Switching-track after the Great Recession

Francesca Vinci[†] and Omar Licandro[*]

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Abstract

We propose a theoretical framework to reconcile episodes of V-shaped and L-shaped recovery encompassing the behaviour of the U.S. economy before and after the Great Recession. In a DSGE model with endogenous growth, negative demand shocks destroy productive capacity, moving GDP to a lower trajectory. A Taylor rule policy designed to reduce the output gap can counterbalance shocks, preventing the destruction of economic capacity and inducing V-shaped recoveries in line with past episodes. However, when shocks are deep and persistent enough potential output measures get revised down (*switching-track*), weakening the recovering role of monetary policy, and inducing an L-shaped recovery.

Keywords: Great Recession, Economic Recovery, Endogenous Growth, Hysteresis, Trend Shift, *Switching-track*, Supply Destruction Prevention, Economic Capacity, Monetary Policy

JEL Codes: E12, E22, E32, O41, E52

[†] European Central Bank, Francesca_Romana.Vinci@ecb.europa.eu.

[*] University of Nottingham, IAE-CSIC and Barcelona School of Economics, Omar.Licandro@nottingham.ac.uk.

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1 Introduction

The Great Recession had a profound impact on the economic performance of OECD countries. Crucially, the crisis had a persistent level effect on GDP, which still remains below its pre-crisis path for the vast majority of advanced economies (Ball, 2014). Focusing on the United States, past recessions were typically followed by a temporary acceleration of growth, with GDP converging back to its pre-recession trajectory. This is commonly referred to as a V-shaped recovery. Conversely, after the 2008 financial shock we saw potential output *switching-track* in conjunction with the crisis, as the deep and persistent fall in economic activity led to a downward swerve of the GDP trend from its original path. Consequently, the output gap closed following the *switching-track* of potential output, rather than faster GDP growth, giving rise to a so-called L-shaped recovery (see Figure 1). This fact challenged the general consensus on the distinct relationship between trend, growth and business cycles. If recessions are not followed by recoveries, downturns will affect the long run path of GDP, implying that potential output cannot be represented by a stable trend in the productive capacity of the economy.

This paper shows that the Great Recession can be seen as a large and persistent demand shock deeply reducing economic activity for an unusually long period, translating into a permanent depletion of productive capacity (a supply-side effect) casting the observed L-shaped recovery. GDP moving down to a lower trajectory gradually induced a change in measured potential output. The economy then converged to its new lower potential output path, ending the recession without a full recovery. In this context, potential output

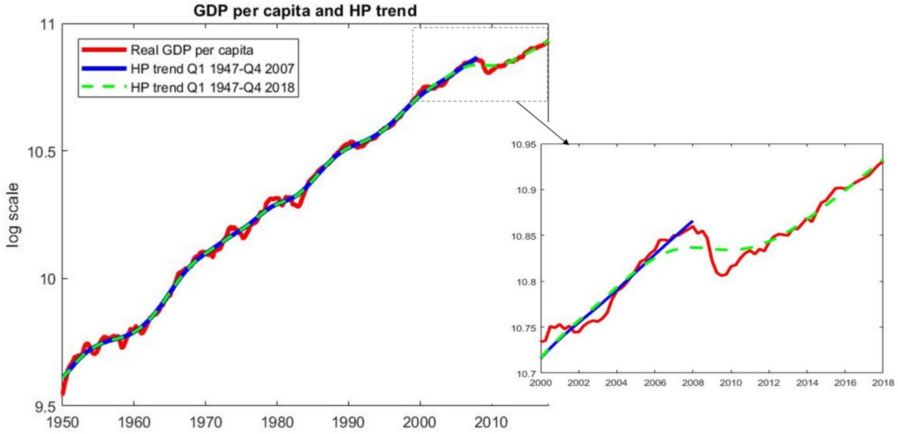

Figure 1: U.S. GDP per capita

is a measure of policy makers' beliefs about the level of GDP that can be feasibly sustained in the long run, a key indicator affecting monetary policy interventions, and ultimately the shape of the recovery.

Figure 2 shows that the output gap closed around 2016 following the *switching-track* process of potential output revisions instead of faster growth, weakening the strength of the policy intervention over time. The estimates of potential output published by the Congressional Budget Office (CBO) each year were revised down as the recession unfolded, leading to the closure of the output gap intrinsic to an L-shaped recovery –see the left panel of Figure 2. Consistently, the output gap estimates published in the Fed's Greenbook were revised over time, showing that the output gap also closed in 2016 –right panel of Figure 2.

To replicate the dynamics of U.S. GDP after the Great Recession, this paper relies on the combination of four key assumptions. First, we embed learning-by-doing à la Romer (1986) into a DSGE model with financial frictions

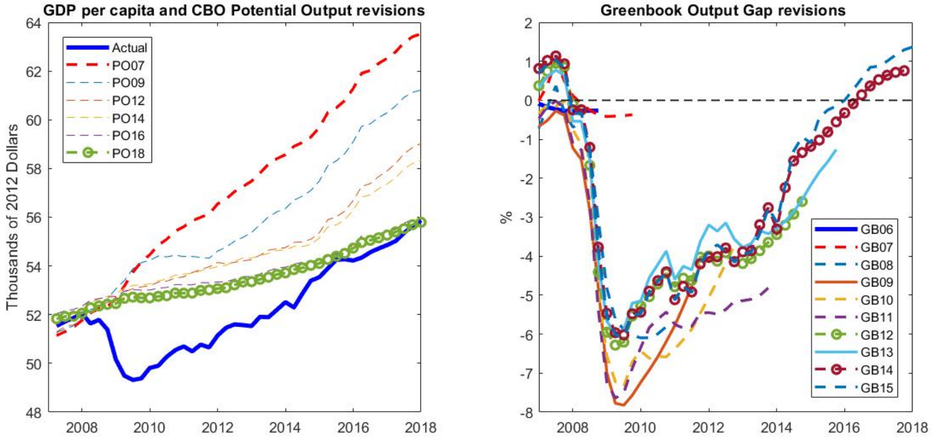

Figure 2: Switching-track

à la Christiano et al. (2014). Under this assumption, aggregate technology faces constant returns to capital. Consequently, a negative shock to the capital stock would not bring the economy to its previous growth trajectory, affecting the level of GDP permanently. We choose this specification to show that a relatively small departure from a standard DSGE model can generate a rich departure from its predictions on the medium to long-run scars of recessions.

Second, in line with Christiano et al. (2014), the Great Recession is modelled as a large negative shock to aggregate demand that induces a surge in bankruptcy. Third, the depreciation rate is assumed to be endogenous and positively related to the bankruptcy rate. A sudden increase in bankruptcy will then deplete the capital stock, inducing a permanent decline in output. Finally, the monetary authority is assumed to follow a standard Taylor rule, targeting inflation and the output gap, but we also assume that the monetary authority revises potential output when recessions are deep and persistent.

This way, we introduce the *switching-track* in the model, consistently with the unprecedented downward revision of potential output estimates that followed the large and long lasting decline in GDP observed during the Great Recession.

Monetary policy plays a fundamental role in our model, by providing countercyclical stimulus to aggregate demand but also protecting the productive capacity of the economy by *preventing capital destruction.* The latter constitutes a novel transmission channel with potentially significant implications for the conduct of monetary policy and, more generally, the consensus concerning its role. The idea that large shocks can negatively affect the productive capacity of the economy permanently has gained traction in the aftermath of the Great Recession, and it became even more prominent in the face of the COVID-19 crisis, especially for monetary policy-makers. During the press conference to announce measures in response the economic shock from COVID-19, Mark Carney (BoE) remarked: *"In this situation, it's disruption not destruction of supply. Part of our job is to make sure that that is indeed the case, and so that we're bridging, and that's very much part of the analysis."*[1] We aim to contribute to this debate and this paper is, to the best of our knowledge, the first to model the *destruction prevention channel* explicitly. Monetary policy operates as a cushion, protecting the economy from negative shocks that destroy its productive capacity.

We also show that in periods characterised by negative shocks that are not overly persistent, the standard Taylor rule is enough to generate a full

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[1] Bank of England Press Conference, 11th March 2020. For similar examples see the blog post by Christine Lagarde, President of the ECB, 9th April 2020 and Fed's Chair Jerome Powell's speech on 9th April 2020 "COVID-19 and the Economy".

recovery, making the economy converge to its past trajectory despite aggregate constant returns to capital. The Taylor rule is then sufficient to drive a V-shaped recovery in normal times. Furthermore, when calibrated to the recessions that followed the 1974 and 1990 oil shocks, the model replicates well the observed V-shaped recoveries. Our model can then reconcile the dynamics of the U.S. economy before and after the Great Recession. This represents another contribution of our work, as existing models provide insights on the possible mechanisms through which endogenous growth can lead to output shortfalls in line with the Great Recession, but such theories tend to remain silent concerning the drivers of recovery in the past.

In particular, Benigno and Fornaro (2018) build a Schumpeterian framework, in the spirit of Aghion and Howitt (1992), with nominal rigidities and a Taylor rule targeting the employment rate. Their model shows two stationary solutions, a good one and a *stagnation trap*, with low growth and unemployment. The Great Recession in this framework can be seen as a fall in demand that moves the economy from the good stationary equilibrium to the stagnation trap. Pessimistic beliefs and the zero-lower bound (ZLB) are crucial to generate their results. In particular, the existence of a stagnation trap is a consequence of the ZLB constraint on monetary policy, which would otherwise restore full employment. When beliefs eventually become optimistic again, the economy escapes the stagnation trap, moving back to the good stationary equilibrium. Since the Taylor rule aims to restore the initial level of employment, but not the initial level of output, the production capacity lost during the recession is not recovered and the economy converges to a lower path, with the initial growth rate but a lower intercept. Similarly, in our paper we find that monetary policy is a key element in determining the level of economic activity after a demand shock bringing the economy to the ZLB. Differently from Benigno and Fornaro (2018), our model shares the standard property of the AK (endogenous growth) framework, featuring a unique stationary growth rate, which makes it suitable for a quantitative analysis capturing the permanent level effects on GDP that followed the Great Recession and the *switching-track* of potential output. Notably, the unique stationary growth rate determines the slope of the balanced growth path GDP trajectory. The intercept of the balanced growth path is in principle indeterminate, and set by the initial stock of capital, *i.e.* the productive capacity of the economy. Shocks that destroy productive capacity reduce the intercept of the balanced growth path, moving the economy to a lower trajectory. By preventing destruction, monetary policy affects the new intercept of the balanced growth path and plays a role in shaping the recovery. When the economy hits the ZLB, the ability of monetary policy to prevent capacity destruction is hampered and this results in a lower intercept in the new steady state.

