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

We embed skill obsolescence and endogenous growth into a New Keynesian model with search-and-matching frictions. The model accounts for key features of the Great Recession: the "productivity puzzle" and the "missing disinflation puzzle." Lower aggregate demand raises long-term unemployment and the training costs associated with skill obsolescence. Lower aggregate 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.

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

THIS PAPER SIMULTANEOUSLY ADDRESSES TWO recent puzzles, associated with the Great Recession and its recovery, which have kept the attention of policymakers and academics alike: the "missing-(dis)inflation" puzzle and the productivity puzzle. Our explanation rests on a learning-by-doing mecha-

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nism coupled with retraining costs necessitated by the skill loss of long-term unemployed. Combining both aspects in a New Keynesian model with search and matching frictions implies low variability of inflation (a flatter Phillips curve), deeper recessions, and permanent scars from recessions in response to a decline in aggregate demand.

Inflation has systematically surprised economic forecasters and policymakers, as it failed to fall significantly during the Great Recession and later failed to rise during the recovery. 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., Hall 2011, Coibion and Gorodnichenko 2015) followed by the missing inflation puzzle (see, e.g., Constancio 2015, Bobeica and Jarocinski 2019). It is also reflected in a continuous undershooting of the inflation targets of the Federal Reserve and the ECB, part of the reason both institutions have begun to review their policy strategies and toolkits (see, e.g., Lagarde 2020, Powell 2020).

One proposed explanation for the relative stability of inflation is based on the idea of anchored expectations as a result of central bank credibility (e.g., Bernanke 2010).[1] 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). Ball and Mazumder (2011), IMF (2013), and Blanchard et al. (2015) find that the Phillips curve has flattened over time but also that it has become more stable recently.

The other macroeconomic puzzle associated with the Great Recession is illustrated by Figure 1, showing the evolution of U.S. real GDP since 2002 and a trajectory of the pre-Great Recession trend line. The figure suggests that 10 years after the onset of the Great Recession actual U.S. real GDP (solid line) is still far below the prerecession trend (dashed line).

More formally, a number of empirical studies that have examined deep recessions around the world find highly persistent effects on output (see, e.g., Cerra and Saxena 2008, IMF 2009, Reinhart and Rogoff 2009). An even starker revelation is the finding that such recessions leave permanent scars by reducing potential output (e.g., Haltmaier 2012, Reifschneider et al. 2013, Ball 2014, Martin et al. 2015) and productivity growth (e.g., Adler et al. 2017, Furceri et al. 2021).

Furthermore, 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 (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., Rogoff 2020, Roubini 2020).

1. 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)).

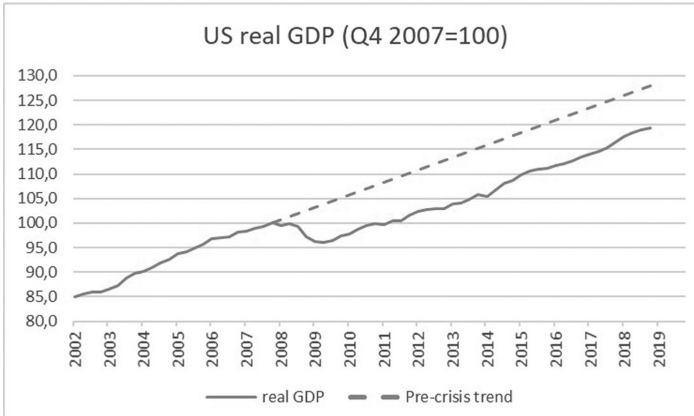

Fig. 1. U.S. Real GDP vs. Precrisis Trend.

Source: FRED

Our novel explanation for both the missing (dis)inflation puzzle and the output/productivity puzzle is based on demand and supply interactions in a monetary Dynamic Stochastic General Equilibrium (DSGE) model with search and matching frictions (e.g., Walsh 2003) that is modified to allow for (i) a learning-by-doing externality implying endogenous human capital accumulation at the aggregate level (see, e.g., Stadler 1990, Chang et al. 2002, Engler and Tervala 2018) and (ii) 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 strong and persistent decline in output growth, relative stability of inflation despite a pronounced fall in output, and a permanent gap between output and the precrisis trend output (output hysteresis).

