Switching-track after the Great Recession Appendix for Online Publication

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1 Model-data Comparison and Data Sources

Taylor Rule: GDP is Real Gross Domestic Product, Billions of Chained 2012 Dollars, Seasonally Adjusted Annual Rate, inflation is Gross Domestic Product: Implicit Price Deflator, Index 2012=100, Seasonally Adjusted (percentage change from a year ago), FFR is the Effective Federal Funds Rate, Percent, Not Seasonally Adjusted. Potential output historical estimates were retrieved from the Congressional Budget Office website.

Data for Model Simulation Comparison: GDP is Real Gross Domestic Product, consumption is Real Personal Consumption Expenditures, investment is Real Gross Private Domestic Investment and private non-residential investment is Private Nonresidential Fixed Investment. All data was retrieved from the FRED database. All variables are expressed in billions of chained 2012 dollars, quarterly, seasonally adjusted annual rates and in per capita terms. Credit is Total Credit to the Non-Financial Corporations, adjusted for breaks, in billions of U.S. Dollars, divided by the GDP deflator. The nominal interest rate is the Effective Federal Funds Rate (quarterly averages). The bankruptcy probability is the estimated risk shock in Christiano, Motto, and Rostagno (2014).

Data for Model Steady State Comparison: All values are averages over the period 1980-2008Q2 or 2008 when data was available annually. The labour share is the average of the share of labour Compensation in GDP, and labour hours are the average of the time series average annual hours worked by persons engaged for United States, calculated as a percentage of total hours in the year. GDP growth per capita was retrieved from FRED (BEA data) and the investment to GDP ratio is calculated in real terms from BEA data. The real interest rate data was retrieved from the World Bank database. The interest spread is the corporate bond credit spread constructed by Gilchrist and Zakrajšek (2012), *i.e.*, the average difference between the interest rate on firm specific loans in COMPUSTAT and the rate the U.S. government would have paid for a comparable maturity. Leverage is proxied by the average of real debt over real assets for the Non-financial private sector in COMPUSTAT, where total assets were deflated using the BEA investment deflator, whilst total debt was deflated using the GDP deflator.

Moment (%)	Model	U.S. Data 1950-1973	U.S. Data 1980-1990	U.S. Data 1980-2008
Labour share	60.8	63.4	61.2	61.0
Labour hours	20.0	22.0	20.0	20.5
Growth GDPpc (quart.)	0.6	0.6	0.5	0.5
Investment share	12.0	11.0	14.0	15.0
Real interest rate (pp)	1.6	0.6	1.7	0.6
Interest spread	1.2	–	1.2	1.6
Leverage	0.5	–	0.3	0.5

Table 1: Aggregate data and model steady state values

The first column in Table 1 reports some key moments of the benchmark simulation. The following columns report the same moments of the data for the periods before the 1974 Oil shock, the 1990 Oil shock and the Great Recession. The latter period was used to calibrate the benchmark model.

2 What if We Relax the AK Assumption?

In the benchmark simulation, we assume $\eta = 1-\alpha$, which implies an aggregate AK technology. Is such a strong assumption necessary to generate our results? To test this, we simulate the model for lower values of η.[1] We pick $\eta = 0.06$ to get a quasi standard Cobb-Douglas technology. As expected, when this version of the model is subject to comparable shocks to simulate the Great Recession, and we keep potential output constant to reproduce a more standard DSGE, the model generates a quick and full recovery.[2] The AK technology, and not the nature of the shocks, is the source of the parallel downward shift of GDP in this model.

We then try an intermediate case, setting $\eta = 0.6$ to get closer to an AK model, and allowing potential output revisions. Figure 1 shows that the shocks result in a persistent recession of reduced depth. Although this version of the model could be a good representation of GDP dynamics in the presence of additional shocks, we prefer our baseline specification, as it captures key aspects of the Great Recession in a parsimonious way.

[1]Note that in this case the model does not grow endogenously any more, implying that the growth rate of the economy converges to zero.

[2]The model would also generate a similar recovery if we reduced the weight of the output gap in the Taylor rule, as the recovery is a consequence of diminishing returns to capital.

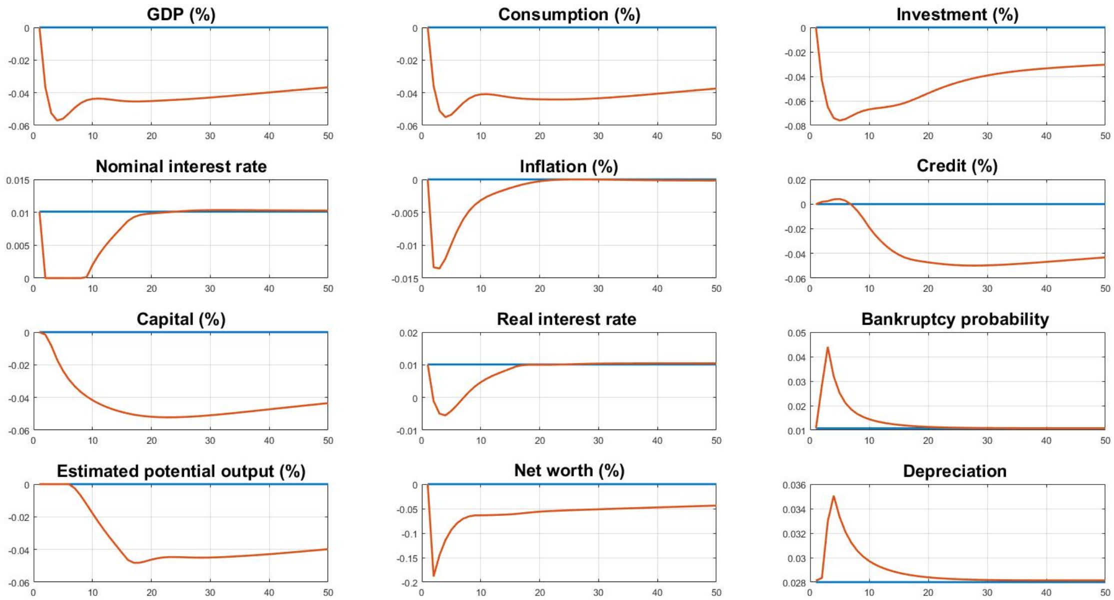

Figure 1: Great Recession shock for $\eta = 0.6$

3 Demand Shocks

This appendix aims to represent demand shocks in normal times, which we characterise as periods subject to shocks that are not as severe and persistent as during the Great Recession. We target an increase in the bankruptcy probability of approximately 0.5 percentage points, to mirror Christiano's estimation for the recessions preceding the financial crisis. Thus, we opt for a 5% increase in risk combined with a 4.5% confidence shock and we reduce the persistence of shocks to 0.7. This is close to pre-Great Recession estimates on confidence shocks documented by Angeletos et al. (2018) and with the analysis of Christiano, Eichenbaum, and Trabandt (2015), who illustrate the increased