Other papers focus on explaining the lack of recovery following financial crises in particular, and thus bring together endogenous growth and financial shocks. Bianchi et al. (2019) also propose a Shumpeterian model, adding financial frictions to explore the properties of different kinds of financial shocks, and their long lasting effects on the economy. Cozzi et al. (2017) propose an estimated Shumpeterian DSGE model and stress how the inclusion of endogenous growth leads to the amplification of financial shocks. Anzoategui et al.

(2019) build on the pioneering work of Comin and Gertler (2006), proposing an endogenous growth model à la Romer (1990) with endogenous diffusion and financial frictions.[2] Their model generates an endogenous response of TFP to aggregate demand shocks through the R&D and diffusion channels. Their analysis also shows that this response is consistent with the observed cyclicality of the speed of diffusion of new technologies. Their estimation reveals that a shock equivalent to a risk shock can generate medium to long-term effects on the level of TFP, and thus output, due to a temporary slowdown in productivity enhancing investments and, most importantly, technology diffusion. Schmöller and Spitzer (2021) draw from Anzoategui et al. (2019) and estimate the model for the Euro Area, highlighting the relevance of the endogenous growth channel to explain the severity and persistence of recessions in Europe as well. Ikeda and Kurozumi (2019) choose a similar framework and, just like us, they propose a model where financial shocks can generate permanent shortfalls in GDP, resulting in a parallel downward shift in the level of economic activity. Queralto (2020) also contributes to this literature, by focusing on banking crises in an open economy expanding product variety framework. The paper shows that financing frictions can affect the introduction of new varieties, and thus endogenous TFP. Garga and Singh (2020) take a similar approach, but focus in the design of optimal monetary policies in their framework. None of these papers discusses the suitability of their approaches to generate V-shaped recoveries in normal times as well as L-shaped recoveries,

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[2] Comin and Gertler (2006) analysed the link between short and medium-term variations in economic activity, drawing attention to medium-term business cycles and pointing out that recessions can have lasting effects.

which is what this paper aims to do.

The rest of the paper is organised as follows: Section 2 discusses the role of capital destruction, Section 3 explains the model, Section 4 reports the calibration, Section 5 contains results for the Great Recession simulations, Section 6 describes normal times, Section 7 concludes.

2 Evidence on Capital-Destruction

In order to represent the dynamic of GDP during the the Great Recession we make the following modelling choices. First, we model the Great Recession as a demand shock that combines higher aggregate risk and lower consumer confidence, reducing investment and consumption demand. Like in Christiano et al. (2014), an increase in credit risk reduces credit and raises the probability of bankruptcy in equilibrium.

Secondly, the rise in bankruptcies that follows the demand shock causes capital destruction and thus a permanent supply effect. To generate this result, we augment the framework in Christiano et al. (2014) by positively linking the probability of bankruptcy to the depreciation rate of capital. During the Great Recession, a surge of bankruptcies thus leads to a depletion of the capital stock. The recession is then driven by a large shock to aggregate demand inducing supply effects. Our choice is motivated by empirical work by Hall (2015, 2016), who identifies the shortfalls in business capital and total factor productivity as the main drivers of the deviation of GDP from its previous trend. This paper represents the idea by associating the Great Recession with a substantial decline of the stock of capital and, through learning-by-doing, of total factor productivity.

Identifying capital destruction in the data is notoriously difficult. National Accounts estimates of the capital stock are constructed using the perpetual inventory method, and typically employ geometric depreciation rates, held constant over time.[3] As a consequence, measurement of the capital stock in National Accounts reflects movements of investment, but cannot reflect cyclical capital destruction. Nonetheless, the idea that recessions destroy capital is not new, and we aim to provide new insights to the existing literature. For example, in a vintage capital framework, Caballero and Hammour (1994) provided a rational to the evidence stated by Davis and Haltiwanger (1990) that job destruction is much more cyclically responsive than job creation.[4] Which bring them to see recessions as cleansing periods, when the productive system eliminates outdated techniques and products. In their view, the associated physical capital becomes obsolete and is then scrapped. More recently, Gourio (2012) built a business cycle model with disaster risk, characterizing disasters as episodes of large capital destruction. He noted that economic downturns are associated with large reallocation of capital, leading to the loss of firm specific specialised capital goods as well as intangible capital. Recent theoretical work by Lanteri (2018) and Kozlowski et al. (2020) also contributes to this literature, and the authors provide empirical grounding for the idea of capital destruction following the Great Recession.

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[3] For the United States, see Fraumeni (1997).

[4] For an analysis of job creation and destruction in vintage capital models, see Boucekkine et al. (1999)

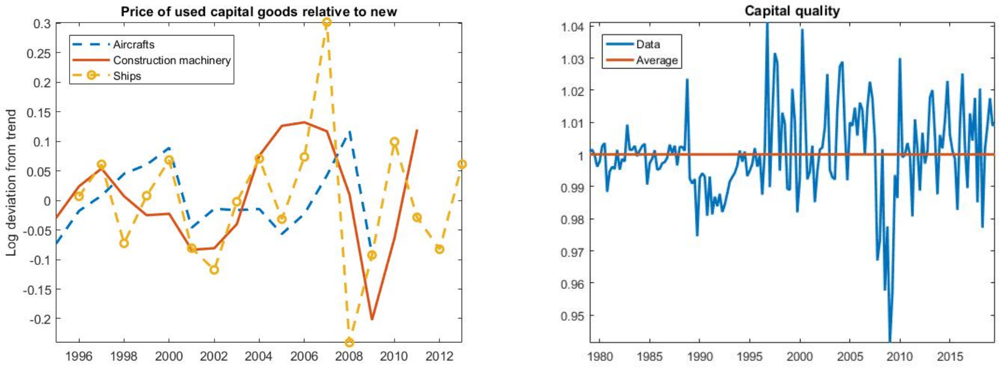

Figure 3: Capital destruction

Left panel: Log-deviation from trend of the price of used compared to new capital goods. Data made available by Lanteri (2018). Right panel: Capital quality. Constructed following methodology suggested by Kozlowski et al. (2020), all details in the Online Appendix.

Lanteri (2018) analyses the dynamics of the second-hand market for equipment in the United States.[5] He finds that quantities sold vary procyclically and that the price of second-hand equipment is procyclical and more volatile than the price of new equipment, showing a significant decline at the beginning of the Great Recession. This evidence indicates that the value of existing capital declined in real terms during the Great Recession (see left panel in Figure 3), suggesting a fall in productive capacity.[6] Additional evidence is provided by Kozlowski et al. (2020), who construct a measure of the quality of corporate non-financial assets. As can be observed in the right panel of Figure 3, their measure of capital quality was unusually low in conjunction with the

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[5] Lanteri (2018) collects data on quantities and prices from sales of second-hand capital, including commercial aircrafts, ships, and construction equipment, among others.

[6] In a recent paper, Gavazza and Lanteri (2021) analysed the market for vehicles, and found that the fall in the price of used cars was associated with a drop in upgrading during the Great Recession. As a consequence, the overall age, and thus quality and value of the vehicle stock declined.

Great Recession, which can be interpreted in their framework as an increase in the depreciation rate of capital (for more detailed information see Online Appendix 7). Overall, these findings suggest that the productive capacity of capital goods fell during the Great Recession, and constitutes additional evidence indicating that downturns can be associated with increasing capital depreciation rates. Motivated by these measures, we introduce an endogenous countercyclical depreciation rate in the model, which results in a decline in the relative price of the second-hand market for capital and the destruction of its productive capacity following a negative shock.

3 The Model

We build a New Keynesian model of endogenous growth by introducing a learning-by-doing technology à la Romer (1986) in a Dynamic Stochastic General Equilibrium model with financial frictions. We build on the financial accelerator framework introduced by Bernanke et al. (1999) and draw from Christiano et al. (2014) for risk shocks. Households gain utility from consumption, dis-utility from labour, and are subject to confidence shocks, *i.e.* reductions in their marginal utility of consumption. The production sector is comprised of a labour union, final good producers, intermediate good producers, capital producers and entrepreneurs. The latter face financial frictions, since they need to fund part of their capital expenditure with external resources, exposing themselves to the possibility of bankruptcy. We model a risk shock as an increase in the probability of bankruptcy for entrepreneurs.

The financial sector acts as an intermediary between the production side and households, by providing loans to entrepreneurs and selling bonds to savers. The monetary authority sets the nominal interest rate according to a Taylor rule, factoring in the deviation of inflation from its target and the output gap. We also assume that potential output is measured as an average of past GDP values, so that large negative shocks lead to downward revisions. The following sections describe the behaviour of all agents in the model.

3.1 Labour Packer

Households, indexed by $\ell \in (0,1)$, supply differentiated labour input to a labour packing firm, *i.e.* a union, which then supplies an homogeneous labour input h_t^p to the production sector. The bundling technology is

$$h_t^p = \left(\int_0^1 h_t(\ell)^{\frac{\varepsilon-1}{\varepsilon}} \mathrm{d}\ell \right)^{\frac{\varepsilon}{\varepsilon-1}}. \tag{1}$$

The parameter $\varepsilon > 1$ represents the elasticity of substitution across types of labour, which are assumed to be gross substitutes, and $h_t(\ell)$ represents hours worked by household ℓ. Labour demand by the labour packer is

$$h_t(\ell) = \left(\frac{W_t(\ell)}{W_t} \right)^{-\varepsilon} h_t^p, \tag{2}$$

where $W_t(\ell)$ is the wage of labour variety ℓ. Substituting (2) into (1), we obtain the aggregate wage index

$$W_t^{1-\varepsilon} = \int_0^1 W_t(\ell)^{1-\varepsilon} \mathrm{d}\ell. \tag{3}$$

Thus total employment (measured in hours worked) is given by

$$h_t \equiv \int_0^1 h_t(\ell)\mathrm{d}\ell = h_t^p \int_0^1 \left(\frac{W_t(\ell)}{W_t}\right)^{-\varepsilon} \mathrm{d}\ell. \tag{4}$$

Defining $\int_0^1 \left(\frac{W_t(\ell)}{W_t}\right)^{-\varepsilon} \mathrm{d}\ell$ as a measure of wage dispersion across varieties implies that if the latter is larger than 1, then aggregate labour used in production is smaller than total employment. However, in this paper we will only consider symmetric equilibria, implying that the total labour supply $h_t^p = h_t$.