In the presence of nominal price rigidity, an adverse demand shock lowers aggregate output, inflation, and job creation. Due to search frictions in the labor market, the share of the long-term unemployed among all job-seekers rises, thereby increasing the training costs of firms that need to upgrade the lost skills of these workers. The focus on skill obsolescence from unemployment as a propagation mechanism is motivated by the fact that, at least in the United States, 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 United States 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., ILO 2013, Banerji et al. 2014).

Apart from raising training costs, a fall in economic activity (lower employment) generates a negative learning-by-doing externality, and thus, slows down the 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. More generally, this mechanism implies that inflation (a forward-looking variable) is less responsive to changes in economic slack implying a flatter Phillips curve as illustrated by Figure 4 (see section 2.2). Thus, our framework provides a potential solution to the (dis)inflation puzzle.

Our framework also gives rise to hysteresis in productivity and output, that is, temporary adverse demand shocks permanently lower the level of productivity and output, thus also contributing to the solution of the above-mentioned productivity/output puzzle. 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 preshock 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, human capital lost during the recession cannot be fully regained during the recovery, implying a permanent output loss reflecting permanently lower human capital/productivity. In this way, our model also provides a potential explanation for the productivity puzzle and the surprisingly big gap between actual GPD and trend GDP in Figure 1.

Our paper connects primarily to the two literatures that deal with (i) the missing-(dis)inflation puzzle and (ii) endogenous growth, hysteresis, and the related productivity/output puzzle.

The missing-(dis)inflation puzzle. In his presidential address, Hall (2011) argued forcefully that the New Keynesian model cannot explain the low degree of disinflation during the Great Recession. King and Watson (2012) confirmed this view, finding a large discrepancy between actual inflation and inflation in the Smets and Wouters (2007) model, an estimated medium-sized DSGE model. Later papers suggest solutions for the puzzle, many of them based on financial frictions. Gilchrist et al. (2017) argue that financially constrained firms have an incentive to raise prices despite falling demand to avoid costly external financing. Del Negro et al. (2015) extend the Smets and Wouters model to include financial frictions and show that this improves the performance of the model in terms of inflation. Christiano et al. (2015) use an estimated DSGE model with unemployment and endogenous labor force participation and show that financial wedge shocks can explain the economic development during the Great Recession. Bianchi and Melosi (2017) argue that the missing deflation can be explained by uncertainty about the mix of future monetary and fiscal policy in the presence of high debt. While these papers provide potential explanations for the missing-(dis)inflation puzzle, they are not able to endogenously replicate the development of productivity and the permanent loss in GDP.

Endogenous growth and output hysteresis. Blanchard (2017) and Cerra et al. (2020) provide recent surveys of the literature on output hysteresis and endogenous growth in business cycle models. Following Stadler (1990), a prominent approach to model hysteresis is the learning-by-doing mechanism in which productivity depends on employment. The idea is that higher employment leads to more learning-by-doing and thus higher human capital. In turn, recessions lead to lower human capital and thus a permanently lower level of productivity and output. This strand of the literature includes Chang et al. (2002), who show that this mechanism improves the performance of an RBC model with respect to output and hours worked, Jorda et al. (2017), who focus on hysteresis with respect to monetary policy shocks, and Engler and Tervala (2018), who analyze fiscal policy. The latter use a New Keynesian model and show that recessions are deeper and more persistent, and that the fiscal output multiplier is much larger in the presence of learning-by-doing than in traditional models. All these papers use a similar learning-by-doing mechanism as we do, but assume a perfectly competitive labor market. One exception is Boitani and Punzo (2019) who also consider labor market frictions and learning-by-doing. However, they focus on the distributive effects of financial shocks and they do not consider training costs as we do.