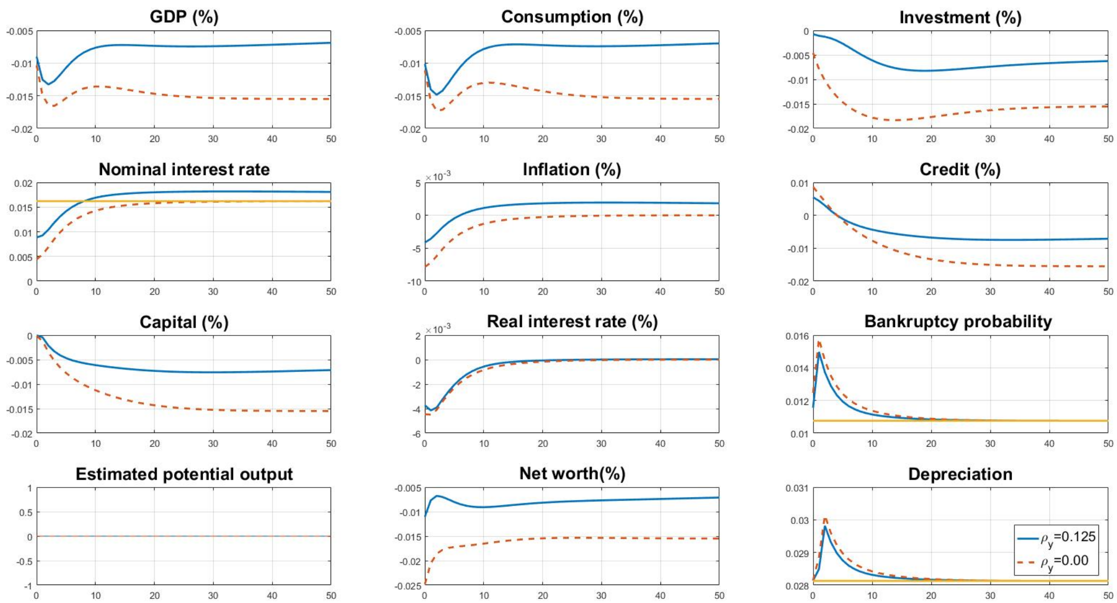

Figure 2: Effects of a small demand shock

persistence of financial shocks during the Great Recession compared to previous downturns. Figure 2 shows that monetary policy drives a V-shaped type of recovery, although the economy will not converge back to the previous steady state within the 50 quarters period. Since we assume that potential output is never revised, the economy will eventually converge to the previous trajectory. In any case, the remaining output gap is small enough not to be perceived as a change of trajectory resulting from the demand shock. In order to understand the mechanics behind the recovery role of monetary policy, it is useful to think about the policy in place as a force counteracting the negative shocks. As the demand shock hits and GDP falls, a larger output gap gives the policy strength, but as the recovery starts to materialise and inflation recovers, the monetary authority faces a trade-off between above target inflation and a negative output gap. The higher weight on inflation in the Taylor rule results in a slowdown in the recovery, although GDP will eventually go back to the initial steady state.

4 Alternative Taylor Rules

In our model, the Taylor rule plays a critical role in shaping economic recoveries.[3] On one side, the existence of a V-shaped recovery relies on the assumption that the weight given to the output gap in the Taylor rule is positive and strong enough to bring the economy back to its original potential output track after a negative supply or demand shock. On the other side, the existence of an L-shaped recovery relies on the revision of potential output estimates during deep and persistent downturns, *i.e.* the *switching-track*. As a result, in our model the shape of economic recoveries critically depends on the specification of the Taylor rule and on the monetary authority's information set when measuring the output gap. In this section, we discuss whether there are alternative rules consistent with the behaviour of the Fed that would call into question our conclusions on the dynamics of economic recovery.

In the note Vinci and Licandro (2021) we show that the classic Taylor rule can adequately summarize the Fed's policy making, supporting our claim

[3] In an AK growth model, the intercept of the balanced growth path for GDP is indeterminate, and pinned down by the initial value of capital and capital accumulation in the transition to the stationary growth rate (the slope of the GDP balanced growth path). A monetary policy set to stabilise the output gap when facing negative supply or demand shocks, increases the intercept of the new balanced growth path by accelerating growth in the transition.

that monetary policy interventions play a critical role in shaping economic recoveries. Nonetheless, the impact of economic activity on monetary policy, as represented by the Taylor rule, could be modelled in different ways. Two other measures of economic activity are widely considered as alternatives to the output gap in the Taylor rule: the unemployment gap and the growth gap. The former is measured as the difference between the unemployment rate and the non-accelerating inflation rate of unemployment (NAIRU), while the latter is measured as the gap between the actual and the long term growth rate. Could these different alternative specifications alter the key result of this paper, *i.e.* that the Taylor rule shapes economic recoveries? Is there an alternative rule, consistent with the historical behaviour of the Fed that would not generate a V-shaped recovery in our model? Firstly, it is important to stress that the NAIRU is estimated similarly to potential output, so that the unemployment gap in the data looks like the mirror image of the output gap, as shown by the left panel of Figure 3.[4] As a consequence, when accurately modelling unemployment, a Taylor rule targeting the unemployment gap will likely yield similar results as a Taylor rule targeting the output gap.[5]

As for the growth gap, we measure it as the distance between quarterly GDP growth, year on year, and the long term growth rate of 2.2%. The resulting growth gap is depicted in the right panel of Figure 3, and although it clearly moved in line with the output gap, it tends to shrink faster. Incorporating the growth gap in the Taylor Rule in our model would then provide

[4]Unemployment data was retrieved from the U.S. Bureau of Labor Statistics, while the NAIRU estimate is taken from CBO data.

