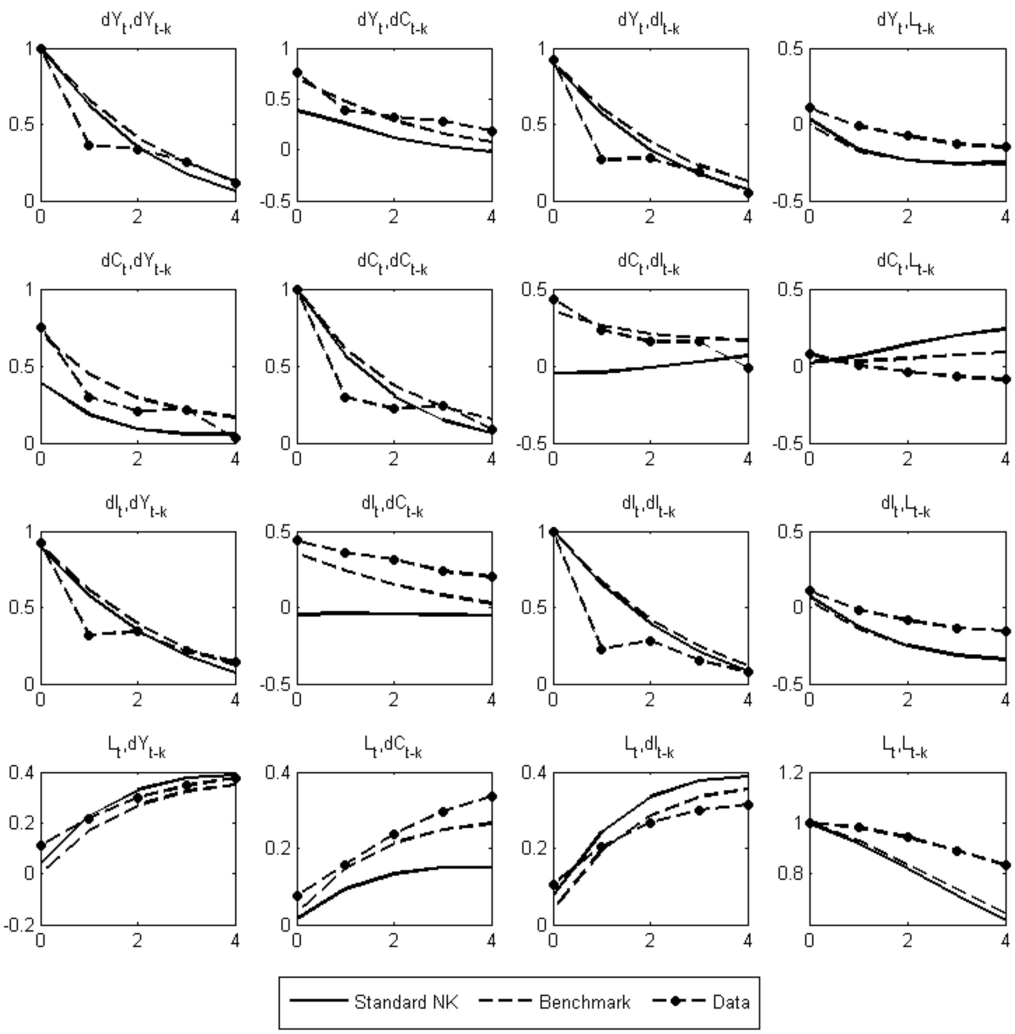
	$\sigma(\Delta C)$	$\sigma(\Delta I)$	$\sigma(\Delta L)$	$\rho(\Delta Y, \Delta C)$
Data	(0.0047)	(0.0202)	(0.0079)	(0.7542)
Standard New Keynesian	0.0042	0.0244	0.0105	0.5148
Benchmark	0.0048	0.0189	0.0078	0.7302
No FN / Growth	0.0043	0.0204	0.0098	0.6142
FN / No Growth	0.0044	0.0229	0.0084	0.6454
	$\rho(\Delta Y, \Delta I)$	$\rho(\Delta C, \Delta I)$	$\rho(\Delta Y, L)$	$\rho(\Delta C, L)$
Data	(0.9192)	(0.4362)	(0.1105)	(0.0746)
Standard New Keynesian	0.9011	0.1215	0.0017	-0.0516
Benchmark	0.9067	0.4019	-0.0360	-0.0402
No FN/ Growth	0.9037	0.2549	0.0019	0.0094
FN / No Growth	0.9073	0.2869	-0.0270	-0.0781