Closely related to this is the literature that seeks to explain the weak development of productivity during and after the Great Recession. Two candidate hypotheses have been forwarded: what Anzoategui et al. (2019) call “bad luck versus an endogenous response” to the recession. In advocating the bad luck hypothesis, Fernald (2015) argues that the slowdown in productivity predated the Great Recession. By contrast, Reifschneider et al. (2013) conjecture that the drop in productivity may be the result of recession-induced decline in productivity-enhancing investments. Their hypothesis is supported by Anzoategui et al. (2019), who use an estimated version of Comin and Gertler’s (2006) business cycle model with endogenous creation and adoption of technology to show that the productivity decline during the Great Recession was primarily due to lower adoption of new technologies. The decline in productivity also dampens the decline in marginal costs and thus the decline in inflation. Likewise, Bianichi et al. (2019) find lower technology utilization in the Great Recession and lower R&D investment prior to the crisis but link this to debt and equity financing in their model. Similarly, Furman (2015) finds that the slowdown in productivity growth across the advanced economies since the Great Recession is driven by too low postcrisis investment. While concentrating on a different mechanism, studies that emphasize the endogenous response of productivity are complementary to ours. The policy issues raised by the productivity puzzle have resurfaced following the recent pandemic-induced deep recession (e.g., Furceri et al. 2021).

Another strand of the literature focuses directly on unemployment hysteresis. Gali (2017) develops a version of the New Keynesian model with insider–outsider labor markets and unemployment hysteresis, while Craighead (2019) models unemployment hysteresis as a deterioration in labor market matching efficiency from higher average duration of unemployment. These studies do not address the missing-(dis)inflation puzzle. Moreover, in contrast to these studies, we focus on output hysteresis since the empirical evidence for (un)employment hysteresis is as yet mixed (see, e.g., Martin et al. 2015, Furceri et al. 2021, Jorda et al. 2017).

Likewise, 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.[2] Waletin 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 2007–09 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.

The remainder of the paper is organized as follows. In Section 1, we present the details of the model and the key aggregate relationships. In Section 2, 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 discuss the role of news shocks as an alternative rationalization of the observed dynamics during the Great Recession. Section 3 gives a summary and concluding remarks.

1. THE MODEL FRAMEWORK

Following the pioneering work of Walsh (2003), the model economy has two sectors: a retail sector and a wholesale sector. The two sector approach makes the model tractable because the problems of price setting and labor market frictions are separated. 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 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. 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 capi-

2. 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.

tal accumulation that allows the model to generate sustained growth.[3] 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 et al. 2011, Uhlig and Krause 2012).

1.1 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 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

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

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

Learning-by-doing as a driver of endogenous growth is introduced in a standard way: higher aggregate economic activity (higher aggregate employment) generates 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.[4] 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. This mechanism is similar to Stadler (1990), Chang et al. (2002), or Engler and Tervala (2018) in that human capital, and, in turn, labor productivity, depends endogenously on the business cycle. Different from these studies, the endogenous link is influenced by labor market frictions. 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.

1.2 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 $C_t = (\int_0^1 C_{k,t}^{1/\mu_p} dk)^{\mu_p}$ 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 $C_{k,t} = (\frac{P_{k,t}}{P_t})^{-\epsilon}C_t$ where $P_t = (\int_0^1 P_{k,t}^{1-\epsilon} dk)^{\frac{1}{1-\epsilon}}$ is the price index.

4. While our emphasis is on knowledge accumulation through learning-by-doing, human capital is a much broader concept that, for example, also includes investments in education (see, e.g., Schwerdt and Turunen 2006).

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 $P_t u_b H_t$, $u_b > 0$. 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). 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 $e_t \sim N(0, \sigma_e^2)$.

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 $Q_{t,t+1} \equiv \beta(\zeta_{t+1}/\zeta_t) U'(C_{t+1}) / U'(C_t)$ 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.

1.3 Firms

Intermediate goods sector. Firms in the intermediate goods sector face standard search and matching frictions (see, e.g., Pissarides 2000) as well as frictions related to skill obsolescence and associated training costs incurred for skill upgrading. 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.[5] The introduction of training costs helps us to model parsimoniously the role of skill losses from prolonged unemployment in depressing job creation during a recession. The alternative would be to allow for skill heterogeneity, whereby upon reemployment the long-term unemployed regain lost skills only slowly. In that case, similar to the existence of training costs, matching with lower productivity workers would reduce firm surplus. Clearly, a model with skill heterogeneity, and implied wage differentials resulting from individual wage bargaining, would be substantially less tractable.

