The long-run effects of monetary policy[*]

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Abstract

A well-worn tenet holds that monetary policy does not affect the long-run productive capacity of the economy. Merging data from two new international historical databases, we find this not to be quite right. Using the trilemma of international finance, we find that exogenous variation in monetary policy affects capital accumulation, and to a lesser extent, total factor productivity, thereby impacting output for a much longer period of time than is customarily assumed. These results are robust to sample cuts, accounting for structural breaks in TFP growth, spillovers across countries, and miscellaneous robustness checks. Monetary policy can have long-run effects.

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When coin is in greater plenty, as a greater quantity of it is required to represent the same quantity of goods, it can have no effect either good or bad, taking a nation within itself, any more than it would make an alteration in a merchant's books; if instead of the Arabian method of notation, which requires few characters, he should make use of the Roman, which requires a great many.

— *Of Money* in Hume (1758)

1. Introduction

Money has long been believed to be neutral in the long-run, as David Hume noted, and as a voluminous literature on monetary economics has argued more formally with rare exceptions.[1] However, the evidence is less clear cut than the elegant logic of the predominant theories would suggest. Barro (2013) provides evidence that high levels of inflation result in a loss in the *rate* of economic growth. Work by Caballero, Hoshi, and Kashyap (2008) and Gopinath, Kalemli-Özcan, Karkarabounis, and Villegas-Sánchez (2017) links interest rates to the *level* of productivity, whereas more recently, Benigno and Fornaro (2018) and Liu, Mian, and Sufi (2018) link low interest rates with the rate of *growth* of productivity. Our paper follows in this more recent tradition and sets out to investigate the link between monetary policy, the growth rate of productivity, and the growth rate of output in the medium to long term.

In monetary economics, most theories embrace the assumption that an exogenous shock to interest rates has only transitory effects on prices and economic activity (see, e.g., Christiano, Eichenbaum, and Evans, 1999; Ramey, 2016; Coibion, Gorodnichenko, and Ulate, 2017). However, recent research by Jordà, Schularick, and Taylor (2019) suggests that previous measures of monetary shocks might have been endogenous responses to the outlook. They introduce a new instrumental variable based on the trilemma of international finance (see, e.g., Obstfeld, Shambaugh, and Taylor, 2004, 2005; Shambaugh, 2004) to document that monetary shocks have larger and more persistent effects than previously measured, and closer in magnitude to measures obtained with narrative shocks (Romer and Romer, 2004) and market-based, high-frequency identified shocks (Gertler and Karadi, 2015). Moreover, they also document that the effects of monetary policy are state-dependent, extending similar results reported in Tenreyro and Thwaites (2016), Angrist, Jordà, and Kuersteiner (2018), and Barnichon and Matthes (2018).

Using the same instrument as Jordà, Schularick, and Taylor (2019) we show, using historical data since 1870 on 17 advanced economies, that monetary shocks have very long-lasting effects on output and productivity. In particular, we augment the data in Jordà, Schularick, and Taylor (2017) and available at `www.macrohistory.net/data`, with data on total factor productivity (TFP) and factor input from Bergeaud, Cette, and Lecat (2016) and available at `http://www.longtermproductivity.com`.[2]

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[1]See, for example, the discussion of Sidrauski's work by Fischer (1983).

[2]We are particularly thankful to Antonin Bergeaud for sharing some of the disaggregated series from their database that we used to construct our own series of adjusted TFP.

We investigate this proposition from a variety of angles, by correcting for spillover effects, considering different samples, and examining state dependence as a function of the business cycle, the level of inflation, and importantly, credit. We also examine the soundness of our findings to alternative definitions of monetary shocks based on Romer and Romer (2004) for the postwar United States. The main result is robust to all these modifications. We then look under the hood to examine through what channels is monetary policy exacting these changes on output growth. We find that the total hours worked response is relatively stable and small. Thus, the main effects on output growth that we uncover appear to come primarily through the responses of real capital accumulation, and to a lesser extent, of utilization adjusted TFP. These results echo the important early findings by Evans (1992) who cast doubt on the exogeneity of TFP shocks, a key tenet of mainstream DSGE models, finding that money, interest rates, and government spending Granger-caused these impulses.

Motivated by these findings, we build a quantitative medium-scale DSGE model with endogenous TFP growth to understand the mechanisms at work and spell out policy implications. TFP growth deviates from the exogenous trend in response to monetary shocks whenever output is different from potential output. A contractionary monetary policy shock lowers output temporarily producing a slowdown in TFP growth. Under a standard Taylor rule, the temporary slowdown in TFP growth accumulates to yield permanently lower trend levels of output and capital. The model can generate this medium run effect on GDP while replicating the conventional textbook results, namely the utilization rates of labor and capital fall temporarily, and capital to TFP ratio exhibits a hump-shaped response. In our empirical analysis, we corroborate these conventional results (Christiano, Eichenbaum, and Evans, 2005) for the historical sample.

Our paper is related to the seminal work by Cerra and Saxena (2008) who documented that output losses in the aftermath of economic and political crises in low-income and emerging economies are highly persistent. More recently, researchers have also documented similar effects following financial crises for advanced economies (see Martin, Munyan, and Wilson, 2015; Haltmaier, 2013). Duval, Hong, and Timmer (2019) find cross-country firm-level evidence for slowdown in TFP growth caused by adverse credit conditions during the global financial crisis. Fatás and Summers (2018) document strong hysteresis effects of fiscal consolidations for advanced economies following the global financial crisis. Over the much longer run, we document a causal effect of monetary policy shocks in a historical panel data for advanced economies.

There is mixed evidence of long-run non-neutrality proposition in monetary economics. In the structural VAR literature, Bernanke and Mihov (1998) fail to reject long-run neutrality in their identified responses to monetary policy shocks since the impulse responses are statistically indistinguishable from zero. Mankiw (2001) however interprets the non-recovery of GDP to zero in Bernanke and Mihov (1998)'s point estimates as evidence of long-run non-neutrality.

Our paper is also related to the recent literature that emphasizes slow recovery following the Great Recession due to endogenous productivity growth (Anzoategui, Comin, Gertler, and Martinez, 2018; Bianchi, Kung, and Morales, 2019), labor force participation (Erceg and Levin, 2014; Galí, 2016), or skill depletion (Kiyotaki and Zhang, 2017). This literature has its origins in the seminal work by

Stadler ([1990](#)) who developed a business cycle model with endogenous technology and sticky wages to generate a persistent effect of monetary shocks on output.[3] Of the recent papers, Moran and Queraltó ([2018](#)) use three-equation VAR models to emphasize an empirical link between TFP growth and monetary policy shocks. We differ in two important ways. One, we investigate and establish that monetary policy shocks can affect level of GDP, capital stock as well as TFP in a panel of 17 countries spanning more than a hundred years. Two, we use externally identified shocks instead of ordering restrictions to identify monetary policy shocks.

Our analysis further provides answer to questions raised by policymakers including Chair Yellen ([2016](#)) recently:

> Are there circumstances in which changes in aggregate demand can have an appreciable, persistent effect on aggregate supply?.... More research is needed, however, to better understand the influence of movements in aggregate demand on aggregate supply.

Aggregate demand shocks, particularly monetary policy shocks, do indeed have long-lasting effects on the level of output, capital stock and TFP in the economy.

2. DATA AND SERIES CONSTRUCTION

The empirical features motivating our analysis rest on two major international and historical databases. Data on macro aggregates and financial variables, including assumptions on exchange rate regimes and capital controls can be found in www.macrohistory.net/data. This database covers 17 advanced economies reaching back to 1870 at annual frequency. Detailed descriptions of the sources of the variables contained therein, their properties, and other ancillary information are discussed in Jordà, Schularick, and Taylor ([2017](#)) and Jordà, Schularick, and Taylor ([2019](#)), as well as references therein. Importantly, we will rely on the trilemma instrument discussed in Jordà, Schularick, and Taylor ([2016](#)), and more recently, Jordà, Schularick, and Taylor ([2019](#)) as the source of exogenous variation in interest rates. We briefly describe the instrument construction below but refer the reader to the last reference for a detailed analysis.

The second important source of data relies on the work by Bergeaud, Cette, and Lecat ([2016](#)) and available at http://www.longtermproductivity.com. This historical database adds to our main database observations on capital stock (machines and buildings), hours worked, and number of employees, and the Solow residuals (raw TFP). In addition, we construct time-varying capital and labor utilization corrected series using the procedure discussed in Imbs ([1999](#)) with the raw data from Bergeaud, Cette, and Lecat ([2016](#)) to construct our own series of utilization-adjusted TFP. We went back to the original sources so as to filter out cyclical variation in input utilization rates in the context of a richer production function that allows for factor hoarding. We explain the details of this correction below.

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[3]See also Fatas ([2000](#)) and Barlevy ([2004](#)).

2.1. Instrument construction

Jordà, Schularick, and Taylor (2019) developed a quasi-natural experiment utilizing the theory of trilemma in international finance: a country with fixed nominal exchange rates and open capital flows loses monetary independence. Variations in the base country interest rates can be used as an instrumental variable to identify exogenous monetary shocks to an open peg country.

The sample is split into three group of countries, *bases* whose currency serve as the anchor for the second group of pegging economies, labeled as the *pegs*, and *floats* are the final group of countries that allow their currency to be freely determined in the market. A country i is defined to be in a peg $q_{i,t} = 1$ at date t if it maintained a peg at dates $t-1$ *and* t. This conservative definition serves to eliminate opportunistic pegging due to country's monetary conditions. In order to construct the instrument, changes in short term nominal interest rate in the base country are first sterilized to remove the component that can be explained by economic conditions in that country. The resulting variation is adjusted for capital openness.

More formally: let $\Delta r_{i,t}$ denote the changes in short term interest rate in country i at date t, $\Delta r_{b(i,t),t}$ be the change in short term interest rate in country i's base country $b(i,t)$ at time t and $\Delta \hat{r}_{b(i,t),t}$ denote the predictable component of variations in base rate. Recognizing that countries are not perfectly open to capital flows, adjustment for capital mobility is constructed using the continuous version $k_{i,t} \in [0,1]$ of capital openness index of Quinn, Schindler, and Toyoda (2011). The resulting instrument is $z_{i,t} \equiv k_{i,t}(\Delta r_{b(i,t),t} - \Delta \hat{r}_{b(i,t),t})$.[4]

2.2. Factor utilization correction

The Imbs (1999) correction follows Burnside and Eichenbaum (1996) in endogenizing the capital utilization rate in a partial equilibrium model. We assume perfectly competitive factor markets and an aggregate production function which is constant returns to scale in effective capital and labor:[5]

$$Y_t = A_t \left(K_t u_t \right)^{\alpha} \left(L_t e_t \right)^{1-\alpha}$$

where Y_t is output, K_t is capital stock, and L_t is total hours worked. u_t and e_t denote the respective factor utilizations. A_t is the utilization adjusted TFP. We assume perfect competition in the input and the output markets. Higher capital utilization increases the depreciation of capital $\delta_t = \delta u_t^{\phi}$ where $\phi > 1$. As a result, firms choose capital utilization rate optimally. Labor hoarding is calculated assuming instantaneous adjustment of effort e_t against a payment of a higher wage $w(e_t)$, while keeping fixed employment (determined one period in advance). The firm's optimization problem is given by:

$$\max_{e_t, u_t, K_t} A_t \left(K_t u_t \right)^{\alpha} \left(L_t e_t \right)^{1-\alpha} - w(e_t) L_t - (r_t + \delta u_t^{\phi}) K_t$$

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[4]See Jordà, Schularick, and Taylor (2019) for implementation details.

[5]We assume that these variables are stationary. In section 5, we construct capital-utilization in a general equilibrium model along with endogenous growth.

Households choose consumption, labor supply and effort to maximize their lifetime utility subject to their budget constraint (with complete asset markets)

$$\max_{c_t, L_t, e_t} \sum_{t=0}^{\infty} \beta^t \left[\ln C_t - \chi \frac{(e_t L_t)^{1+\nu}}{1+\nu} \right]$$

Normalizing the long-run capital-utilization and labor-utilization rates to one, the utilization rates can be derived from following :

$$u_t = \left(\frac{\frac{Y_t}{K_t}}{\frac{Y}{K}} \right)^{\frac{\delta}{r+\delta}} ; \quad e_t = \left(\frac{\frac{Y_t}{C_t}}{\frac{Y}{C}} \right)^{\frac{1}{1+\nu}} \frac{L}{L_t}$$

where Y, C, L and K are the steady-state values of output, consumption, labor and capital.

The Solow residual then can be decomposed into utilization-adjusted TFP and utilization corrections:

$$TFP_t \equiv \frac{Y_t}{K_t^\alpha L_t^{1-\alpha}} = A_t \times u_t^\alpha e_t^{1-\alpha}$$

To construct steady state values of Y, C, L and K, we extract a HP-filter trend from the data series. We will show later that our empirical results are robust to computing moving averages over a 10 year window, using time-varying values of α constructed from labor-income data, and reasonable parameters of the aggregate capital depreciation rate. Bergeaud, Cette, and Lecat (2016) constructed capital stock for machines and buildings separately using the perpetual inventory method with data on investment in machines and buildings and different depreciation rates. We will show robustness of our results to choosing different depreciation parameters. We wish to emphasize that our estimation of productivity assumes misallocation related-wedges are absent. We have not yet found the data to take into account markups in our productivity estimation. See Basu and Fernald (2002) and Syverson (2011) for extensive discussions on what determines productivity.

3. Monetary shocks have long lasting effects

3.1. Empirical approach

The basic empirical approach relies on local projections (Jordà, 2005) estimated with instrumental variables (LPIV). Several applications of these methods are available in the literature, though a more general discussion of the method can be found in Ramey (2016), Stock and Watson (2018) and Jordà, Schularick, and Taylor (2019). Based on the latter, we estimate in particular:

$$y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \widehat{\Delta r}_{i,t} \beta_h + x_{i,t} \gamma_h + v_{i,t+h}; \qquad h = 0, 1, \dots, H; i = 1, \dots, N; t = t_0, \dots, T \quad (1)$$

where $y_{i,t+h}$ is the outcome variable for country i observed h periods from today; $\alpha_{i,h}$ are country fixed effects, $\widehat{\Delta r}_{i,t}$ refers to the instrumented change in the short-term government bond (3-months

Table 1: *Trilemma instrument: first stage evidence*

pegs ($q = 1$)	All years	PreWW2	PostWW2
$z_{i,t}$	0.52***	0.35**	0.56***
t-statistic	[8.62]	[2.05]	[8.97]
Obs	672	148	524

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Full sample: $1890 - 2015$ excluding WW1: $1914 - 1919$ and WW2: $1939 - 1947$. Pre-WW2 sample: 1870-1938 (excluding 1914-1919). Post WW2 sample: $1948 - 2015$. These regressions include country fixed effects as well as up to two lags of the first difference in log real GDP, log real consumption, investment to GDP ratio, credit to GDP, short and long-term government rates, log real house prices, log real stock prices, and CPI inflation. In addition we include world GDP growth to capture global cycles. See text.

in duration), our stand-in for the policy rate which we instrument with $z_{i,t}$, the trilemma instrument borrowed from Jordà, Schularick, and Taylor (2019) as discussed earlier; and $x_{i,t}$ collects all additional controls including lags of the outcome and interest rates, as well as lagged values of other macro aggregates. Moreover, we control for global business cycle effects through a global GDP control variable to parsimoniously soak up time effects. We estimate Equation 1 with instrumental variable methods and report cluster robust standard errors.

Table 1 reports the first-stage regression of the pegging country's short term interest rate $\Delta r_{i,t}$ on the instrument $z_{i,t}$ with controls $x_{i,t}$, country fixed effects and (robust) clustered standard errors. The t-statistic is well above 3 for full sample and post-WW2 samples illustrating that it is not a weak instrument. We refer the reader to Jordà, Schularick, and Taylor (2019) for detailed discussion on the instrument and proceed henceforth assuming the reader is on board regarding instrument relevance and strength.

3.2. Main results

The main story is illustrated by the response of real GDP to a shock to domestic interest rates using the trilemma instrument. Before we show the main results, we highlight the value of our instrumental variable with a comparison of the response of GDP per capita to a shock in the short-term domestic interest rate calculated using selection-on-observables identification versus identification with the trilemma instrument. This is shown in Table 2. The table reports coefficient estimates of the impulse response calculated with each identification approach for the full and post-WW2 samples. *LP-OLS* refers to identification via selection, *LP-IV* to the trilemma instrument identification. The samples are restricted to pegging economies to match the samples in both cases.[6]

Table 2 is organized as follows. We provide the coefficient estimates by row and provide a test of the null hypothesis that *LP-OLS* and *LP-IV* estimates are equivalent for the two samples considered: full and post-WW2. The differences between identification schemes could not be starker. Both are economically and statistically, but the *LP-IV* response is considerably larger at all horizons. We display these results graphically in Figure 1.