3.2 Households

There is a continuum of households of measure one. The ℓ-type household consumes, supplies labour, buys bonds and owns firms subject to wage frictions à la Rotemberg (1982); when changing its wage, it incurs in a cost assumed to be proportional to aggregate output.[7] Since households are assumed to be identical, differing only on the type of labour they offer, labour market equilibrium is symmetric. We will then omit index ℓ to simplify notation.

A representative household, offering a particular type of labour, maximises utility subject to its budget constraints and labour demand (2),

$$\max_{c_t, w_t, B_{t+1}} \quad u_t = E_t \left[\sum_{j=0}^{\infty} \beta^j \epsilon_t^c \left(\log\left(c_{t+j} - \chi c_{t-1+j}\right) - \psi \frac{h_{t+j}^{1+\nu}}{1+\nu} \right) \right] \tag{5}$$

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[7] We choose this specification for price and wage frictions because they are better suited in the context of large shocks compared to the standard Calvo style. The letter imply a constant probability of resetting prices, which does not account for size effects. For a detailed discussion see Karadi and Reiff (2019).

$$\text{s.t.} \quad B_{t+1} + P_t c_t = R_{t-1} B_t + P_t w_t h_t - \frac{\chi^{\omega}}{2} \left(\frac{w_t}{w_{t-1}} - 1 \right)^2 P_t Y_t + D_t - \tau_t, \quad (6)$$

where c_t is consumption and h_t is labour, $\beta \in (0, 1)$ is the time discount factor, $\chi > 0$ regulates the degree of habit formation, $\nu > 0$ is the inverse of labour supply elasticity, $\psi > 0$ is a parameter regulating labour hours in steady state and $\chi^w > 0$ regulates price frictions. B_{t+1} represent risk-less one period nominal bonds, purchased at time t, earning the risk-less nominal interest factor R_t.[8] Variable w_t represents the real wage rate, P_t is the price of the final good, D_t are profits redistributed to households by firms and τ_t are taxes. ϵ_t^c is a confidence shock, affecting the marginal utility of consumption, which follows an AR(1) process: $\log(\epsilon_t^c) = \rho_c \log(\epsilon_{t-1}^c) + \epsilon_{c,t}$, where $\rho_c \in (0, 1)$ and $\epsilon_{c,t} \sim N(0, \sigma_c^2)$. This is a simple way of generating the fall in consumption demand as well as the nominal interest rate observed during the Great Recession.[9]

The FOCs for c_t and B_{t+1} in real terms are:

$$\lambda_t = (c_t - \chi c_{t-1})^{-1} \epsilon_t^c - \beta \chi E_t (c_{t+1} - \chi c_t)^{-1} \epsilon_{t+1}^c \quad (7)$$

$$\lambda_t = \beta E_t R_t \frac{\lambda_{t+1}}{\pi_{t+1}}, \quad (8)$$

where λ_t is the Lagrange multiplier associated to the budget constraint and $\pi_t = \frac{P_t}{P_{t-1}}$.

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[8] All nominal variables in this paper are defined in an arbitrary numeraire.

[9] Guerrieri and Lorenzoni (2017) provide insights into the underlying mechanism through the lens of a model with heterogeneous households. They show that when the economy's borrowing capacity is impaired, debtors reduce their demand for loans and creditors increase precautionary savings, resulting in lower demand and a fall in the nominal interest rate.

The FOC for w_t gives the wage Phillips curve:

$$w_t = \frac{\varepsilon}{\varepsilon - 1}\frac{\psi h_t^{\nu}\epsilon_t^c}{\lambda_t} + E_t\left[\beta\frac{\lambda_{t+1}}{\lambda_t}\Omega_{t+1}Y_{t+1}\frac{1}{h_t}\right] - \Omega_t\pi_t\frac{Y_t}{h_t} \tag{9}$$

$$\Omega_t = \frac{\chi^w}{\varepsilon - 1}(\pi_t^w - 1)\pi_t^w \tag{10}$$

$$\frac{w_t}{w_{t-1}} = \frac{\pi_t^w}{\pi_t}, \tag{11}$$

where ε is the degree of substitution across labour types. The RHS of (9) shows that wages depend on the wage mark-up, the marginal rate of substitution and expectations. The expectation term implies that the labour supply is forward looking, and therefore will be less sensitive to contemporaneous shocks. Equation (11) is an identity to pin down the equilibrium.

3.3 Final Good Sector

The final good Y_t is produced under perfect competition and can be turned into consumption or investment, as well as used to cover the costs associated with financial, price and wage frictions. Production uses intermediate goods as inputs according to the following CES technology

$$Y_t = \left(\int_0^1 y_t(i)^{\frac{\theta-1}{\theta}}\mathrm{d}i\right)^{\frac{\theta}{\theta-1}}, \tag{12}$$

with the elasticity of substitution $\theta > 1$. The associated demand function for intermediate goods is

$$y_t(i) = \left(\frac{p_t(i)}{P_t}\right)^{-\theta} Y_t, \tag{13}$$

with aggregate price index

$$P_t = \left(\int_0^1 p_t(i)^{1-\theta} \mathrm{d}i \right)^{\frac{1}{1-\theta}}. \tag{14}$$

3.4 Intermediate Good Sector

Each intermediate firm i, $i \in (0,1)$ operates under monopolistic competition. It employs capital services and labour by the mean of the following technology

$$y_t(i) = a_t K_t^{\eta} k_t(i)^{\alpha} h_t(i)^{1-\alpha}, \qquad \alpha \in (0,1), \tag{15}$$

where K_t represents a measure of knowledge, freely available to all firms and acquired through learning-by-doing. We assume that $K_t = k_t$, where $k_t = \int_0^1 k_t(i)\mathrm{d}i$. This implies that K is a pure externality that comes from the aggregate level of capital employed in the economy, and $0 \leq \eta \leq 1-\alpha$ represents the strength of the spillovers. a_t is an aggregate productivity shock, following

$$\log(a_t) = \rho_a \log(a_{t-1}) + \epsilon_{a,t},$$

$\rho_a \in (0,1)$ and $\epsilon_{a,t} \sim \mathrm{N}(0, \sigma^2)$. This is a moderate shock, typical of business cycle dynamics.

Solving the cost minimisation problem of the intermediate firm i, the FOCs for labour and capital services are

$$w_t = (1-\alpha) s_t \frac{y_t(i)}{h_t(i)}, \tag{16}$$

$$r_t^k = \alpha s_t \frac{y_t(i)}{k_t(i)}, \tag{17}$$

where r_t^k is the real rental rate of capital and s_t is the real marginal cost (Lagrangian multiplier) of producing $y_t(i)$, the same for all firms. Combining both FOCs

$$s_t = \alpha^{-\alpha}(1-\alpha)^{\alpha-1}\ \frac{w_t^{1-\alpha}(r_t^k)^\alpha}{a_t K_t^\eta}. \tag{18}$$

Intermediate good producers are monopolistically competitive and they face an adjustment cost when changing prices. Following Rotemberg (1982), the adjustment cost increases with the magnitude of the change in prices and the size of the economy. It is given by

$$\frac{\phi_p}{2}\left(\frac{P_t(i)}{P_{t-1}(i)} - 1\right)^2 Y_t, \tag{19}$$

where $\phi_p \geq 0$ is a measure of price rigidities. Using the demand function for intermediate goods and assuming symmetry, the first order condition of the optimization problem yields the New Keynesian Phillips curve:

$$(1-\theta) + \theta s_t - \pi_t\phi_p(\pi_t - 1) + \beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\pi_{t+1}\phi_p(\pi_{t+1}-1)\frac{Y_{t+1}}{Y_t}\right] = 0. \tag{20}$$

3.5 Capital Producers

There is a unit mass of identical perfectly competitive capital producers. Each period t, the representative capital producer buys from entrepreneurs the current capital k_t and uses it to produce new capital k_{t+1} by combining it with investment i_t, and then sells k_{t+1} units to entrepreneurs at nominal price q_t.

Since on average current capital depreciates at rate δ_t, $\delta_t \in (0,1)$, the average nominal price of second-hand capital is $q_t(1-\delta_t)$. Where note that $1-\delta_t$ relates to the relative price of second-hand to new capital in Lanteri (2018). The behaviour of the endogenous depreciation rate δ_t is modelled in the following subsection. The evolution law of raw capital reads

$$k_{t+1} = i_t \left(1 - S\left(\frac{i_t}{i_{t-1}}\right)\right) + (1-\delta_t)k_t. \tag{21}$$

As in Christiano et al. (2014), investment is subject to the adjustment cost function $S\left(\frac{i_t}{i_{t-1}}\right)$. This assumption helps reducing the volatility of investment and tames inflation as the reaction of investment to shocks is smoother. As we will show at the end of Section 5, the Great Recession generates a temporary increase in δ_t, destroying productive capacity permanently.

Capital producers maximise their flow of profits, where $\hat{q}_t = q_t/P_t$ is the real price of capital, subject to the evolution law of capital above. The FOC reads:

$$1 = \hat{q}_t \left(1 - S'\left(\frac{i_t}{i_{t-1}}\right) \frac{i_t}{i_{t-1}} - S\left(\frac{i_t}{i_{t-1}}\right)\right) + \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \hat{q}_{t+1} S'\left(\frac{i_{t+1}}{i_t}\right)\left(\frac{i_{t+1}}{i_t}\right)^2. \tag{22}$$

3.6 Entrepreneurs and Financial Intermediation

This section closely follows Christiano et al. (2014), with a few differences designed to generate an endogenous depreciation rate depending on the fraction of firms going bankrupt. There is a unit mass of perfectly competitive entrepreneurs. At the end of any period t, each entrepreneur has a net worth

N, $N > 0$.[10] Even if the net worth of a particular entrepreneur is changing over time, we omit index t to simplify notation. At equilibrium, net worth is distributed $f_t(N)$ across entrepreneurs, with total net worth

$$\bar{N}_{t+1} = \int_0^\infty N f_t(N)\,\mathrm{d}N. \tag{23}$$

At the end of period t, entrepreneurs use their net worth N and loans B^N_{t+1}, $B^N_{t+1} \geq 0$, to acquire capital k^N_{t+1} from capital producers.[11] They pay price q_t for any capital unit they buy such that

$$q_t k^N_{t+1} = N + B^N_{t+1}. \tag{24}$$

At equilibrium, all capital is allocated to entrepreneurs, s.t.,

$$k_{t+1} = \int_0^\infty k^N_{t+1} f_t(N) dN. \tag{25}$$

As shown below, like in Christiano et al. (2014), the equilibrium debt-to-net-worth ratio does not depend on N, implying that loans and capital are proportional to it. At $t+1$, entrepreneurs use capital k^N_{t+1} to produce capital services ωk^N_{t+1} that they sell to intermediate firms at price $r^k_{t+1} P_{t+1}$, where ω is an entrepreneur specific productivity shock and P_{t+1} is the aggregate price index. Entrepreneurs draw the idiosyncratic productivity ω at period t after

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[10] As for financial frictions, the model mainly draws from Bernanke et al. (1999), so we assume that the entrepreneur employs its own net worth N as well as loans from financial intermediaries, *i.e.* mutual funds, to finance his venture.