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.[6] 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 versus 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 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

5. 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."

6. 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 toward infinity and unemployment toward zero, since the ratio of vacancy creation costs to labor productivity would converge toward zero.

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

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

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 equilibrium, 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 $w_t^d \equiv w_t/H_t$.

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 $E_t \sum_{i=0}^{\infty} \omega^i Q_{t,t+i}(P_{k,t}/P_{t+i} - p_{t+i}^I)Y_{k,t+i}$ subject to the total demand for good k, $Y_{k,t+i} = (P_{k,t}/P_{t+i})^{-\epsilon} Y_{t+i}$, 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, equation (27) can be rewritten as

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

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

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

1.4 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 ϕ_π, $\phi_y > 0$ 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 then show that with a policy rule that responds to output growth, the model does better at fitting the empirical evidence.

With respect to the policy rule specification, two points are worth mentioning. First, in a working paper version, we show that our main results remain intact when allowing for interest rate smoothing (see Lechthaler and Tesfaselassie 2021). Second, while we abstract from issues related to the zero lower bound (ZLB) on the nominal interest rate so as to focus on the effects of skill loses and training costs—within an otherwise linear DSGE model—we conjecture that a binding ZLB constraint would reinforce the endogenous decline in productivity, employment and output. Indeed, Anzoategui et al. (2019) find the ZLB to be an important factor propagating the endogenous decline in productivity in the wake of the Great Recession.

2. NUMERICAL RESULTS

2.1 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, 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 com-

TABLE 1
Parameter Configuration

Parameter	Description	Value
β	Subjective discount factor	0.99
σ	Coefficient of relative risk aversion	1
ω	Fraction of nonoptimizing 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
B	Learning-by-doing coefficient	0.027
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

mon 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, 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% 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).[7] The 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 implied value of the scale parameter in the human capital accumulation equation B is 0.027, a value that is consistent with the steady-state annualized growth and the steady-state employment rate. The human capital depreciation rate δ_H is set at

7. We think that the chosen value is reasonable, as Pissarides (2009) considers fixed matching costs that may also include "costs of finding out about the qualities of the particular worker, of interviews, and of negotiating with her."

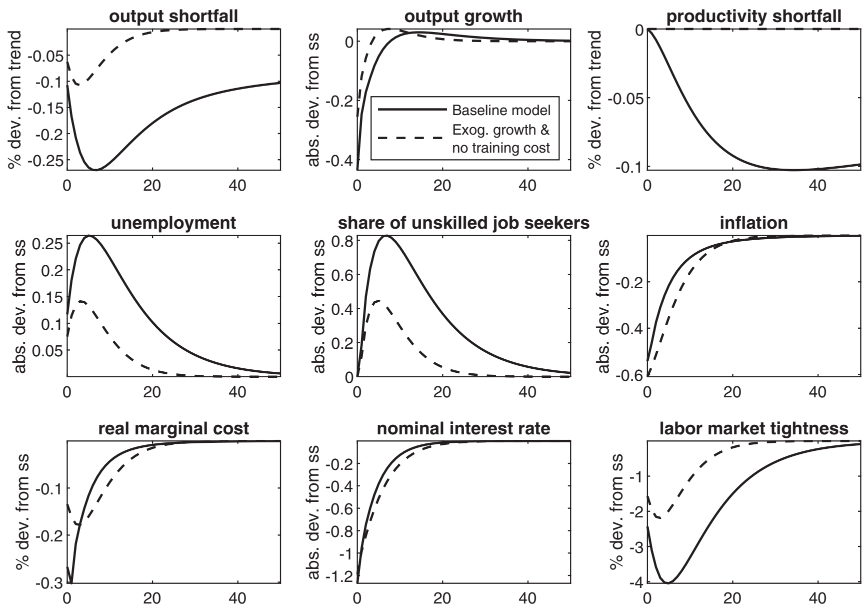

Fig. 2. Impulse Responses to a Decline in the Discount Factor Shock.