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[6]The plots and inference are robust to using real GDP per capita. See Table A1

Table 2: *LP-OLS vs. LP-IV. Attenuation bias of real GDP responses to interest rates. Trilemma instrument. Matched samples*

Responses of real GDP at years 0 to 10 ($100 \times$ log change from year 0 baseline).

| Year	(a) Full Sample		OLS-IV	(b) Post-WW2		OLS-IV
	LP-OLS	LP-IV	p-value	LP-OLS	LP-IV	p-value
	(1)	(2)	(3)	(4)	(5)	(6)
$h = 0$	0.08**	-0.04	0.18	0.05**	0.07	0.79
	(0.03)	(0.09)		(0.02)	(0.07)	
$h = 2$	-0.27	-1.63***	0.00	-0.21	-1.42***	0.00
	(0.16)	(0.39)		(0.13)	(0.42)	
$h = 4$	-0.11	-2.22***	0.00	-0.01	-1.54**	0.01
	(0.26)	(0.56)		(0.21)	(0.63)	
$h = 6$	-0.01	-2.55***	0.00	0.11	-2.14***	0.00
	(0.29)	(0.67)		(0.22)	(0.58)	
$h = 8$	-0.30	-3.47***	0.00	0.18	-2.02***	0.00
	(0.29)	(0.85)		(0.22)	(0.59)	
$h = 10$	-0.33	-4.20***	0.00	0.35	-1.68***	0.00
	(0.36)	(1.15)		(0.27)	(0.65)	
$h = 12$	-0.58	-6.77***	0.00	0.24	-2.62***	0.00
	(0.42)	(2.08)		(0.33)	(0.95)	
KP weak IV		68.34			69.18	
H_0: $LATE = 0$	0.00	0.00		0.00	0.00	
Observations	607	607		482	482	

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Cluster robust standard errors in parentheses. Full sample: $1890 - 2015$ excluding WW1: $1914 - 1919$ and WW2: $1939 - 1947$. Post WW2 sample: $1948 - 2015$. *Matched sample* indicates LP-OLS sample matches the sample used to obtain LP-IV estimates. *KP weak IV* refers to the Kleibergen-Paap test for weak instruments. $H_0 : subATE = 0$ refers to the *p*-value of the test of the null hypothesis that the coefficients for $h = 0, ..., 10$ are jointly zero for a given subpopulation. $OLS = IV$ shows the *p*-value for the Hausmann test of the null that OLS estimates equal IV estimates. See text.

Regardless of the sample used, a 1 percentage point increase in domestic short-term interest rates has sizable and long-lasting effects on GDP. In the full sample, GDP declines by over 6 percent over 12 years. The effect, while still large, is considerably more muted in the post-WW2 sample. The drop 12 years after impact is about half, at 2.7 percent. This is a far cry from traditional notions of long-run neutrality found in the literature.

What is the source of this persistent decline? We decompose GDP into its components, namely, hours worked (employees times number of hours per employee); capital stock (measured capital in machines and buildings); and the Solow residual (using a Cobb-Douglas production function) labeled as total factor productivity (TFP). (Using the Imbs (1999) correction, in a moment we decompose the Solow residual into factor-utilization plus a residual utilization-adjusted TFP.)

Figure 1: *Baseline response to 100 bps trilemma shock: Real GDP*
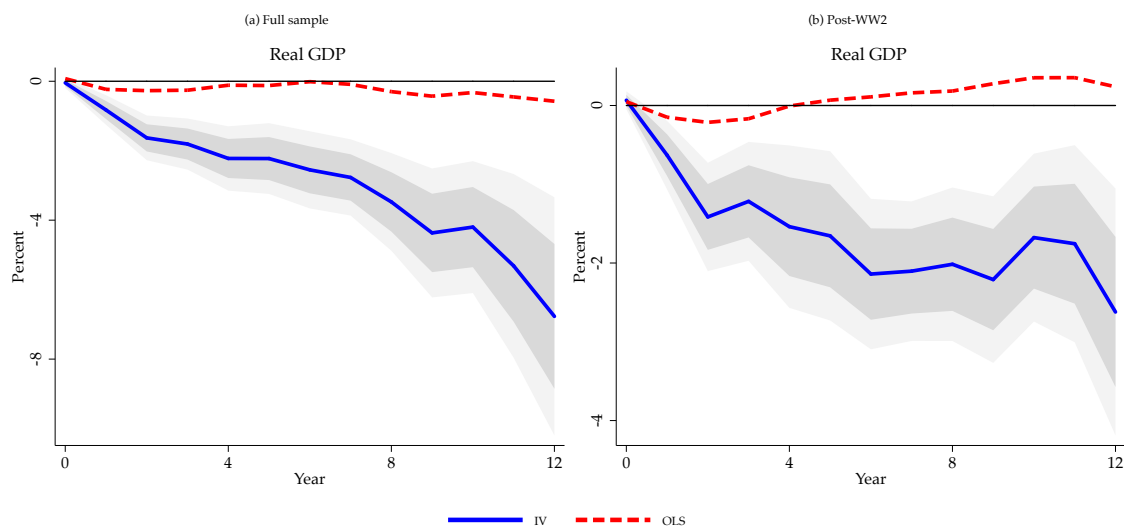
(a) Full sample

(b) Post-WW2

Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Full sample: 1890–2015 (World Wars excluded). Post-WW2 sample: 1948–2015. See text.

Figure 2 displays the responses of each of these components to the same shock to the domestic short-term interest rate instrumented with the trilemma, both for the full and the post-WW2 samples. The figure displays the responses of total hours worked, capital and raw TFP without error bands to provide a clearer sense of the dynamic paths. A more detailed figure is provided in the appendix A.1, which includes the error bands.

Several features deserve mention. Figure 2 shows that there are similar declines in capital and raw TFP whereas total hours worked exhibits a much flatter pattern. Because capital enters the production function with a smaller weight, it should be clear from the figure that most of the decline in GDP is explained by TFP variable, and then capital, with total hours worked mostly flat. To be sure, the response of hours worked conforms well with the textbook response to a monetary shock. Total hours fall in the short-run, but then recover quickly and remain mostly flat.

Capital accumulation also follows textbook dynamics in the short-run. The response is initially muted but builds up over time. But unlike the textbook model, capital does not appear to recover even 12 years after the shock. Similarly, TFP falls gradually rather than suddenly. Over time, the decline in TFP accelerates, ending at a level 3 (1) percent lower in full (post WW2) sample by year 12 relative to year 0.

We present the responses of the various components of the Solow residual in Figure 3 for both the full and post-WW2 samples. Utilization rates of labor and capital exhibit cyclical dynamics: falling in the short-run and then recovering back to zero. In a sense, this pattern is mechanical. It reflects the restriction imposed on the calculation that utilization rates must return to zero eventually (Imbs, 1999).

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Figure 2: *Baseline response to 100 bps trilemma shock: Real GDP and components*
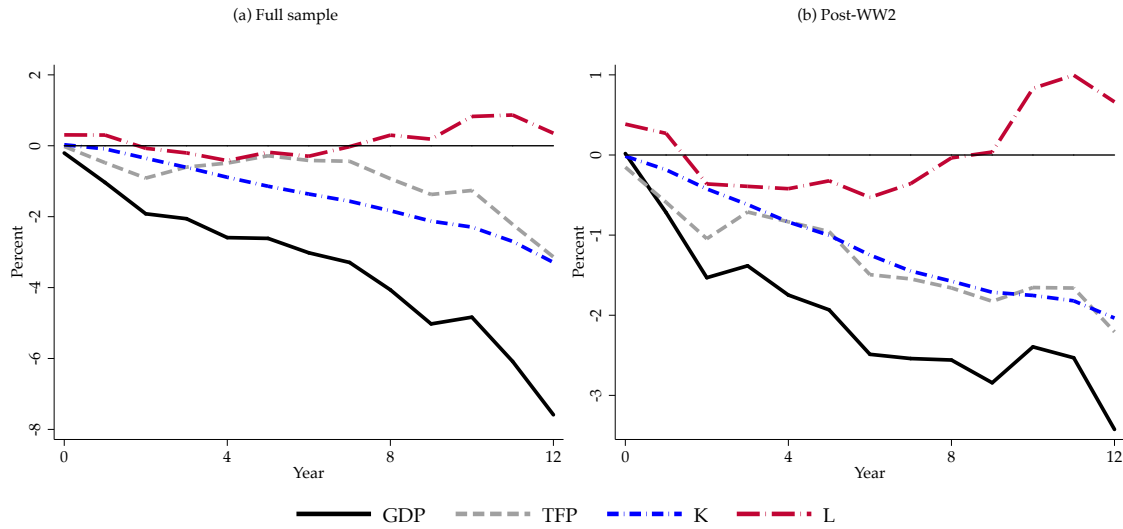
(a) Full sample

(b) Post-WW2

Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Full sample: 1890–2015 (World Wars excluded). Post-WW2 sample: 1948–2015. See text.

Figure 4 presents the evolution of capital to utilization adjusted TFP ratio in response to the trilemma shock. The hump-shaped response replicates the conventional justification for including investment adjustment costs in typical DSGE models (Christiano, Eichenbaum, and Evans, 2005).[7]

One explanation for the long-lasting effects of the monetary shock could be that domestic interest rates remain elevated for a long period of time as well. In other words, persistence is generated by a delayed response in interest rates. A simple check of this proposition can be done in two steps.

Figure 5 shows that the short-term real interest rate does indeed take approximately 8 years to return to zero, while the nominal interest rate returns to zero after 4 years. The response of nominal interest rate is typical of what has been reported often in the literature (see, e.g., Christiano et al., 1999; Ramey, 2016). Secondly, we can calculate the responses of the main variables normalized by the response of interest rates over time to sterilize the dynamics of interest rates themselves. This is no different than calculating a multiplier (see, e.g., Ramey, 2016; Ramey and Zubairy, 2018).

Thus, in Figure 6 we show the ratio of the cumulative change in GDP to the area under the real interest rate path in Figure 5. In a given period, the difference in the level of real interest rate relative to the counterfactual path measures the tightness of monetary policy. We consider these cumulative gaps as a measure of overall monetary policy tightness (the area under the solid line in Figure 5). By year 12, the multiplier is -1 in the full sample and -0.8 in the post-WW2 sample,

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[7]We later show the robustness of using a more commonly used utilization adjusted TFP series constructed by Fernald (2014) for the post-WW2 US, which requires more detailed data than is available for the historical panel of 17 countries. Reassuringly, the results for utilization adjusted TFP using the two methods are qualitatively similar.

Figure 3: *Baseline response to 100 bps trilemma shock: TFP and utilization*
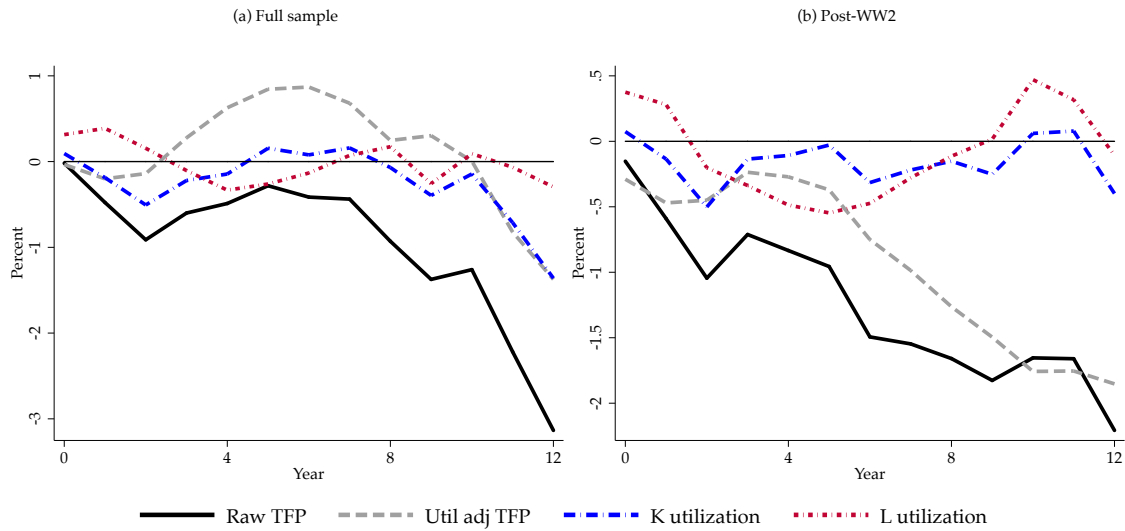
(a) Full sample

(b) Post-WW2

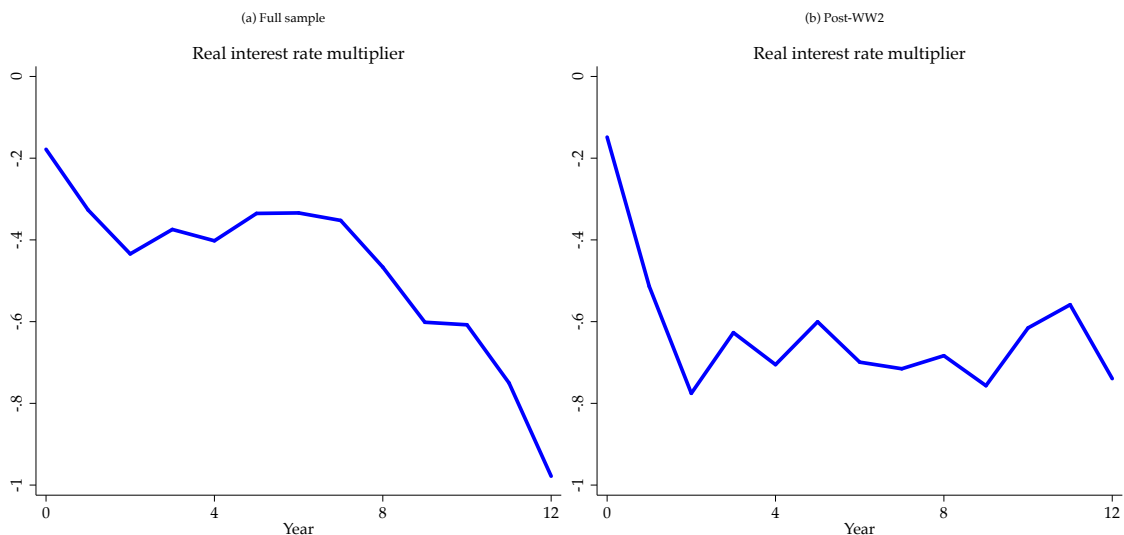Raw TFP · · · · · Util adj TFP · — · — K utilization · · — · · L utilization

Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Full sample: 1890–2015 (World Wars excluded). Post-WW2 sample: 1948–2015. See text.

Figure 4: *Baseline response to 100 bps trilemma shock: Capital to utilization adjusted TFP*
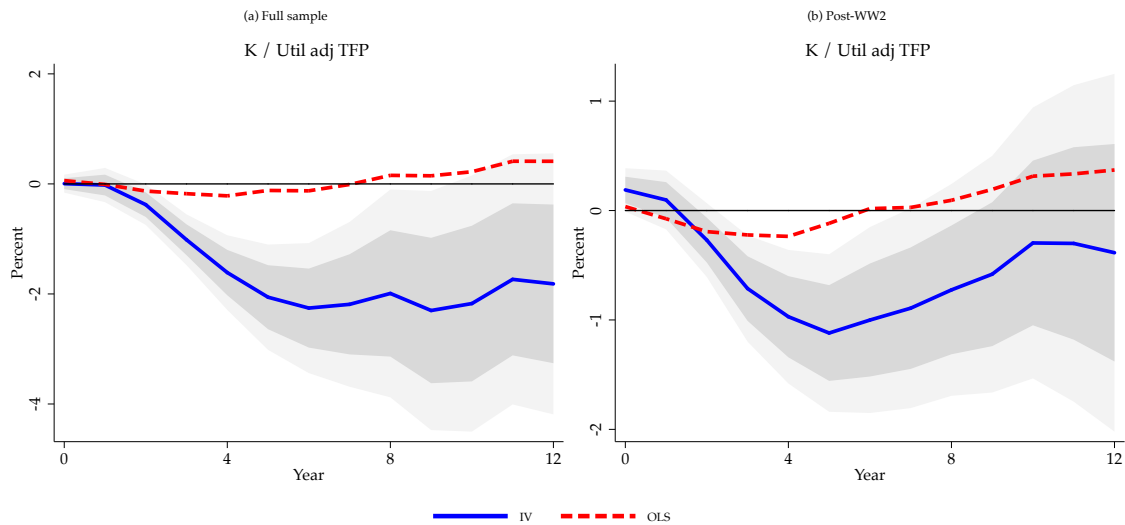
(a) Full sample

K / Util adj TFP

(b) Post-WW2

K / Util adj TFP

IV — — — OLS

Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Full sample: 1890–2015 (World Wars excluded). Post-WW2 sample: 1948–2015. See text.

Figure 5: *Baseline response to 100 bps trilemma shock: Short term real interest rate*
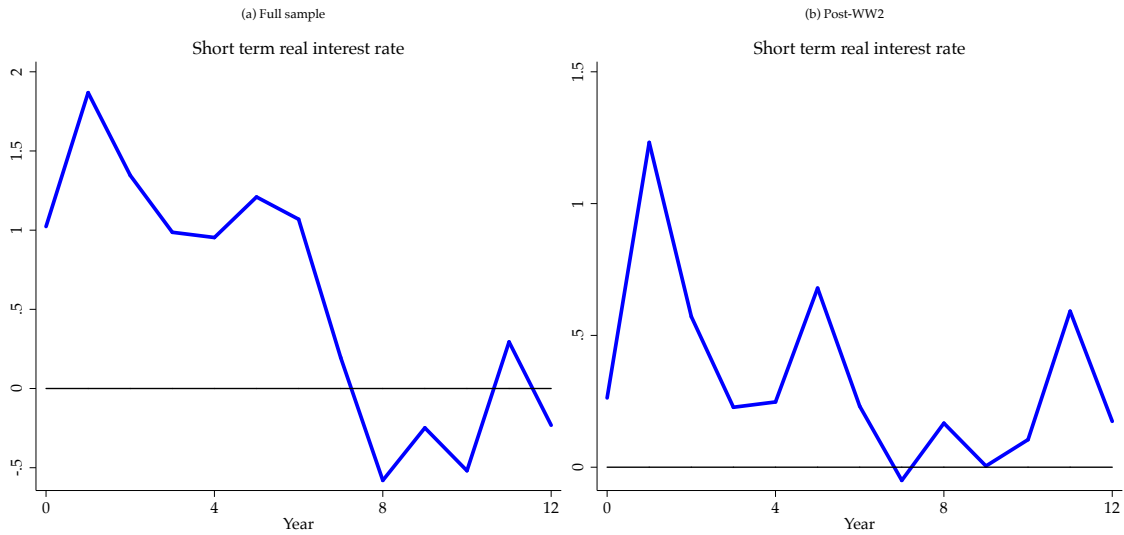
(a) Full sample

Short term real interest rate

(b) Post-WW2

Short term real interest rate

Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses of short term real interest rate for pegging economies. Inflation expectations constructed from the impulse response of consumer price level index to the same trilemma shock. Full sample: 1890–2015 (World Wars excluded). Post-WW2 sample: 1948–2015. See text.

