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Working Paper

Endogenous growth, skill obsolescence and output hysteresis in a New Keynesian model with unemployment

Kiel Working Paper, No. 2162

Provided in Cooperation with:
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Suggested Citation: Lechthaler, Wolfgang; Tesfaselassie, Mewael F. (2020) : Endogenous growth, skill obsolescence and output hysteresis in a New Keynesian model with unemployment, Kiel Working Paper, No. 2162, Kiel Institute for the World Economy (IfW), Kiel

This Version is available at:
https://hdl.handle.net/10419/224060

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KIEL INSTITUTE FOR THE WORLD ECONOMY

KIEL WORKING PAPER

Endogenous Growth, Skill Obsolescence and Output Hysteresis in a New Keynesian Model with Unemployment

No. 2162 August 2020

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Kiel Institute for the World Economy
ISSN 1862–1155

Leibniz Association

ABSTRACT

ENDOGENOUS GROWTH, SKILL OBSOLESCENCE AND OUTPUT HYSTERESIS IN A NEW KEYNESIAN MODEL WITH UNEMPLOYMENT[1]

Wolfgang Lechthaler and Mewael F. Tesfaselassie

We embed human capital-based endogenous growth into a New-Keynesian model with search and matching frictions in the labor market and skill obsolescence from long-term unemployment. The model can account for key features of the Great Recession: a decline in productivity growth, the relative stability of inflation despite a pronounced fall in output (the "missing disinflation puzzle"), and a permanent gap between output and the pre-crisis trend output. In the model, lower aggregate demand raises unemployment and the training costs associated with skill obsolescence. Lower employment hinders learning-by-doing, which slows down human capital accumulation, feeding back into even fewer vacancies than justified by the demand shock alone. These feedback channels mitigate the disinflationary effect of the demand shock while amplifying its contractionary effect on output. The temporary growth slowdown translates into output hysteresis (permanently lower output and labor productivity).

Keywords: endogenous growth, search and matching, unemployment, nominal rigidity, monetary policy, output hysteresis.

JEL: E24, E31, E32

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[1]Acknowledgements: Financial support from the German Science Foundation is gratefully acknowledged.

1 Introduction

The slow recovery after the Great Recession, including the failure of output to return to pre-recession trend, as well as the "missing disinflation" despite the sharp contraction in GDP have left many academics and policymakers puzzled, also because traditional macroeconomic models are unable to rationalize these phenomena.[1] In this paper, we provide a novel explanation for both phenomena using a New-Keynesian DSGE model with endogenous growth and skill loss during unemployment. The combination of both aspects generates a strong contraction in growth and employment, a mild reaction in inflation as well as a permanent output loss in response to demand shocks.

Figure 1 shows time-series of US log real GDP since 2002 and a trajectory of the pre-Great Recession trend line. The figure suggests that ten years after the onset of the Great Recession actual US real GDP (blue line) is still below the pre-recession trend (black line).

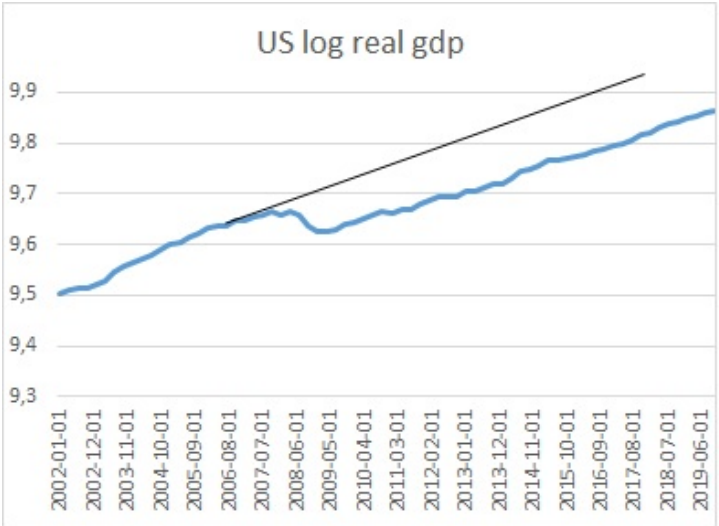

Figure 1: US log real GDP vs pre-recession trend. Source: FRED

More formally, a number of recent empirical studies that have examined deep recessions

[1]For instance, in its June 2016 Global Economic Outlook, the OECD pointed out that "eight years after the financial crisis, the recovery remains disappointingly weak". Furthermore it warned that a prolonged period of low growth "has precipitated a self-fulfilling low-growth trap" (OECD (2016)). Similar warnings have also been echoed by the IMF (2016) and Obstfeld (2016). The fact that much of the discussion in the 2017 ECB Sintra Forum on Central Banking focused on the themes of slow recovery and long-term growth reflected the ongoing concerns of policymakers on the subject matter.

around the world find highly persistent effects on output (see, e.g., Cerra and Saxena (2008), Reinhart and Rogoff (2009), and IMF (2009)). An even starker revelation is the finding that such recessions leave permanent scars by reducing potential output (see, e.g., Haltmaier (2012), Reifschneider et al (2013) and Ball (2014a)).[2]

At the same time, inflation has systematically surprised economic forecasters and policymakers, as it failed to fall significantly during the Great Recession and later failed to rise despite the turnaround in the economy. This has led to the so-called missing disinflation puzzle—the absence of a dramatic decline in inflation during the Great Recession (see, e.g., Coibon and Gorodnichenko (2015)) followed by the missing inflation puzzle (see, e.g., Constâncio (2015), Bobeica and Jarociński (2019)). One proposed explanation for the relative stability of inflation is based on the idea of anchored expectations as a result of central bank credibility (Bernanke (2010) and IMF (2013)).[3] Another proposed explanation for the relative stability of inflation is the flattening of the Phillips curve (i.e., a weakening of the relationship between economic activity and inflation). However, recent empirical evidence points to a stable Phillips curve relationship since the mid-1990s (Ball and Mazumder (2011), IMF (2013), Blanchard, Cerutti and Summers (2015)).

Our novel explanation for the missing disinflation puzzle is based on demand and supply interactions in a monetary DSGE model with labor market frictions that is modified to allow for (1) a learning-by-doing externality implying endogenous human capital accumulation at the aggregate level and (2) training costs associated with skill obsolescence from prolonged periods of unemployment. The model is able to account for key features of the Great Recession: a decline in productivity growth, the relative stability of inflation despite a pronounced fall in output and a permanent gap between output and the pre-crisis trend output.

[2]The ongoing economic fallout from the coronavirus-related global pandemic of 2020, which led to the widespread shutdown of economies around the world, has reinforced policymakers' concerns about the long-term damage to the economy even if the pandemic turns out to be short-lived (see, e.g., remarks made by Jerome Powell, the Fed Chair, at the Economic Update, PIIE virtual event, May 13, 2020). Some have even argued that the macroeconomic effects of the pandemic will be worse than the Great Recession (e.g., Roubini (2020) and Rogoff (2020).

[3]In this regard, Ball and Mazumder (2011) find evidence that expectations of inflation have become partially anchored at the Fed's inflation target of 2%, although survey measures of household inflation expectations render less support for anchoring (Coibon and Gorodnichenko (2015)).

In the model an adverse aggregate demand shock has detrimental effects on job creation and unemployment for two reasons. First, due to search frictions the rise in the duration of unemployment spells and workers' skill obsolescence associated with it increase training costs of firms. Second, lower aggregate employment generates a negative learning-by-doing externality on human capital formation and thus leads to anticipations of a future productivity growth slowdown. The focus on skill obsolescence from unemployment as a propagation mechanism is motivated by the fact that, at least in the US, the post-2009 labor-market recovery has been unique for the behavior of unemployment duration and long-term unemployment. According to Gordon (2013) long-run unemployment (27 weeks or longer) in the U.S. has risen to a level that has not previously been observed in the history of the postwar era. We emphasize the importance of skill obsolescence and human capital because the empirical literature points to significant skill attrition as a result of prolonged unemployment spells (see, e.g., Banerji et. al. (2014) and ILO (2013)).

The *anticipated endogenous* growth effect (i.e., from demand shocks to unemployment and in turn to future productivity) resonates with the recent 'news' shock literature (e.g., Christiano, Ilut, Motto and Rostagno (2010)), since anticipation of future productivity is a key propagation channel from aggregate demand shocks to inflation. However, crucially, in the present paper it is temporary demand shocks that lead to anticipations of productivity growth slowdown as an endogenous outcome rather than the economy responding to an exogenous arrival of news about future productivity.

To be more specific, we incorporate human capital-based endogenous growth through a learning-by-doing externality into the familiar two-sector New-Keynesian model with search and matching frictions in the labor market. The two-sector framework, with a 'retail' sector and a 'wholesale' sector, follows the pioneering work of Walsh (2003). The retail sector consists of monopolistically competitive firms, which are subject to nominal price rigidity, sell output to households and buy their input from a perfectly competitive input market. In turn, the input is produced using labor and aggregate human capital in the wholesale sector where the labor market is subject to search frictions. Newly

hired workers with an unemployment spell of at least one period suffer skill obsolescence and thus need skill upgrading before production takes place with the most advanced technology, with firms paying for the training costs. Growth is endogenous and is driven by a learning-by-doing externality in the labor market (e.g., Stadler (1990), Chiang Gomes Schorfheide AER (2002)). Along a balanced growth path, consumption, output, the real wage and human capital grow at the same rate.