0.019, as in Jones et al. (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. This is in line with Brave et al. (2012), who estimate a medium-scale New-Keynesian DSGE model. The innovation of the shock has a standard deviation of 0.01.

2.2 Main 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 unskilled job seekers refer to workers whose skills were rendered obsolete by longer term unemployment. 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 impulse response named "productivity shortfall" is defined analogously. 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).

The impulse responses show that in response to a rise in the discount factor, inflation and output growth fall while unemployment rises. As discussed above with a rise in the discount factor (a rise in the ratio ζ_{t+1}/ζ_t) 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 reduces output growth and increases unemployment more strongly than it does under the standard model (dashed line). By contrast, inflation declines less strongly in the baseline model even if there is a more pronounced initial decline in the real marginal cost. 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 the fall in productivity, as both tend to push up real marginal cost.

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.[8] 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. To make this contribution more transparent, we recalibrate the shock in the baseline model such that the reduction in output growth in the first period is of equal size in both models. This implies that the standard deviation of the shock in the baseline model is reduced from 0.01 (as in Figure 2) to 0.00645. The result is illustrated in Figure 3. It can easily be seen that, despite the equal decline in the first period output growth 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.

An alternative way to illustrate our result is to plot the Phillips curve implied by the baseline model and compare it to the Phillips curve implied by the standard model. This is done in Figure 4, which is based on stochastic simulations of both models conditional on the discount factor shock. We plot the realizations of the unemploy-

8. Direct evidence on the behavior of training costs during the Great Recession is hard to come by (as also noted in Acharya et al. 2018). However, the result of skill loss during long-term unemployment is well supported by empirical evidence (see, e.g., ILO 2013, Banerji et al. 2014). Coupled with the fact that most of the crisis response measures during the Great Recession were devoted to infrastructure spending, tax cuts, and other measures to increase aggregate demand (ILO 2014), this suggests that firms had to bear at least part of the burden from crisis-led skill attrition.

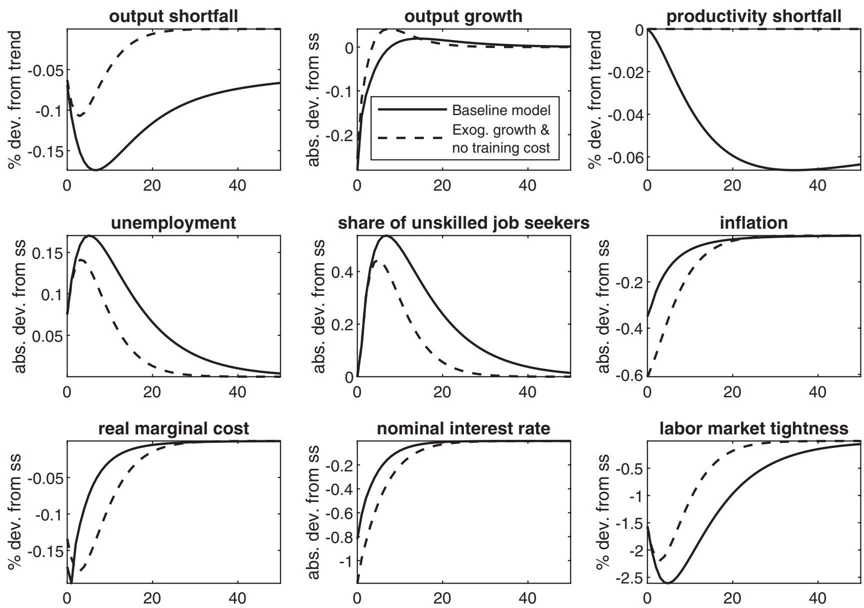

Fig. 3. Impulse Responses to a Decline in the Discount Factor Shock.

Notes: Standard deviation of the shock under the baseline model is set at 0.00645.