Panel B: $\rho_I = 0.9$

	$\sigma(\Delta C)$	$\sigma(\Delta I)$	$\sigma(\Delta L)$	$\rho(\Delta Y, \Delta C)$
Data	(0.0047)	(0.0202)	(0.0079)	(0.7542)
Standard New Keynesian	0.0058	0.0328	0.0105	0.0869
Benchmark	0.0052	0.0222	0.0078	0.5332
No FN / Growth	0.0057	0.0272	0.0098	0.2136
FN / No Growth	0.0051	0.0279	0.0085	0.3642
	$\rho(\Delta Y, \Delta I)$	$\rho(\Delta C, \Delta I)$	$\rho(\Delta Y, L)$	$\rho(\Delta C, L)$
Data	(0.9192)	(0.4362)	(0.1105)	(0.0746)
Standard New Keynesian	0.8517	-0.4256	0.1329	0.1382
Benchmark	0.8746	0.0871	0.0802	0.1490
No FN/ Growth	0.8488	-0.3001	0.1071	0.1673
FN / No Growth	0.8714	-0.1183	0.1208	0.1327

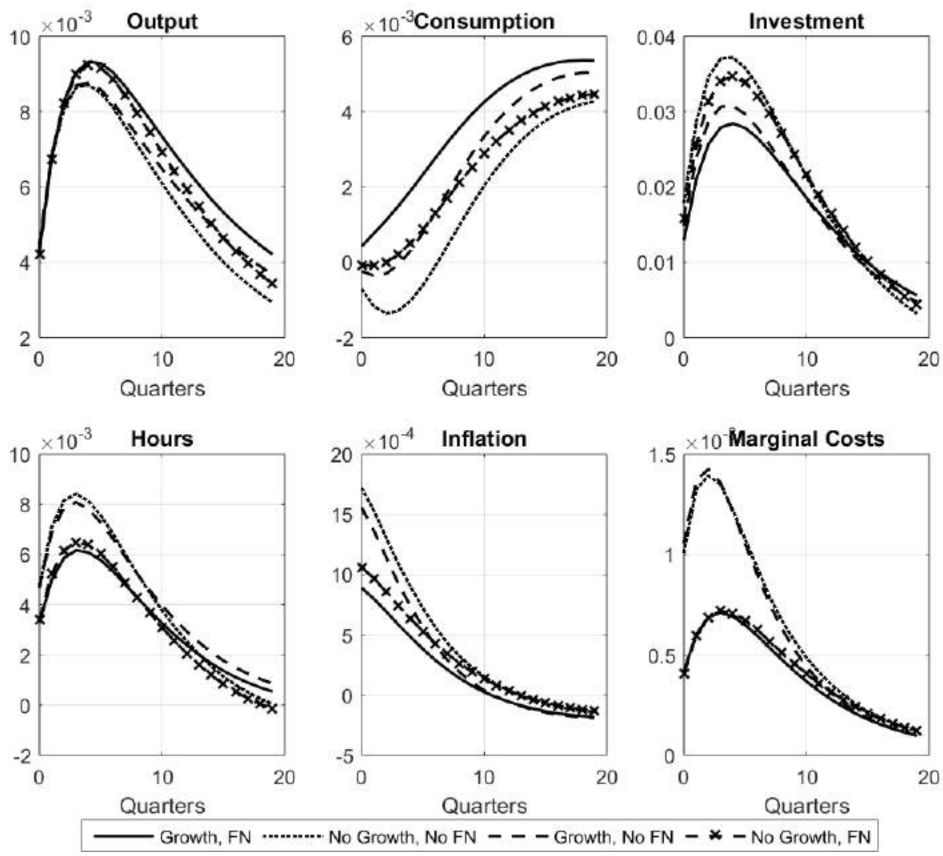
Note: this table shows selected moments generated from the standard New Keynesian model (with no FN and no Growth), from our benchmark model with FN and growth, from a model with no FN and growth (i.e., No FN / Growth) and from a model with FN and no growth (i.e., FN / No Growth) . "σ " denotes standard deviation, "Δ " refers to the first difference operator, and ρ is a coefficient of correlation. The variables Y, I, C, and L are the natural logs of these series. Moments in the data are computed for the sample 1960q1-2007q3 and are shown in parentheses.