In the presence of nominal price rigidity, and given the aggregate level of human capital, an adverse demand shock lowers aggregate output, retail inflation and job creation by wholesale firms.[4] Due to search frictions in the labor market the share of new hires with at least one period of unemployment rises, thereby increasing the training costs of firms. Moreover, a fall in economic activity (lower employment) generates a negative learning-by-doing externality and thus slows down accumulation of human capital. Wholesale firms respond to anticipations of lower future productivity growth and higher training costs by decreasing job creation, thereby amplifying the impact of the adverse demand shock on unemployment. The adverse supply side response of wholesale firms to anticipations of lower productivity growth and higher training costs raises retail firms' future real marginal costs, which mitigates the disinflationary impact of the adverse demand shock.

The balanced growth restriction and the standard search and matching framework imply that endogenous growth gives rise to a hysteresis-like effect of temporary adverse demand shocks on the level of output.[5] In the absence of the endogenous human capital channel the initial fall in output growth is followed by output growth overshooting so that eventually the level of output returns to its pre-shock balanced growth path. In other words, the adverse demand shock does not lead to a permanent output loss. By contrast, when the endogenous human capital channel is operative, output growth remains persistently below its steady state and recovers smoothly overtime without overshooting, implying

[4]The transmission mechanism is well-known. Due to sticky prices an adverse demand shock lowers input demand by retail firms and thus the relative input price. The decline in the relative input price lowers real marginal costs of retail firms and contributes to lower inflation. At the same time, given labor productivity, the lower match-surplus in the wholesale sector lowers job creation, and thus the job-finding rate, raising unemployment. As policy responds to lower inflation both the nominal and real interest rate fall.

[5]Blanchard (2017) provides a survey of the literature on hysteresis.

a permanent output loss reflecting the permanently lower human capital. Due to the balanced growth restriction the ratio of output to human capital is stationary, and so is unemployment.[6]

The remainder of the paper is organized as follows. In section 2 we review the related literature. In section 3 we present the details of the model and the key aggregate relationships. In section 4 we discuss model calibration and present simulation results based on impulse response functions. The main issue is the transmission of aggregate demand shocks. We also present sensitivity analysis (e.g., to monetary policy specification) and the role of news shocks as an alternative rationalization of the observed dynamics during the Great Recession. Section 5 gives a summary and concluding remarks.

2 Related literature

The paper overlaps with a number of distinct literatures on learning-by-doing based endogenous growth, skill loss from unemployment, the role of anticipations about future productivity changes (news shock) in business cycle fluctuations, as well as nominal rigidity and labor market frictions.

Endogenous growth and business cycle: In terms of methodology, there exists a small body of theoretical work that examines the relation between business cycle persistence and long-run output in the presence of endogenous growth. Much of this work dates back to the 1990s and early 2000s, with a heavy focus on the real side of the economy (e.g., King, Plosser and Rebelo (1988)). Chiang, Gomes and Schorfheide (2002) use learning-by-doing as a propagation mechanism in a real business cycle model. In their model, an increase in the number of hours worked contributes to future improvements in labor skills. An exception is Stadler (1990) who compares the properties of real and monetary business cycle models in the presence of endogenous growth arising from learning-by-doing. A temporary shock is shown to induce a permanent upward shift in the aggregate

[6]One possible mechanism that can generate unemployment hysteresis is labor force participation decision, whereby a prolonged recession induces long-term unemployed to drop out of the labor force.

production function, thus having long-run effects. Stadler (1990) assumes one-period predetermined wages and abstracts from labor market frictions. Engler and Tervala (2018) use a two-country New-Keynesian model to show that the fiscal output multiplier is much larger in the presence of learning-by-doing.[7] Unlike our paper all these models abstract from labor market frictions.

Unemployment and skill loss: The issue of skill loss during unemployment has received more attention following the persistence of unemployment during the Great Recession. Esteban-Pretel and Faraglia (2010) analyze skill loss during unemployment in a New-Keynesian model and show that the skill loss mechanism helps to explain the magnitude of the response of unemployment to monetary shocks. Acharya et al (2018) analyze monetary policy in a model with the zero-lower bound constraint and hysteresis effects whereby skill loss generates multiplicity of steady-state unemployment.[8] Walentin and Westermark (2018) quantify the importance of human capital dynamics and job mismatch in slowing down the recovery from the Great Recession. They find that the increase in unemployment during 2007-2009 had long-lasting effects through the skill loss it induced, mainly in terms of increased unemployment and reduced GDP. None of these studies considers endogenous growth as we do.

New-Keynesian models with frictions in the labor market: More generally, there is an extensive literature focusing on business cycle and unemployment using the New-Keynesian framework with search frictions in the labor market. A non-exhaustive list includes Walsh (2003), Trigari (2009) on inflation persistence, Blanchard and Gali (2010), Faia (2009), Thomas (2008) and Ravenna and Walsh (2011) on optimal monetary policy, Krause and Lubik (2007) and Christoffel and Kuester (2008) on real wage rigidity. These papers do not consider endogenous growth either.

[7] There exist models that generate hysteresis for reasons other than learning-by-doing. Gali (2016) develops a version of the New Keynesian model with insider-outsider labor markets and unemployment hysteresis and argues that the model can account for the high persistence of European unemployment. Craighead (2019) models unemployment hysteresis as deterioration in labor market matching efficiency from higher average duration of unemployment. By contrast, our framework focuses on output hysteresis.

[8] Esteban-Pretel and Faraglia (2010) and Acharya et al (2018) assume that new hires are equally productive as existing workers once a fixed training cost to 'upgrade' the human capital of new hires has been paid.

News shocks and the business cycle: Beaudry and Portier (2004, 2006) first resurrected the old idea (dating back to Pigou) that news shocks are important drivers of the business cycle. The idea is that these shocks change expectations about the future, affecting consumption-savings as well as work-leisure decisions. Barsky and Sims (2009), and Barsky, Basu and Lee (2014) present evidence that news shocks are positively correlated with consumption and negatively correlated with inflation. Barsky and Sims (2009) show that the disinflationary nature of news shocks found in the data contradicts the implications of the standard New Keynesian model augmented with a policy rule that responds to the output gap (as in Taylor (1993)). They show that with a policy rule that responds to output growth the model does better at fitting the empirical evidence.[9] Christiano, Ilut, Motto and Rostagno (2010) analyze the role of monetary policy in stock market booms in the New-Keynesian model augmented with habits in consumption and investment adjustment costs. Good news about future improvements in technology creates the expectation that future marginal cost and thus future inflation will be low. This induces an inflation-forecast targeting central bank to reduce the nominal rate of interest, thereby creating an immediate expansion. Although the expansion is associated with higher current marginal cost, inflation nevertheless drops because of the lower future expected marginal costs.[10]

3 The model framework

Following the pioneering work of Walsh (2003) the model economy has two sectors: a retail sector and a wholesale sector. Firms in the wholesale sector combine raw labor and human capital to produce output and sell their output to the retail sector in a perfectly competitive market. The labor market is subject to search frictions.

Each retail firm transforms the wholesale good into a differentiated final good and sells

[9] Alternative modifications include real wage rigidity (Barsky and Sims (2009), Barsky, Basu and Lee (2014)).

[10] Consumption habits and adjustment costs imply a smoothing incentive so that consumption and investment rise in advance of the productivity change. Hours also increase because habit persistence breaks the tight link between hours and consumption.

it to households in a monopolistically competitive market. Retails firms set prices under Calvo-type nominal price staggering. Each household consists of a continuum of employed and unemployed (and searching) workers who pool their income.[11] Household utility depends on consumption.

Endogenous growth is assumed to arise due to learning-by-doing externalities, whereby human capital accumulation depends on aggregate employment and thus on the business cycle. The idea is that lower aggregate employment associated with decreased economic activity slows down human capital accumulation. As is common in the endogenous growth literature the change in human capital is linear in the level of human capital. It is the absence of diminishing returns in human capital accumulation that allows the model to generate sustained growth.[12] Importantly, a temporary decline in the rate of productivity growth implies permanently lower levels of aggregate human capital and aggregate output. Furthermore, we assume that long-term unemployed workers experience skill obsolescence and thus need training before becoming productive at a new job.

We analyze the response of the economy to an unanticipated but persistent rise in the stochastic discount factor (an intertemporal preference shift). The discount factor shock is commonly considered to be a proxy for financial market turmoil because of its effect on the real rate of interest, and thus the cost of capital. The discount factor shock is thus a simple stand-in for the driver of the Great Recession (see, e.g., Christiano, Eichenbaum and Rebelo (2011), Uhlig and Krause (2012)).