[11] As usual, for an arbitrary asset X, X_{t+1} refers to the amount of this asset transferred from t to $t+1$.

buying capital k^N_{t+1}. Idiosyncratic productivity ω is assumed to be i.i.d. across time and firms, drawn at t from the c.d.f. $\mathrm{F}_t(\omega)$, log-normally distributed, with unit mean and standard deviation σ_t.

An entrepreneur with net worth N obtains a loan B^N_{t+1} from mutual funds at the interest factor Z_{t+1}. The interest factor is contingent on the state of the economy in $t+1$ and, as shown below, it is independent of N at equilibrium. For this reason, index N is omitted. On top of aggregate risks, the debt contract has to take into account the presence of idiosyncratic risk, since entrepreneurs facing low realizations of the shock ω may be unable to repay the loan, and go bankrupt. Conversely, entrepreneurs with sufficiently high returns on their capital will repay their loans and make positive cash flow. For a given state contingent interest factor Z_{t+1}, let us define $\bar{\omega}_{t+1}$ as the state contingent productivity ω that zeroes the entrepreneur's cash flow at $t+1$, *i.e.*,

$$\Pi^N_{t+1}(\bar{\omega}_{t+1}) = \bar{\omega}_{t+1} R^k_{t+1}\, q_t k^N_{t+1} - B^N_{t+1} Z_{t+1} = 0, \tag{26}$$

where $\Pi^N_{t+1}(\omega)$ represents the entrepreneur's cash flow.[12] If $\omega > \bar{\omega}_{t+1}$, then $\Pi^N_{t+1}(\omega) > 0$, whilst if $\omega < \bar{\omega}_{t+1}$, the entrepreneur goes bankrupt. The fraction of firm that go bankrupt at period t is then $\mathrm{F}_{t-1}(\bar{\omega}_t)$.

At $t+1$, after production takes place, an ω-type successful entrepreneur sells its undepreciated capital $(1-\hat{\delta}_{t+1})\omega$ back to capital producers at price q_{t+1}. The depreciation rate of capital is $\hat{\delta}_{t+1} = \delta \left(\frac{\mathrm{F}_{t-1}(\bar{\omega}_t)}{\mathrm{F}(\bar{\omega})}\right)^{a_{\bar{\omega}}}$, $a_{\bar{\omega}} \geq 0$, where $\delta \in (0,1)$ is a parameter representing the depreciation rate at steady state. This specification includes negative network spillovers from entrepreneurs that

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[12] Like Z_{t+1}, $\bar{\omega}_{t+1}$ is independent of N at equilibrium. For this reason, index N is omitted.

went bankrupt in the previous period. It is a simplified way of representing the negative network effects on capital value associated with the disruptions in the production process generated by economic downturns and bankruptcy. A larger bankruptcy rate will make the capital of surviving firms less productive in the future due to the destroyed links. When the probability of bankruptcy is at its steady state value $\mathrm{F}(\bar{\omega})$, the impact of spillovers is normalised to 1. The ex-post return at $t+1$ to a unit of capital bought at t for an ω-type successful entrepreneur is ωR^k_{t+1}, with

$$R^k_{t+1} = \frac{r^k_{t+1} P_{t+1} + (1 - \hat{\delta}_{t+1}) q_{t+1}}{q_t}. \tag{27}$$

R^k_{t+1} is the state contingent expected nominal return conditional on being successful.

In case of bankruptcy, the mutual fund pays a monitoring cost μ, $\mu \in (0,1)$, to appropriate the payments generated by the capital services provided to intermediate firms as well as the capital stock, which is then liquidated, subject to physical depreciation and obsolescence. Moreover, when an entrepreneur goes bankrupt, the steady state depreciation rate of capital is κ, $\kappa \in (\delta, 1)$ which is meant to capture both physical depreciation and obsolescence, obsolescence being measured by the difference $\kappa - \delta$. Negative network spillovers affect bankrupt entrepreneurs too, so that $\hat{\kappa}_{t+1} = \kappa \left(\frac{\mathrm{F}_{t-1}(\bar{\omega}_t)}{\mathrm{F}(\bar{\omega})} \right)^{a_{\bar{\omega}}} \quad a_{\bar{\omega}} \geq 0$. The ex-post return to capital for bankrupt ω-type entrepreneur is ωR^f_{t+1}, with

$$R^f_{t+1} = \frac{r^k_{t+1} P_{t+1} + (1 - \hat{\kappa}_{t+1}) q_{t+1}}{q_t} \tag{28}$$

which in this case is appropriated by mutual funds. R^f_{t+1} is the the state contingent expected nominal return conditional on going bankrupt

At time t mutual funds issue bonds to households at the risk-less factor R_t to raise the resources needed to finance entrepreneurs. They also receive a transfer from the Monetary Authority. The transfer is financed by a tax on household's profits from entrepreneurial activity, and is thus proportional to the return to capital of successful entrepreneurs. The parameter ξ regulates the size of the transfer. This is a measure implemented to relax the cash constraint, aiming to promote credit provision in bad times, and will assure steady state values in line with U.S. data. For simplicity, let us assume that mutual funds specialise in entrepreneurs with net worth N and operate under perfect competition. Since the interest factor Z_{t+1} is state contingent, at each state of nature a zero profit condition holds, *i.e.*,

$$(1-\mu)q_t k^N_{t+1}\int_0^{\bar{\omega}_{t+1}} \omega R^f_{t+1}\mathrm{dF}_t(\omega) + \big(1-\mathrm{F}_t(\bar{\omega}_{t+1})\big)B^N_{t+1}Z_{t+1} + \\ + \xi\int_0^{\bar{\omega}_{t+1}} \omega \mathrm{dF}_t(\omega) R^k_{t+1} q_t k^N_{t+1} = B^N_{t+1}R_t. \tag{29}$$

Divide both sides by $R^k_{t+1}q_t k^N_{t+1}$, use (26) and define leverage $L_t = \frac{N+B^N_{t+1}}{N}$ to get

$$(1-\mu)\frac{R^f_{t+1}}{R^k_{t+1}}\int_0^{\bar{\omega}_{t+1}} \omega \mathrm{dF}_t(\omega) + \bar{\omega}_{t+1}(1-\mathrm{F}_t(\bar{\omega}_{t+1})) + \xi\int_0^{\bar{\omega}_{t+1}} \omega \mathrm{dF}_t(\omega) = \frac{R_t}{R^k_{t+1}}\frac{L_t-1}{L_t}.$$

The zero profit condition above can then be used to find an expression for leverage

$$L_t = \left(1 - \frac{R^k_{t+1}}{R_t}\Big(\bar{\omega}_{t+1}(1-\mathrm{F}_t(\bar{\omega}_{t+1})) + (1-\mu)H_t(\bar{\omega}_{t+1}) + \xi G_t(\bar{\omega}_{t+1})\Big)\right)^{-1}, \tag{30}$$

where

$$H_t(\bar{\omega}_{t+1}) = \frac{R^f_{t+1}}{R^k_{t+1}} \int_0^{\bar{\omega}_{t+1}} \omega \mathrm{dF}_t(\omega) \quad \text{and} \quad G_t(\bar{\omega}_{t+1}) = \int_0^{\bar{\omega}_{t+1}} \omega \mathrm{dF}_t(\omega).$$

$G(\bar{\omega})$, $G(\bar{\omega}) < 1$, represents unsuccessful entrepreneurs' contribution to the average ω, and $H(\bar{\omega})$, $H(\bar{\omega}) < G(\bar{\omega})$, is corrected by the ratio of unsuccessful to successful returns.

Notice that the loan contract (Z_{t+1}, B^N_{t+1}) can be also written as a contract on $(\bar{\omega}_{t+1}, L_t)$. Any pair $(\bar{\omega}_{t+1}, L_t)$ that satisfies (30) is a $(t+1)$-state contingent contract offered to entrepreneurs. As it will become clear below, at equilibrium, the conditions of the loan contract $(\bar{\omega}_{t+1}, L_t)$ are the same for all entrepreneurs irrespective of their net worth N. On one side, for a given net worth N, choosing loan B^N is equivalent to choosing leverage L. On the other side, setting the nominal interest factor Z determines the cut-off productivity $\bar{\omega}$.

At time $t+1$, for any realization of the aggregate shocks, the debt contract $(\bar{\omega}_{t+1}, L_t)$ for an entrepreneur with net worth N is expected to generate the cash flow

$$\int_{\bar{\omega}_{t+1}}^{\infty} \Pi^N_{t+1}(\omega)\, \mathrm{dF}(\omega) = \Big(1 - \Gamma_t(\bar{\omega}_{t+1})\Big)\, R^k_{t+1} L_t N, \tag{31}$$

where $\Big(1 - \Gamma_t(\bar{\omega}_{t+1}\Big)$ is the expected share of total revenues retained for successful entrepreneurs, with

$$\Gamma_t(\bar{\omega}_{t+1}) = G_t(\bar{\omega}_{t+1}) + \bar{\omega}_{t+1}\Big(1 - \mathrm{F}_t(\bar{\omega}_{t+1})\Big) \tag{32}$$

being the expected share going to the mutual fund.