Figure 6: *Cumulative change in real GDP / Cumulative short term expected real interest rate gap*

(a) Full sample

Real interest rate multiplier

(b) Post-WW2

Real interest rate multiplier

Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Plots path of cumulative change in real GDP divided by cumulative change in short term nominal interest rate for pegging economies. Full sample: 1890–2015 (World Wars excluded). Post-WW2 sample: 1948–2015. See text.

virtually identical and sizable.[8] These numbers compare with those obtained in the literature using VAR and Romer and Romer (2004) shocks for the US.[9]

4. THREATS TO IDENTIFICATION AND ROBUSTNESS

4.1. Open economy threats to Identification

We use a variant of the well known Mundell-Fleming-Dornbusch model to illustrate how (static) identification of monetary policy shocks using the trilemma mechanism can be obtained. The model incorporates the innovations in Blanchard (2016) and Gourinchas (2018), which embed various financial spillovers. Intuition is best communicated in a static setting. Later we extend the model to a dynamic setting with rational expectations.

Suppose there are two countries: a small domestic economy and a large foreign country. Foreign variables are denoted with an asterisk, and we refer to this large country as the US for simplicity. Assume prices are perfectly rigid. The following equations describe the setup, for given interest rate policies in the two countries.

$$Y = A + NX \tag{2}$$

$$A = \xi - cR - fE \tag{3}$$

$$NX = a(Y^* - Y) + bE \tag{4}$$

$$Y^* = A^* = \xi^* - cR^* \tag{5}$$

$$E = d(R^* - R) + gR^* + \chi \tag{6}$$

where $a, b, c, d, f, g, \chi \geq 0$. Domestic output is equal to the sum of domestic absorption A and next exports NX. Domestic absorption depends on an aggregate demand shifter ξ, and negatively on the domestic policy rate R. f denotes financial spillovers through the exchange rate (e.g. balance sheet exposure of domestic producers in a dollarized world).[10] If $f \geq 0$, then a depreciation of the exchange rate E hurts absorption. Net exports depends positively on US output Y^*, negatively on domestic output Y, and positively on the exchange rate. US output is determined in similar fashion except that the US is considered a large country, so it is treated as a closed economy. Finally, the exchange rate depends on the difference between domestic and US interest rates and on a risk-premium shock. The term g is intended to capture risk-premium effects associated with US monetary policy.

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[8]For real GDP per capita, the multiplier is -1.4 in the full sample and -1.3 in the post-WW2 sample by year 12.

[9]In their online appendix (Table A.1), Nakamura and Steinsson (2018) report the multiplier of monthly industrial production to monetary shocks over 36 months to lie between 1 and 2 using the local projections specification for VAR shocks and Romer-Romer shocks.

[10]Jiang, Krishnamurthy, and Lustig (2018) provide a micro-foundation to generate these spillovers associated with the global financial cycle (Rey, 2015).

Let ΔR^* be the instrument $z_{i,t} \equiv k_{i,t}(\Delta r_{b(i,t),t} - \Delta \hat{r}_{b(i,t),t})$ described earlier. By construction, the change in US interest rates is unpredictable by US macro economic-conditions. We next show the threats to identification of domestic monetary shocks that arise in this open economy model.

4.1.1 Textbook specification with hard pegs

Under the assumption that $f = g = \chi = 0$, the model reduces to the textbook Mundell-Fleming-Dornbusch version. In this model, the change in output can be decomposed into two conventional sources:

$$\Delta Y = \underbrace{-c\Delta R}_{\text{object of interest}} + \Delta NX$$

A change in interest rates in the US will affect the home economy through two channels: domestic absorption and net exports. An endogenous increase in domestic interest rates reduces absorption and hence output. This generates an improvement in net exports through a contraction in demand for imports. A contraction in the US economy from an increase in interest rates reduces demand for domestic exports. Endogenous movements in the exchange rate also affect net exports. When the domestic economy follows a *hard peg* policy, the domestic monetary authority follows an interest rate policy that guarantees the fixed exchange rate. Consequently, a change in US policy rate ΔR^*, changes the home policy rate by one to one, i.e. $\Delta R = \Delta R^*$.

Proposition 1. *Let $g = f = \chi = 0$. If the domestic policy maker fixes the exchange rate ($\Delta E = 0$), then a change in the US policy rate ΔR^*, changes the home policy rate one to one, i.e. $\Delta R = \Delta R^*$, and negatively affects domestic output:*

$$\Delta Y = \frac{1}{1+a}\left[-c\Delta R + a\Delta Y^*\right]$$

Since this endogenous change in home rates is exogenous to home country conditions, it can be used to identify the effects of a closed-economy monetary policy shock. As evident in the proposition, the total effect on home output will be dampened by $1 + a$ because of the endogenous contraction in imports from abroad,. If the US interest rate shock is purely exogenous, the demand for home output in the US contracts, worsening the output drop at home. These two forces pose a threat to identification of a domestic monetary policy shock.

4.1.2 Financial spillovers with dirty float policy

Having shown the threat to identifications in the simple model, we now allow for financial spillovers i..e $g > 0$ and $f > 0$. We also depart from a hard peg policy to allow for dirty floats policy, which we define as follows: the domestic economy follows a *dirty float* policy if the endogenous (to US interest rate movements) change in home interest rate is less than under a hard peg, i.e. $abs(\Delta R) < abs(\Delta R_{\Delta E=0})$. We surmise a general Taylor rule where the domestic economy puts non-zero weight on output stability, along with exchange rate stability in setting domestic interest rates.

Proposition 2. *If the domestic policy maker manages a dirty float (i..e $|\Delta R| \leq \frac{d+g}{d} |\Delta R^*|$, then the effect on domestic output is given by::*

$$(1+a)\Delta Y = -c\Delta R + a\Delta Y^* + (b-f)\Delta E$$

Two additional sources of spillovers open up in this extended environment. A global financial cycle spillover $g > 0$ amplifies the effects on home interest rates. Under a hard peg policy, an increase in US interest rates increases home interest rates by $\frac{d+g}{d} > 1$. Partial flexibility in exchange rates under a dirty float reduces the pass-through to home interest rates. This flexibility in exchange rates activates financial and trade spillovers due to dependence of A and NX on E.

Controls for net exports and exchange rate identify the effects of a closed economy monetary shock. Next we discuss the corrections for spillovers motivated by our reduced form model.

4.1.3 Controlling for base country GDP growth, current account and exchange rate

A monetary tightening in the base country may reduce the demand for goods from the pegging economy. This effect would amplify the effect of the trilemma shock on home output. Another implication from the Mundell-Fleming-Dornbusch model is that there are financial spillovers that may amplify the effects through the exchange rate channel. To orthogonalize these effects, we control for base country's GDP growth rate, exchange rate of the pegging economy with respect to the USD and the current account of the peg. Since we do not have exchange rate data with respect to other countries, we indirectly control for those spillovers using the current account of the peg country at each horizon. We estimate the following specification:

$$y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \widehat{\Delta r_{i,t}}\beta_h + x_{i,t}\gamma_h + \left(B_{b(i,t),t+h}, CA_{i,t+h}, XRUSD_{i.t+h} \right) \hat{\gamma}_h + v_{i,t+h}, \quad \text{for } h = 0, ..., H-1$$

where $B_{b(i,t),t+h}$ is GDP growth of base country $b(i,t)$ at time $t+h$ where i is the pegging country, $CA_{i,t+h}$ is the current account and $XRUSD_{i,t+h}$ is the exchange rate with respect to USD of country i at time $t+h$.

Figure 7 plots the IRFs to trilemma identified shock. The identified monetary policy shocks have quantitatively and statistically significant effects on domestic output twelve years later. Controlling for variables motivated by Proposition 2 does not affect our estimates until year 4. Thereafter, the effects are somewhat attenuated but statistically significant.

4.2. Spillover correction for the trilemma instrument

A violation of the exclusion restriction could occur if base rates affect home outcomes through channels other than movements in home rates or the spillovers highlighted inProposition 2. Additional influences via such channels are sometimes referred to as *spillover effects*. These could occur if base rates proxy for factors common to all countries. That said, these factors would have to persist despite

Figure 7: *Response to 100 bps trilemma shock with controls motivated by Proposition 2: Real GDP*
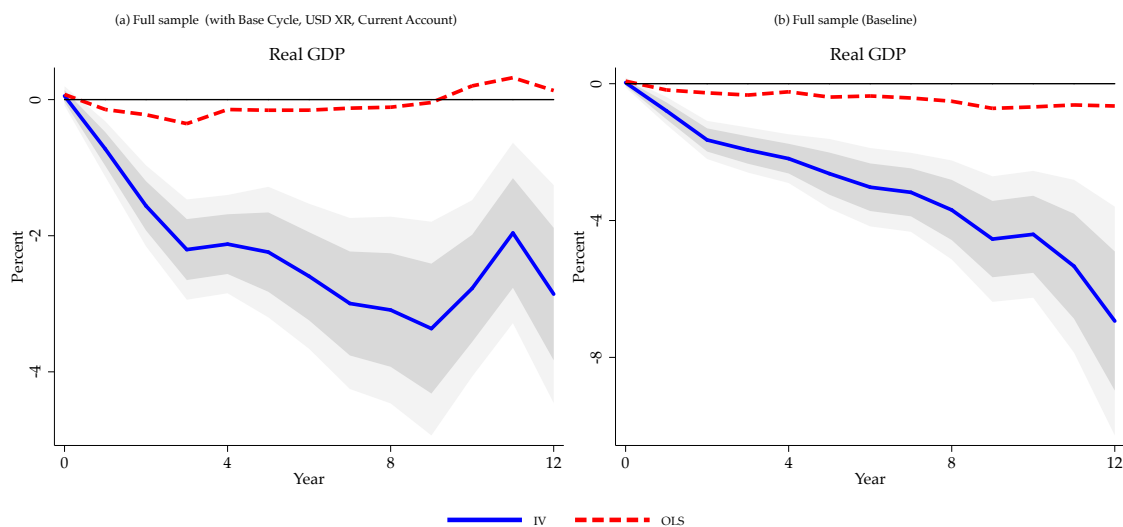
Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Full sample: 1890–2015 (World Wars excluded). Post-WW2 sample: 1948–2015. LP-OLS estimates displayed as a dashed red line, LP-IV estimates displayed as a solid blue line and 1 S.D. and 90% confidence bands. See text.

having included global GDP to soak up such business cycle variation. We now assess such spillover effects more formally, using two separate approaches: a) a control function approach developed in Jordà, Schularick, and Taylor (2019), and b) controlling for foreign variables at each horizon to orthogonalize any spillover channels from the interest rate channel.

4.2.1 Synthetic control function approach

First test for exclusion restriction violation follows the control function approach developed in Jordà, Schularick, and Taylor (2019). It exploits the presence of subpopulation of floats in our sample which for example contain information about the global factors at the time of the trilemma shock. Figure 8 shows our spillover-adjusted estimates of response of output to a 100 bps monetary policy shock.

4.2.2 Orthogonalized interest rate channel

A second approach that attempts to provide validity to the exclusion restriction is directly controlling for a primary channel through which the spillover effects may originate. This reduction in demand my arise from other trading partners when the tightening affects other countries as well. Or the interest rate channel induced contraction in pegging economy by reducing demand for other countries' output may be subject to *spillbacks*. If the transmission is primarily driven by

Figure 8: *Response to 100 bps trilemma shock with spillover corrections: Real GDP*
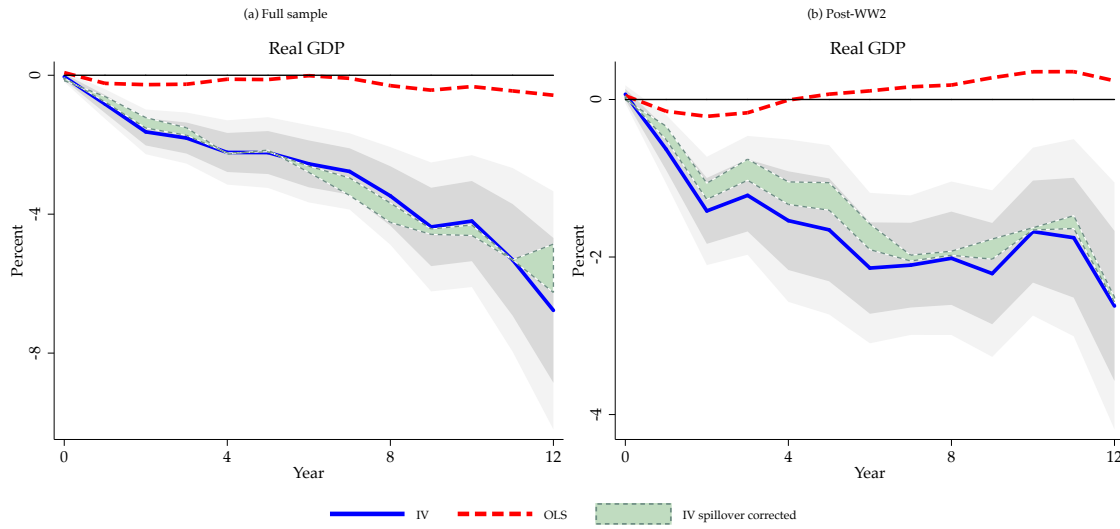
(a) Full sample

(b) Post-WW2

Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Full sample: 1890–2015 (World Wars excluded). Post-WW2 sample: 1948–2015. LP-OLS estimates displayed as a dashed red line, LP-IV estimates displayed as a solid blue line and 1 S.D. and 90% confidence bands, LP-IV spillover corrected estimates displayed as a light green shaded area with dashed border, using $\lambda \in [1, 18]$. See text and Jordà, Schularick, and Taylor (2019).

increased trade, controlling for global GDP growth can potentially absorb these effects allowing us to orthogonalize domestic demand effects with respect to international spillbacks. We augment the baseline specification as follows:

$$y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \widehat{\Delta r_{i,t}}\beta_h + x_{i,t}\gamma_h + G_{t+h}\hat{\gamma}_h + v_{i,t+h}, \quad \text{for } h = 0, ..., H - 1$$

where G_{t+h} is global GDP growth at time $t + h$.

Figure 9 produces the results from the estimation with global GDP growth at each horizon. In comparison to the baseline specification, we still find very persistent and significant effects on GDP.

4.3. Accounting for structural breaks

Fernald (2014) and Gordon (2016) have convincingly argued that there are structural breaks in TFP growth in the US economic trajectory. It is plausible that there are structural breaks in other economies' TFP growth rates. If these structural breaks implying slowdown in TFP growth occur around the identified monetary shocks, it could bias our results leading us to attribute the persistent effects incorrectly to monetary shocks. To address this concern, we first estimate five structural breaks in TFP growth for each country in our sample using the UD-max statistic of Bai & Perron (1998). We report these estimated structural break dates in the appendix A.2. Then in our baseline

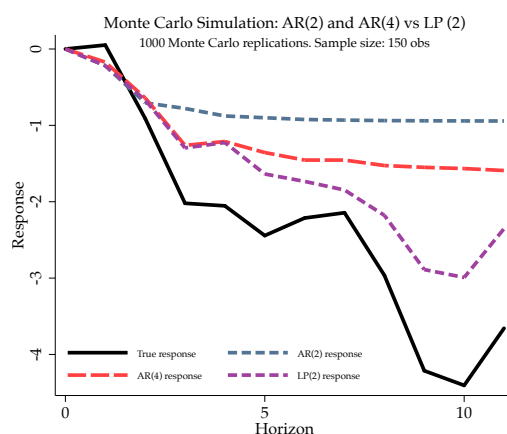**Figure 9:** *Response to 100 bps trilemma shock with foreign variables controlled: Real GDP*
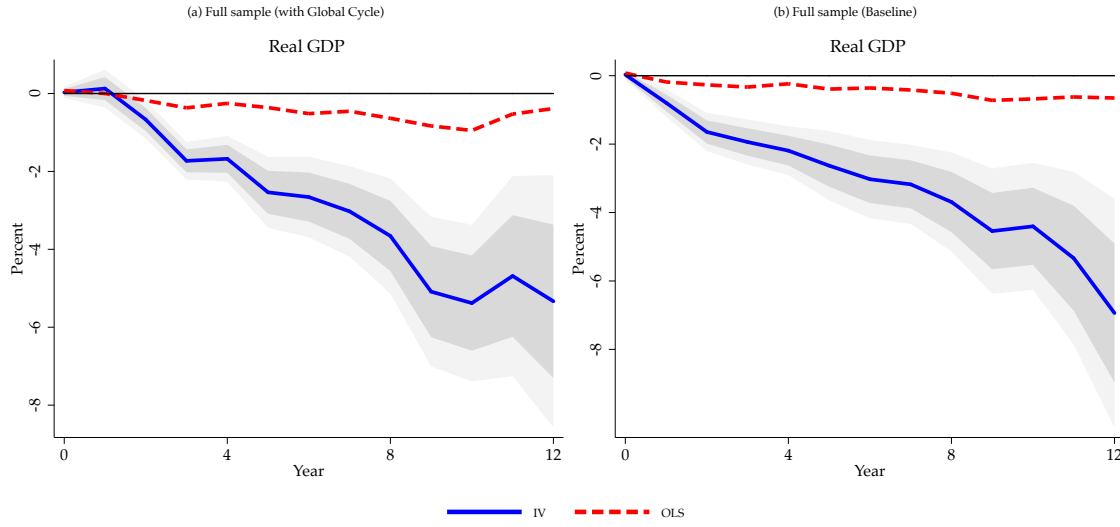
Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Full sample: 1890–2015 (World Wars excluded). Post-WW2 sample: 1948–2015. LP-OLS estimates displayed as a dashed red line, LP-IV estimates displayed as a solid blue line and 1 S.D. and 90% confidence bands. See text.

specification, we allow output growth to lie in either of the five regimes at horizon zero as well as horizon h: i.e.

$$y_{i,t+h} - y_{i,t-1} = \alpha_{i,h} + \sum_{k-1}(D_{i,k,t} + D_{i,k,t+h}) + \widehat{\Delta r}_{i,t}\beta_h + x_{i,t}\gamma_h + v_{i,t+h},$$

where $D_{i,k,t+h}$ is country-specific dummy for TFP growth regime k (Bai-Perron) at horizon $h = 0, ..., H - 1$ and $k \in (1, 5)$. Notice that this specification is conservative whereby we allow horizon h regime changes in the estimation along with horizon 0 regimes.