3.1 Labor market and human capital dynamics

We start by describing the aggregate relationships in the labor market within the wholesale sector and the endogeneity of aggregate human capital dynamics. The size of the labor force is normalized to one. At the beginning of each period a fraction δ of previously employed workers are separated from their jobs. These unemployed workers immediately

[11] As is well-known locating labor market frictions and nominal price rigidities in different sectors as well as income pooling by workers make the model tractable.

[12] Human capital externalities have implications for welfare, and thus optimal monetary and fiscal policies, depending on the inefficiencies they generate under competitive equilibrium.

engage in job search. As a result aggregate employment evolves according to the dynamic equation

$$N_t = (1-\delta)N_{t-1} + M_t, \tag{1}$$

where M_t is the number of newly formed matches in period t, which become productive immediately. Moreover, the number of searching workers in period t is given by

$$S_t = 1 - (1-\delta)N_{t-1}, \tag{2}$$

and the unemployment rate after hiring takes place is $u_t = 1 - N_t$.

The number of newly created matches, M_t, is determined by a constant returns-to-scale matching function, with the number of searching workers, and the number of posted vacancies as its arguments

$$M_t = \mu S_t^{\alpha} V_t^{1-\alpha}, \tag{3}$$

where $\mu > 0$ is a scale parameter describing the efficiency of the labor market and $\alpha > 0$ is the elasticity of the matching function. Dividing equation (3) by V_t and defining labor market tightness as $\theta_t \equiv V_t/S_t$ we can write the vacancy filling rate as

$$q(\theta_t) \equiv \frac{M_t}{V_t} = \mu\theta_t^{-\alpha}. \tag{4}$$

Learning-by-doing as a driver of endogenous growth is introduced in a standard way: higher aggregate economic activity (higher aggregate employment) imposes a positive externality on the accumulation of aggregate human capital (due to enhanced opportunities of learning-by-doing). Let H_t denote aggregate human capital in the economy, which can have the interpretation of aggregate knowledge. Its dynamic development is given by

$$H_{t+1} = (1-\delta_H)H_t + BN_tH_t, \tag{5}$$

where δ_H is the depreciation rate of human capital and $B > 0$ is a scale parameter. One

can rewrite equation (5) in terms of the gross growth rate of human capital

$$\Gamma_{H,t+1} \equiv \frac{H_{t+1}}{H_t} = 1 - \delta_H + BN_t. \tag{6}$$

which shows that a fall in aggregate employment today leads to a fall in future productivity growth. Interestingly, as will be seen below, the reaction to anticipations of future productivity changes relates our analysis to the news shock literature discussed in the introduction to the paper.

3.2 Households

There is a representative household with a continuum of members over the unit interval. The period utility function features external habit persistence

$$U_t = \frac{\left(C_t - h_p \bar{C}_{t-1}\right)^{1-\sigma} - 1}{1-\sigma}, \tag{7}$$

where $\sigma > 0$, $0 \leq h_p \leq 1$ and $\bar{C}_t$ represents aggregate consumption, which in equilibrium is equal to C_t. Habits in consumption play a key role in generating a boom accompanied by a disinflation in response to a positive news shock, a pattern consistent with the data (e.g., Christiano et al. (2010)).

Household consumption C_t is a Dixit-Stiglitz composite of a continuum of differentiated goods $C_t = \left(\int_0^1 C_{k,t}^{1/\mu_p} dk\right)^{\mu_p}$ where each good is indexed by k, $\mu_p = \frac{\epsilon}{\epsilon-1}$ and ϵ is the elasticity of substitution between goods. Optimal consumption allocation across goods gives the demand equation $C_{k,t} = \left(\frac{P_{k,t}}{P_t}\right)^{-\epsilon} C_t$ where $P_t = \left(\int_0^1 P_{k,t}^{1-\epsilon} dk\right)^{\frac{1}{1-\epsilon}}$ is the price index.

In a given period a fraction N_t of household members are employed by firms and earn a nominal wage W_t. The rest earn nominal unemployment benefits of $P_t u_b H_t$, $u_b > 0$.[13] As is common in the literature, we assume that the income is pooled within the household so that unemployed workers do not face lower consumption than employed workers. The household maximizes lifetime utility $E_t \sum_{i=0}^{\infty} \beta^i \zeta_{t+i} U_{t+i}$, where β is the subjective discount factor and ζ_t is a discount factor shock given by $\log \zeta_t = \rho_\zeta \log \zeta_{t-1} + e_t$, $0 < \rho_\zeta < 1$ and

[13] The presence of H_t ensures that along a balanced growth path real unemployment benefits grow at the same rate as aggregate labor productivity (see, e.g., Pissarides (2000)).

$e_t \sim N(0, \sigma_e^2)$.

The household's budget constraint is

$$P_t C_t + B_t = W_t N_t + P_t u_b H_t (1 - N_t) + R_{t-1} B_{t-1} + D_t. \tag{8}$$

where R_t is the nominal interest rate on bond holdings B_t, and D_t is aggregate nominal profit from ownership of retail firms.

It is straightforward to derive the familiar consumption Euler equation

$$1 = E_t \left(Q_{t,t+1} \frac{R_t}{\Pi_{t+1}} \right), \tag{9}$$

where $\Pi_t \equiv P_t / P_{t-1}$ is gross inflation rate and $Q_{t,t+1} \equiv \beta \left(\zeta_{t+1} / \zeta_t \right) U'(C_{t+1}) / U'(C_t)$ is the household's stochastic discount factor, which is used to discount future real payoffs from bond holdings and to discount future real profits of firms. Using the utility function (7) we rewrite $Q_{t,t+1}$ in stationary variables,

$$Q_{t,t+1} \equiv \beta \frac{\zeta_{t+1}}{\zeta_t} \left(\frac{C_{t+1} - h_p C_t}{C_t - h_p C_{t-1}} \right)^{-\sigma} \equiv \beta \frac{\zeta_{t+1}}{\zeta_t} \left(\frac{\Gamma_{H,t+1} c_{t+1} - h_p c_t}{c_t - h_p \Gamma_{H,t}^{-1} c_{t-1}} \right)^{-\sigma}, \tag{10}$$

where $c_t = C_t / H_t$ is stationary due to the balanced growth property. Holding $\Gamma_{H,t+1}$ and the real rate of interest constant, c_t falls in response to a decline in the discount factor shock (i.e., a rise in ζ_{t+1}/ζ_t), as it gives households an incentive to substitute future consumption for current consumption. Moreover, given the real rate of interest c_t falls in response to a decline in expected future human capital growth $\Gamma_{H,t+1}$. This is a partial equilibrium effect. In general equilibrium future human capital growth depends on current aggregate employment (see equation (6)) and thus indirectly on aggregate consumption.

3.3 Firms

3.3.1 Intermediate goods sector

Firms in the intermediate goods sector face standard search and matching frictions as well as frictions related to skill obsolescence and associated training costs incurred for

skill upgrading.[14] There is an unlimited number of potential entrants that need to post a vacancy at real cost $H_t\kappa$ to have the chance to find a worker and enter the market. In addition, potential entrants anticipate to pay training costs if the matched worker needs skill upgrade.[15]

At the vacancy creation stage the expected training cost per hired worker TC_t is given by

$$TC_t = \frac{[1-\theta_{t-1}q(\theta_{t-1})]u_{t-2}}{S_t}(\chi H_t), \tag{11}$$

where the term $(1-\theta_{t-1}q(\theta_{t-1}))u_{t-2}$ is the number of job seekers in period t whose last job was in period $t-3$ or earlier. This term divided by S_t thus represents the probability that a firm matches with a job seeker who as of period t had been unemployed for at least two periods (where a period represents a quarter), and thus needs to upgrade the worker's skill at a cost equal to χH_t.[16] By contrast, a searching worker in period t whose last job was in period $t-2$ or $t-1$ (i.e., had been unemployed for at most one period) does not need a skill upgrade. These two types of workers maybe differentiated as long-term unemployed vs. short-term unemployed.

Note that we can rewrite the definition of job seekers, as given in equation (2), in term of the mass of short-term and long-term unemployed

$$S_t = \delta N_{t-1} + [1-\theta_{t-1}q(\theta_{t-1})]\delta N_{t-2} + [1-\theta_{t-1}q(\theta_{t-1})]u_{t-2}, \tag{12}$$

where the last term represents the pool of long-term unemployed and the sum of the first two terms represents the pool of short-term unemployed. An adverse shock in period t-1 that lowers employment N_{t-1} and the job-finding rate $\theta_{t-1}q(\theta_{t-1})$ also increases the

[14] A detailed discussion of the standard search and matching model can be found in, for e.g., Pissarides (2000).

[15] Following Pissarides (2009) training costs are assumed to be sunk. Among others, Acharya et al. (2018) follow a similar approach. Pissarides (2009) argues that "the attractive feature of making them sunk,...,is that they can be interpreted as a component of the cost of frictions that characterize search models, so they are an alternative way of calibrating frictions to the conventional proportional [vacancy posting] costs."