[5]We do not run this type of exercise using our framework since there is no unemployment in our model.

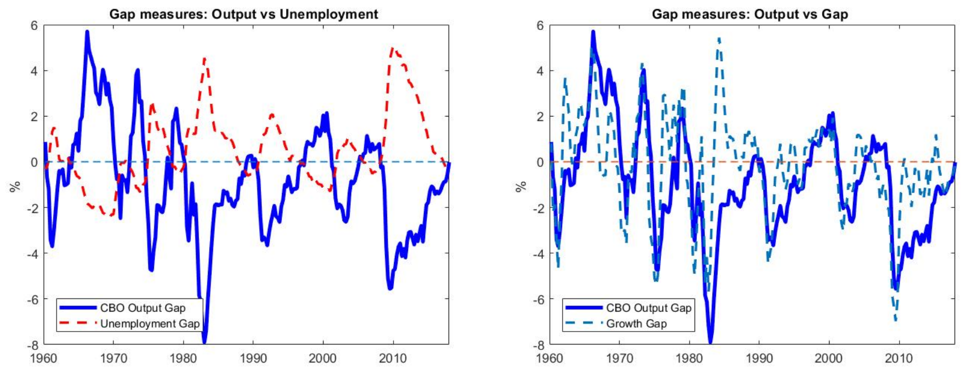

Figure 3: Alternative output gap measures

less stimulus after negative shocks, which might not be enough to generate V-shaped recoveries before the Great Recession.

To do this, we substitute the Taylor Rule in the model with a growth rule[6]

$$R_t = \bar{R} + \rho_\pi(\pi_t - \bar{\pi}^m) + \rho_y \log\left(\frac{\widehat{\mathrm{GDP}}_t}{\widehat{\mathrm{GDP}}_{t-4}}\right). \tag{1}$$

We then run the model to replicate the 1974 and the 1990 oil driven recessions. Figure 4 shows that the model still generates a V-shaped recovery, but this is incomplete, as GDP fails to reach its previous steady state. Nevertheless, the distance is small. If we were to increase the persistence of the shocks then model results would start to diverge more significantly. Overall, these findings suggest that a growth Taylor Rule and an output gap Taylor Rule are almost equivalent with moderate shocks consistent with historical data, validating the thesis that V-shaped recoveries were policy driven.

[6] Output is de-trended in steady state in our model, hence growth is null. Consequentially, the year on year growth gap is equivalent to the deviation of the log of de-trended GDP from its fourth lag.

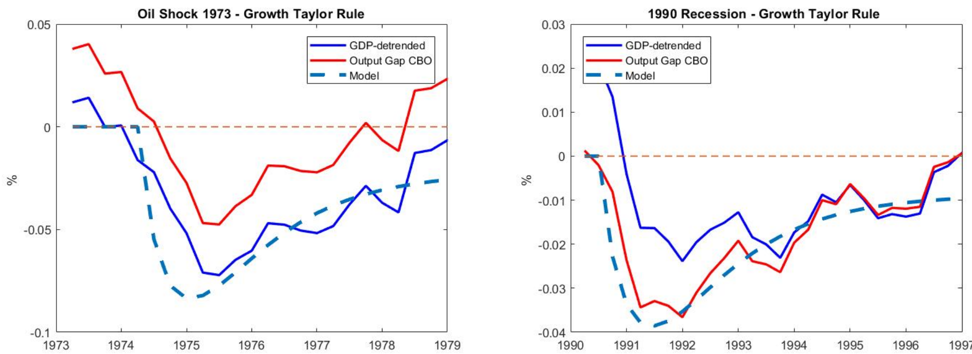

Figure 4: 1974 and 1990 Oil Shock Recessions - Model vs data

5 Taylor Rule Mechanics

With a positive weight in the output gap, the Taylor rule implies that a negative output gap will put pressure on the nominal interest rate to fall. However, in our simulations we find that adding to the Taylor rule a positive weight on the output gap generates higher nominal interest rates and inflation in equilibrium, compared to pure inflation targeting (see Figure 7 in the main text and Figure 2). More importantly, the real interest rate is also higher, depressing economic activity instead of promoting it. This appears to be puzzling. In order to understand how a positive weight on the output gap can generate an increase in both the nominal interest rate and inflation, we propose a simple exercise of comparative statics. In our model, as in the standard New Keynesian model, the nominal interest rate and inflation are determined by the intersection of the Euler equation and the Taylor rule. These can be represented by the following linear relationships between inflation and the nominal interest rate, ignoring the ZLB constraint,

$$\text{Taylor rule} : R = \frac{1+gz}{\beta} + 1.5\ (\pi - \bar{\pi}) + 0.125\ \log\left(\frac{G\hat{D}P_t}{G\bar{\hat{D}}P}\right) \tag{2}$$

$$\text{Euler equation} : R = \frac{1+gz}{\beta}\frac{\hat{\lambda}_t}{\hat{\lambda}_{t+1}}\frac{\pi_{t+1}}{\pi_t}\ \pi. \tag{3}$$

At any period t, equilibrium inflation π_t and nominal interest rates R_t are the pair $\{\pi, R\}$ that solves (2) and (3). The straight-lines crossing point SS in both plots in Figure 5 represent (2) and (3) at the non-stochastic steady state.

How would equilibrium change if we considered the response of the economy to a TFP shock? To answer this question, we use values of $\frac{\hat{\lambda}_t}{\hat{\lambda}_{t+1}}$, $\frac{\pi_{t+1}}{\pi_t}$ and $\frac{G\hat{D}P_t}{G\bar{\hat{D}}P}$ from our baseline TFP shock simulation at times 1 and 5 to plot (2) and (3). The left panel in Figure 5 represents both equations in a pure inflation targeting economy –when zeroing the coefficient of the output gap in (2). As the shock hits, the Taylor rule does not move but the Euler equation moves upwards, and then gradually comes back to the initial value. The transition is consistent with the IRFs in of a the TFP shock, resulting in a temporary increase in the nominal interest rate and inflation. The real interest rate goes up during the transition, since the slope of the Taylor rule is larger than one.

We repeat the exercise for the scenario in which the weight on the output gap is positive. The right panel in Figure 5 shows that in this case the Taylor rule shifts to the right as the output gap pushes the intercept down, so that R_t and π_t are higher in equilibrium at time 1, compared to the pure inflation targeting case. More importantly, the effect on the real interest rate relative to the pure inflation targeting scenario depends on the slope of the Euler equation, in turn effected by aggregate shocks and the policy intervention.