Figure 10 compares the estimated impulse response when including structural breaks in the left panel and the baseline specification of no structural breaks in the right panel. Taking structural breaks in account does not change the result that there are persistent effects on output of monetary shocks.[11]

4.4. Levels, differences, and number of lags

We report the robustness of IRFs estimated in the baseline to adding the control variables $x_{i,t}$ in levels instead of first differences in the left panel of Figure 11, as well as to including up to 5 lags of the control variables in the right panel.

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[11]In the appendix A.2, we report the IRFs when controlling for country specific structural breaks in growth rate of real GDP per capita.

Figure 10: *Response to 100 bps trilemma shock with structural breaks: Real GDP*
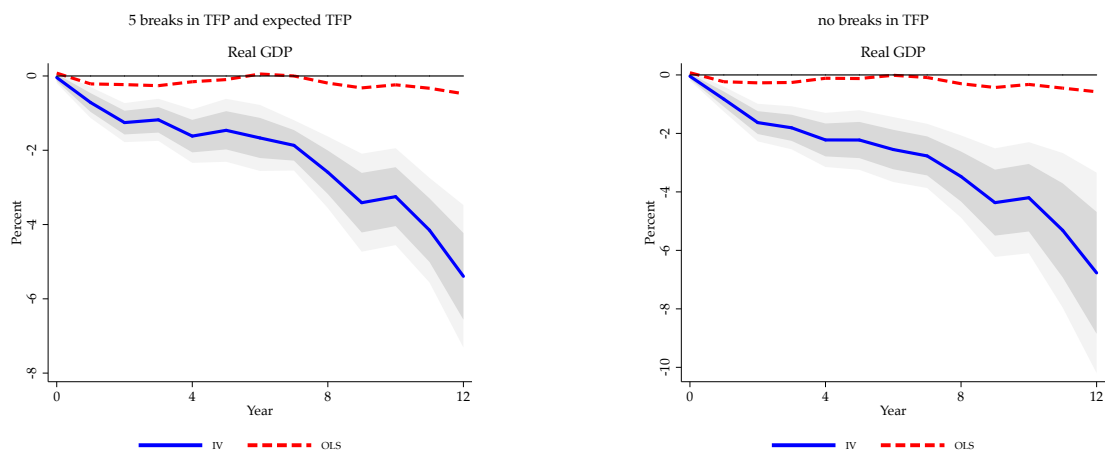
5 breaks in TFP and expected TFP

Real GDP

no breaks in TFP

Real GDP

Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Full sample: 1890–2015 (World Wars excluded). Post-WW2 sample: 1948–2015. LP-OLS estimates displayed as a dashed red line, LP-IV estimates displayed as a solid blue line and 1 S.D. and 90% confidence bands. See text and Jordà, Schularick, and Taylor (2019).

Figure 11: *Response to 100 bps trilemma shock with controls in levels: Real GDP*
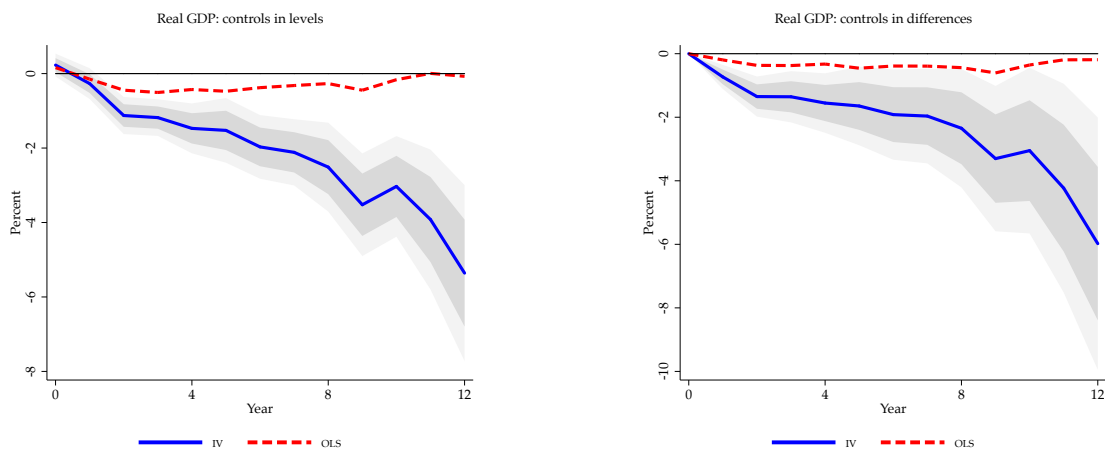
Real GDP: controls in levels

Real GDP: controls in differences

Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Full sample: 1890–2015 (World Wars excluded). LP-OLS estimates displayed as a dashed red line, LP-IV estimates displayed as a solid blue line and 1 S.D. and 90% confidence bands. See text and Jordà, Schularick, and Taylor (2019).

Figure 12: *Estimated IRFs using LP(p) and AR(p)*

Monte Carlo Simulation: AR(2) and AR(4) vs LP (2)
1000 Monte Carlo replications. Sample size: 150 obs

Notes: Solid black line denotes the basline response of real GDP in pegging economies to a 100 bps shock in domestic interest rate instrumented with the trilemma. Sample: 1890–2015 (World Wars excluded).

4.5. Why might VARs not find persistent effects?

That a misspecified VAR suffers from compounding of model mis-specification errors gives local projections approach is a well-known advantage. We provide an example here that suggests why researchers may not be able to estimate the long-run effects that we find when estimating VARs in finite samples with few lags. Using the estimated IRFs in the baseline model for the full sample over 12 years, we recover the coefficients of an invertible MA(12) process and generate data using this data generating process. Figure 12 compares the IRFs obtained from estimating AR(2), AR(4), and a local projection with 2 lags. AR(4) outperforms AR(2) in replicating the true impulse response at horizons greater than two. The misspecification errors get compounded at higher horizons under AR(2) versus AR(4), while local projection is not prone to this problem.

4.6. Is the US different?

The US for most of our historical sample is not a pegging economy (apart from the Gold standard years). It is the quintessential base country for many economies in our sample. For this reason, the trilemma instrument mechanically sets aside any information coming from the US during estimation. It is natural to wonder the extent to which US data conforms with the patterns presented so far.

In this section, we examine US data post-WW2. This allows us to incorporate three useful modifications. First, we use higher frequency quarterly data. Second, we use the alternative utilization adjusted series for TFP constructed by Fernald (2014). Third, in order to achieve identification we rely on the instrumental variable constructed by Romer and Romer (2004) based on the Federal Reserve staff's implied forecast errors for the policy rate, and extended to recent years by Wieland and Yang (2016).

Figure 13: *Baseline response to 100 bps Romer and Romer (2004) shock : US postwar data*
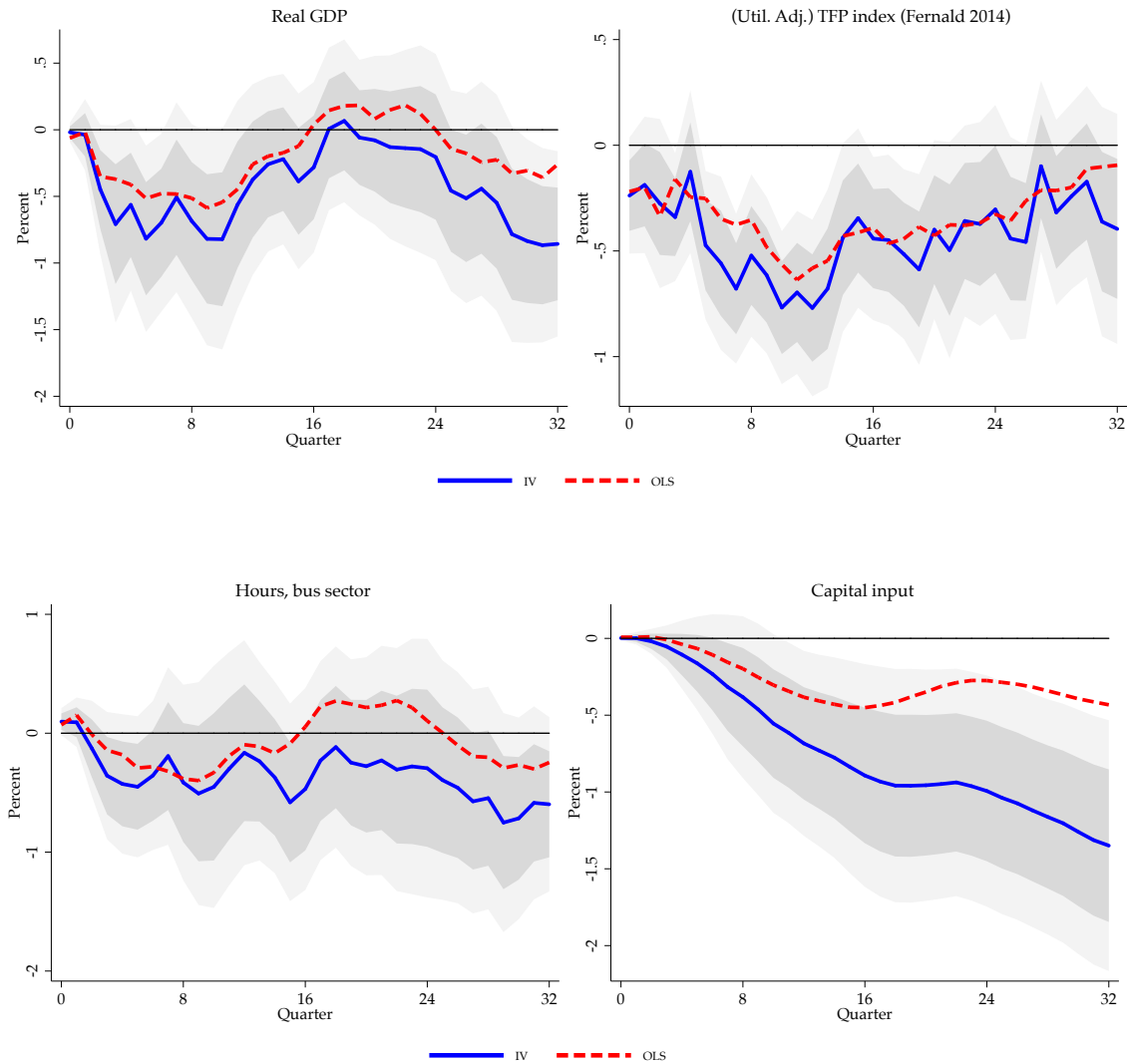
Real GDP

(Util. Adj.) TFP index (Fernald 2014)

Hours, bus sector

Capital input

Notes: Response to a 100 bps shock in federal funds rate rate instrumented with policy forecast residuals (Romer and Romer, 2004; Wieland and Yang, 2016). Responses of real GDP, utilization-adjusted TFP (Fernald, 2014), capital stock and hours worked for US economy. Quarterly sample: 1969-Q1: 2007-Q4. Quarterly data series are taken from Fernald (2014).

It turns out that results based on U.S. data largely confirm the results we reported in the previous section for non-U.S. pegging economies. Figure 13 plots the the path of real GDP along with its three components: total hours worked, capital, and utilization adjusted TFP. The responses are qualitatively similar to those in the long-run panel, although the amplitudes are more muted. Quarterly data is naturally noisier than yearly data, but smoothing over a temporary recovery in GDP 4 to 5 years after the shock, real GDP ends nearly one percent lower 8 years after impact.

Figure 14: *Baseline response to 100 bps Romer and Romer (2004) shock: US postwar data*

Instrument: Romer & Romer (2004) residuals
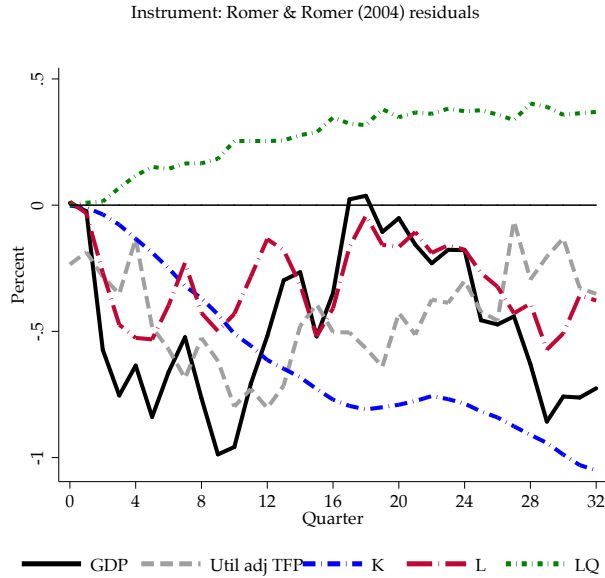
Notes: Response to a 100 bps shock in overnight federal funds rate rate instrumented with policy forecast residuals (Romer and Romer, 2004; Wieland and Yang, 2016). Responses of real GDP, capital stock, total hours worked, labor composition/quality, and raw TFP for US. Quarterly sample: 1969-Q1: 2007-Q4. Quarterly data series are taken from Fernald (2014). See text.

Utilization adjusted TFP and hours exhibit a similar u-shaped pattern, with TFP nearly back to zero by year 8. Strikingly, capital accumulation exhibits a protracted decline over the entire period, ending about 1.25 percent lower after eight years. For comparison, we plot the various components on the same graph in Figure 14.[12]

The data for utilization-adjusted TFP series are based on sectoral data for the US that account for heterogeneity across workers and types of capital. Fernald (2014) notes that there are various other corrections that are not conducted in the quarterly series due to the lack of rich-industry level data.

The finding that monetary policy shocks can affect utilization-adjusted TFP echo the Evans (1992)'s critique of using Solow residuals as productivity shocks in RBC models. While the construction of quarterly utilization-adjusted TFP series is detailed and thorough, our analysis suggests caution against using the quarterly-adjusted residuals as "pure" TFP shocks (i.e. perfectly

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[12]We estimate the following specification for the US economy:

$$y_{t+h} - y_{t-1} = \alpha_h + \widehat{\Delta r_t} \, \beta_h + \boldsymbol{x}_t \, \boldsymbol{\gamma}_h + v_{t+h}; \qquad h = 0, 1, \ldots, H; i = 1, \ldots, N; t = t_0, \ldots, T$$

where y_{t+h} is the outcome variable at horizon h, $\widehat{\Delta r_t}$ is the instrumented change in the Federal Funds rate, $\boldsymbol{x}_t$ is the set of controls that includes contemporary and four lags of log real GDP, log CPI, and changes in federal funds rate. We do not include the contemporary variable when it is same as the dependent variable. We report robust standard errors.

orthogonal to demand shocks).[13],[14]

5. A MODEL OF HYSTERESIS

Impulse responses calculated with standard methods that internally favor reversion to the mean will tend to underestimate the value of the response at longer horizons. By relying on local projections, we allow the data to more directly speak as to its long-run properties. The evidence presented in the previous sections strongly indicate that these long-run effects are important and require further investigation. In order to think through a possible mechanism that explains our empirical findings, we augment a textbook New Keynesian model with endogenous growth in a stylized manner. We present the different components of the model in the next few sections, starting with the production side of the economy.

5.1. Monopolistically competitive producers

Assume there is a continuum of differentiated intermediated good producers that sell the intermediate good Y_{kt}. These goods can be aggregated into a Dixit-Stiglitz final composite good Y_t as follows:

$$Y_t = \left[\int_0^1 Y_{kt}^{\frac{1}{1+\lambda_p}} dk \right]^{1+\lambda_p}$$

where $\lambda_p > 0$ is the price markup. The iso-elastic demand for intermediate good k is given by:

$$Y_{kt} = \left(\frac{P_{kt}}{P_t} \right)^{-\frac{1+\lambda_p}{\lambda_p}} Y_t$$

The zero profit condition for competitive final good producers implies that the aggregate price index is

$$P_t = \left[\int_0^1 P_{kt}^{-\frac{1}{\lambda_p}} dk \right]^{-\lambda_p}$$

Each intermediate good k is produced by a price-setting monopolist using labor L_{kt} and physical capital K_{kt}[15]:

$$Y_{kt} = (Z_t L_{kt})^{1-\alpha} K_{kt}^{\alpha}$$

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[13]Ramey (2016) also documents that utilization adjusted TFP series fail Granger causality tests (See Table 11 in her paper). We are grateful to Valerie Ramey for alerting us to that analysis.

[14]In the appendix B, we show that similar results are obtained with samples beginning until at least 1973Q2. However, these persistent effect results are not robust to considering even shorter samples for the US economy. This is consistent with the findings of Coibion, Gorodnichenko, and Ulate (2017).