[16] The presence of H_t ensures that along the balanced growth path the vacancy posting cost and the training cost grow at the same rate as aggregate labor productivity. Without the above assumption vacancies would overtime converge towards infinity and unemployment towards zero, since the ratio of vacancy creation costs to labor productivity would converge towards zero.

share of long-term unemployment in total job seekers in period t and thus the expected training cost, as given in equation (11).

Each firm can employ only one worker and produces with aggregate human capital H_t. Since training costs are sunk, new and continuing workers receive the same wage rate. Let J_t denote the value of an existing match. The value of a vacancy is then given by $q(\theta_t)(J_t - TC_t - \kappa H_t)$. Free entry of firms drives down the value of a vacancy to zero so that

$$\kappa H_t = q(\theta_t)\,(J_t - TC_t) \tag{13}$$

which is the standard vacancy creation condition, adjusted for the presence of a training cost and a balanced growth path. The cost of posting a vacancy equals the net benefit of posting a vacancy, the potential profits that can be earned in case the search for a worker was successful. If the cost of posting a vacancy were lower than the expected profit of posting a vacancy, new vacancies would be posted, lowering the vacancy filling rate and thereby expected profits until the incentive to post further vacancies vanishes. Likewise, an increase in the training cost has similar effects on the incentive to post vacancies. But crucially, the training cost depends on the probability that a new hire comes from the long-term unemployed who need skill upgrading.

Active firms in this sector face a perfectly competitive output market. Let P_t^I denote the nominal market price and $p_t^I \equiv P_t^I/P_t$ the real market price. Then the value of a filled job is defined as

$$J_t = H_t p_t^I - w_t + (1-\delta)E_t\left\{Q_{t,t+1}J_{t+1}\right\} \tag{14}$$

where $w_t = W_t/P_t$ is real wage. The value of a firm consists of contemporaneous profits plus the expected future value of the match discounted by the appropriate discount factor. Combining equations (13) and (14) the vacancy creation condition can be written as

$$\frac{\kappa H_t}{q(\theta_t)} + TC_t = H_t p_t^I - w_t + (1-\delta)E_t\left\{Q_{t,t+1}\left(\frac{\kappa H_{t+1}}{q(\theta_{t+1})} + TC_{t+1}\right)\right\} \tag{15}$$

where $\kappa H_t/q(\theta_t)$ is the expected vacancy posting cost. Equation (15) says that in equi-

librium the sum of vacancy posting and training costs must equal the contemporaneous profits generated by a worker plus the discounted savings in future vacancy posting and training costs. A negative demand shock, for instance, decreases p_t^I, and thus match surplus, which induces fewer job creation until market tightness θ_t falls sufficiently and the probability of filling a job $q(\theta_t)$ rises to keep the value of a vacant job at zero (this implies that workers have a lower probability of finding a job). Note that the training cost is a predetermined endogenous variable. Thus, the presence of training costs amplifies the effect of the demand shock on market tightness and in turn unemployment.

Dividing equation (15) by the growing labor productivity H_t we get a stationary version of the vacancy creation condition

$$\frac{\kappa}{q(\theta_t)} + tc_t = p_t^I - \frac{w_t}{H_t} + (1-\delta)E_t\left\{Q_{t,t+1}\Gamma_{H,t+1}\left(\frac{\kappa}{q(\theta_{t+1})} + tc_{t+1}\right)\right\} \tag{16}$$

where $tc_t \equiv TC_t/H_t$. From the right hand side of equation (16) we see that endogenous growth feeds back into vacancy creation through two counteracting effects. Lower expected consumption growth implies a lower discount rate (higher stochastic discount factor) but also lower expected savings in vacancy posting and training costs.

Wage setting. The wage rate is set under the standard assumption of Nash bargaining. Moreover, as remarked above, wage bargaining is assumed to happen after training costs have been paid, so that new and continuing workers receive the same wage rate. The real value to the household of an employed worker is given by

$$V_t^e = w_t + E_t\left\{Q_{t,t+1}\left[(1-\delta(1-\theta_{t+1}q(\theta_{t+1})))V_{t+1}^e + \delta(1-\theta_{t+1}q(\theta_{t+1}))V_{t+1}^u\right]\right\} \tag{17}$$

where $\theta_{t+1}q(\theta_{t+1}) = M_{t+1}/S_{t+1}$ is an unemployed worker's job finding rate. The corresponding real value of an unemployed worker is given by

$$V_t^u = u_b H_t + E_t\left\{Q_{t,t+1}\left[\theta_{t+1}q(\theta_{t+1})V_{t+1}^e + (1-\theta_{t+1}q(\theta_{t+1}))V_{t+1}^u\right]\right\} \tag{18}$$

Thus the household surplus from an employment relationship is given by

$$S_t^h = w_t - u_b H_t + (1-\delta)E_t\left\{Q_{t,t+1}(1-\theta_{t+1}q(\theta_{t+1}))S_{t+1}^h\right\} \tag{19}$$

Given that in equilibrium the value of a vacancy is zero, the firm's surplus is equal to J_t. Under Nash bargaining the optimal surplus sharing rule is given by $S_t^h = [(1-\nu)/\nu]J_t$, where ν is the bargaining power of the firm and J_t satisfies equation (13). Using the surplus sharing rule to substitute out S_t^h in equation (19) and in turn using equation (13) to substitute out $\kappa/q(\theta_t)$ gives, after rearranging, the wage setting equation

$$w_t = \nu u_b H_t + (1-\nu)\left(H_t p_t^I + (1-\delta)E_t\left\{Q_{t,t+1}\theta_{t+1}q(\theta_{t+1})\left(\frac{\kappa H_{t+1}}{q(\theta_{t+1})} + TC_{t+1}\right)\right\}\right) \tag{20}$$

which in stationary form becomes

$$w_t^d = \nu u_b + (1-\nu)\left(p_t^I + (1-\delta)E_t\left\{Q_{t,t+1}\theta_{t+1}q(\theta_{t+1})\Gamma_{H,t+1}\left(\frac{\kappa}{q(\theta_{t+1})} + tc_{t+1}\right)\right\}\right) \tag{21}$$

where $w_t^d \equiv w_t/H_t$.

3.3.2 Final goods sector

Each firm k in the final goods sector produces a differentiated final good using a linear technology $Y_{k,t} = Y_{k,t}^I$ implying that the firm's real marginal cost, $mc_{k,t}$, is given by p_t^I. Price setting is subject to Calvo-type price staggering, where only a fraction $1-\omega$ of randomly selected firms can optimally set their price, while the fraction ω of firms keep their prices unchanged. Let $P_{k,t}$ denote firm $k's$ output price. Each firm k maximizes lifetime profit $E_t\sum_{i=0}^{\infty}\omega^i Q_{t,t+i}\left(P_{k,t}/P_{t+i} - p_{t+i}^I\right)Y_{k,t+i}$ subject to the total demand for good k, $Y_{k,t+i} = \left(P_{k,t}/P_{t+i}\right)^{-\epsilon}Y_{t+i}$, where $Y_{t+i} = C_{t+i} + H_{t+i}\kappa V_{t+i} + \chi\frac{u_{t-1+i}}{S_{t+i}}q(\theta_{t+i})V_{t+i}$ is total aggregate demand that includes the vacancy posting costs and training costs. The resulting optimal price is

$$p_t^* = \mu_p\frac{E_t\sum_{i=0}^{\infty}\omega^i Q_{t,t+i}p_{t+i}^I\frac{Y_{t+i}}{Y_t}\left(\frac{P_{t+i}}{P_t}\right)^{\epsilon}}{E_t\sum_{i=0}^{\infty}\omega^i Q_{t,t+i}\frac{Y_{t+i}}{Y_t}\left(\frac{P_{t+i}}{P_t}\right)^{\epsilon-1}}, \tag{22}$$

where $p_t^* \equiv P_t^*/P_t$, $y_t = Y_t/H_t$ and μ_p is the price markup in the absence of price staggering. Endogenous growth feeds back into optimal pricing through two counteracting effects. Lower expected growth implies a lower discount rate (higher stochastic discount factor) but also lower expected future demand growth.