Figure 1: Cross-correlogram of the key macroeconomic variables in the benchmark model



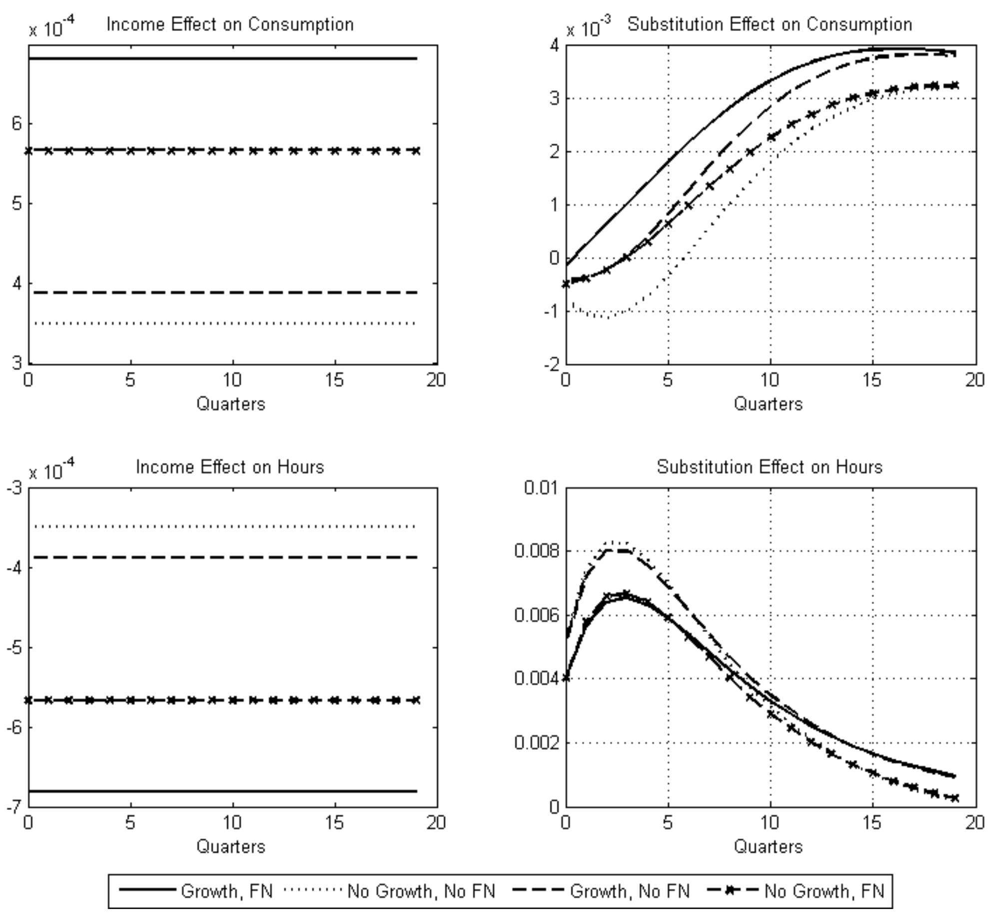
Note: this figure plots the cross-correlations of output, consumption, investment, and hours in the data, in the benchmark (FN/G) model and in the standard New Keynesian (No FN/No G) one, for our benchmark calibration: the MEI shock accounts for 50 percent of the variance of output growth, the neutral technology shock for 35 percent, the monetary policy shock for 7 percent, and the preference shock for 8 percent.