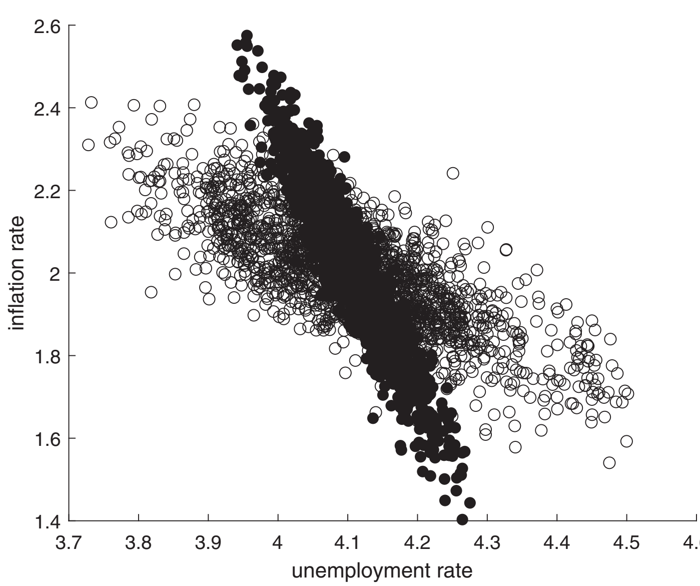

Fig. 4. The Phillips Curve Conditional on the Discount Factor Shock.

Notes: Empty circles: Baseline model; filled circles: Exogenous growth and no training cost.

ment rate on the horizontal axis and realizations of the inflation rate on the vertical axis. It can clearly be seen that the baseline model implies a flatter Phillips curve, that is, the same deviations in unemployment are associated with smaller movements in the inflation rate.

We turn next to the long-run 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. The reason is that the lost human capital is not regained so that productivity stays at a permanently lower level. 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 preshock 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 during adjustment in the baseline model is more than double that of the standard model. Also note that the permanent scarring effects are sizeable: the permanent shortfall in output and productivity is about one-fourth of the initial drop in output growth. Thus, our model also provides a potential explanation for the productivity/output puzzle.

The permanent scarring effects of recessions are a major concern for policymakers and our model provides a potential explanation based on lost human capital growth. It also implies alarm about the potential long-term effects of the current Covid-19 pandemic, which led to an unprecedented increase in unemployment in the United States and many other countries. Our model suggests that a quick and forceful reaction of fiscal and monetary policy is warranted to stabilize employment, so that workers stay employed or that laid-off workers remain connected to their employers in order to facilitate quick rehiring.

Our results are similar to the ones in Engler and Tervala (2018) in the sense that learning-by-doing amplifies the downturn and makes it more persistent. Note, however, that in our model, the quantitative difference between baseline and standard model is much larger. As will become clearer below, this is due to the interplay between learning-by-doing and training costs of the long-term unemployed, a mechanism that is absent in Engler and Tervala (2018), who assume a perfectly competitive labor market.

Our results are also broadly in line with recent empirical findings regarding the presence of output hysteresis (e.g., Jorda et al. 2017, Furceri et al. 2021) and the fall in productivity growth after deep recessions (e.g., Adler et al. 2017, Furceri et al. 2021) and with the observed relative stability of inflation despite the pronounced fall in GDP during the Great Recession (see, e.g., Blanchard et al. 2015, Coibion and Gorodnichenko 2015, Bobeica and Jarocinski 2019). While we focus on output hysteresis, the stationarity of (un)employment in our framework arises from the standard assumption that we impose, namely, that along a balanced growth path aggregate output and aggregate human capital grow at the same rate. Here, we note that the evidence