Equation (22) can be rewritten as

$$p_t^* = \mu_p \frac{F_{n,t}}{F_{d,t}}, \tag{23}$$

where $F_{n,t}$ and $F_{d,t}$ are auxiliary variables given by

$$F_{n,t} = p_t^I y_t c_t^{-\sigma} + \omega Q_{t,t+1} \Gamma_{H,t+1} \Pi_{t+1}^{\epsilon} F_{n,t+1}, \tag{24}$$

and

$$F_{d,t} = y_t c_t^{-\sigma} + \omega Q_{t,t+1} \Gamma_{H,t+1} \Pi_{t+1}^{\epsilon-1} F_{d,t+1}. \tag{25}$$

Under Calvo-type price staggering the aggregate price index can be rewritten as

$$1 = (1-\omega) p_t^{*(1-\epsilon)} + \omega \Pi_t^{\epsilon-1}. \tag{26}$$

Aggregating both sides of the market clearing condition for the intermediate good and using the demand equation for the final good k leads to a relationship between aggregate final output y_t and intermediate good output y_t^I,

$$y_t^I = \Delta_t y_t, \tag{27}$$

where $\Delta_t \equiv \int_0^1 (P_{k,t}/P_t)^{-\epsilon} \, df$ is a measure of price dispersion, which can be rewritten as

$$\Delta_t = (1-\omega) p_t^{*-\epsilon} + \omega \Pi_t^{\epsilon} \Delta_{t-1}. \tag{28}$$

As aggregate output in the intermediate good sector is equal to aggregate employment, Eq. (27) can be rewritten as

$$N_t = \Delta_t y_t. \tag{29}$$

Finally, the aggregate resource constraint in stationary form is given by

$$y_t = c_t + \kappa V_t + t c_t q(\theta_t) V_t. \tag{30}$$

3.4 Monetary policy

Closing the model requires specification of monetary policy. The central bank is assumed to follow a simple policy rule by adjusting the nominal interest rate in response to deviations of inflation and output growth from their respective target levels, Π and g_Y, where the latter is equal to steady state output growth consistent with steady state inflation (which is pinned down by the inflation target).

$$\frac{R_t}{R} = \left(\frac{\Pi_t}{\Pi}\right)^{\phi_\pi} \left(\frac{Y_t/Y_{t-1}}{g_Y}\right)^{\phi_y} \tag{31}$$

where $\phi_\pi, \phi_y > 0$ and R is the steady state gross nominal interest rate. Regarding the presence of output growth in the policy rule, Barsky and Sims (2009) show that the disinflationary nature of news shocks found in the data contradicts the implications of the standard New Keynesian model augmented with the standard policy rule that responds to the output gap. They show that with a policy rule that responds to output growth the model does better at fitting the empirical evidence.

While the simple policy rule (31) is standard in the New-Keynesian literature and thus represents our baseline specification, we also discuss the role of policy inertia,

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_r} \left(\left(\frac{\Pi_t}{\Pi}\right)^{\phi_\pi} \left(\frac{Y_t/Y_{t-1}}{g_Y}\right)^{\phi_y}\right)^{1-\rho_r} \tag{32}$$

where $0 < \rho_r < 1$. The role of inertia in policy rules have been extensively discussed in the literature on optimal monetary policy (see, e.g., Woodford (2003)).

4 Numerical Results

4.1 Calibration

The model is calibrated to fit some broad long-run properties of the U.S. economy. Table 1 shows the calibration of the model to a quarterly frequency.

The steady state growth rate of the economy and the steady state rate of inflation are set,

Table 1: Parameter configuration

Parameter	Description	Value
β	subjective discount factor	0.99
σ	coefficient of relative risk aversion	1
ω	fraction of non-optimizing firms	0.75
ϵ	elasticity of substitution between final goods	6
Γ_H	steady state growth	1.0075
Π	steady state inflation	1.005
h_p	degree of habit persistence	0.8
δ_H	human capital depreciation rate	0.019
δ	job separation rate	0.1
α	elasticity of the matching function	0.5
ν	firm's share of surplus	0.5
u_b	unemployment benefit	0.75
κ	vacancy posting cost	0.07
χ	training cost	0.25
ϕ_p	inflation coefficient	1.5
ϕ_y	output growth coefficient	1
ρ_ζ	persistence of discount factor shock	0.8
σ_e	standard deviation of shock innovation	0.01

respectively, at 3% and 2% (both annualized). The elasticity of the matching function α is set at 0.5, and the job separation rate δ is set at 0.1, values that are common in the literature (see, e.g., Pissarides (2009)). The Hosios condition for efficiency implies that the firm's share of surplus ν is equal to α so ν is set at 0.5. The scale parameter in the matching function μ and steady state labor market tightness are set such that the steady state job-finding rate is 0.7 (e.g., Blanchard and Gali (2010)) and the steady state job-filling rate is 0.9 (e.g., Andolfatto (1996) and Arsenau and Chugh (2012)). The chosen values for the job-finding rate and the job separation rate, as well as the definition of job seekers, imply a steady state unemployment u of 0.04 and a steady state employment N of 0.96. Following Blanchard and Gali (2010) the steady state aggregate hiring costs (i.e., the sum of vacancy posting and training costs) represent 1 percent of steady state aggregate output. Given the parameters and steady state targets set as above the implied value of the unemployment benefit parameter u_b is 0.75 (the corresponding replacement rate is 0.91). We target a steady state ratio of training costs to vacancy posting costs equal to 0.3, which is at the lower end of values considered in Pissarides (2009).[17] The

[17]We think the chosen value is reasonable, as Pissarides (2009) considers fixed matching costs that

training cost parameter χ and the cost of posting a vacancy κ are set consistent with the resulting steady state solution of the model.

The scale parameter in the human capital accumulation equation B is consistent with the steady state annualized growth and the steady state employment rate. The human capital depreciation rate δ_H is set at 0.019, as in Jones, Manuelli and Stachetti (2000). With a habit persistence parameter value of 0.8, both parameters help the model generate higher inflation in response to a bad news shock (anticipated decline in future productivity growth), as in Christiano et. al. (2010). Finally, the discount factor shock ζ_t is assumed to follow an AR(1) process with an autocorrelation coefficient of 0.8. The innovation of the shock has a standard deviation of 0.01.

4.2 Baseline Results

Figure 2 shows impulse responses of output growth, productivity growth, the unemployment rate, the share of unskilled job seekers in total job seekers, the rate of inflation, the real marginal cost, the nominal interest rate and labor market tightness to a one standard deviation innovation to the discount factor shock. The solid line represents our baseline model with endogenous growth and skill obsolescence from unemployment while the dashed line shows the standard model with exogenous growth and no skill obsolescence (as in the standard search and matching model with nominal rigidities). Output growth, productivity growth, the nominal interest rate and inflation are shown as annualized absolute deviations from steady state, while the unemployment rate and the share of unskilled job seekers in total job seekers are shown as absolute deviation from steady state. The impulse response named 'output shortfall' shows the gap between actual output and output in the absence of the discount factor shock, expressed as a percentage of the latter. The other remaining variables are shown as percentage deviations from the respective steady state.

The impulse responses show that in response to a rise in the discount factor, inflation

may also include "costs of finding out about the qualities of the particular worker, of interviews, and of negotiating with her".

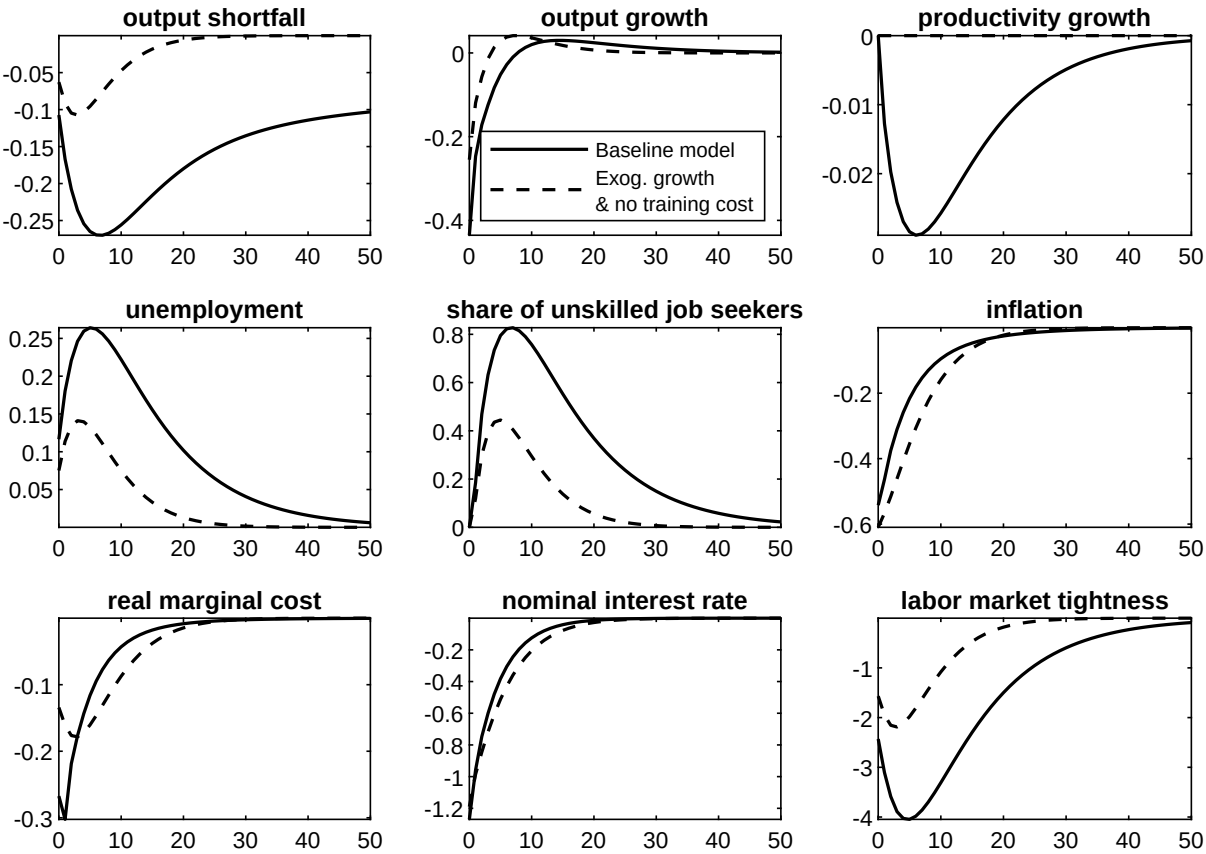

Figure 2: Impulse responses to a decline in the discount factor shock.

and output growth fall while unemployment rises. As discussed above with a rise in the discount factor households have an incentive to substitute future consumption for current consumption, which leads to a fall in aggregate demand, and given nominal rigidity, to a fall in output growth and inflation. In the baseline model (i.e., with endogenous growth and skill obsolescence, as shown by the solid line) a rise in the discount factor (a rise in the ratio ζ_{t+1}/ζ_t) reduces output growth and increases unemployment more strongly than it does under the standard model (dashed line). By contrast inflation declines less strongly than it does under exogenous growth.[18] This is the case despite the more pronounced decline on impact in the real cost in the baseline model. The reason is that inflation is forward looking and the fall in future real marginal cost is less pronounced in the baseline case owing to the presence of training costs and a fall in future productivity growth, as both tend to push up real marginal cost.