For any state of nature in $t+1$, the entrepreneur chooses the contract that maximises expected profit, which is equivalent to[13]

$$\max_{\bar{\omega}_{t+1}} \frac{1-G_t(\bar{\omega}_{t+1})-\bar{\omega}_{t+1}\big(1-\mathrm{F}_t(\bar{\omega}_{t+1})\big)}{1-\frac{R^k_{t+1}}{R_t}\Big(\bar{\omega}_{t+1}(1-\mathrm{F}_t(\bar{\omega}_{t+1}))+(1-\mu)H_t(\bar{\omega}_{t+1})+\xi G_t(\bar{\omega}_{t+1})\Big)}=$$

$$=\max_{\bar{\omega}_{t+1}} L_t(\bar{\omega}_{t+1})\big(1-\Gamma_t(\bar{\omega}_{t+1})\big). \quad (33)$$

Thus the FOC pinning down the equilibrium $\bar{\omega}_{t+1}$ reads:

$$\frac{1-\mathrm{F}_t(\bar{\omega}_{t+1})}{1-\Gamma_t(\bar{\omega}_{t+1})}=\frac{\frac{R^k_{t+1}}{R_t}\Big(1-\mathrm{F}_t(\bar{\omega}_{t+1})-\mathrm{G}'_t(\bar{\omega}_{t+1})\big(1-\frac{R^F_{t+1}}{R^k_{t+1}}(1-\mu)-\xi\big)\Big)}{1-\frac{R^k_{t+1}}{R_t}\Big(\bar{\omega}_{t+1}(1-\mathrm{F}_t(\bar{\omega}_{t+1}))+(1-\mu)H_t(\bar{\omega}_{t+1})+\xi G_t(\bar{\omega}_{t+1})\Big)}. \quad (34)$$

This shows that the loss of accepting a higher threshold for entrepreneurs equals the benefit of higher leverage. The LHS is the elasticity of the share the entrepreneur keeps w.r.t. $\bar{\omega}_{t+1}$, whilst the RHS is the elasticity of leverage w.r.t. $\bar{\omega}_{t+1}$.[14] Also, notice that this specification implies that the elasticity of leverage is affected by credit subsidies.

It is easy to see that the equilibrium $\bar{\omega}_{t+1}$ does not depend on N. From (30), leverage does not depend on it either. Consequently, from (26), mutual funds set the same $(t+1)$-state contingent interest factor Z_{t+1} irrespective of net worth.

Let us assume the standard deviation of $\mathrm{F}_t(\omega)$ follows

$$\log\left(\frac{\sigma_t}{\bar{\sigma}}\right)=\rho_\sigma \log\left(\frac{\sigma_{t-1}}{\bar{\sigma}}\right)+\epsilon_{\sigma,t},$$

with $\bar{\sigma}>0$, $\rho_\sigma \in (0,1)$ and the risk shock $\epsilon_{\sigma,t}$ being i.i.d. Notice that a higher value of σ_t implies a higher probability of drawing a low value of ω. As the variance of the shock increases, the tails of the distribution get thicker, increasing the probability

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[13] Use (30) to substitute for L_t in (31), then divide by $R^k_{t+1}N$ to get (33).

[14] The FOC also shows that our framework reduces to the standard model in Christiano et al. (2014) in the case $R^k = R^F$ and $\xi = 0$.

of tail events and modifying the threshold for $\bar{\omega}$, *i.e.*. increasing the probability of bankruptcy.

Let us finally assume that at the end of period $t+1$ (after entrepreneurs pay back to mutual funds their period t debt) a fraction $(1-\gamma)$ of successful entrepreneur's cash flow $\Pi_{t+1}^{N}(\omega)$ gets transferred to households, $\gamma \in (0,1)$. Moreover, each entrepreneur receives a transfer $w^e \, P_{t+1} k_{t+1}^{N}$ from households, $w^e \in (0,1)$, as a form of insurance, to compensate for risk taking, and assuring that bankrupt entrepreneurs will keep a strictly positive net worth allowing them to buy some capital for the following period.

Since liquidating the capital of failed entrepreneurs generates physical capital depletion, the depreciation of capital is endogenous and depends on the fraction of entrepreneurs going bankrupt. The aggregate depreciation rate at time t reads

$$1-\delta_t = (1-\hat{\kappa}_t)\,\mathrm{F}_{t-1}(\bar{\omega}_t) + (1-\hat{\delta}_t)\big(1-\mathrm{F}_{t-1}(\bar{\omega}_t)\big).$$

The intuition is that when bankruptcy happens some capital (tangible or intangible) is destroyed in the process, reducing the overall value of capital. The externality aims to capture negative disruptive spillovers generated by bankruptcy. These could be the result of some specialised machines not being reallocated as effectively as in normal times or knowledge embedded in intangible capital being lost. Moreover, we think of depreciation spillovers as (small) bankruptcy shocks with aggregate effects through the production network, resulting in an increase in the depreciation rate of capital for the whole economy. This interpretation draws inspiration from Acemoglu et al. (2016), who document significant network-based propagation channels stemming from small shocks.

3.7 Aggregate Economy

The quantity of capital produced by capital producers must be equal to the capital purchased by entrepreneurs:

$$k_{t+1} = \int_0^\infty k_{t+1}^N f_t(N) dN.$$

From (24), (30) and the definition of leverage, $L_t = \frac{N+B_{t+1}^N}{N}$, the equation above becomes

$$q_t k_{t+1} = \frac{1}{1 - \frac{R_{t+1}^k}{R_t}\Big(\bar{\omega}_{t+1}(1 - \mathrm{F}_t(\bar{\omega}_{t+1})) + (1-\mu)\mathrm{H}_t(\bar{\omega}_{t+1}) + \xi G_t(\bar{\omega}_{t+1})\Big)} \bar{N}_{t+1}. \quad (35)$$

Consequently, the level of capital in the economy depends on aggregate net worth, as defined in (23), and financial conditions.

All intermediate firms face the same wage and capital cost, therefore, by symmetry:

$$\frac{k_t(i)}{h_t(i)} = \frac{k_t}{h_t}, \quad (36)$$

for all $i \in (0,1)$. Also, market clearing for capital and labour implies $\int_0^1 k_t(i) \mathrm{d}i = k_t$ and $\int_0^1 h_t(i)\mathrm{d}i = h_t$. Notice that if firms could change their prices in every period, they will choose the same price and produce the same quantity. In which case, $p_t(i) = P_t$ and $y_t(i) = Y_t$, hence aggregate production would become

$$Y_t = a_t k_t^{\alpha+\eta} h_t^{1-\alpha}. \quad (37)$$

Therefore, if $\eta = 1-\alpha$ aggregate technology has an AK structure. Aggregate profits of all entrepreneurs at the end of time t are $[1-\Gamma_{t-1}(\bar{\omega}_t)]R_t^k q_{t-1} k_t$, so that aggregate net worth at $t+1$ is:

$$\bar{N}_{t+1} = \gamma[1 - \Gamma_{t-1}(\bar{\omega}_t)]R_t^k q_{t-1} k_t + P_t w^e k_t. \quad (38)$$

Using the aggregate production function and $K_t = k_t$:

$$r_t^k = \alpha s_t a_t k_t^{\alpha+\eta-1} h_t^{1-\alpha} \tag{39}$$

$$w_t = (1-\alpha) s_t a_t k_t^{\alpha+\eta} h_t^{-\alpha} \tag{40}$$

$$s_t = \frac{1}{\alpha^\alpha (1-\alpha)^{1-\alpha}} \frac{1}{a_t k_t^\eta} w_t^{1-\alpha} (r_t^k)^\alpha. \tag{41}$$

All bonds held by households must be equal to the amount of loans in aggregate, and transfers to mutual funds must equal taxes:

$$q_t k_{t+1} - \bar{N}_{t+1} = B_{t+1}$$

$$\xi \int_0^{\bar{\omega}_{t+1}} \omega \mathrm{dF}_t(\omega) R_{t+1}^k q_t k_{t+1}^N = \tau_t.$$

Output is allocated to consumption and investment, but also to intermediary production aimed to cover price and wage adjustment costs as well as monitoring costs, *i.e.*:

$$Y_t = \underbrace{c_t + i_t}_{\text{GDP}} + \mu \int_0^{\bar{\omega}_t} \omega d\mathrm{F}(\omega) R_t^F \frac{\hat{q}_{t-1}}{\pi_t} k_t + \frac{\phi_p}{2} (\pi_t - 1)^2 Y_t + \frac{\chi^w}{2} (\pi_t^w - 1)^2 Y_t. \tag{42}$$

GDP is then defined as the sum of consumption and investment, measuring aggregate demand.

3.8 Monetary Authority

The monetary authority uses the Taylor rule to set the nominal interest rate, subject to the zero lower bound constraint:

$$R_t^m = \bar{R} + \rho_\pi (\pi_t - \bar{\pi}^m) + \rho_y \log\left(\frac{\widehat{\mathrm{GDP}}_t}{y_t^p}\right) \tag{43}$$

$$R_t = \max(1, R_t^m), \tag{44}$$

where R_t is the nominal interest factor, $\bar{R}$ and $\bar{\pi}$ are target values, $\rho_\pi > 0$ and $\rho_y > 0$ are policy parameters, and y_t^p

$$y_t^p = y_{t-1}^p + \rho \left(\frac{1}{n} \sum_{j=1}^{n} \widehat{\text{GDP}}_{t-4-j} - y_{t-1}^p \right), \quad 0 < \rho < 1, \tag{45}$$

is a measure of potential output. It is computed as a moving average of past GDP values, de-trended by the stationary growth rate of the economy g_z, so that $\widehat{\text{GDP}}_t = \frac{\text{GDP}_t}{(1+g_z)^t}$.[15] We define this measure to take into account the revisions carried out by central banks in the context of the Great Recession. We implicitly assume that the monetary authority does not have full information about the functioning of the economy, and it infers the underlying path from observed values of GDP. In particular, our measure takes into account the lag in potential output revisions, as we disregard the most recent 4 periods. This implies that the estimate of potential output is not very sensitive to negative shocks if they are small in size and duration. We set n equal to 10, to allow the central bank to consider a long enough period of time in the estimation of the underlying trend, but also react relatively quickly to shocks.

As we will show in the following sections, the Taylor rule provides stimulus to the economy, inducing it to close the output gap after a negative shock. Despite the fact that the aggregate technology is AK, and because of the monetary policy intervention, GDP appears to fluctuate around a stable linear trend in normal times,

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[15] An alternative practice in the literature is to model potential output as the level of output that would prevail without nominal rigidities. We do not adopt this measure because the level of output at the balanced growth path in an AK economy is fundamentally indeterminate, and as such depending on the policy intervention itself. Moreover, central banks commonly use measures of potential output as deviations of output from trend. For example, see Edge et al. (2008) for a discussion of the Fed's FRB/US model or Vetlov et al. (2011), for the ECB's NAWM.

appearing consistent with diminishing returns to capital. However, if the shock is large and prolonged, potential output will be revised downwards and the stimulus to the economy will lose strength over time. As a result, the economy will reveal its AK structure and the recovery will fail to materialise.