[15]We can append fixed cost in the production function to eliminate steady state profits. This is usually done to justify no entry and exit in the steady state in a DSGE model (Christiano et al. 2005, Justiniano, Primiceri, and Tambalotti 2013, Smets and Wouters 2007). In a micro-founded model of growth, positive rents are needed to incentivize investment in growth (Romer, 1990).

where Z_t is the aggregate TFP. The variable Z_t denotes a non-stationary TFP series that we describe in the next subsection.[16] Firms may not be able to adjust their price in a given period, but they will always choose inputs to minimize total cost each period. The cost minimization yields the input demand functions.

$$W_t = (1 - \alpha) \, mc_{kt} F_t^{1-\alpha} \left(\frac{K_{kt}}{L_{kt}} \right)^{\alpha}$$

$$R_t^k = \alpha \, mc_{kt} F_t^{1-\alpha} \left(\frac{K_{kt}}{L_{kt}} \right)^{\alpha-1}$$

The first order condition implies that the capital labor ratio at the firm level is independent on firm-specific variables:

$$\frac{K_{kt}}{L_{kt}} = \frac{K_t}{L_t} = \frac{\alpha}{1 - \alpha} \frac{W_t}{R_t^k}$$

Thus, (nominal) marginal cost is independent of firm specific variables:

$$P_t mc_{kt} = P_t mc_t = \frac{1}{F_t^{1-\alpha}} \left(\frac{R_t^k}{\alpha} \right)^{\alpha} \left(\frac{W_t}{1 - \alpha} \right)^{1-\alpha}$$

Each firm k is assumed to set prices on a staggered basis following Calvo (1983). With probability $(1 - \theta_p)$, a firm adjusts its price independent of previous history. A resetting firm chooses $\tilde{P}_{kt}$ to maximize:

$$\mathbb{E}_t \sum_{s=t}^{\infty} \theta_p^{s-t} Q_{t,s} \left[\frac{\tilde{P}_{kt}}{P_s} - mc_s \right] Y_s(k)$$

subject to demand for its product

$$Y_{kt} = \left(\frac{P_{kt}}{P_t} \right)^{-\frac{1+\lambda_p}{\lambda_p}} Y_t$$

where the stochastic discount factor in period s relative to period t is given by:

$$Q_{t,s} = \beta^{s-t} \frac{\Lambda_s}{\Lambda_t} \frac{P_t}{P_s}$$

and Λ_t is the marginal utility of consumption defined later. The first order condition is :

$$\mathbb{E}_t \sum_{s=t}^{\infty} \theta_p^{s-t} Q_{t,s} \left[\frac{\tilde{P}_t}{\Pi_{t,s}} - (1 + \lambda_p) \, mc_s \right] \left(\frac{\tilde{P}_t}{\Pi_{t,s}} \right)^{-\frac{1+\lambda_p}{\lambda_p}} Y_s = 0$$

By the law of large numbers, the law of motion of the aggregate price index P_t is given by:

$$P_t^{\frac{1}{\lambda_p}} = (1 - \theta_p)(\tilde{P}_t)^{\frac{1}{\lambda_p}} + \theta_p P_{t-1}^{\frac{1}{\lambda_p}}$$

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[16]Relative to the conventional literature, we will allow for an endogenous relationship between TFP growth and output gap.

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5.2. Hysteresis effects

In order to be able to capture the empirical features describe in the previous sections, we examine a richer specification of the low of motion for total factor productivity than is conventional. In particular, we assume that the law of motion for Z_t is:

$$\log Z_t = \log Z_{t-1} + \mu_t + \eta \log \left(Y_{t-1} / Y_{t-1}^{f,t-1} \right)$$

where μ_t is the exogenous component of the TFP growth rate, that may be subject to trend shocks. $Y_{t-1}^{f,t-1}$ is the flexible price level of output in period $t-1$ conditional on Z_{t-1}, and will be referred to as the *potential* output at time $t-1$. The second component denotes the endogenous component of TFP growth, where η is the elasticity of TFP growth rate with respect to fluctuations in output due to nominal rigidities. We refer to this as the *hysteresis elasticity* (to be consistent with DeLong and Summers 2012).

   The above law of motion allows business cycles to affect TFP growth rate only in the presence of nominal rigidities or inadequate stabilization. For clarity, we employed this reduced form equation.[17] A micro-founded model of innovation and productivity growth that yields this exact representation under monetary policy shocks can be found in the recent literature embedding endogenous growth into DSGE models (Bianchi et al., 2019; Garga and Singh, 2016). The effects of business cycles on TFP growth rate that are unrelated to nominal rigidities can be denoted by time varying values of μ_t, which may depend on other shocks (markup shocks, stationary TFP shocks, discount factor shocks, capital quality shocks etc.). For ease of exposition, we only focus on the hysteresis effects induced by the presence of nominal rigidities and treat μ_t to be an exogenous series. Movements in this series can be used to induce state-dependent hysteresis effects of monetary policy shocks.

   This functional dependence creates a role for hysteresis stabilization by central banks in a reduced form manner (Yellen, 2016). [18] Long-run effects of monetary policy shocks depend on the value of η. To clarify, in this paper, we are only able to discuss the sign and the magnitude of η in response to temporary monetary shocks denoted as η^{mp}. We assume that $\eta^{mp} > 0$ and the exact quantitative magnitudes can extracted from the empirical IRFs estimated above.

5.3. Households

Rest of the model components are standard. We briefly summarize them here and leave the detailed derivations to the appendix.

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[17]A similar setup was used by Stadler (1990) in his seminal work.

[18]Theoretically, there is no apriori reason to expect η to be positive. While a 'cleansing' effect of recessions may induce counter-cyclicality, recessions may reduce funding access to firms to conduct R&D, skill development, and learning-by-doing. The sign on the cyclicality of TFP misallocation is also ambiguous and depends on the assumptions in a model.

5.3.1 Households

Each household supplies differentiated labor indexed by j. Household j chooses consumption C_t, risk-free nominal bonds B_t, investment I_t and capital utilization u_t to maximize the utility function, with external habits over consumption:

$$\mathbb{E}_t \Sigma_{s=t}^{\infty} \beta^{s-t} \left[\log(C_{j,s} - hC_{j,s-1}) - \frac{\omega}{1+\nu} L_{j,s}^{1+\nu} \right]$$

where h is the degree of habit formation, $\nu > 0$ is the inverse Frisch elasticity of labor supply, $\omega > 0$ is a parameter that pins down the steady-state level of hours, and the discount factor β satisfies $0 < \beta < 1$. We assume perfect consumption risk sharing across the households. As a result, household's budget constraint in period t is given by

$$P_t C_t + P_t I_t + B_{t+1} = B_t(1+i_t) + B_{j,t}^S + (1+\tau^w)W_t L_{j,t} + \Gamma_t + T_t + R_t^K u_t K_t^u - P_t a(u_t) K_t^u \quad (7)$$

where I_t is investment, $B_{j,t}^S$ is the net cash-flow from household j's portfolio of state-contingent securities. Labor income $W_t L_{j,t}$ is subsidized at a fixed rate τ_w. Households own an equal share of all firms, and thus receive Γ_t dividends from profits. Finally, each household receives a lump-sum government transfer T_t. Since households own the capital and choose the utilization rate, the amount of effective capital that the households rent to the firms at nominal rate R_t^K is :

$$K_t = u_t K_t^u$$

The (nominal) cost of capital utilization is $P_t a(u_t)$ per unit of physical capital. As in the literature (Smets and Wouters 2007) we assume $a(1) = 0$ in the steady state and $a'' > 0$. Following Christiano, Eichenbaum, and Evans (2005), we assume investment adjustment costs in the production of capital. Law of motion for capital is as follows:

$$K_{t+1}^u = \left[1 - S\left(\frac{I_t}{(1+g_{ss})I_{t-1}} \right) \right] I_t + (1-\delta_k)K_t^u$$

where $g_{ss} \equiv \bar{\mu}$ is the steady state growth rate of Z_t. Utility maximization delivers the first order condition linking the inter-temporal consumption smoothing to the marginal utility of holding the risk-free bond

$$1 = \beta \mathbb{E}_t \left[\frac{\Lambda_{t+1}}{\Lambda_t} (1+i_t) \frac{P_t}{P_{t+1}} \right] \quad (8)$$

The stochastic discount factor in period $t+1$ is given by:

$$Q_{t,t+1} = \beta \frac{\Lambda_{t+1}}{\Lambda_t} \frac{P_t}{P_{t+1}}$$

where Λ_t is the marginal utility of consumption given by:

$$\Lambda_t = \frac{1}{C_t - hC_{t-1}} - \frac{h\beta}{C_{t+1} - hC_t}$$

The household does not choose hours directly. Rather each type of worker is represented by a wage union who sets wages on a staggered basis. Consequently the household supplies labor at the posted wages as demanded by firms.

We introduce capital accumulation through households. Solving household problem for investment and capital yields the Euler condition for capital:

$$q_t = \beta\mathbb{E}_t\left[\frac{\Lambda_{t+1}}{\Lambda_t}\left(\frac{R^K_{t+1}}{P_{t+1}}u_{t+1} - a(u_{t+1}) + q_{t+1}(1 - \delta_k)\right)\right]$$

where the (relative) price of installed capital q_t is given by

$$q_t\left[1 - S\left(\frac{I_t}{(1 + g_{ss})I_{t-1}}\right) - S'\left(\frac{I_t}{(1 + g_{ss})I_{t-1}}\right)\frac{I_t}{(1 + g_{ss})I_{t-1}}\right]$$
$$+ \beta\frac{\Lambda_{t+1}}{\Lambda_t}q_{t+1}\frac{1}{(1 + g_{ss})}\left(\frac{I_{t+1}}{I_t}\right)^2 S'\left(\frac{I_{t+1}}{(1 + g_{ss})I_t}\right) = 1$$

Choice of capital utilization rate yields:

$$\frac{R^K_t}{P_t} = a'(u_t)$$

5.3.2 Wage setting

Wage Setting follows Erceg, Henderson, and Levin (2000) and is relatively standard. Perfectly competitive labor agencies combine j type labor services into a homogeneous labor composite L_t according to a Dixit-Stiglitz aggregation:

$$L_t = \left[\int_0^1 L_{j,t}^{\frac{1}{1+\lambda_w}}dj\right]^{1+\lambda_w}$$

where $\lambda_w > 0$ is the nominal wage markup. Labor unions representing workers of type j set wages on a staggered basis following Calvo (1983), taking given the demand for their specific labor input:

$$L_{j,t} = \left(\frac{W_{j,t}}{W_t}\right)^{-\frac{1+\lambda_w}{\lambda_w}}L_t, \qquad \text{where } W_t = \left[\int_0^1 W_{j,t}^{\frac{-1}{\lambda_w}}dj\right]^{-\lambda_w}$$

In particular, with probability $1 - \theta$, the type-j union is allowed to re-optimize its wage contract and it chooses $\tilde{W}$ to minimize the disutility of working for laborer of type j, taking into account

the probability that it will not get to reset wage in the future.[19] The first order condition for this problem is given by:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\beta \theta_w)^s \Lambda_{t+s} \left[(1 + \tau_t^W) \tilde{W}_t - (1 + \lambda_w) \omega \frac{L_{j,t+s}^{\nu}}{\Lambda_{t+s}} \right] L_{j,t+s} = 0 \tag{9}$$

By the law of large numbers, the probability of changing the wage corresponds to the fraction of types who actually change their wage. Consequently, the nominal wage evolves according to:

$$W_t^{\frac{1}{\lambda_w}} = (1 - \theta_w) \tilde{W}_t^{\frac{1}{\lambda_w}} + \theta_w W_{t-1}^{\frac{1}{\lambda_w}}$$

where the nominal wage inflation and price inflation are related to each other :

$$\pi_t^w = \frac{W_t}{W_{t-1}} = \frac{w_t}{w_{t-1}} \frac{1}{\pi_t} \frac{1}{1 + g_t}$$

where $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the inflation rate, $w_t \equiv \frac{W_t}{P_t Z_t}$ is the productivity adjusted real wage and g_t is the growth rate of Z_t.

5.4. Government

The central bank follows a Taylor rule in setting the nominal interest rate. It responds to deviations in inflation, output and output growth rate from time-t natural allocations.

$$\frac{1 + i_t}{1 + i_{ss}} = \left(\frac{1 + i_{t-1}}{1 + i_{ss}} \right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi_{ss}} \right)^{\phi_\pi} \left(\frac{Y_t}{Y_t^{f,t}} \right)^{\phi_y} \right]^{1 - \rho_R} \left(\frac{Y_t / Y_{t-1}}{Y_t^{f,t} / Y_{t-1}^{f,t-1}} \right)^{\phi_{dy}} \epsilon_t^{mp} \tag{10}$$

where i_{ss} is the steady state nominal interest rate, $Y_t^{f,t}$ is the time-t natural output, ρ_R determines interest-rate smoothing and $\epsilon_t^{mp} \sim N(0, \sigma_r)$ is the monetary policy shock.

We assume government balances budget every period:

$$P_t T_t = \tau^p \int_0^1 p_{it} x_{it} di + \tau^w W_t L_t + P_t G_t$$

where G_t is the government spending, which is determined exogenously as as a fraction of GDP

$$G_t = \left(1 - \frac{1}{\lambda_t^g} \right) Y_t$$

---

[19]We assume imperfect wage indexation in our nominal wage rigidity assumption. We ignore specifying it here for ease of exposition. See appendix for details.

27

where the government spending shock follows the process:

$$\log \lambda_t^g = (1 - \rho_g)\lambda^g + \rho_g \log \lambda_{t-1}^g + \epsilon_t^g; \quad \epsilon_t^g \sim N(0, \sigma_g)$$

5.5. Market clearing

Market clearing requires

$$Y_t = C_t + I_t + a(u_t)K_t^u + G_t$$

5.6. Simulations

As the DSGE model is intentionally standard, we take parameters from the literature Justiniano et al. (2013). We report these in Table 4. The steady state parameters imply (annualized) real interest rate of 2.40%, and an investment-GDP ratio of 17%. For the monetary shock process, we chose the following parameters $\sigma_r = 0.02$ and $\rho_R = 0.8$.[20] The short term nominal interest rate increases by about 10 basis points on impact in the three simulations that we report here.

The new parameter in our model, relative to the business cycles literature, is η: the hysteresis elasticity. Table 3 reports the point estimates for η implies by the estimated impulse responses. We take an average of the IRF of raw TFP and the IRF of GDP to the respective monetary policy shock in computing this elasticity. Following the persistent drop in output after the Great Recession in the US, DeLong and Summers (2012) infer that this parameter could be as high as 0.24. In our calibration henceforth, we use the value of 0.18.

Figure 15 plots the model-implied impulse responses for output, capital stock, real interest rate and capital to utilization adjusted TFP after a monetary policy shock. Solid line reports the IRFs for endogenous growth model with $\eta = 0.18$, and dashed line reports IRFs for the comparable exogenous growth benchmark i.e. $\eta = 0$. The IRFs for output and capital stock are plotted in percent deviations from an exogenous trend. For real interest rate, we plot the actual path of real interest rate. Capital to utilization adjusted TFP ratio is in percent deviation from steady state ratio. Time is in quarters.

The model replicates the estimated empirical patterns. There is a persistent decline in capital stock, output and TFP. Furthermore, the endogenous growth model exhibits considerable amplification to the transitory shock because of the large hysteresis elasticity.

We define the accumulated gaps in TFP growth rate as the *hysteresis*. We next show the path of output, and capital when the central bank sets interest rates following an augmented Taylor rule:

$$\frac{1+i_t}{1+i_{ss}} = \left(\frac{1+i_{t-1}}{1+i_{ss}}\right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi_{ss}}\right)^{\phi_\pi} \left(\frac{Y_t}{Y_t^{f,t}}\right)^{\phi_y} \left(\frac{H_t}{H_t^{f,t}}\right)^{\phi_H}\right]^{1-\rho_R} \left(\frac{Y_t/Y_{t-1}}{Y_t^{f,t}/Y_{t-1}^{f,t-1}}\right)^{\phi_{dy}} \epsilon_t^{mp}$$

---

[20]Note that this exercise is merely illustrative. A detailed investigation is pending until the next iteration of the draft.

Table 3: *Point estimates for hysteresis elasticity η*

	pegs (trilemma)	
Data	1890-2015	1948-2015
η	0.18	0.42

Notes: The point estimates are calculated by taking an average of the IRF of raw TFP and the IRF of GDP to the monetary policy shock. Figure 2 report the IRFs for GDP and TFP.

Table 4: *Parameters*

Steady State Parameters				
β	δ_k	α	μ	
Discount factor	Capital depreciation rate	Capital share	Trend growth rate	
0.999	0.025	0.28	2%	

Parameters Characterizing the Dynamics					
ν	λ_p	λ_w	θ_p	θ_w	h
Inverse Frisch elasticity	Price s.s. markup	Wage s.s. markup	Price Calvo probability	Wage Calvo probability	(Internal) habit
1.00	0.15	0.15	0.750	0.750	0.5
$\frac{a''(1)}{a'(1)}$	$S''(1)$	ϕ_π	ϕ_y	$1 - \frac{1}{\lambda_g}$	η
Capital utilization cost	Investment adjustment cost	Taylor rule inflation response	Taylor rule (normalized) output response	Government spending share	Hysteresis elasticity
4	2	1.50	0.125	0.20	0.05

Notes: The table shows the parameter values of the model for the baseline calibration. See text.

where H_t is hysteresis and follows the law motion given by:

$$H_t = H_{t-1} + g_t - g_t^f$$

We set $\phi_H = 0.2$ to plot the graphs. Figure 16 contrasts the path of output and capital stock after a similar 10 bps shock to the federal funds rate. The real interest rate increases by less than in the case of the standard Taylor rule (Equation 10). This is because, under a hysteresis targeting rule, the central bank accommodates above-target inflation at a later time in order to target zero output hysteresis. Expectations of a high inflation rate induce less contraction in the economy as well as a sharp recovery of GDP to the pre-shock trend.