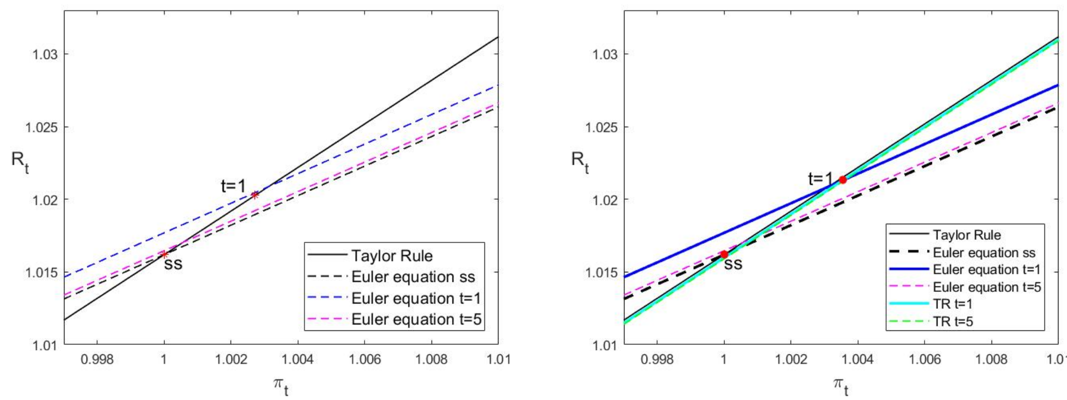

Figure 5: TFP shock mechanics with no weight on the output gap

This simple exercise shows that a positive weight on the output makes the the monetary authority offer a lower nominal interest rate for each level of inflation, stimulating substitution from savings to consumption through the Euler equation. The resulting dynamic can entail a larger interest rate compared to inflation targeting, but this equilibrium result does not imply a contractionary policy impact.

6 Energy

In order to account for oil price shocks in our model, we draw inspiration from papers in the literature who explicitly model energy as a production input (see for example Rotemberg and Woodford (1996) and Herrera et al. (2019)).

Let energy be a production input for intermediate producers, with $e(i)$ representing the consumption of energy by firm i –let us omit the time index t to simplify notation. The supply of energy is infinitely elastic at price p_e. Let us then add energy $e(i)$ to the production technology so that:

$$y(i) = AaK^{\eta}e(i)^{\beta}\Big(\underbrace{k(i)^{\alpha}h(i)^{1-\alpha}}_{x(i)}\Big)^{1-\beta}, \tag{4}$$

where $\beta \in (0,1)$ represents the energy share in production and $A > 0$ is an arbitrary constant. We will solve the problem in two stages. In the first stage, and following the same logic as in the main text, there exist a marginal cost $p_x = \alpha^{-\alpha}(1-\alpha)^{1-\alpha}(r^k)^{\alpha}w^{1-\alpha}$ that minimizes the cost of producing one unit of $x(i)$. Notice that $x(i)$ represents the value added generated by i and p_x represents its shadow price. Since capital and labour services are homogeneous, p_x is the deflator of value added.

In the second stage, and following a similar logic, firm i chooses $e(i)$ and $x(i)$ in order to minimize the cost of producing output $y(i)$. From the first order conditions of the minimization problem

$$\frac{e(i)}{x(i)} = aK^{\eta}\left(\frac{p_x}{p_e}\right)^{\beta} x(i),$$

under the normalisation assumption that $A = \left(\frac{\beta}{1-\beta}\right)^{-\beta}$. After substitution of this equation in (4), production of good i becomes

$$y(i) = \underbrace{a\left(\frac{p_x}{p_e}\right)^{\beta} K^{\eta}}_{\text{TFP}}\ \Big(\underbrace{k(i)^{\alpha}h(i)^{1-\alpha}}_{x(i)}\Big).$$

We can then interprete shocks to the energy price (relative to the GDP deflator) as TFP shocks. Consequentially, an oil price shock will reflect in a

TFP shock, bringing about a fall in GDP and a rise in production costs. To replicate the reaction of the model to the oil shock recessions, we then impose a TFP shock, combined with and confidence shock to capture the observed fluctuations in consumer sentiment.

7 Capital Quality

In this section we compare the depreciation rate in our model for the Great Recession to a measure of capital quality constructed by Kozlowski, Veldkamp, and Venkateswaran (2020). They employ the Fed's Flow of Funds data for non-financial assets held by corporations, at market value (MV) and historical cost (HC). We replicate their methodology with quarterly series, assuming the depreciation rate to be at our steady state value. They define a capital quality shock as a decline in the productive value of installed capital, which is equivalent to a rise in depreciation in our model. Assuming: $k_t = \phi_t \hat{k}_t$, the capital used in production k_t depends on the installed capital $\hat{k}_t$ and the shock ϕ_t, equal to 1 in normal times.

Let us denote by k_t the stock of capital at the end of period t, and by x_t and p_t real investment and the price of capital at time t, respectively. Past capital (net of depreciation) and current investment cumulate in $\hat{k}_t$ that suffers a quality shock ϕ_t before becoming the end of period capital k_t, *i.e.*:

$$\hat{k}_t = x_t + (1 - \delta) k_{t-1} \qquad \text{and} \qquad k_t = \phi_t \hat{k}_t. \tag{5}$$

Kozlowski et al. (2020) assume that historical capital is measured following

$$\mathrm{HC}_t = p_{t-1}x_t + (1-\delta)\mathrm{HC}_{t-1}. \tag{6}$$

Then, assuming $p_t k_t = \mathrm{MV}_t$, from (5) and (6) we can recover

$$p_{t-1}\hat{k}_t = (1-\delta)p_{t-1}k_{t-1} + p_{t-1}x_t = (1-\delta)\mathrm{MV}_{t-1} + \mathrm{HC}_t - (1-\delta)\mathrm{HC}_{t-1}.$$

then using the non-residential investment deflator from BEA:

$$\phi_t = \frac{k_t}{\hat{k}_t} = \frac{p_t k_t}{p_{t-1}\hat{k}_t}\frac{PriceIndex_{t-1}}{PriceIndex_t}.$$

The resulting measure has an average value of 1.01 in the interval we consider, and displays a large negative realization in conjunction with the Great Recession. This mostly captures variations in the market value of structures, as the methodology behind the data adjusts the market value of commercial real estate. In this sense, this series complements Lanteri (2018)'s data, which was informative as to the value of equipment.