[18]The nominal interest rate falls on impact, with the decline somewhat more amplified under endogenous growth because of the much stronger fall in output growth.

Moreover, the rise in the future share of unskilled job seekers in total job seekers, which is more pronounced under the baseline model, is a consequence of the stronger disincentive for job creation by firms, as reflected in a larger decline on impact in labor market tightness (see equation (15)). The rise in the future share of unskilled workers raises future training costs and thus contributes to further increases in unemployment. In Figure 2 one can see a widening of the gap between unemployment in the baseline model and unemployment in the standard model.

The concurrence of a stronger fall in output and a weaker fall in inflation already suggests that our model with endogenous growth and skill obsolescence can contribute to the explanation of the missing-inflation puzzle—the moderate drop in inflation during the Great Recession. In order to make this contribution more transparent we recalibrate the shock in the baseline model such that on impact output growth falls and unemployment rises roughly equally as in the standard model.[19] The result is illustrated in Figure 3. It can be easily seen that, despite output growth falling on impact to an equal degree in both models, the fall in inflation in the baseline model is about half the corresponding fall in inflation in the standard model. Thus for a given fall in output our model is able to produce a much smaller drop in inflation than the standard model.

We turn next to the long-run output effects. As discussed above, in the presence of learning-by-doing future productivity growth declines endogenously reflecting lower current employment. While the stationary output growth eventually returns to the initial steady state by construction, the level of output is permanently lower, a hysteresis-like phenomenon. As can been seen from the panel 'output shortfall' the output shortfall in the baseline model (solid line) is never made up, settling around 0.1% of the pre-shock output level. By contrast, in the standard model (dashed line), the initial fall in output growth is followed by output growth overshooting so that the output shortfall is only temporary, as output returns back to the trend level that is exogenous in the standard model and thus not affected by the shock. Moreover, the maximum output shortfall dur-

[19] To be specific, the standard deviation of the shock in the baseline model is reduced from 0.01 (as in Figure 2) to 0.00645.

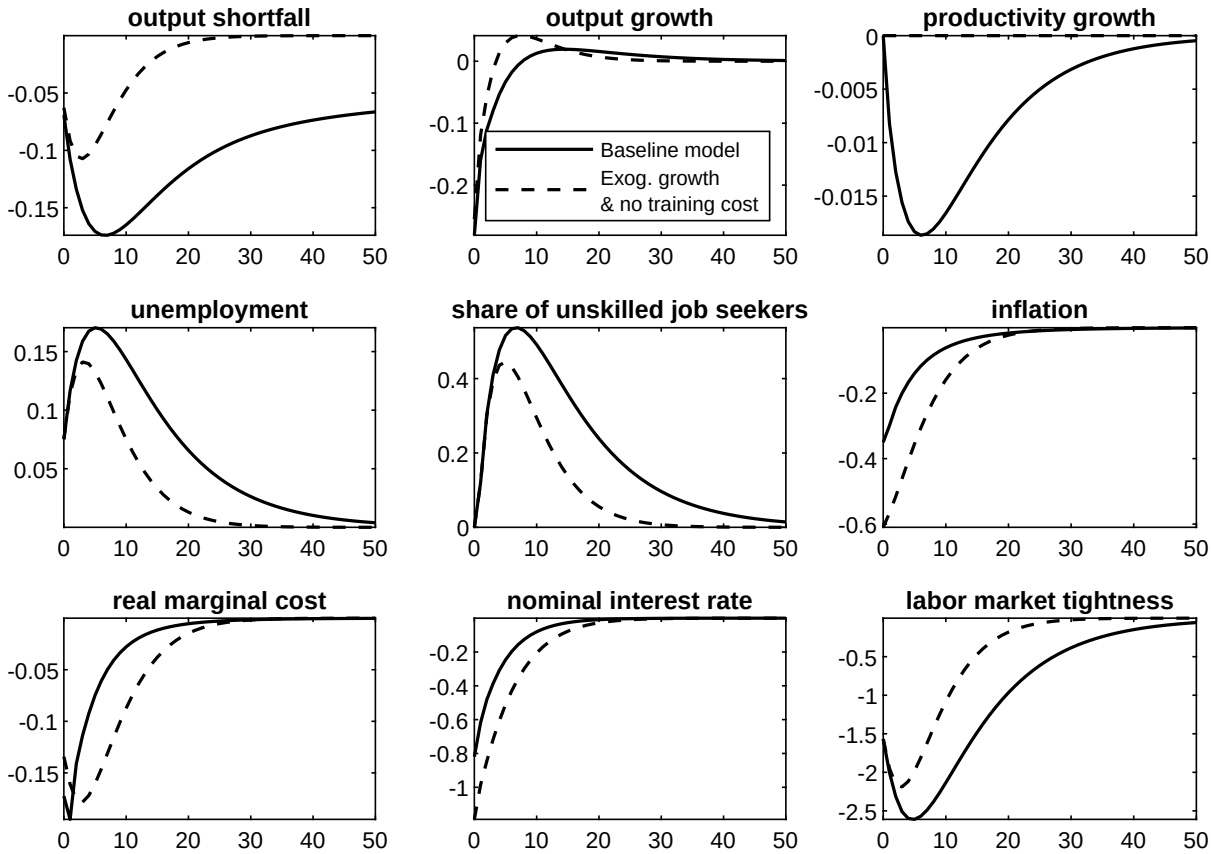

Figure 3: Impulse responses to a decline in the discount factor shock. Standard deviation of the shock under the baseline model is set at 0.00645.

ing adjustment in the baseline model is more than double that of the standard model. Finally, Note that, unlike output, unemployment is stationary in the model so that it eventually returns to the initial steady state level, although at a much slower rate than in the standard model.[20]

Our baseline model features two separate but closely related deviations from the standard model, endogenous growth based on human capital and learning-by-doing and training costs related to the skill loss of long-term unemployed workers. Both deviations are necessary to yield realistic impulse responses, but to make their respective contributions more transparent figure 4 shows the role of each in isolation. The dot-dash line in the figure shows impulse responses when only the training cost channel is shut down, while the dotted line shows impulse responses when only the endogenous growth channel is shut

[20]The stationarity of unemployment arises from the balanced growth restriction and linearity of the intermediate sector production function.