4 Baseline Calibration

We calibrate the model on quarterly data for the United States, considering the period 1980-2008 as our reference.[16] In order for the model to have an aggregate AK technology, we set $\eta = 1 - \alpha$. Returns to capital are then constant, generating endogenous growth. We consistently de-trend all non-stationary variables using the the stationary growth rate g_z, so that $\tilde{c}_t = \frac{c_t}{(1+g_z)^t}$, $\tilde{y}_t = \frac{Y_t}{(1+g_z)^t}$, and so on. Then we solve the stationarised system of non-linear equations, calibrating the model to match some key data moments.[17]

To characterise the stationary equilibrium, we target a labour share of 60.8%, in line with the average value of the share of labour compensation in GDP. This is achieved by setting $\alpha = 0.24$ and assuming a price mark-up of 25%. The latter implies a value of 5 for the elasticity of substitution across intermediate good, θ. We also calibrate the model to have zero inflation in steady state and a quarterly growth rate of 0.6%. The latter depends on the return to capital and the financial

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[16] We choose data covering this time span to characterise the steady state of the model since we do not take a stand on whether an endogenous growth model has always been a good representation of GDP, as it is possible that that the U.S. economy evolved from a Neoclassical structure to an AK structure over time due to technological change. For example, the increasing importance of intangible capital, human capital and knowledge spillovers for production, as documented by Haskel and Westlake (2018), could have led to such a transformation in the production technology.

[17] Table 1 in the Online Appendix shows the comparison between the steady state of the model and U.S. data. For a description of the data, see Online Appendix 1.

frictions. We set the scaling parameter $\psi = 16.8$ to labour hours in steady state be 0.2, in line with the average of annual hours worked by persons engaged. We set γ to 0.966 (close to Bernanke et al. (1999)). Concerning the depreciation rate, we set δ to 0.028 and κ to 0.04. These are somewhat higher than standard values, but we make this choice because our definition of capital is wider compared to National Accounts, including all categories of intangible capital. Although these stocks are not fully included in GDP measures, they do affect the outcome of production, and they depreciate faster than traditional measures of capital, so we account for their depreciation in our calibration. Monitoring costs are set to $\mu = 0.21$, in line with Christiano et al. (2014) and within the rage suggested by Carlstrom and Fuerst (1997). We set $\xi = (1-\mu)\big(1 - \frac{R^F_{ss}}{R^k_{ss}}\big)$ to obtain a steady state bankruptcy rate of approximately 1%, similarly to Christiano et al. (2014).

For Rotemberg adjustment costs, we follow the approaches proposed by Ascari and Rossi (2012) and Born and Pfeifer (2020), calculating them as follows:

$$\phi_p = \frac{(\theta - 1)\theta^p}{(1-\theta^p)(1-\beta\theta^p)} \tag{46}$$

$$\chi^w = \frac{(\epsilon - 1)\frac{\theta-1}{\theta}(1-\alpha)\theta^w}{(1-\theta^w)(1-\beta\theta^w)}, \tag{47}$$

where $\theta^w = \theta^p = 0.75$ represent the probabilities of not being able to reset prices and wages.

Finally, we set $a_{\bar{\omega}}$ to 0.15, which implies that a 1% deviation of the probability of bankruptcy from its normal value leads to an increase in the depreciation rate of approximately 0.1%. This is considerably smaller compared to

Parameter	Value	Description
Preferences		
β	0.99	Discount factor
χ	0.7	Habit formation parameter
ν	1	Inverse of Frisch elasticity
ψ	16.8	Scaling parameter for labour hours
Frictions		
θ	5	Substitution in final good
ε	21	Substitution in labour input
ϕ_p	46.6	Rotemberg price adjustment parameter
χ^w	141.7	Rotemberg wage adjustment parameter
S"	5	Investment adjustment costs
μ	0.21	Monitoring costs
γ	0.966	Fraction of profits going to entrepreneur
w^e	0.0005	Transfer from household
ξ	0.009	Transfer to financial intermediaries
Technology		
α	0.24	Private returns to capital
η	0.76	Knowledge spillovers in production
δ	0.028	Successful entrepreneurs' depreciation rate
κ	0.04	Bankrupt entrepreneurs' depreciation rate
$a_{\bar{\omega}}$	0.15	Strength of depreciation spillovers
Monetary Policy		
ρ_π	1.5	Policy response to inflation
ρ_y	0.125	Policy response to output gap
ρ	0.7	Speed of potential output revision
n	10	Number of past periods in moving average

Table 1: Quarterly calibration parameters

the values in Lanteri (2018)'s data and capital quality shocks in Kozlowski et al. (2020), but our choice is conservative as the model is not expected to represent all dimensions of the data. Our view is that there is sufficient evidence to support the capital destruction channel as quantitatively relevant, but a precise estimate to base the calibration on is not available. We therefore choose the parameter $a_{\bar{\omega}}$ to bring our model simulations close to the fall in GDP observed in the data. The persistence of the confidence and risk shocks during the Great Recession, $\rho_c = 0.9$ and $\rho_\sigma = 0.97$ respectively, are taken from Christiano et al. (2014).

5 The Great Recession

Great Recession Shock. We model the Great Recession as the reaction of the economy to a large and persistent demand shock that combines a risk shock and a confidence shock, both hitting at the same time.[18] The magnitude of the risk shock is set to 15.7% increasing the bankruptcy probability from a baseline value of 1% to 4%, in line with the smoothed bankruptcy rate estimated by Christiano et al. (2014). We set the size of the confidence shock to 12.56%, in line with the decline of the HP-filtered University of Michigan's consumer sentiment for the U.S. at the start of the Great Recession.

The confidence shock brings the economy to the ZLB region. However, since our model does not capture the unconventional monetary policies implemented by the Fed, nor forward guidance, the model economy remains in the ZLB region only for a few quarters after the occurrence of the Great Recession shock. We use U.S. data to build an alternative measure of the nominal

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[18] In order to appropriately account for the sizeable deviation of endogenous variables from the original steady state and the ZLB constraint, we solve the model non-linearly, employing a Newton-type method (Adjemian et al., 2011) (Juillard et al., 1996).

interest rate consistent with the standard Taylor rule, i.e.,[19]

$$\mathrm{TR}_t = \max\left\{0, \overline{TR} + 1.5\left(\pi_t - \bar{\pi}\right) + 0.5\,\log\left(\frac{\mathrm{GDP}_t}{y_t^p}\right)\right\},$$

setting the target nominal interest rate $\overline{TR}$ to 3.64%, the 2004-2007 average of the Federal Funds Rate (FFR), and the inflation target $\bar{\pi}$ to its official value of 2%. Quarterly GDP is measured in real terms and potential output y_t^p is real-time CBO data (in 2012 dollars).[20] Inflation is measured as the GDP deflator.[21] In line with our simulations, as displayed in Figure 4, the nominal interest rate TR_t predicted by the Taylor rule shows a much shorter ZLB episode compared to the Federal Funds Rate.

Summing up: The Great Recession shock combines a 15.7% risk shock and a 12.56% confidence shock. As a result, the bankruptcy rate increases in line with data, and the simulated nominal interest follows the hypothetical FFR predicted by the Taylor rule applied to observed inflation and output gaps.

Data Comparison. In order to compare the simulations with key data dynamics in the U.S., we follow the approach of Christiano et al. (2015) to estimate targets gap ranges from the data. We measure the deviation of variables from the path they would have followed, had the recession not happened, by calculating the percentage difference from a linear trend, fitted on past data. In order to select time intervals, we aim to follow the CBO's methodology

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[19] A similar exercise was also conducted by the Board of Governors of the Federal Reserve System, among others, with comparable results. See link here.

[20] Real-time CBO data are constructed employing the estimates published by the CBO at the beginning of each year. It thus captures the unfolding of all revisions.

[21] Additional details on data series used can be found in the Online Appendix.

for projections of potential output as closely as possible. *"Typically, a trend is considered to extend from at least one previous business cycle through the most recent quarter of data (because the peak of the current cycle is not known at the time of a forecast)."*[22] They consider full peak-to-peak business cycles, so we build our estimates by including data from the business cycles peaks preceding the Great Recession, up to the period before the downturn. We construct min-max targets by considering the intervals $[x : 2008Q2]$, with $x = (1990Q3, 2001Q1)$. We consider aggregate series retrieved from the FRED database for GDP, consumption, investment, credit and the Federal Funds Rate. Finally, in order to compare the *switching-track* of potential output in our model and in the data, we employ the measure of potential output we built to calculate the Taylor rule. More details on data sources can be found in the Online Appendix.

The Great Recession. Figure 4 shows impulse responses for some key variables in our model to the Great Recession shock. The fall in confidence slows down consumption demand, and the sharp rise in risk depresses investment demand and raises bankruptcy. As bankruptcy rates increase, capital depreciates faster resulting in capital destruction. Even when the shock subsides and financial variables converge back to the previous steady state values, due to capital destruction the negative effects on GDP, consumption and investment do not dissipate and the economy displays an L-shaped recovery. Our model fits the data quite well, especially for GDP and consumption, which both fall by almost 10% at the new steady state, converging monotonically in the same

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[22] From the report: 'Revisions of CBO's potential output since 2007', (Shackleton, 2014).

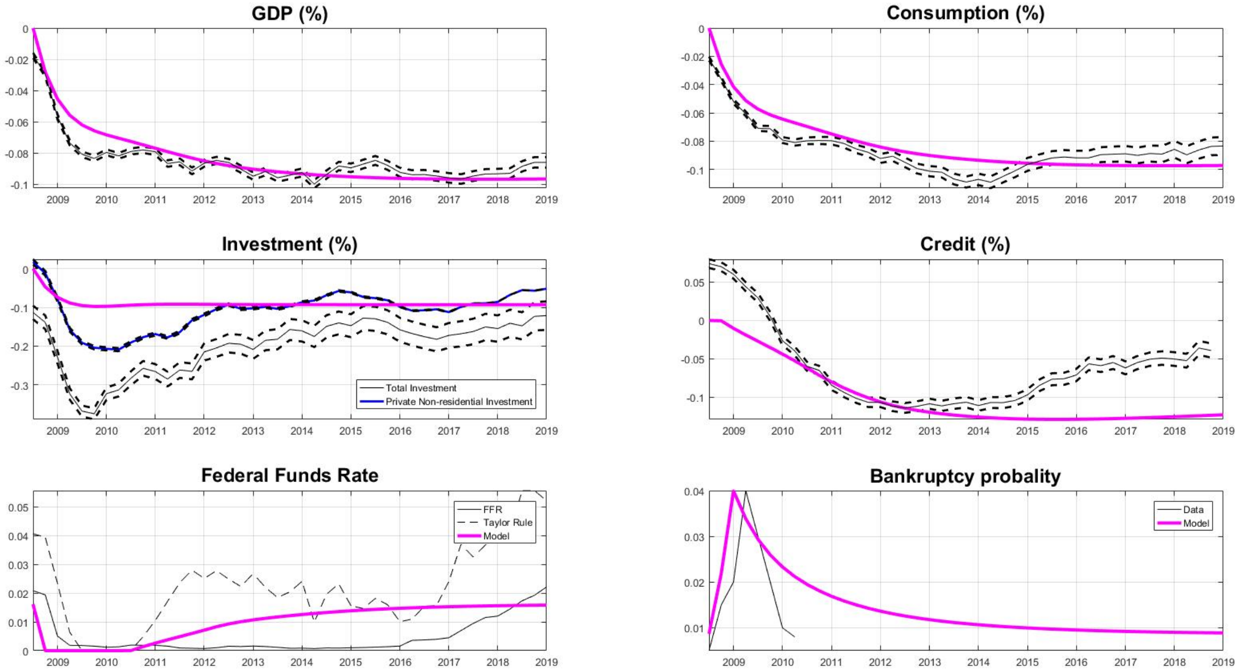

Figure 4: Model impulse responses to Great Recession shock vs U.S. data

way as the data. As for investment, the simulation does not capture the full depth of the total shortfall, which was partially driven by the the real estate market. Nonetheless, results are more in line with private non-residential investment data. The model fits the data for credit well at the beginning of the sample, set aside the collapse of the credit boom that we do not model, and performs worse for later periods. This is likely because we are not modelling unconventional monetary policies providing credit easing. The behaviour of the nominal interest rate is in line with the Taylor rule estimate, and thus does not replicate the Federal Funds Rate after 2010, which remains for a long