Mapping into our model, $\phi_t = \frac{1-\delta_t}{1-\delta}$. We normalise the data to average 1 to ease comparison, and Figure 6 shows that our model is consistent with the dynamics of the data. The magnitude of the model's fall in capital value is considerably smaller compared to the constructed measure, confirming our conservative approach.

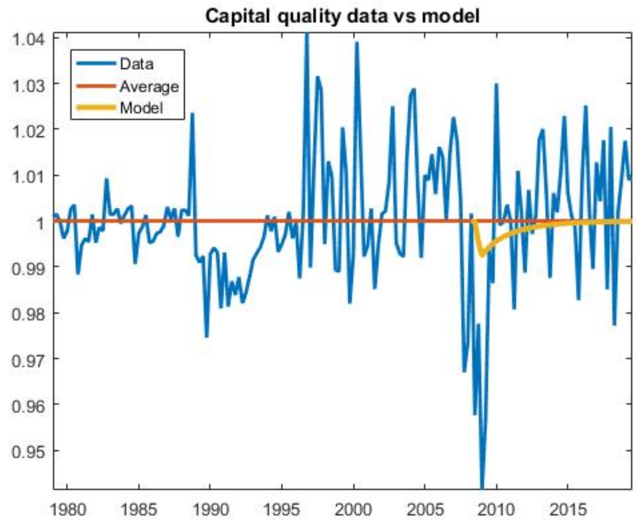

Figure 6: Capital quality measure from Kozlowski et al. (2020) in the data and the model

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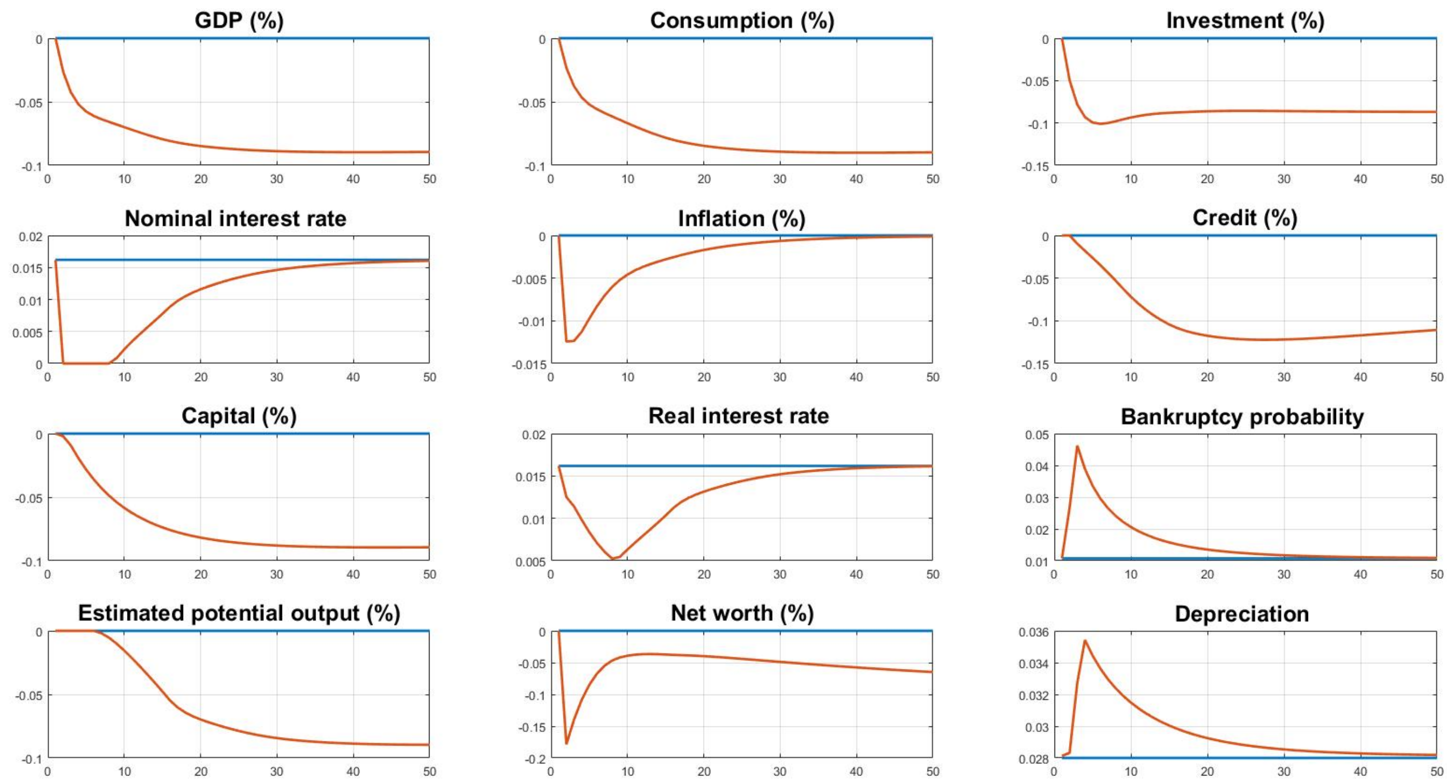