Figure 15: *Response of Output, Capital Stock, Real interest rate and Capital to TFP ratio to a 10 bps increase in nominal interest rate*
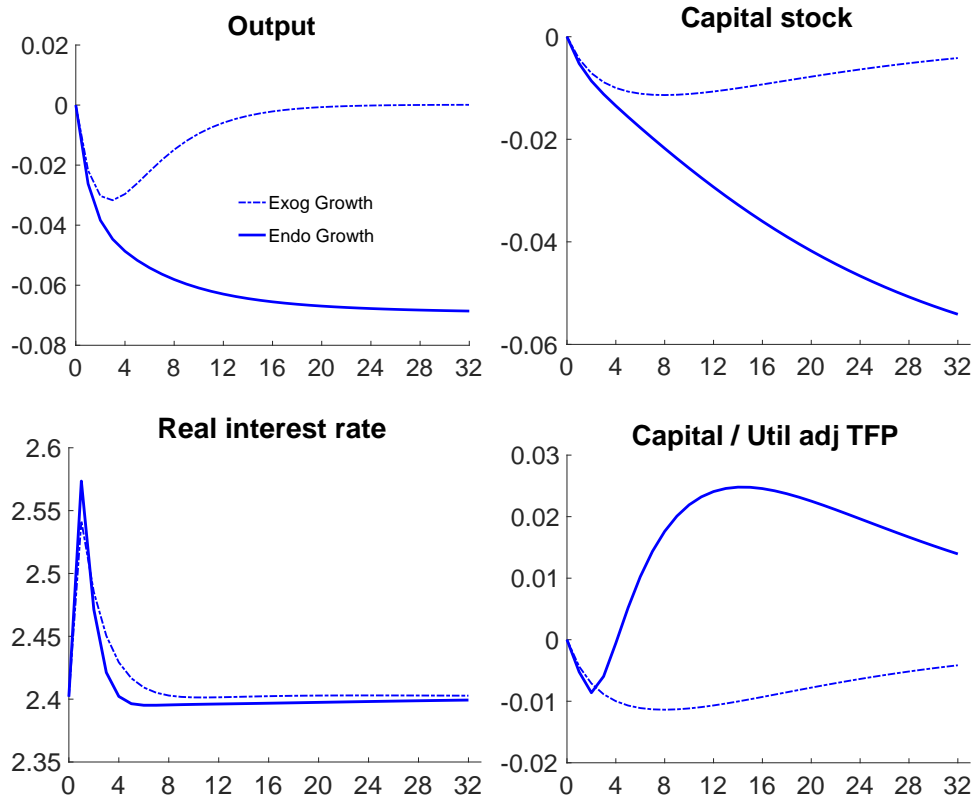
Notes: The figure plots the model-implied IRFs for output, capital stock, real interest rate and capital to utilization adjusted TFP to a transitory shock to the assumed Taylor rule. Solid line reports the IRFs for endogenous growth model with $\eta = 0.18$, and dashed line reports IRFs for the comparable exogenous growth benchmark i.e. $\eta = 0$. Time is in quarters. IRFs are traced following a one-time exogenous shock in the federal funds rate of about 10 basis points. The IRFs for output and capital stock are plotted in percent deviations from an exogenous trend. For real interest rate, we plot the actual path of real interest rate. Capital to utilization adjusted TFP ratio is in percent deviation from steady state ratio.

6. CONCLUSION

In this paper, we set out to investigate the widely accepted proposition of long-run money non-neutrality. Using panel-data spanning over a century and trilemma-identified monetary policy shocks, we find that monetary policy shocks indeed have long-run effects on output, capital and TFP. Furthermore, in the quarterly data for the US since 1969, we find that capital stock is permanently lower after a temporary monetary policy shock identified using a separate instrument. At the same time, capital to TFP ratio exhibits a hump-shaped relation as commonly found in the empirical macro-economics literature using vector-autoregression estimation. We reconcile these findings using a simple extension of the Smets and Wouters (2007) medium-scale DSGE model, where TFP growth depends on deviations of output from its flexible-price counterpart. Using the model, we show that a central bank that also targets hysteresis in its policy rule can offset the long-run effects of monetary policy.

Figure 16: *Responses of output, capital, real interest rate and inflation rate to 10 bps increase in nominal interest rate under a Taylor rule and a Hysteresis targeting rule with $\eta = 0.18$*
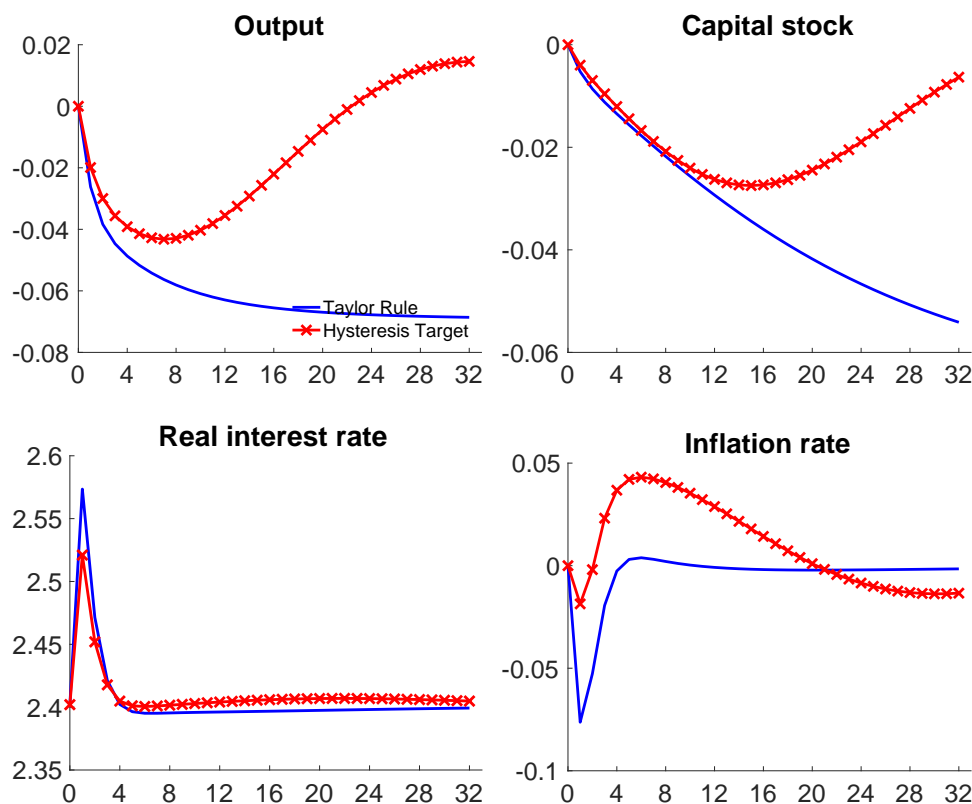
Notes: The figure plots the model-implied IRFs for output, capital, real interest rate and net inflation rate. Time is in quarters. IRFs are traced following a one-time exogenous shock in the federal funds rate of 10 bps (annualized). The IRFs for output and capital stock are plotted in deviations from an exogenous trend. See text for details.

REFERENCES

Angrist, J. D., Ò. Jordà, and G. M. Kuersteiner (2018). Semiparametric estimates of monetary policy effects: String theory revisited. *Journal of Business and Economic Statistics 36*(3), 371–387.

Anzoategui, D., D. Comin, M. Gertler, and J. Martinez (2018). Endogenous technology adoption and r&d as sources of business cycle persistence. Technical report, New York University Working paper.

Barlevy, G. (2004). The cost of business cycles under endogenous growth. *American Economic Review 94*(4), 964–990.

Barnichon, R. and C. Matthes (2018). Functional approximations of impulse responses (fair). *Journal of Monetary Economics forthcoming*.

Barro, R. J. (2013). Inflation and economic growth. *Annals of Economics and Finance 14*(1), 85–109.

Basu, S. and J. G. Fernald (2002). Aggregate productivity and aggregate technology. *European Economic Review 46*(6), 963–991.

Benigno, G. and L. Fornaro (2018). Stagnation traps. *The Review of Economic Studies 85*(3), 1425–1470.

Bergeaud, A., G. Cette, and R. Lecat (2016). Productivity trends in advanced countries between 1890 and 2012. *Review of Income and Wealth 62*(3), 420–444.

Bernanke, B. S. and I. Mihov (1998, December). The liquidity effect and long-run neutrality. *Carnegie-Rochester Conference Series on Public Policy 49*(1), 149–194.

Bianchi, F., H. Kung, and G. Morales (2019). Growth, slowdowns, and recoveries. *Journal of Monetary Economics forthcoming*.

Blanchard, O. (2016, July). Currency wars, coordination, and capital controls. Working Paper 22388, National Bureau of Economic Research.

Burnside, C. and M. Eichenbaum (1996). Factor-hoarding and the propagation of business-cycle shocks. *The American Economic Review 86*(5), 1154.

Caballero, R. J., T. Hoshi, and A. K. Kashyap (2008). Zombie lending and depressed restructuring in japan. *The American Economic Review 98*(5), 1943–1977.

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics 12*(3), 383–398.

Cerra, V. and S. C. Saxena (2008). Growth dynamics: the myth of economic recovery. *American Economic Review 98*(1), 439–457.

Christiano, L., M. Eichenbaum, and C. Evans (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy 113*(1).

Christiano, L. J., M. Eichenbaum, and C. L. Evans (1999). Monetary policy shocks: What have we learned and to what end? In J. B. Taylor and M. Woodford (Eds.), *Handbook of Macroeconomics*, Volume 1 of *Handbook of Macroeconomics*, Chapter 2, pp. 65–148. Elsevier.

Coibion, O., Y. Gorodnichenko, and M. Ulate (2017, July). The cyclical sensitivity in estimates of potential output. Working Paper 23580, National Bureau of Economic Research.

DeLong, B. J. and L. H. Summers (2012). Fiscal policy in a depressed economy. *Brookings Papers on Economic Activity 1*, 233–297.

Duval, R., G. H. Hong, and Y. Timmer (2019). Financial Frictions and the Great Productivity Slowdown. *The Review of Financial Studies*.

Erceg, C. J., D. W. Henderson, and A. T. Levin (2000). Optimal monetary policy with staggered wage and price contracts. *Journal of Monetary Economics 46*(2), 281–313.

Erceg, C. J. and A. T. Levin (2014). Labor force participation and monetary policy in the wake of the great recession. *Journal of Money, Credit and Banking 46*(S2), 3–49.

Evans, C. L. (1992). Productivity shocks and real business cycles. *Journal of Monetary Economics 29*(2), 191–208.

Fatas, A. (2000). Do business cycles cast long shadows? short-run persistence and economic growth. *Journal of Economic Growth 5*(2), 147–162.

Fatás, A. and L. H. Summers (2018). The permanent effects of fiscal consolidations. *Journal of International Economics 112*, 238–250.

Fernald, J. (2014). A quarterly, utilization-adjusted series on total factor productivity. Working Paper Series 2012-19, Federal Reserve Bank of San Francisco.

Fischer, S. (1983, November). Inflation and growth. Working Paper 1235, National Bureau of Economic Research.

Galí, J. (2016). Hysteresis and the european unemployment problem revisited. Technical report, National Bureau of Economic Research.

Garga, V. and S. R. Singh (2016). Output hysteresis and optimal monetary policy. Technical report, Brown University Mimeo.

Gertler, M. and P. Karadi (2015, January). Monetary Policy Surprises, Credit Costs, and Economic Activity. *American Economic Journal: Macroeconomics 7*(1), 44–76.

Gopinath, G., c. Kalemli-Özcan, L. Karkarabounis, and C. Villegas-Sánchez (2017). Capital allocation and productivity in south europe. *Quarterly Journal of Economics 132*(4), 1915–1967.

Gordon, R. J. (2016). *The rise and fall of American growth: The US standard of living since the civil war*. Princeton University Press.

Gourinchas, P.-O. (2018). Monetary policy transmission in emerging markets: An application to chile. In E. G. M. . E. P. . D. Saravia (Ed.), *Monetary Policy and Global Spillovers: Mechanisms, Effects and Policy Measures*, Chapter 8, pp. 279–324. Central Bank of Chile.

Haltmaier, J. (2013). Do recessions affect potential output?

Hume, D. (1758). *Essays and Treatises on Several Subjects*. A. Millar, A. Kincaid, and A. Donaldson.

Imbs, J. M. (1999). Technology, growth and the business cycle. *Journal of Monetary Economics 44*(1), 65 – 80.

Jiang, Z., A. Krishnamurthy, and H. Lustig (2018). Dollar safety and the global financial cycle. Technical report, Stanford University, Graduate School of Business.

Jordà, Ò. (2005, March). Estimation and Inference of Impulse Responses by Local Projections. *American Economic Review 95*(1), 161–182.

Jordà, O., M. Schularick, and A. M. Taylor (2016). The great mortgaging: housing finance, crises and business cycles. *Economic Policy 31*(85), 107–152.

Jordà, O., M. Schularick, and A. M. Taylor (2017). Macrofinancial history and the new business cycle facts. *NBER Macroeconomics Annual 31*(1), 213–263.

Jordà, O., M. Schularick, and A. M. Taylor (2019). Large and State-Dependent Effects of Quasi-Random Monetary Experiments. *Journal of Monetary Economics forthcoming*.

Justiniano, A., G. E. Primiceri, and A. Tambalotti (2013). Is there a trade-off between inflation and output stabilization? *American Economic Journal: Macroeconomics 5*(2), 1–31.

Kiyotaki, N. and S. Zhang (2017). Intangibles, inequality and stagnation.

Liu, E., A. Mian, and A. Sufi (2018). Low interest rates, market power, and productivity growth. mimeograph.

Mankiw, N. G. (2001). The inexorable and mysterious tradeoff between inflation and unemployment. *The Economic Journal 111*(471), 45–61.

Martin, R., T. Munyan, and B. A. Wilson (2015). Potential output and recessions: are we fooling ourselves? *FRB International Finance Discussion Paper #1145*.

Moran, P. and A. Queraltó (2018). Innovation, productivity, and monetary policy. *Journal of Monetary Economics*.

Nakamura, E. and J. Steinsson (2018). Identification in macroeconomics. *Journal of Economic Perspectives 32*(3), 59–86.

Obstfeld, M., J. C. Shambaugh, and A. M. Taylor (2004). Monetary sovereignty, exchange rates, and capital controls: The trilemma in the interwar period. *IMF Staff Papers 51*(3S1), 75–108.

Obstfeld, M., J. C. Shambaugh, and A. M. Taylor (2005). The trilemma in history: Tradeoffs among exchange rates, monetary policies, and capital mobility. *The Review of Economics and Statistics 87*(3), 423–438.

Quinn, D., M. Schindler, and A. M. Toyoda (2011). Assessing measures of financial openness and integration. *IMF Economic Review 59*(3), 488–522.

Ramey, V. (2016). Chapter 2 - macroeconomic shocks and their propagation. Volume 2 of *Handbook of Macroeconomics*, pp. 71 – 162. Elsevier.

Ramey, V. A. and S. Zubairy (2018). Government spending multipliers in good times and in bad: Evidence from us historical data. *Journal of Political Economy 126*(2), 850–901.

Rey, H. (2015). Dilemma not trilemma: the global financial cycle and monetary policy independence. Technical report, National Bureau of Economic Research.

Romer, C. D. and D. H. Romer (2004, September). A new measure of monetary shocks: Derivation and implications. *American Economic Review 94*(4), 1055–1084.

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy 98*.

Shambaugh, J. C. (2004). The effect of fixed exchange rates on monetary policy*. *The Quarterly Journal of Economics 119*(1), 301–352.

Smets, F. and R. Wouters (2007). Shocks and frictions in us business cycles: A bayesian dsge approach. *American Economic Review 97*(3), 586–606.

Stadler, G. W. (1990). Business cycle models with endogenous technology. *The American Economic Review 80*(4), 763.

Stock, J. H. and M. W. Watson (2018). Identification and estimation of dynamic causal effects in macroeconomics using external instruments. *The Economic Journal 128*(610), 917–948.

Syverson, C. (2011). What determines productivity? *Journal of Economic literature 49*(2), 326–65.

Tenreyro, S. and G. Thwaites (2016, October). Pushing on a String: US Monetary Policy Is Less Powerful in Recessions. *American Economic Journal: Macroeconomics 8*(4), 43–74.

Wieland, J. F. and M.-J. Yang (2016). Financial dampening. Technical report, National Bureau of Economic Research.