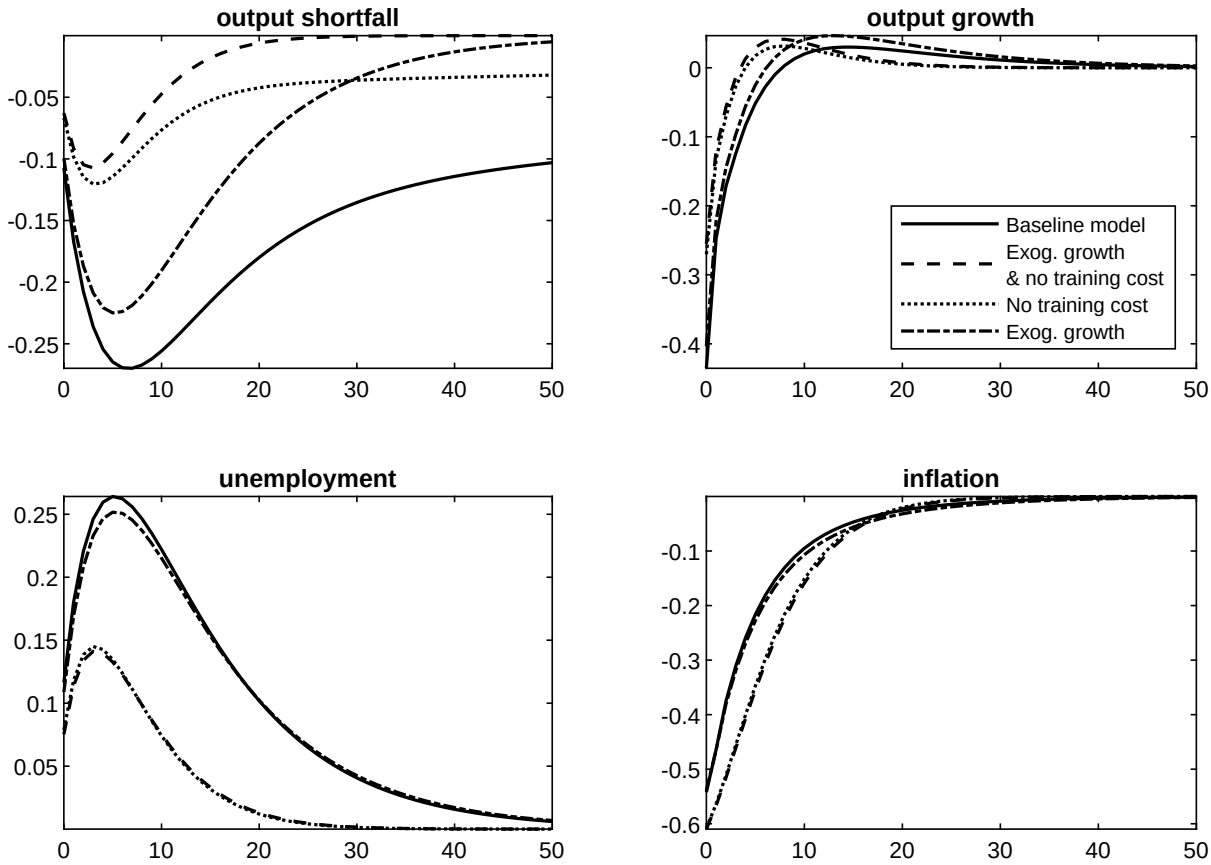

Figure 4: Impulse responses to a decline in the discount factor shock. Solid line: with endogenous growth and with training cost (with skill obsolescence). Dashed line: with exogenous growth but no training cost (no skill obsolescence). Dotted line: Model with endogenous growth but no skill obsolescence. Dot-dash line: Model with exogenous growth and skill obsolescence

down. Three observations can be made from this figure. First, the introduction of the training cost channel is key in the amplification of the fall in output growth, the rise in unemployment and the mitigation of the fall in inflation. Second, the endogenous growth channel is responsible for the output hysteresis, as can be seen from the panel 'output shortfall'. Third, the effect of endogenous growth is larger in the presence of training costs (solid line vs. dot-dash line) than in the absence of training costs (dotted line vs. dashed line), suggesting a complementarity between the two channels.

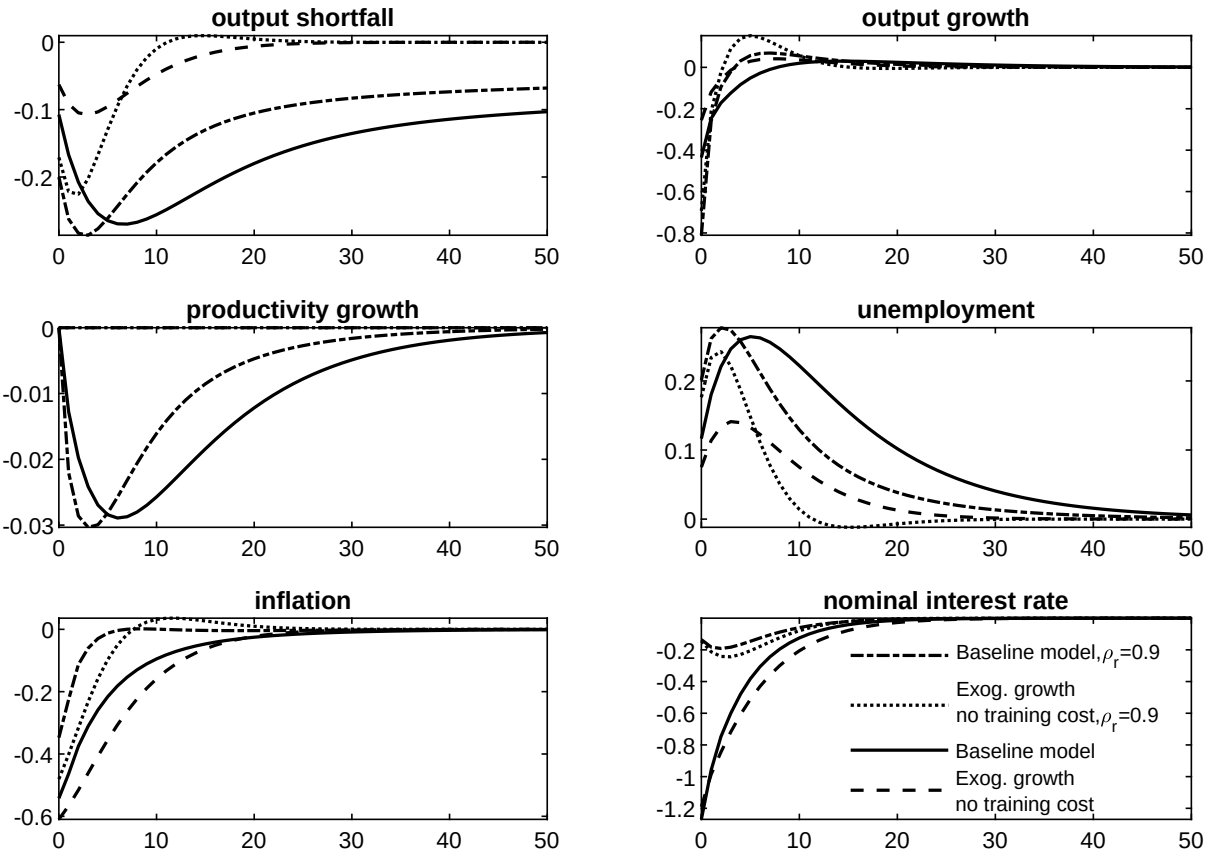

Figure 5: Impulse responses to a rise in the discount factor under policy inertia. Standard deviation of the shock is set at 0.01. The solid and dashed lines are identical to the corresponding lines shown in Figure 2.

4.3 The effect of policy inertia

When there is policy inertia (i.e., nominal interest rate smoothing) the central bank reacts to the rate of inflation more strongly in the long run than in the short run. This can have powerful effects given the forward-looking nature of inflation in the New-Keynesian model (Woodford (2003)). Figure 5 shows the effect of the discount factor shock in the presence of inertia in the policy rule (with the persistence parameter ρ_r in (32) set at 0.9, a value that is consistent with empirical estimates, see, e.g., Clarida, Gali, Gertler (1998)). Compared to the benchmark calibration with no policy inertia (i.e. $\rho_r = 0$, as shown in Figure 2 and replicated in the Figure 5) inflation is now more stable. The fact that the nominal interest rate remains depressed for a longer period than implied by the non-inertia policy mitigates the decline in inflation, although the initial muted response of the interest rate means that initially unemployment and the output shortfall increase by

more that they do in the absence of policy inertia. The reason is that given the forward-looking behavior of job creation the presence of history dependence in monetary policy has a stabilizing effect on employment fluctuations. Importantly, the stabilizing effect of policy inertia is more pronounced in the model with endogenous growth, as policy inertia affects anticipations of future training costs and human capital growth that are otherwise absent in the exogenous growth model.

4.4 Supply-side view of the Great Recession–growth shocks

An interesting question is whether news shocks about future productivity growth can provide an alternative rationalization for the dynamics of the economy during the Great Recession (e.g., Blanchard (2017)). The idea is that these supply-side shocks lead to lower aggregate demand, and thus a recession, as anticipated future declines in productivity growth have a negative wealth effect on current consumption. Figure 6 shows impulse responses to a negative productivity growth shock that is anticipated to hit after 4 periods and with the same degree of persistence as the discount factor shock. The standard deviation of the shock is such that productivity growth declines by about half a percentage point (annualized) in period 4.

In the baseline model (solid line) inflation rises at the time of arrival of the news shock, as lower productivity growth raises future real marginal costs and inflation is forward-looking. The rise in inflation is in sharp contrast to the decline in inflation under a discount factor shock, as shown in Figure 2 and the decline in inflation during and after the Great Recession. In the standard model (dashed line) inflation falls initially (though only mildly but then inflation subsequently overshoots its steady state. When the productivity growth slowdown realizes in period 4 it raises the real marginal cost of final goods firms, contributing to the rise in inflation above the steady state along the adjustment path.