Figure 7: The Great Recession (baseline): Quarterly model simulations

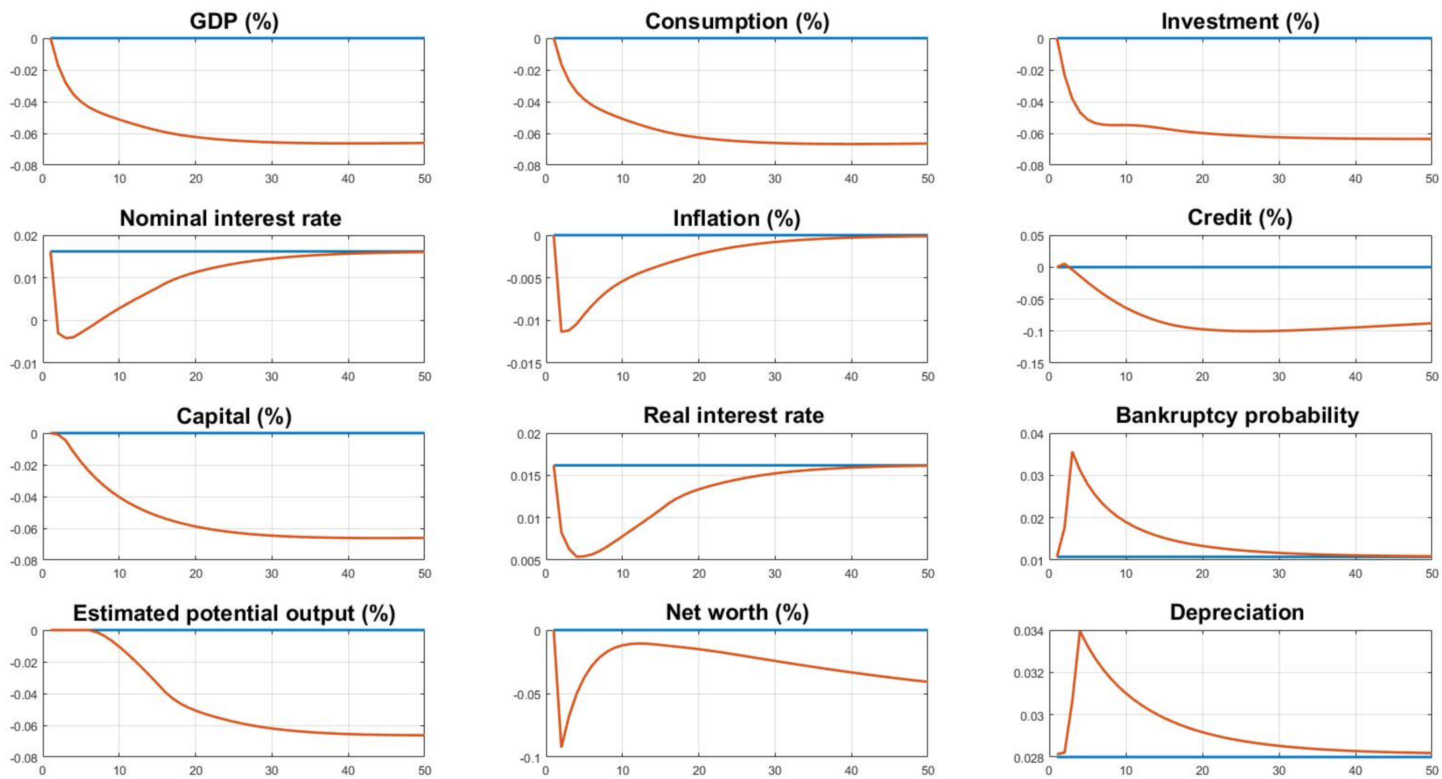

Figure 8: The Great Recession: Quarterly model simulations, without the ZLB constraint

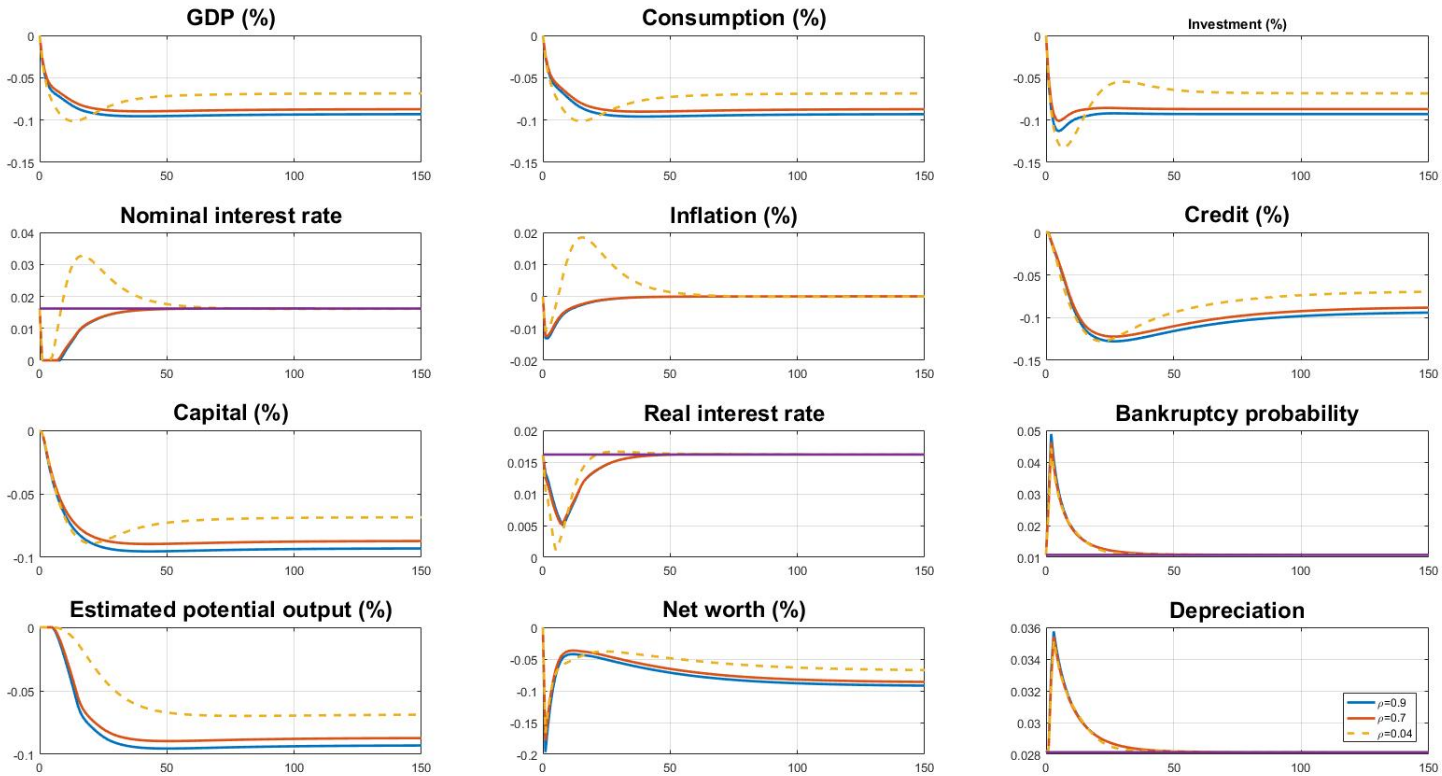

Figure 9: The Great Recession for different values of potential output revision intensity

Note that GDP, consumption and investment fall more as the shock hits when the revision of potential output is slower than baseline, *i.e.* the policy intervention is stronger. This is a consequence of the ZLB binding, as stronger demand stimulus generates higher inflation compared to the baseline, resulting in a sharp fall in the real interest rate with a binding ZLB. The latter provides stimulus to the marginal utility of consumption, but results in a sharper contraction in the labour supply, negatively affecting the level of economic activity. As soon as the nominal interest rate leaves the ZLB, the real interest rate re-bounces and monetary policy generates a partial recovery.