Yellen, J. L. (2016). Macroeconomic research after the crisis. *Speech at the "The Elusive 'Great' Recovery: Causes and Implications for Future Business Cycle Dynamics" conference, Federal Reserve Bank of Boston, October.*

A. Appendix: Additional Graphs Related to Trilemma Shock

A.1. [Figure 2](#) IRFs with error bands

Figure A1: *Full Sample: Real GDP and components*
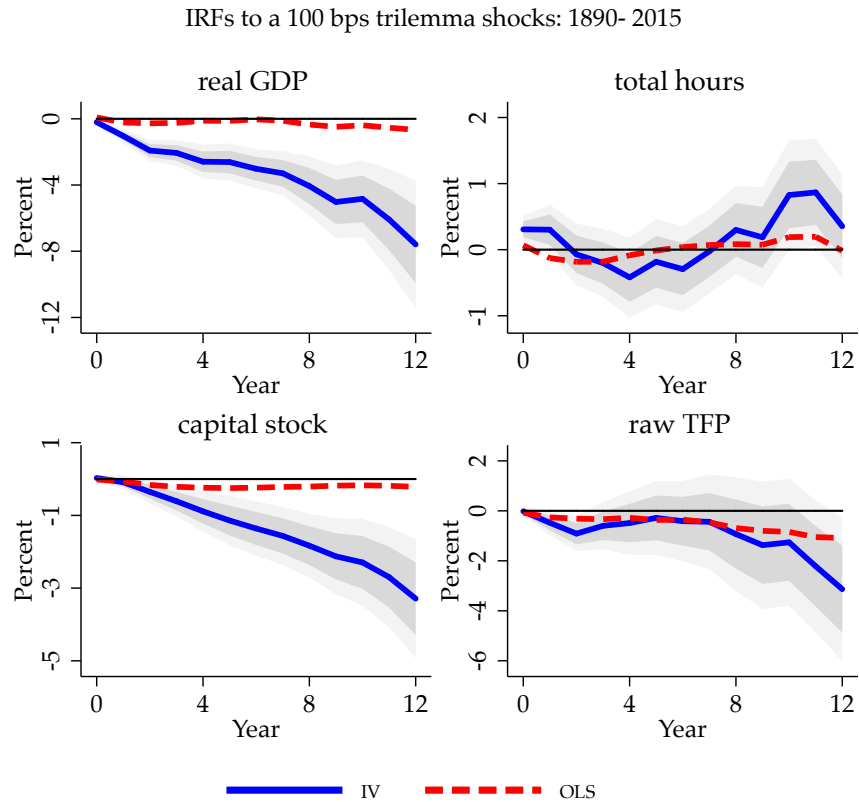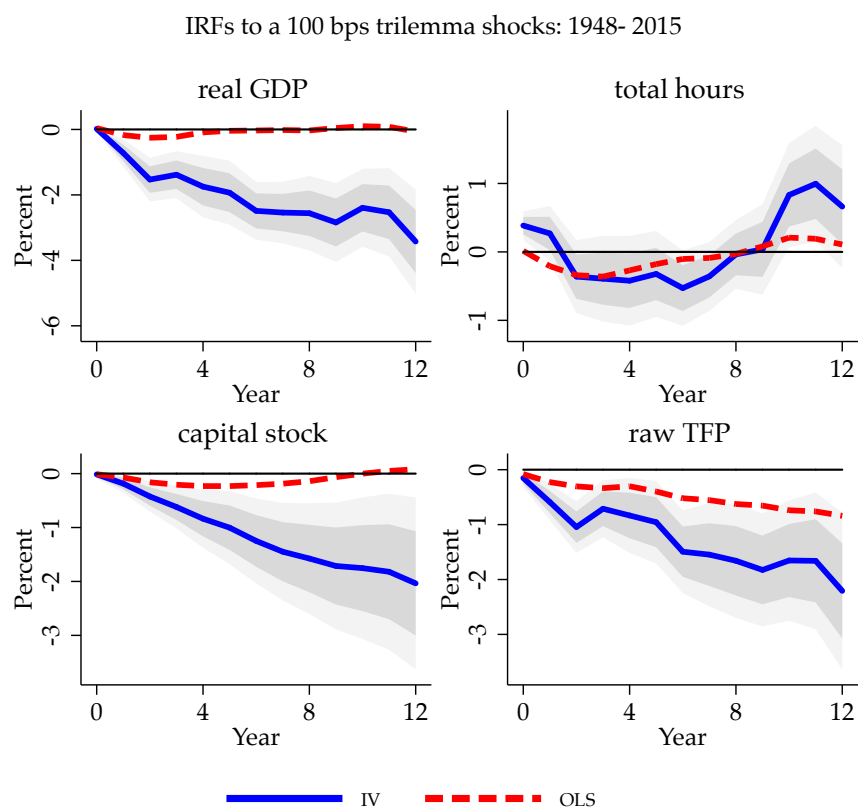
IRFs to a 100 bps trilemma shocks: 1890- 2015

Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Full sample: 1890–2015 (World Wars excluded). See text.

IRFs to a 100 bps trilemma shocks: 1948- 2015

Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Post-WW2 sample: 1948–2015. See text.

A.2. IRFs with Structural Breaks in GDP per capita

We show an alternate selection of structural breaks based on real GDP per capita.

Figure A3: *Response to 100 bps trilemma shock with structural breaks: Real GDP*
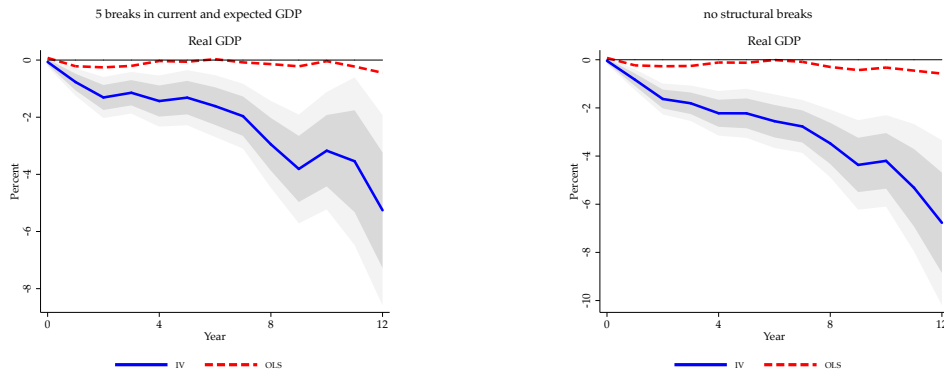
Notes: Response to a 100 bps shock in domestic interest rate instrumented with the trilemma. Responses for pegging economies. Full sample: 1890–2015 (World Wars excluded). Post-WW2 sample: 1948–2015. LP-OLS estimates displayed as a dashed red line, LP-IV estimates displayed as a solid blue line and 1 S.D. and 90% confidence bands. See text and Jordà, Schularick, and Taylor (2019).

Structural Breaks in TFP growth and GDP growth

TFP growth for AUS

TFP growth for AUS

TFP growth for BEL

TFP growth for CAN

TFP growth for CHE

TFP growth for DEU

TFP growth for DNK

TFP growth for ESP

TFP growth for FIN

TFP growth for FRA

TFP growth for GBR

TFP growth for ITA

TFP growth for JPN

TFP growth for NLD
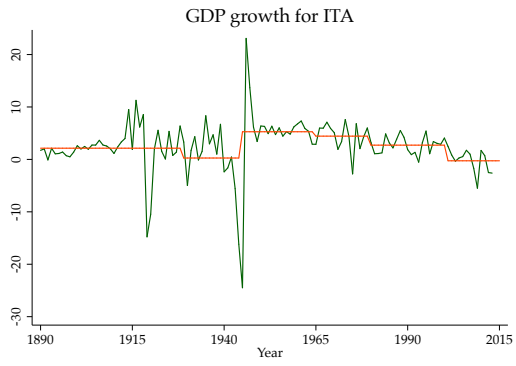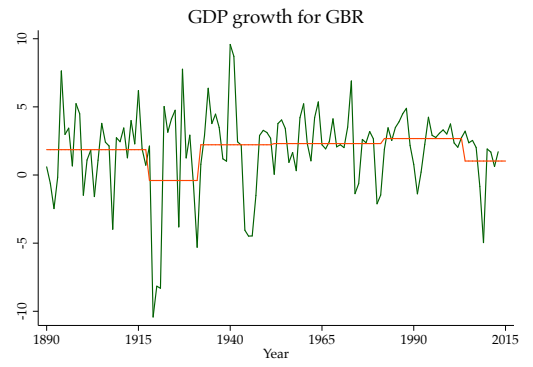

TFP growth for NOR

TFP growth for PRT

TFP growth for SWE

TFP growth for USA

GDP growth for USA

GDP growth for AUS

GDP growth for BEL

GDP growth for CAN

GDP growth for CHE

GDP growth for DEU

GDP growth for DNK

GDP growth for ESP

GDP growth for FIN

GDP growth for FRA

GDP growth for GBR

GDP growth for ITA

GDP growth for JPN

GDP growth for NLD

GDP growth for NOR

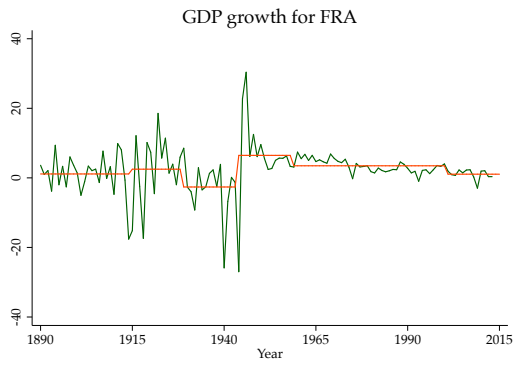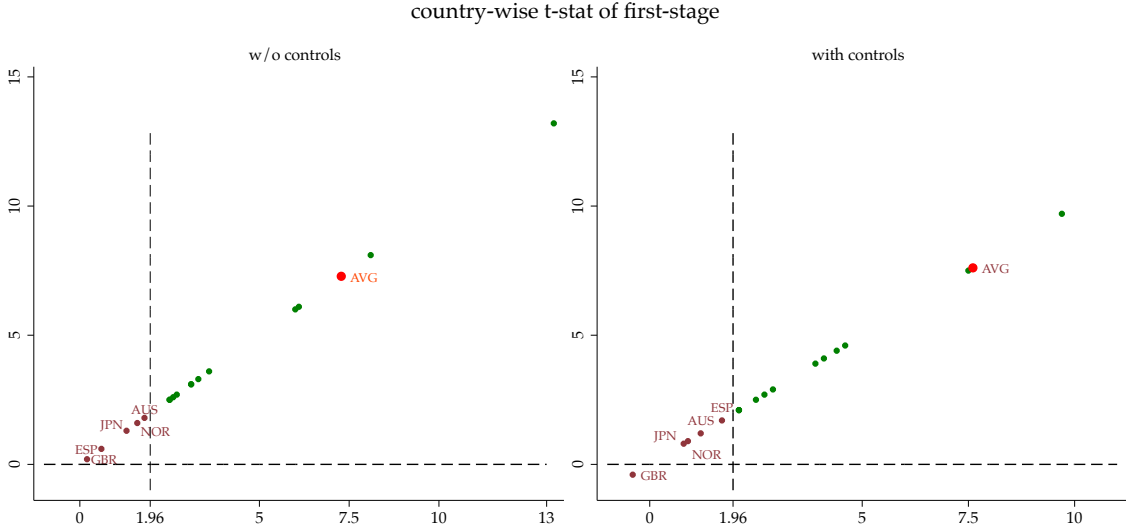GDP growth for PRT

GDP growth for SWE

A.3. First stage t-statistic for each country

country-wise t-stat of first-stage

Notes: The figures report the first-stage t-statistics for each country during its peg. The change in peg country's short term interest rate is regressed on the instrument z. The instrument is the change in base country's short term interest which is orthogonal to base country conditions. AVG denotes the t-statistic for the pooled sample.

A.4. Country Specific IRFs over 1890-2015

JPN

NLD

NOR

PRT

SWE

LATE

IV — — — OLS

47
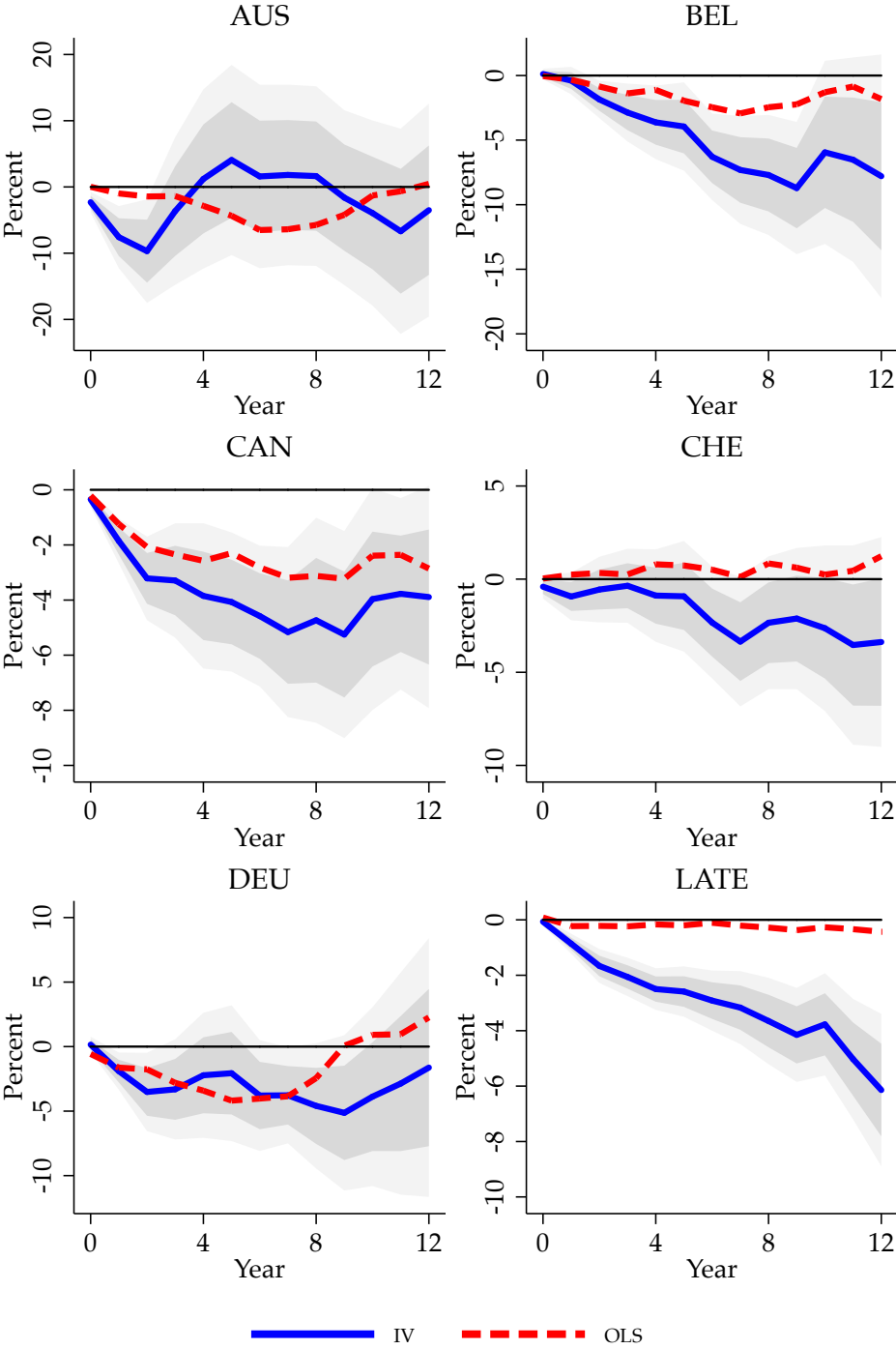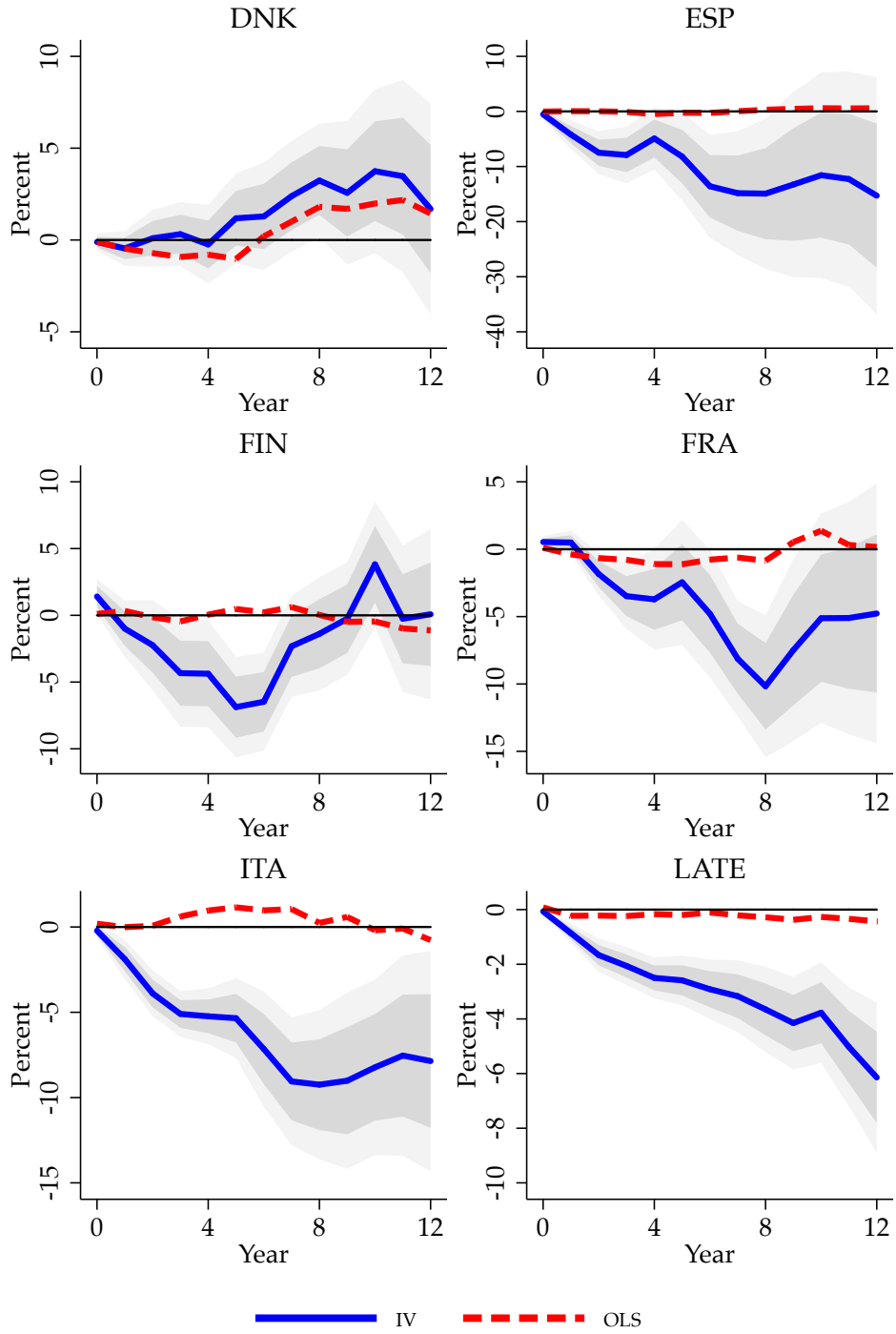
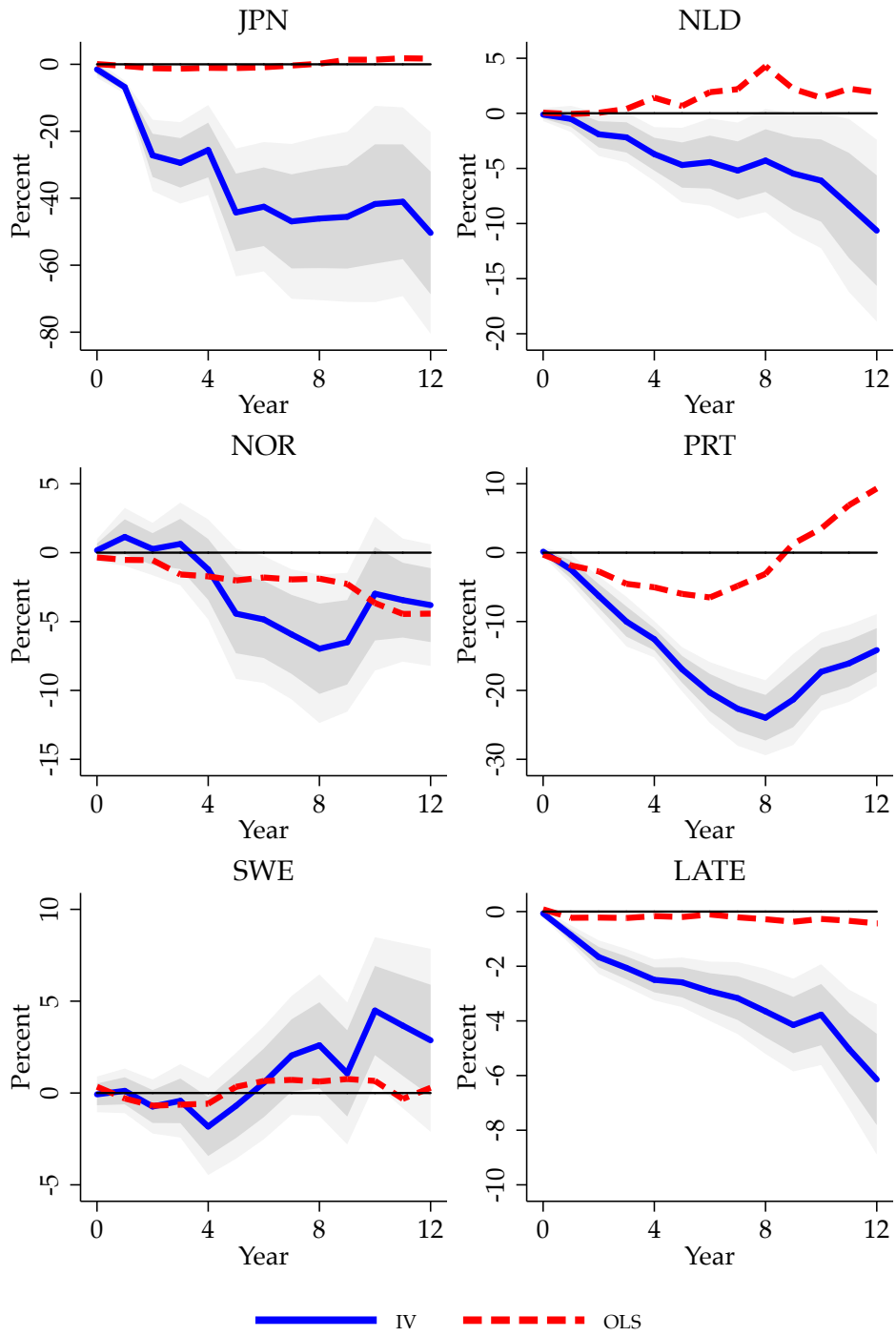# B. Appendix: Graphs Related to Romer and Romer (2004) Surprises