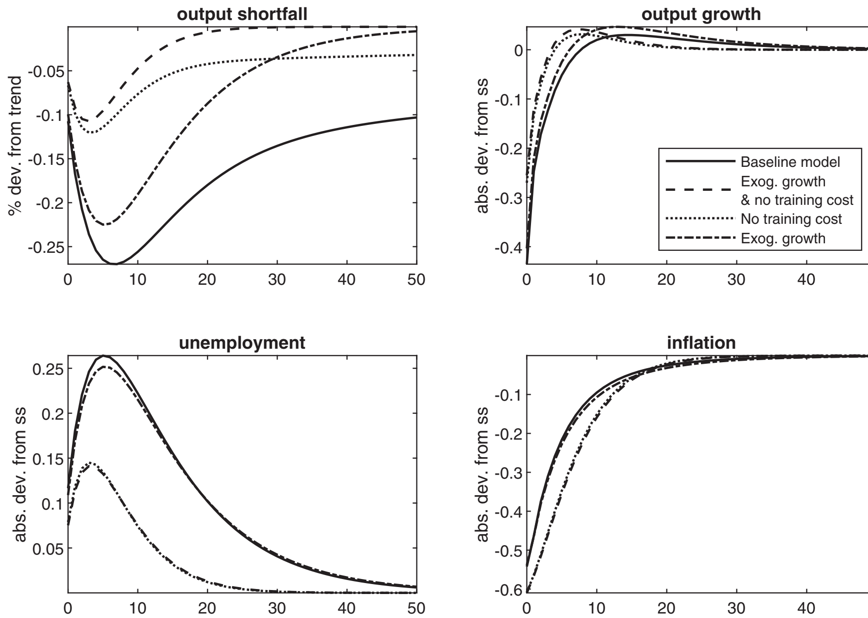

Fig. 5. Impulse Responses to a Decline in the Discount Factor Shock.

NOTES: 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.

on the presence of employment hysteresis is somewhat mixed. Jorda et al. (2017) find that, in response to exogenous monetary policy shocks, total hours (hours per worker and number of workers) show no signs of hysteresis. Martin et al. (2015) find that employment displays no hysteresis after normal recessions but it does after severe recessions, as is found in Furceri et al. (2021).

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 impulse responses that are broadly consistent with the recent empirical findings discussed above, but to make their respective contributions more transparent, Figure 5 shows the role of each in isolation. The dotted line in the figure shows impulse responses when only the training cost channel is shut down, while the dot-dashed line shows impulse responses when only the endogenous growth channel is shut 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

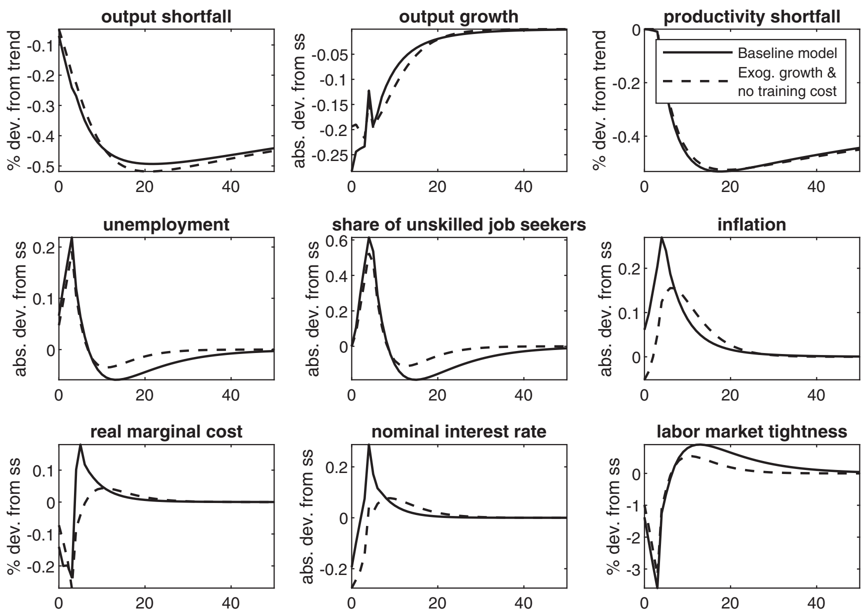

Fig. 6. Impulse Responses to a News Shock about Future Productivity Growth.

NOTES: Productivity growth is anticipated to decline in period 4.

is larger in the presence of training costs (solid line versus dot-dash line) than in the absence of training costs (dotted line vs. dashed line), suggesting a complementarity between the two channels.

2.3 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 four 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 in period 4 by about half a percentage point (annualized).