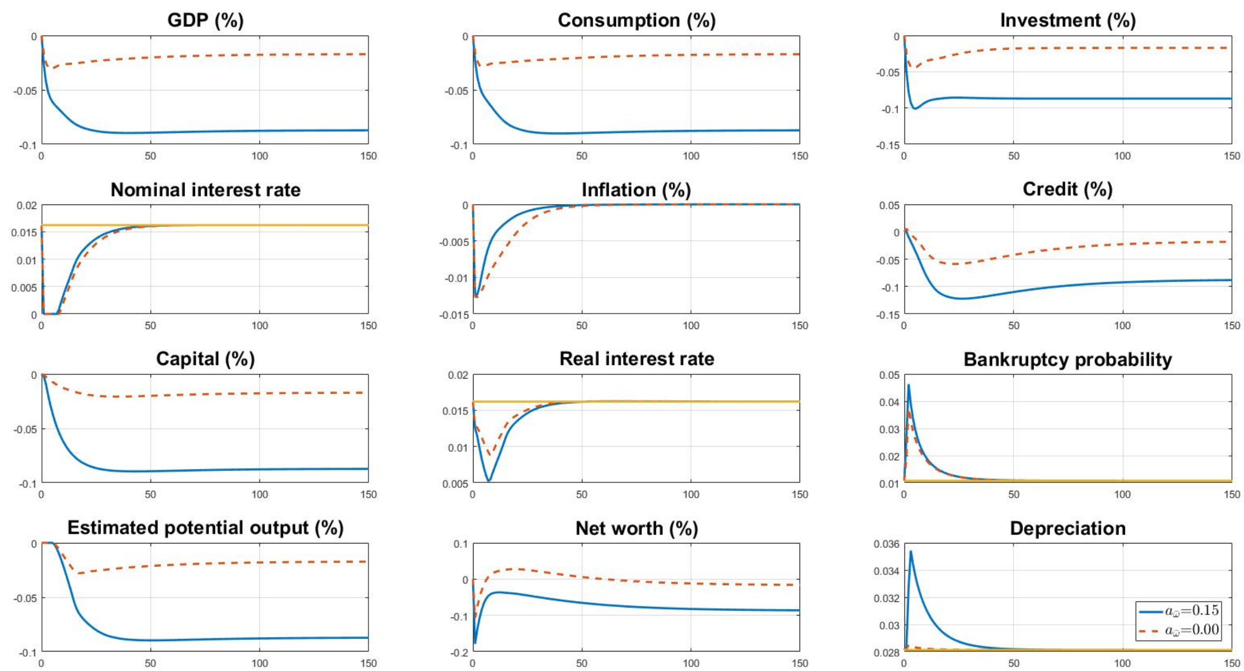

Figure 10: Baseline simulation vs case without disruption spillovers

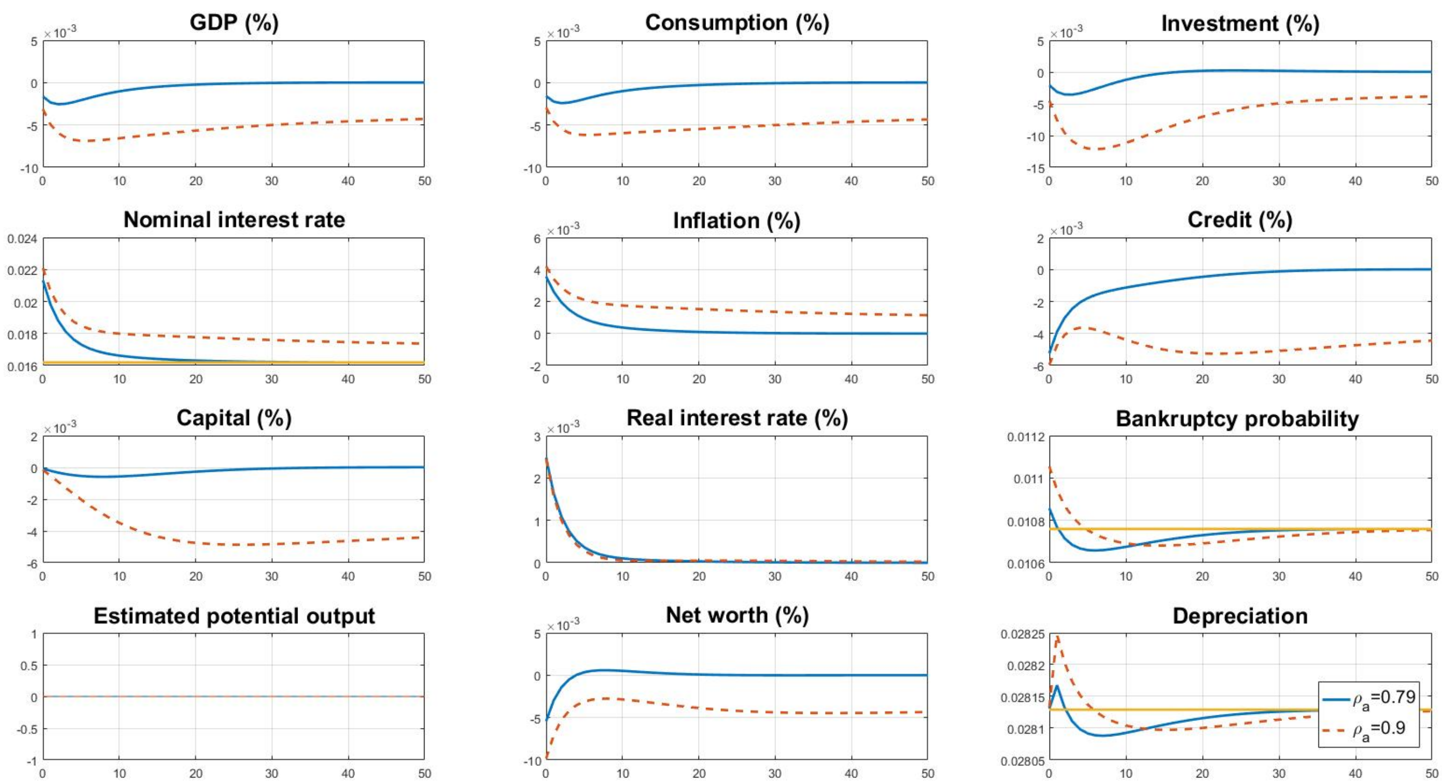

Figure 11: TFP shock for different values of persistence: Baseline calibration