In both models, unemployment rises and continues to rise until period 4, the period

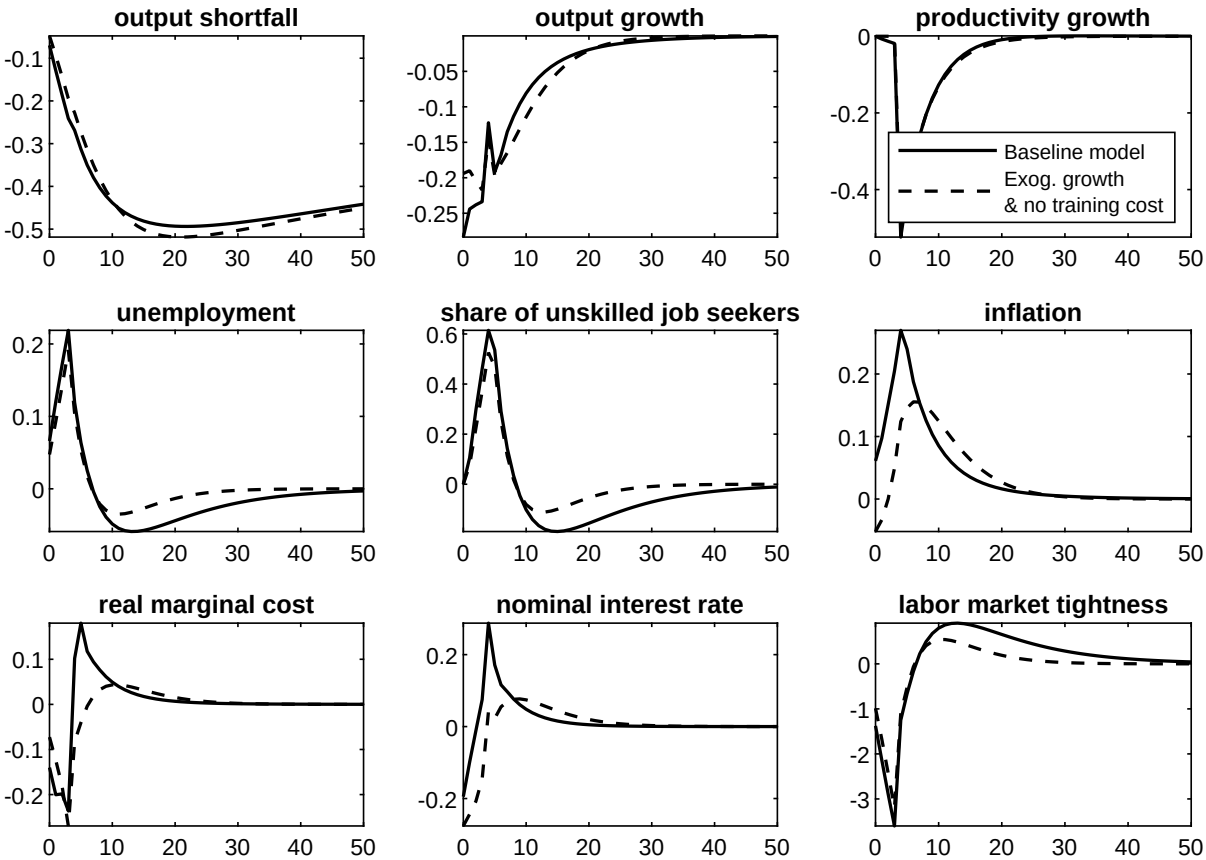

Figure 6: Impulse responses to a news shock about future productivity growth. Productivity growth is anticipated to decline in period 4.

when the productivity shock hits,[21] and then it starts to fall afterward, with the fall being somewhat larger under the baseline model.[22] In contrast to the smooth adjustment of unemployment under the discount factor shock, unemployment declines along the adjustment path (somewhat more strongly under the baseline model). In accordance with the response of unemployment, output growth declines initially (and more strongly under the baseline model).

In Figure 7 the negative productivity growth shock is anticipated to hit after 8 periods. In the standard model inflation falls upon arrival of the news and does so more strongly than shown in Figure 6. The stronger initial fall in inflation is due to the fact that the anticipated growth shock has a stronger expectational effect–consumption demand falls

[21] There are fewer vacancies posted before the productivity shock hits because of the expectation that with some probability the worker will still be employed by the time productivity growth falls, implying a lower match surplus.

[22] The fall in unemployment at the time when productivity slowdown materializes is similar to those reported elsewhere in the literature (see, e.g., Gali, Smets and Wouters (2011)).

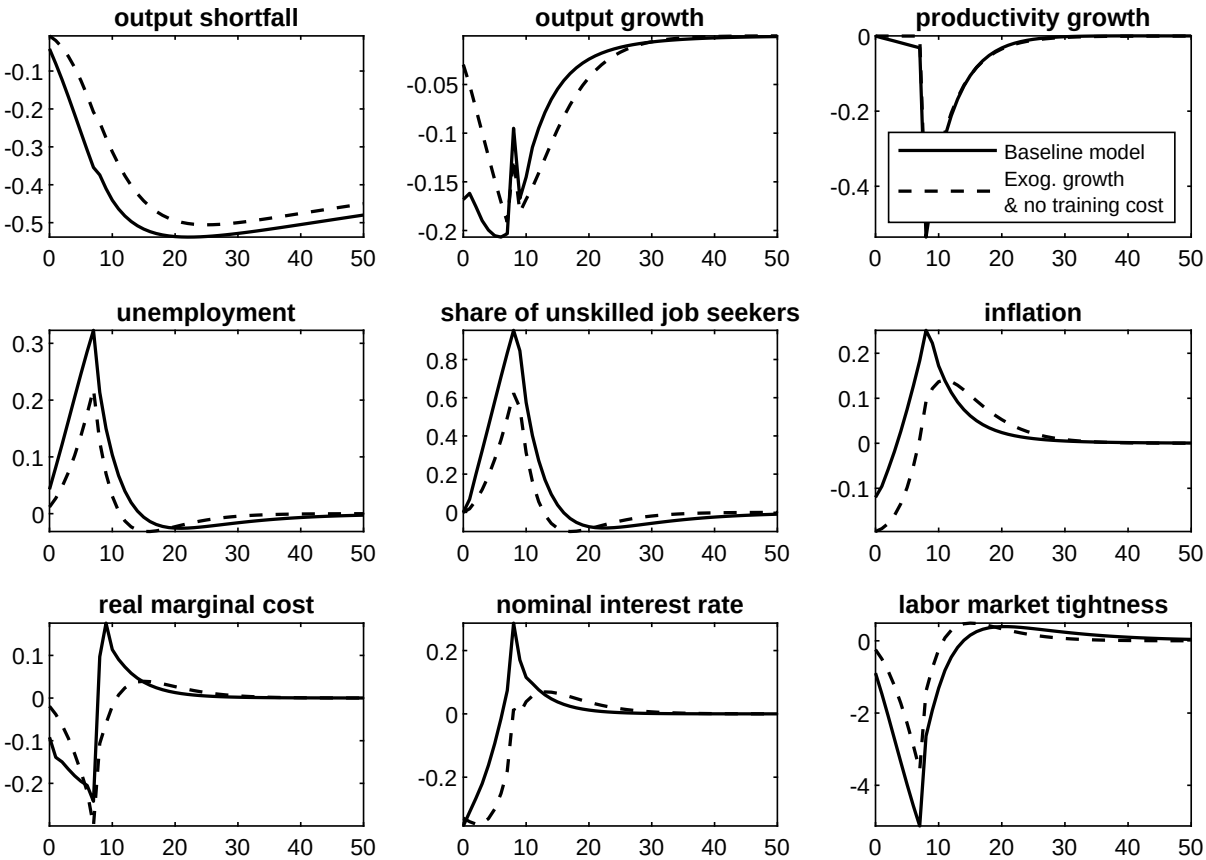

Figure 7: Impulse responses to a news shock about future productivity growth. Productivity growth is anticipated to decline in period 8.

more strongly in anticipation of future income losses. In the baseline model inflation again rises but the rise is less pronounced compared to that shown in Figure 6.

Together, Figure 6 and Figure 7 show that the assumption about the timing of the growth shock is critical for whether within the standard model a news shock can provide an alternative rationalization of the dynamics of unemployment during the Great Recession. Moreover, the standard model with a news shock does poorly in accounting for inflation dynamics. Within the baseline model the rise in inflation in response to the news shock goes counter to the disinflationary nature of the Great Recession.

5 Summary and concluding remark

We embed human capital-based endogenous growth into a two-sector New-Keynesian model with search frictions in the labor market and skill obsolescence from long-term unemployment. In the presence of aggregate demand shocks, the model is able to account for key features of the Great Recession: a decline in productivity growth, mild disinflation despite a pronounced rise in unemployment, and output hysteresis—a permanent gap between output and pre-crisis trend output. In the model, an unanticipated adverse demand shock increases both unemployment and the share of long-term unemployed in the pool of job seekers. The latter raises expected training costs of new hires because the long-term unemployed suffer skill obsolescence from longer unemployment spell. Moreover, lower economic activity associated with a decline in aggregate employment generates a negative learning-by-doing externality, which slows down future productivity growth. For these reasons firms post even less vacancies than justified by the demand shock alone. These supply-side feedback effects mitigate the adverse demand shock's disinflationary effect while amplifying its contractionary effect on output. The temporary growth slowdown translates into permanently lower output associated with permanently lower productivity.

The degree to which output hysteresis manifests is shown to depend on the monetary policy specification (within the class of simple rules). It would be interesting to study the implications under fully optimal monetary policy.

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