Figure 2: Impulse Responses to MEI Schock



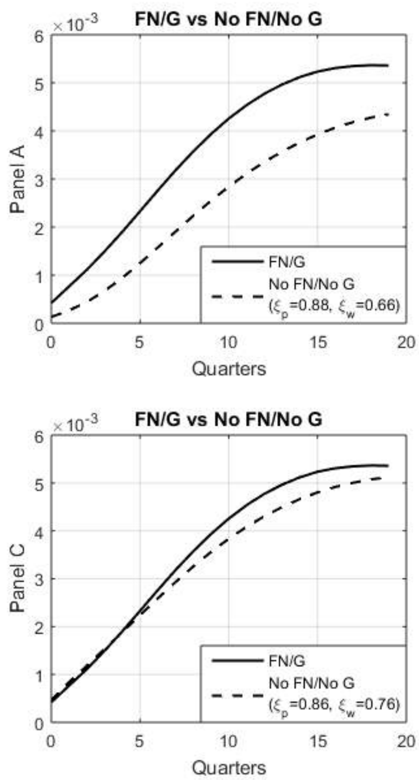
Note: this figure plots the impulse response of output, consumption, investment, hours, inflation and marginal costs for our benchmark calibration: the MEI shock accounts for 50 percent of the variance of output growth, the neutral technology shock for 35 percent, the monetary policy shock for 7 percent, and the preference shock for 8 percent. It does so for 4 versions of the model: our benchmark model with FN and growth, the standard New Keynesian model (with no FN and no Growth), the model with no FN and growth (i.e., No FN / Growth) and the model with FN and no growth (i.e., FN / No Growth).

Figure 3: Hicksian decomposition according to King (1991)



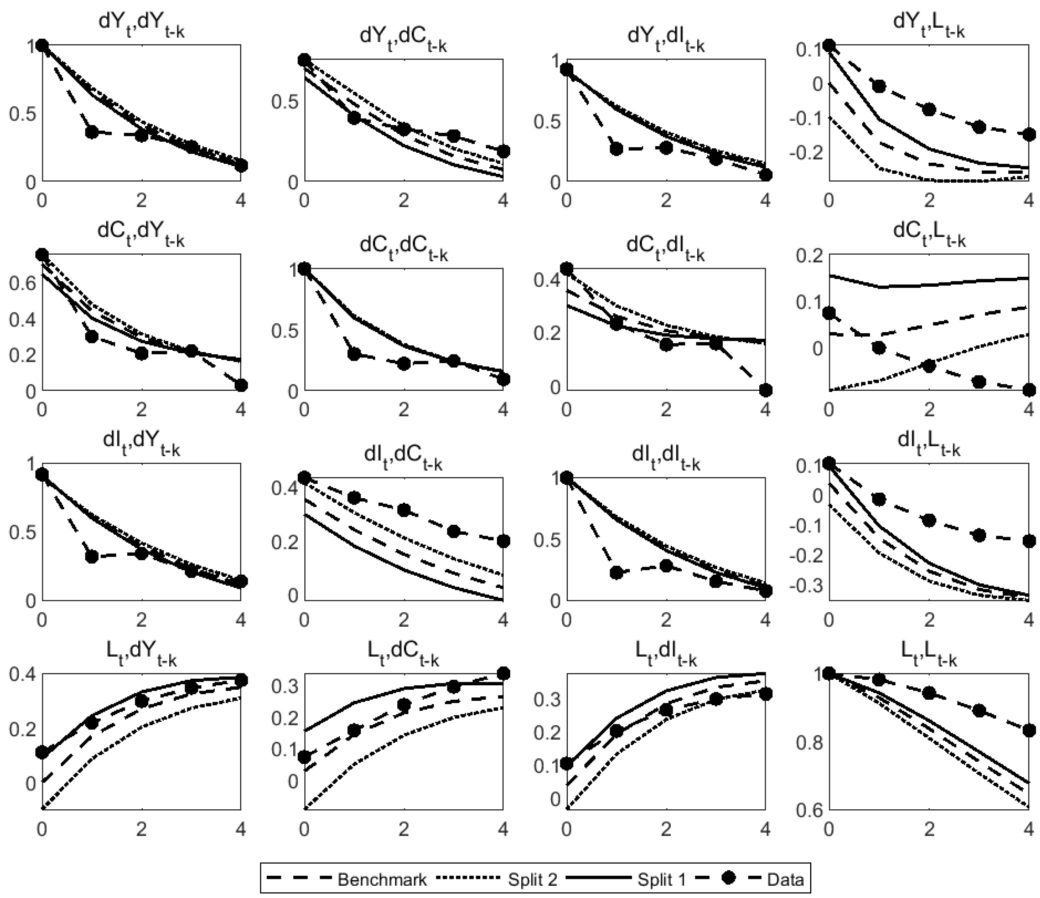
Note: this figure plots the income and substitution effects according to the Hicksian decomposition in King (1991) for our benchmark calibration. It does so for 4 versions of the model: our benchmark model with FN and growth, the standard New Keynesian model (with no FN and no Growth), the model with no FN and growth (i.e., No FN / Growth) and the model with FN and no growth (i.e., FN / No Growth).