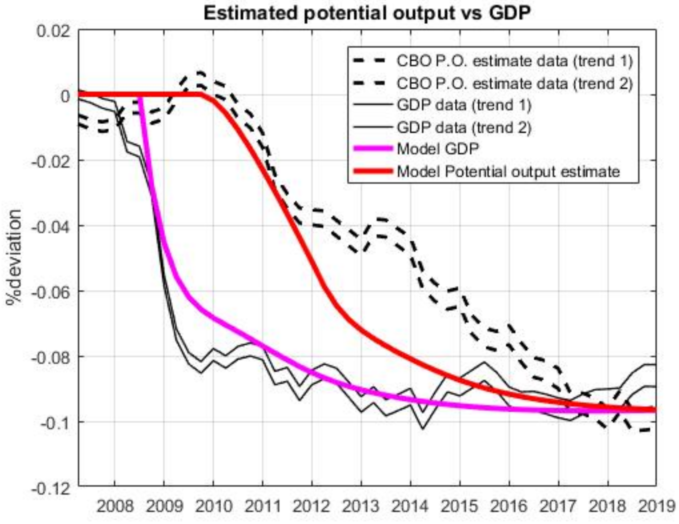

Figure 5: GDP and potential output

while at the ZLB, likely due to unconventional monetary policies.

Switching-Track. Figure 5 clearly shows that the model economy replicates quite well the *switching-track* of potential output in the data.[23] The simulated output gap shrinks with time, thus reducing its impact on the Taylor rule. Our simulations are in line with the U.S. experience, and our specification approximates well the timing of output gap dynamics observed in the data.

Model's Mechanics. As it is common in financial crises, following the Great Recession shock credit declines and net worth contracts, mirroring a stock

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[23] The figure shows a slight increase in potential output in 2013, which is the result of the comprehensive revision of the national income and product accounts (NIPAs) to include new investment categories. This led to an increase in GDP value. We adjusted the potential output measures published, following the methodology indicated by the CBO in their 2014 report, but a small margin of error remains.

market crash. Monetary policy is in place to mitigate the shock, but the ZLB constraint limits its effectiveness and, most importantly, the severity and the length of the recession put downward pressure on potential output estimates, giving rise to a *switching-track*. Without a strong policy intervention, the economy switches track moving to a lower GDP trajectory, revealing its AK nature.[24] When we compare the results of our baseline simulation with a simulation in which the Fed's measure of potential output is much less sensitive to past observed data, the policy is much stronger, and the negative level effects on the trajectory of GDP are considerably reduced, showing the policy's potential to partially prevent the destruction of productive capacity.[25] A slower revision of potential output (inducing a weaker *switching-track*) results in lower depreciation, directly preventing the destruction of productive capacity and sustaining consumption and investment demand. As a result, inflation gets stronger and the real interest rate rises faster, promoting savings and a stronger recovery compared to the baseline simulation. The policy then induces households to consume and save more, and entrepreneurs to invest more, with the economy settling on a higher level.

Capital Destruction Channels. In our model, bankruptcy destroys capital through two different channels: A *liquidation channel* operates directly through the partial destruction of the capital stock of entrepreneurs going

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[24] The impulse response of the main variables to the Great Recession shock is in Figure 7 in the Online Appendix. The level effect on GDP would have been less severe had the ZLB not been binding. Impulse response functions are reported in Figure 8 in the Online Appendix.

[25] Figure 9 in the Online Appendix depicts, for different values of the potential output revision coefficient in the Taylor rule ρ, the impulse response of the main variables to the Great Recession.

bankrupt, and a *disruptive spillovers channel* through the negative externalities that bankruptcy has on the the productive capacity of capital for all entrepreneurs. The first captures the direct destruction of capital that follows bankruptcy, as we assume that bankrupt firms face a liquidation cost in terms of capital equal to $\kappa - \delta > 0$. These firms are hit by the risk shock the hardest, but their aggregate effect is not strong enough to generate a downturn as large as the Great Recession. The same demand shock generates a permanent level effect on GDP even with no disruptive spillovers, but the magnitude of the impact is considerably smaller.[26] The second channel is the result of disruptive spillovers, capturing the idea that in downturns most firms are worse off, not just the ones that exit.[27] This modelling choice is indirectly supported by Lanteri (2018) data, which shows that the price of used capital goods relative to new ones fell in the whole secondary market, and not just for bankrupt firms. This second channel is key to replicate the magnitude of the Great Recession in the model.

Welfare Losses. In order to evaluate the impact of the switching-track, we calculate consumption equivalent welfare losses for different intensities of potential output revision ρ in (45). In each case, we compare the path of utility following the Great Recession shock to the path of utility at the initial balanced growth path (where the economy would have stayed had the Great Recession not happened). The Baseline column in Table 2 gives the welfare

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[26] See Figure 10 in the Online Appendix.

[27] In a similar spirit, Guerrieri et al. (2020) provide a theoretical argument in favour of a business exit multiplier in the context of the COVID-19 crisis, showing that the exit of some firms may lead to negative amplification effects in the economy.

Revision intensity	Faster than baseline	Baseline	Slower than baseline
ρ	0.9	0.7	0.04
Welfare losses	-7.3%	-6.8%	-6.4%

Table 2: Welfare losses for different intensity of potential output revision

losses produced by the Great Recession demand shock when output gap is revised following the baseline revision rule. The other two columns do the same for alternative revision rules. Comparing columns, we conclude that faster revision rules generate larger losses, which implies that a weaker policy intervention in the model wouldn't have been optimal.

In an AK world, when capital is destroyed output moves to a lower path. The optimal reaction to such a shock is to remain in the new lower balanced growth path. Any policy forcing households to save more than optimal in order to make capital return to its previous trajectory is suboptimal. Why is it then the case that a Taylor rule forcing output to go back to its previous track generates welfare gains? The fundamental reason lies in the *destruction prevention* channel of monetary policy. In an economy with a negative externality stemming from *disruptive spillovers*, the cushioning effect of the policy intervention tames bankruptcy down and lowers depreciation, counteracting the shocks and allowing higher levels of consumption in the new steady state, without forcing excessive savings along the transition.

6 Normal Times and V-Shaped Recoveries

In this section, we begin by studying the mechanics of our model, and show that it can generate policy-driven V-shaped recoveries when shocks are not overly severe or particularly persistent. Moreover, we show that these mechanics can help our model replicate the dynamics of pre-Great Recession recoveries.[28] Throughout this section, we hold the value of potential output constant, so that the output gap measures the deviation of GDP from the initial steady state.

We do not update the potential output measure because the revision procedure adopted after the Great Recession started was the first of its kind in the U.S. monetary policy history, as documented by Coibion et al. (2017). Figure 6 illustrates this point for the two most recent recessions before 2008 using CBO historical data. These are the the 1990 recession and the 2000 dot.com recession. In both cases, the CBO revisions of potential output projections are minor. Older vintages are unfortunately not available, so we rely on the statement in Shackleton (2014) concerning the CBO's methodology: *"Recessions typically have little effect on historical estimates of potential output because the methodology aims to exclude cyclical effects"*. The Great Recession was the only exception to this rule.

6.1 TFP Shocks

To show the dynamics of V-shaped recoveries in our model, let us consider a textbook minus 1% TFP shock with persistence $\rho_a = 0.79$. The persistence of the shock is in line with the literature, and was selected to illustrate a case where the economy quickly recovers to the previous steady state.[29] In Figure

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[28] Since in normal times the ZLB is never binding, we solve the model with perturbation methods.

[29] The Taylor rule systematically generates a full recovery after a TFP shock. As can be observed in Figure 11 in the Online Appendix, the recovery is faster the less persistent the

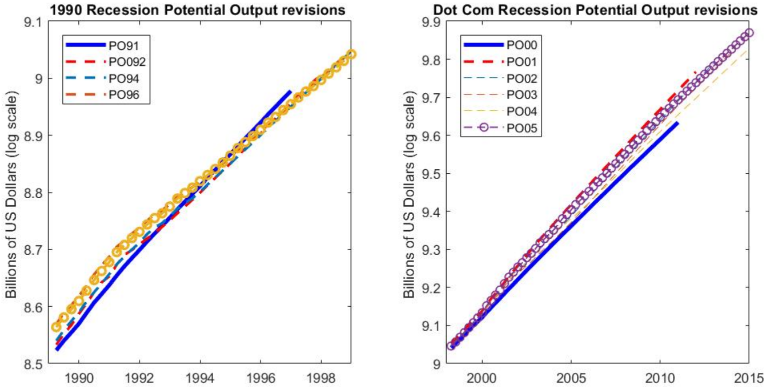

Figure 6: Potential output revisions in past recessions (CBO data)

7, we plot simulation results for our baseline calibration as well as for a pure inflation targeting, *i.e.* following a Taylor rule with no weight on the output gap. This figure shows that small shocks have permanent effects on GDP when $\rho_y = 0$, whilst the economy recovers when $\rho_y = 0.125$. A positive weight on the output gap implies that the monetary authority will respond with stimulus to aggregate demand when the output gap is negative, by offering a lower nominal interest rate for each level of inflation. A negative TFP shock reduces the supply of output, which puts pressure on prices to increase, raising inflation. The presence of the output gap in the Taylor rule, compared to a scenario where the weight of the output gap is zero, puts additional pressure on prices by leading to higher consumption and investment.