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

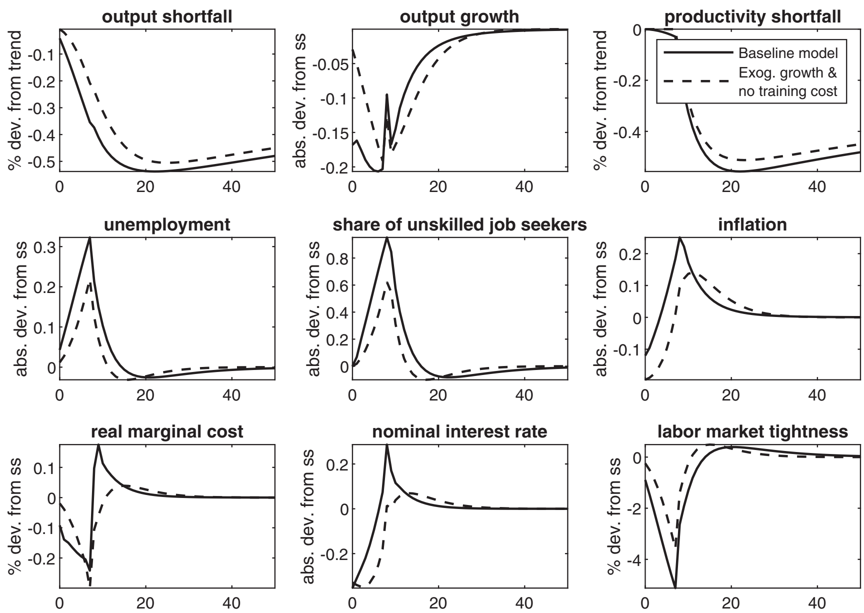

Fig. 7. Impulse Responses to a News Shock about Future Productivity Growth.

NOTES: Productivity growth is anticipated to decline in period 8.

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 when the productivity shock hits,[9] and then it starts to fall afterward, with the fall being somewhat larger under the baseline model.[10] 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 eight 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

9. 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.

10. The fall in unemployment at the time when productivity slowdown materializes is similar to those reported elsewhere in the literature (see, e.g., Gali et al. 2011).

to the fact that the anticipated growth shock has a stronger expectational effect—consumption demand falls 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, Figures 6 and 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 because inflation fell during this period. Within the baseline model, the rise in inflation in response to the news shock goes counter to the disinflationary nature of the Great Recession.

More generally, our analysis suggests that it is crucial for empirical research to disentangle exogenous shifts in growth expectations from endogenous shifts (as in our model) when analyzing the sources of recessions. In this sense, while Blanchard et al. (2015) conjecture that supply shocks may be behind both the initial deep recession and the lower output later, our analysis reveals the need to look at the different behavior of inflation as a way to differentiate supply-driven from demand-driven deep recessions.

3. SUMMARY AND CONCLUDING REMARK

Standard macroeconomic models have a hard time replicating the recent experience with the Great Recession, a substantial downfall in output coupled with a surprisingly mild disinflation, as well as recent empirical evidence that temporary shocks can have permanent effects for productivity and output. We contribute to the nascent literature that develops models of endogenous growth seeking to solve these puzzles, by combining a New Keynesian model with search and matching frictions on the labor market, learning-by-doing and skill loss of long-term unemployed that necessitates retraining. The combination of both learning-by-doing and training costs is crucial for yielding quantitative meaningful deviations from the standard model, potentially permanent effects of recessions and a flattening of the Phillips curve that can explain the missing disinflation puzzle. Both aspects complement each other while failing to provide quantitative meaningful effects in isolation.

More generally, the result that temporary shocks can have permanent effects raises important questions for macroeconomic stabilization policy, whether monetary and fiscal policy can and should be used more proactively in recessions in order to avoid permanent income losses (as suggested, e.g., by Engler and Tervala 2018, Jorda et al. 2017). We consider this as a fruitful avenue for future research.

Finally, our main results have also implications for fiscal policy responses to the Covid-19 pandemic that led to even sharper downturns than the Great Recession in many countries. Interestingly, there exists quite some variation in how governments dealt with this situation. While the United States relied heavily on financial support for unemployed workers, many countries in Europe used short-time work schemes to preserve employment relationships. From the perspective of our model, it is crucial to maintain human capital so as to avoid the permanent scars from deep recessions. Short-time work might be a potent tool in this respect but only if the skills upheld are still in demand once the pandemic is over.

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