Figure 4: Impulse Responses of Consumption to a MEI Shock



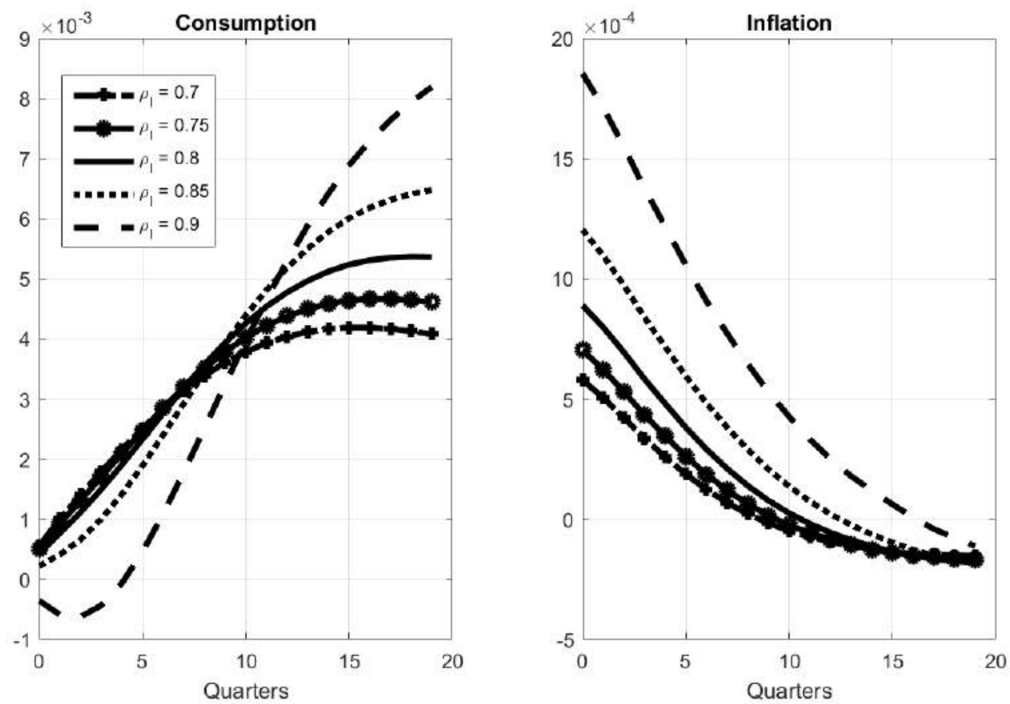
Note: this figure plots the impulse response of consumption to a positive MEI shock in the benchmark (FN/G) and standard New Keynesian (No FN/No G) models. For the standard model, we consider values of the Calvo probabilities of wage and price non reoptimization for which the impact response of consumption to a MEI shock matches that from the FN/G model.

Figure 5: Cross-correlogram of the key macroeconomic variables in the benchmark model for alternative splits



Note: this figure plots the cross-correlations of output, consumption, investment, and hours for our benchmark calibration for alternative splits. Benchmark: the MEI shock accounts for 50 percent of the variance of output growth, the neutral technology shock for 35 percent, the monetary policy shock for 7 percent, and the preference shock for 8 percent. Split 1: the MEI shock accounts for 60 percent of the variance of output growth, the neutral technology shock for 25 percent, the monetary policy shock for 7 percent, and the preference shock for 8 percent. Split 2: the MEI shock accounts for 40 percent of the variance of output growth, the neutral technology shock for 45 percent, the monetary policy shock for 7 percent, and the preference shock for 8 percent.

Figure 6: Impulse Responses of Consumption and Inflation to a MEI Shock for different persistence



Note: this figure plots the impulse response of consumption and inflation to a positive MEI shock in the benchmark model for different levels of persistence of the MEI shock, given our benchmark calibration: the MEI shock accounts for 50 percent of the variance of output growth, the neutral technology shock for 35 percent, the monetary policy shock for 7 percent, and the preference shock for 8 percent.