More importantly, the presence of the output gap in the Taylor rule enables the *prevention destruction channel* of monetary policy to operate. The stimulus affects demand by lowering the wedge between the return to capital

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shock is.

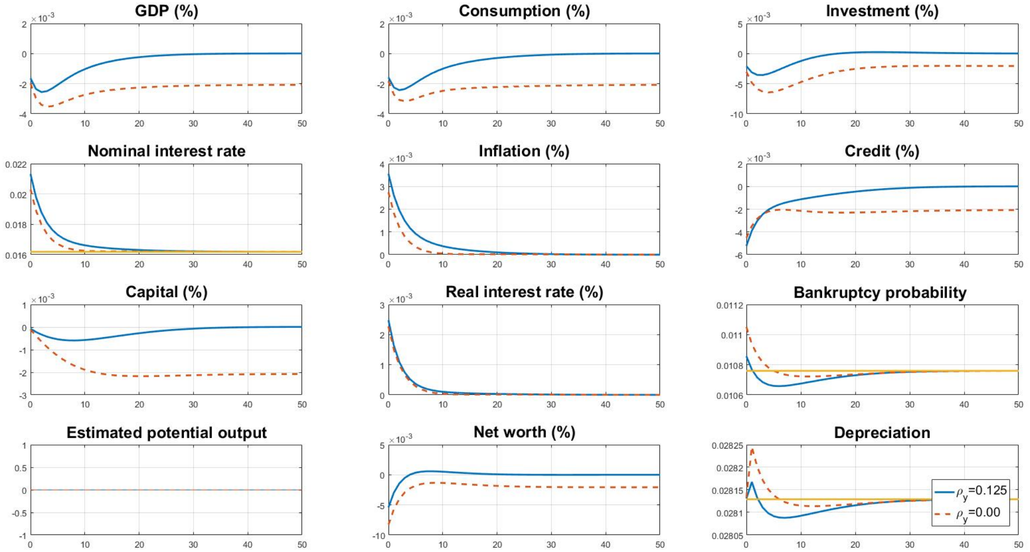

Figure 7: Effects of a 1% negative TFP shock

for successful entrepreneurs and the risk-less rate, thus effectively reducing the influence of financial frictions on the economy.[30] The condition for leverage (30), clearly shows that a fall in the wedge implies that financial intermediaries offer contracts with lower leverage for each feasible value of $\bar{\omega}$. In equilibrium, the entrepreneur then finds it optimal to pick a contract with lower leverage and lower $\bar{\omega}$, keeping a larger share of her returns. Bankruptcy is thus reduced, leading to less capital destruction. The spread between the interest rate on loans and the risk-less rate is also reduced as a consequence of the policy intervention, so that a positive weight on the output gap tames risk in the economy overall, sustains aggregate demand and prevents capital destruction, keeping

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[30] See Figure 12 in the Online Appendix.

Weight on the output gap	$\rho_y = 0$	$\rho_y = 0.125$
150 periods	-0.22%	-0.08%

Table 3: Welfare losses of TFP shock for different weights on the output gap

output and savings higher until the output gap closes. By preventing capital destruction monetary policy leads to a V-shaped recovery.

Table 3 shows the welfare gains associated to monetary policy.[31] For a pure inflation targeting Taylor rule, with $\rho_y = 0$, a minus 1% transitory TFP shock generates sizeable 0.22% (consumption equivalent) welfare losses. When the output gap is added to the Taylor rule, with standard (quarterly measured) $\rho_y = 0.125$, we find that following the mandate of economic stability in monetary policy interventions unequivocally improves welfare, more than halving welfare losses of recessions from 0.22% to 0.08% –see Table 3.[32]

6.2 Historical V-Shaped Recoveries

This section exemplifies the ability of our model to generate V-shaped recoveries in line with the recovery episodes that followed the 1974 and 1990 oil shock recessions.[33]

Shocks. Both recessions followed large oil price increases, concomitantly associated with strong declines on consumers confidence. We quantify oil shocks

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[31] In order to compute welfare gain and losses, we run the simulation with second-order perturbation methods.

[32] In the Online Appendix 3, we show that small demand shocks are also associated with V-shaped recoveries.

[33] We don't aim to replicate the 1980 oil shock because the recession was driven by the disinflation effort initiated by Paul Volker. Similarly, we do not attempt to replicate the the dot.com recession as it was primarily driven by the collapse of the equity market.

using the HP filtered cyclical component of the ratio between the GDP deflator and the U.S. Crude Oil Composite Acquisition Cost by Refiners, both expressed as indexes with 2012 set equal to one. For the confidence shocks, we consider the HP filtered cyclical component of the Michigan Consumer Sentiment index. In the simulations below, the size and persistence of both shocks in the 1974 and 1990 recessions map the observed movements in the above variables during both recessions.[34]

The 1974 Oil Shock Recession. In October 1973, the Organization of Arab Petroleum Exporting Countries (OAPEC, the Arab majority of the OPEC) announced large cuts in oil production and an oil embargo affecting the U.S., among other countries. By March 1974, when the embargo ended, oil prices had tripled. Such a disruption in oil supply and increase in oil prices led to a deep recession, cumulating a large decline in U.S. GDP between the last quarter of 1973 and the first quarter of 1975, the size of the U.S. output gap reaching 5% according to Fed and CBO data.

In order to characterise the recovery that followed the First Oil shock, we construct a measure of output gap by de-trending real GDP consistently with the methodology we followed for the Great Recession.[35] Figure 8 shows that de-trended GDP follows closely the CBO output gap despite expected differences in methodology as well as differences driven by data revisions, as documented by Orphanides (2003). More importantly, Figure 8 shows for both

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[34] Figures 13 and 14 in the Online Appendix show large negative oil and confidence shocks in 1974 and 1990, larger in 1974 and more persistent in 1990.

[35] GDP is linearly de-trended including data from two previous business cycle peaks, in line with CBO methodology.

measures of the output gap that the First Oil shock recession was followed by a V-shaped recovery, bringing GDP back to its previous track by the end of 1978.

Let us here use our baseline model to replicate the reaction of the U.S. economy to the 1979 oil shock.[36] In line with Rotemberg and Woodford (1996) and Herrera et al. (2019), we include oil in the model as an input of production. In our framework oil shocks are equivalent to TFP shocks, resulting in rising production costs and a reduction in GDP. We thus represent oil price shocks as TFP shocks, and set the size of the shock to generate a fall in GDP in line with data.[37] Consistently with the movements in oil prices and consumer's confidence reported above, we model the First Oil Shock as a negative 18% TFP shock and a negative 16% confidence shock, setting the persistence of the shocks to 0.82 and 0.7, respectively, in line with the persistence of the shocks in the data (approx 3 years for the oil shock and 2 years for the confidence shock). The left panel in Figure 8 compares the dynamics of the model with the CBO output Gap and our measure of de-trended GDP, and shows that the model replicates well the V-shaped recovery observed in the data.

The 1990 Recession. The 1990 recession was triggered by the Iraqi invasion of Kuwait in August 1990, lasting less than one year and leading to an increase in oil prices that was smaller and shorter than after the First Oil shock. However, the recovery was slow, as can be seen by comparing both

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[36] Note that we did not modify our baseline calibration for this exercise to ease comparison with previous results, but also because some key steady state moments remained in line with the data even considering previous time periods (see Table 1 in the Online Appendix).

[37] See the Online Appendix for a formal argument in favour of using TFP shocks to represent oil price shocks in our framework.

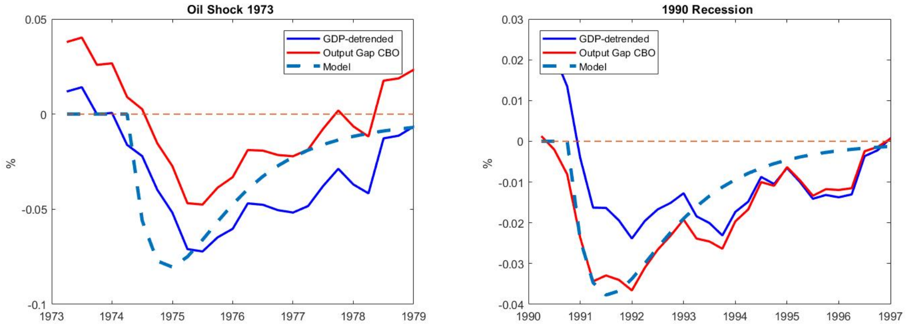

Figure 8: 1974 and 1990 Oil Shock Recessions - Model vs data

panes in Figures 8, and jobless –see Schreft et al. (2003). The fundamental reason is widely attributed to the persistent drop in confidence that followed the spike in oil prices. The Michigan consumer sentiment index shows longer persistence after the starting of the 1990 that after the start of the 1974 oil shock recession. Similarly to the 1974 excise, the right panel in Figure 8 compares to the CBO output gap and detrended GDP to the response of the model to a combined negative 15% TFP and 6% confidence shocks. The persistence of the shocks is 0.82 and 0.84, respectively, also in line with the persistence of the shock in the data (approx 3 years for the oil shock and 4 years for the confidence shock). The resulting dynamics follow closely the slow-V-shaped recovery in the data. Overall, these findings show that our model can generate V-shaped recoveries in line with historical episodes.

7 Conclusion

Our paper contributes to the literature by showing that an endogenous growth model can reproduce the dynamics of U.S. GDP well, once the role of monetary policy is taken into account. In our framework, the differentiating factors between the Great Recession and previous recessions were the size and persistence of the shocks, the extend of the subsequent capital destruction, the binding of the zero lower bound and the introduction of the *switching-track*. The dynamics of the COVID-19 crisis also support our narrative, as the shock was extremely large, but relatively short lived. Substantial monetary policy easing enacted by the Fed, coupled with little to no revision of potential output measures, led to a full V-shaped recovery in the United States.

This paper opens several avenues for future research. Firstly, it would be interesting to explore alternative endogenous growth channels, such as Research and Development driven growth. Secondly, we are keen to further investigate the destruction prevention channel of monetary policy and its implications for optimal monetary interventions. Lastly, this paper does not fully address the role of unconventional monetary policies implemented following the financial crisis. It would be interesting to explore this aspect, by evaluating further the impact of central bank credit policies on the recovery process in our model, following the example of Gertler and Karadi (2011).

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