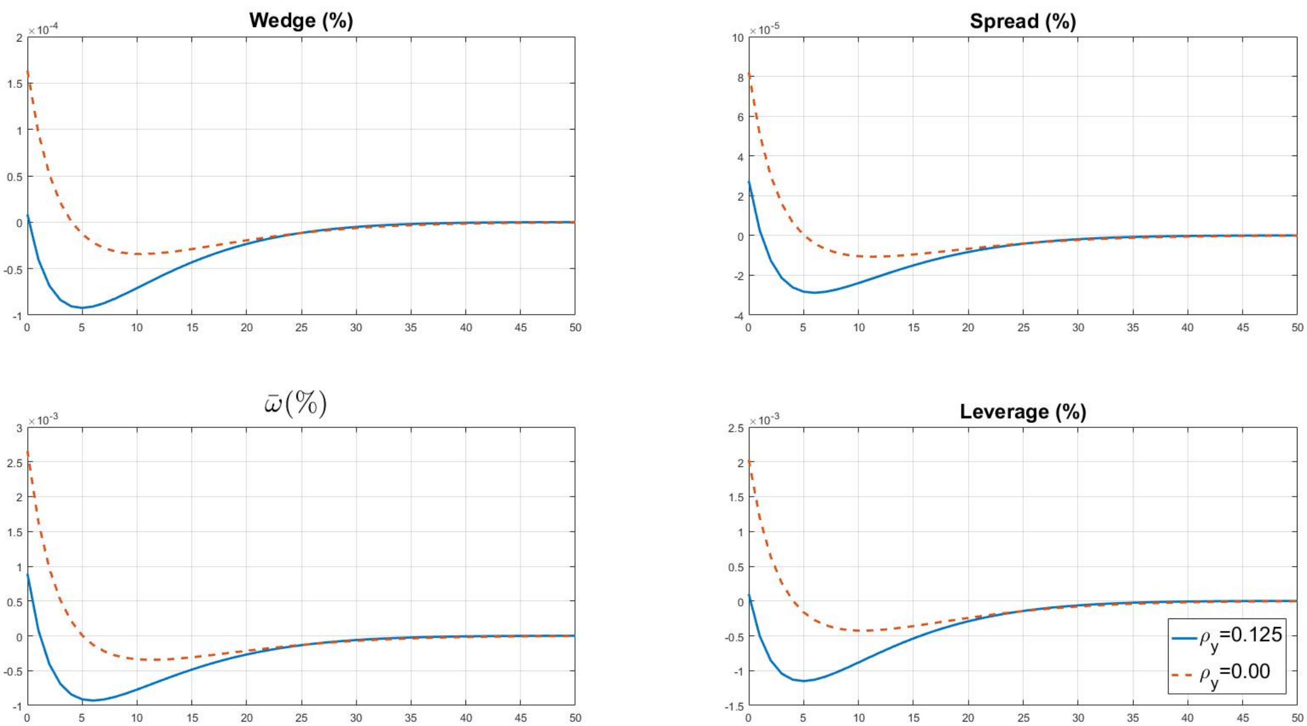

Figure 12: TFP shock: Additional variables

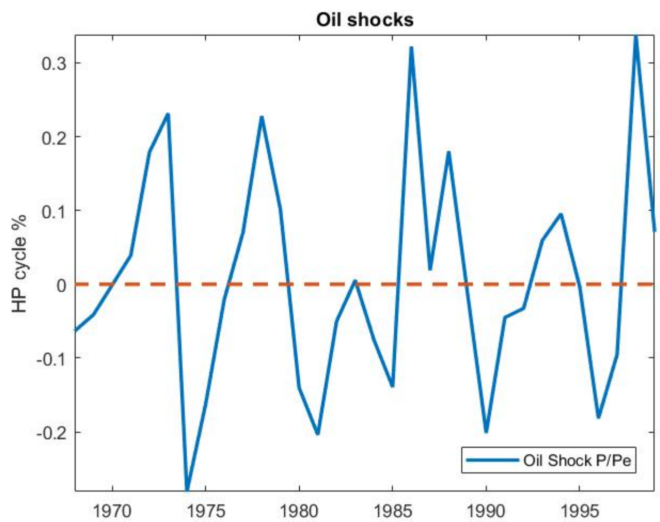

Figure 13: Oil shocks measure

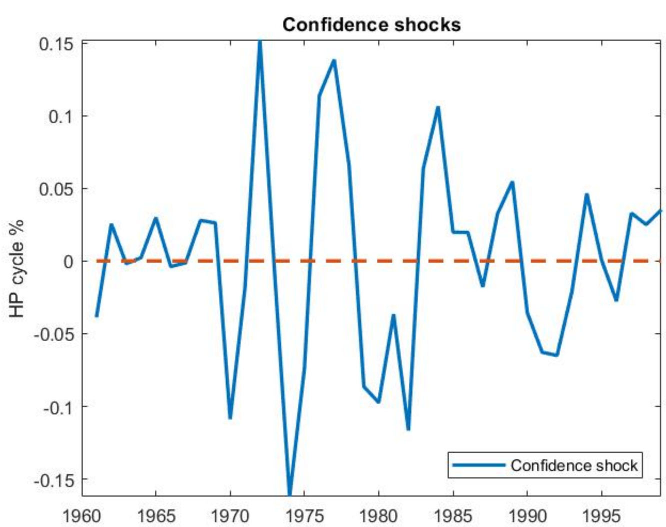

Figure 14: Confidence shocks measure