B.1. Different sample selection for US

Figure A4: *Response to 100 bps Romer and Romer (2004) shock*

(a) *Full sample: 1969Q2: 2008Q3*   **(b)** *Sample: 1973Q2: 2008Q3*
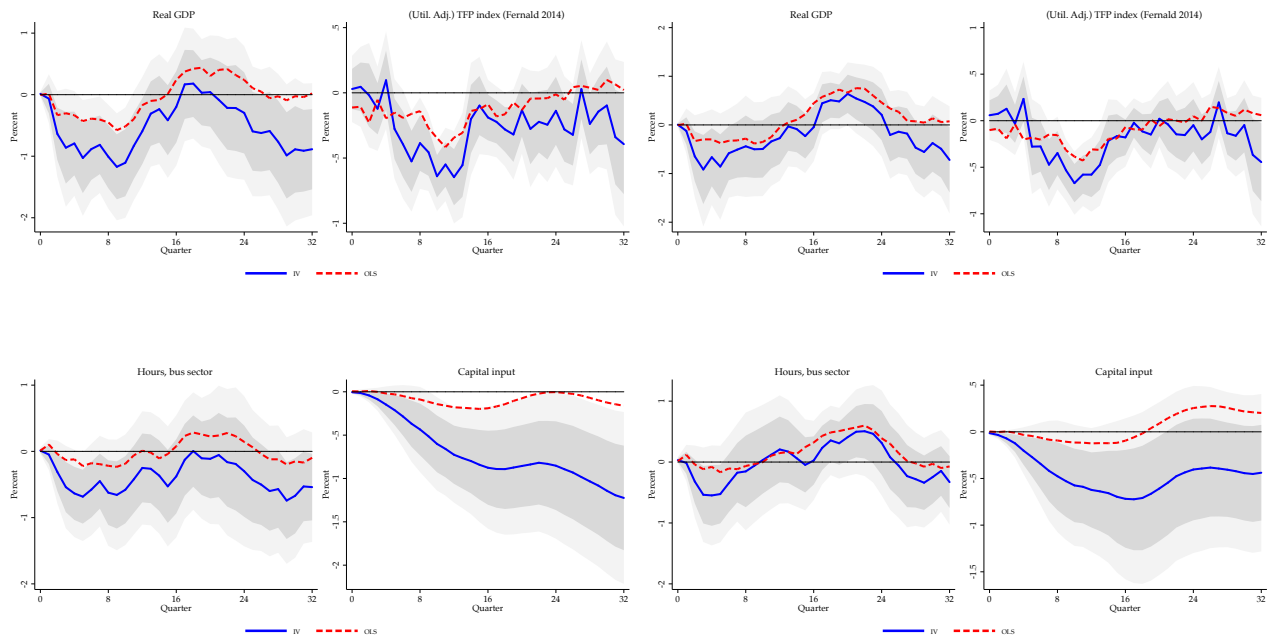
Notes: Response to a 100 bps shock in federal funds rate rate instrumented with policy forecast residuals (Romer and Romer, 2004; Wieland and Yang, 2016). Responses of real GDP, utilization-adjusted TFP (Fernald, 2014), capital stock and hours worked for US economy. Quarterly samples: a) 1969-Q2: 2008-Q3, b) 1973-Q2: 2008-Q3. Quarterly data series are taken from Fernald (2014).

Figure A5: *Response to 100 bps Romer and Romer (2004) shock*

(a) *Sample: 1979Q3: 2008Q3*   **(b)** *Sample: 1984Q1: 2008Q3*

Notes: Response to a 100 bps shock in federal funds rate rate instrumented with policy forecast residuals (Romer and Romer, 2004; Wieland and Yang, 2016). Responses of real GDP, utilization-adjusted TFP (Fernald, 2014), capital stock and hours worked for US economy. Quarterly samples: a) 1979-Q3: 2008-Q3, b) 1984-Q1: 2008-Q3. Quarterly data series are taken from Fernald (2014).

Figure A6: *Response to 100 bps Romer and Romer (2004) shock*

(a) *Sample: 1969Q2: 2002Q4*

(b) *Sample: 1987Q1: 2008Q3*
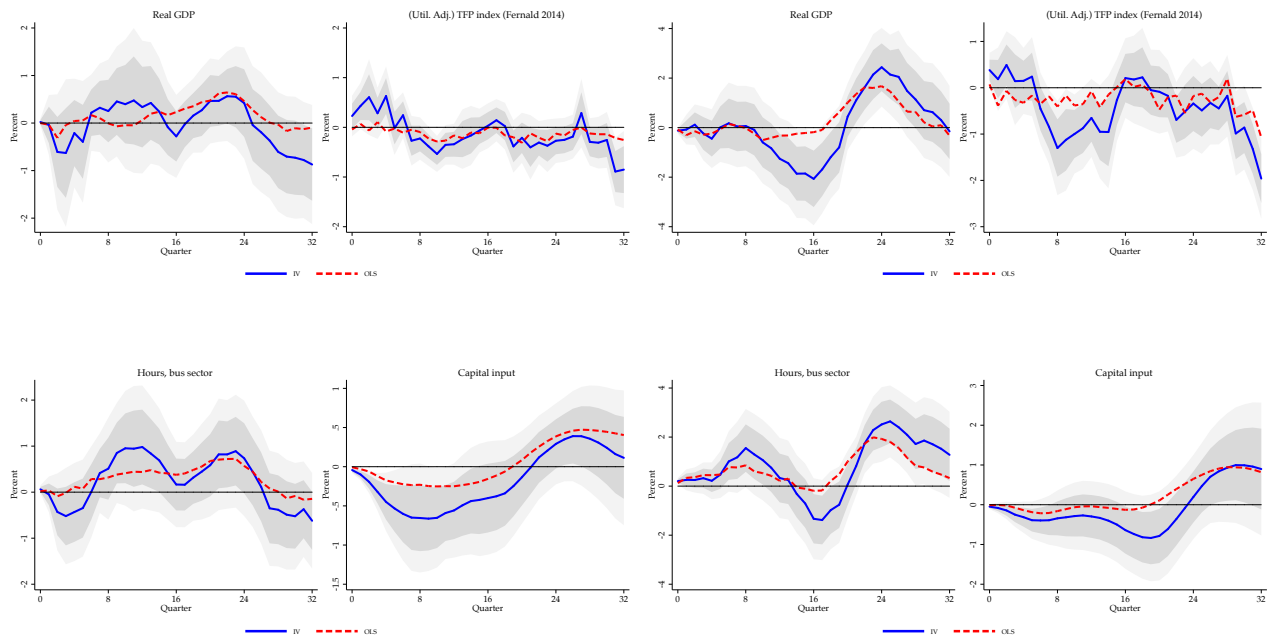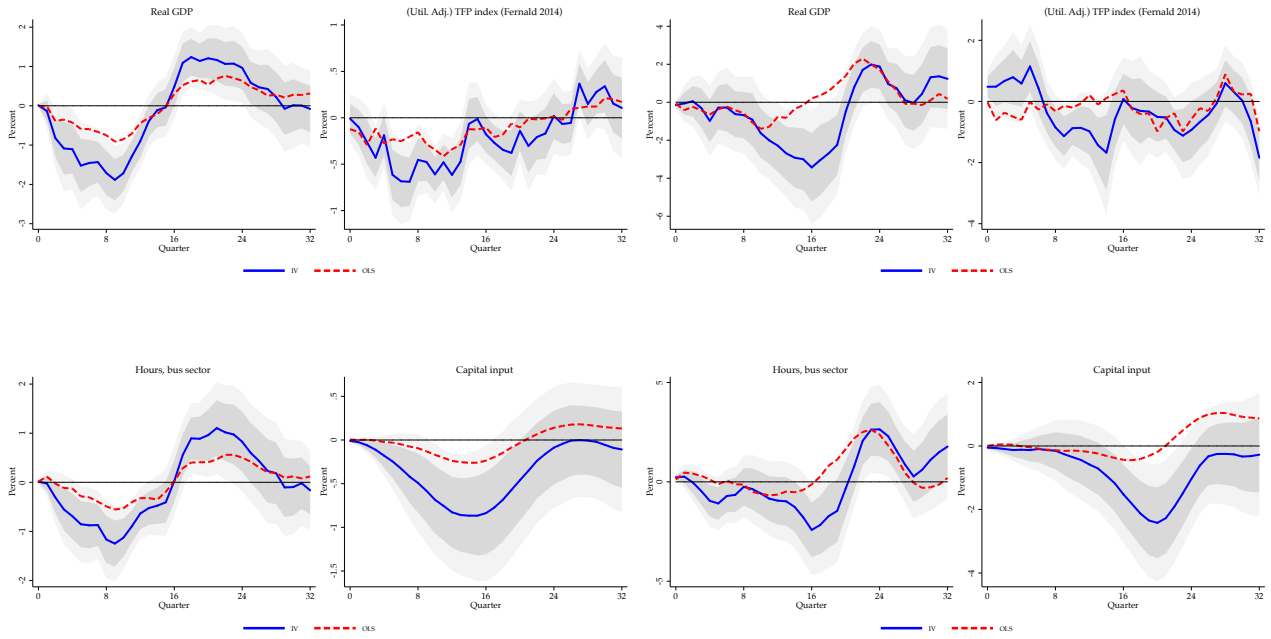

Notes: Response to a 100 bps shock in federal funds rate rate instrumented with policy forecast residuals (Romer and Romer, 2004; Wieland and Yang, 2016). Responses of real GDP, utilization-adjusted TFP (Fernald, 2014), capital stock and hours worked for US economy. Quarterly samples: a) 1969-Q2: 2002-Q4, b) 1987-Q1: 2008-Q3. Quarterly data series are taken from Fernald (2014).

C. Appendix: Related Tables

Table A1: *LP-OLS vs. LP-IV. Attenuation bias of real GDP per capita responses to interest rates. Trilemma instrument. Matched samples*

Responses of real GDP per capita at years 0 to 10 ($100 \times$ log change from year 0 baseline).

Year	(a) Full Sample		OLS-IV	(b) Post-WW2		OLS-IV
	LP-OLS	LP-IV	*p-value*	LP-OLS	LP-IV	*p-value*
	(1)	(2)	(3)	(4)	(5)	(6)
$h = 0$	0.07***	-0.07	0.09	0.04**	0.09	0.47
	(0.03)	(0.09)		(0.02)	(0.06)	
$h = 2$	-0.28*	-1.72***	0.00	-0.25*	-1.47***	0.00
	(0.16)	(0.34)		(0.13)	(0.38)	
$h = 4$	-0.16	-2.53***	0.00	-0.08	-1.83***	0.00
	(0.26)	(0.50)		(0.21)	(0.57)	
$h = 6$	-0.06	-2.87***	0.00	0.02	-2.37***	0.00
	(0.29)	(0.66)		(0.23)	(0.55)	
$h = 8$	-0.36	-3.55***	0.00	0.10	-2.04***	0.00
	(0.29)	(0.84)		(0.22)	(0.55)	
$h = 10$	-0.40	-4.05***	0.00	0.26	-1.63***	0.00
	(0.35)	(1.08)		(0.24)	(0.62)	
KP weak IV		79.66			84.86	
H_0: $LATE = 0$	0.00	0.00		0.00	0.00	
Observations	607	607		482	482	

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Cluster robust standard errors in parentheses. Full sample: $1890 - 2015$ excluding WW1: $1914 - 1919$ and WW2: $1939 - 1947$. Post WW2 sample: $1948 - 2015$. *Matched sample* indicates LP-OLS sample matches the sample used to obtain LP-IV estimates. *KP weak IV* refers to the Kleibergen-Paap test for weak instruments. H_0 : $subATE = 0$ refers to the *p*-value of the test of the null hypothesis that the coefficients for $h = 0, ..., 10$ are jointly zero for a given subpopulation. $OLS = IV$ shows the *p*-value for the Hausmann test of the null that OLS estimates equal IV estimates. See text.

D. Appendix: DSGE model

D.1. Stationary Allocation

We normalize the following variables :

$$y_t = Y_t/Z_t$$

$$c_t = C_t/Z_t$$

$$k_t = K_t/Z_t$$

$$k_t^u = K_t^u/Z_{t-1}$$

$$\mathbb{I}_t = I_t/Z_t \quad \text{capital investment}$$

$$\mathbb{G}_t = G_t/Z_t \quad \text{Govt Spending}$$

$$w_t = W_t/(Z_t P_t)$$

$$r_t^k = R_t^k/P_t$$

$$\lambda_t = \Lambda_t Z_t$$

$$\tilde{\Gamma}_t \equiv \frac{\Gamma_t}{P_t Z_t}$$

Definition 1 (normalized equilibrium). 19 endogenous variables $\{\lambda_t, g_{t+1}, i_t, \pi_t, \pi_t^w, X_{1t}^p, X_{2t}^p, X_{it}^w, X_{2t}^w, c_t, y_t, z_t, k_{t+1}^u, r_t^K, \mathbb{I}_t, q_t, u_t, k_t, w_t, L_t\}$, 3 shocks $\{\lambda_t^g, \epsilon_t^{mp}, \mu_t\}$ given the natural rate allocation variables $\{y_t^f, g_{t+1}^f\}$.

Consumption Euler Equation

$$1 = \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}}{\lambda_t(1+g_{t+1})} \frac{1+i_t}{\pi_{t+1}} \right] \tag{11}$$

$$\lambda_t = \frac{1}{c_t - \frac{hc_{t-1}}{1+g_t}} - \frac{h\beta}{c_{t+1}(1+g_{t+1}) - hc_t} \tag{12}$$

Price-Setting

$$\frac{X_{1t}^p}{X_{2t}^p} = \left(\frac{1 - \theta_p \pi_t^{\frac{1}{\lambda_p}}}{1 - \theta_p} \right)^{-\lambda_p} \tag{13}$$

$$X_{1t}^p = \lambda_t y_t mc_t + \theta_p \beta \pi_{t+1}^{\frac{1+\lambda_p}{\lambda_p}} X_{1t+1}^p \tag{14}$$

$$X_{2t}^p = \frac{1}{1+\lambda_p} \lambda_t y_t + \theta_p \beta \pi_{t+1}^{\frac{1}{\lambda_p}} X_{2t+1}^p \tag{15}$$

Wage-Setting

$$\frac{X_{1t}^w}{X_{2t}^w} = \left(\frac{1 - \theta_w (\pi_t^w)^{\frac{1}{\lambda_w}}}{1 - \theta_w} \right)^{-\lambda_w + (1+\lambda_w)\nu} \tag{16}$$

$$X_{1t}^w = \omega L_t^{1+\nu} + \theta_w \beta \left((\pi_{ss}^w)^{1-\iota_w} (\pi_{W,t}^w)^{\iota_w} \right)^{-\frac{(1+\lambda_{w,t+1})(1+\nu)}{\lambda_{w,t+1}}} \pi_{W,t+1}^{\frac{(1+\lambda_w)(1+\nu)}{\lambda_w}} X_{1t+1}^w \tag{17}$$

$$X_{2t}^w = \frac{1 + \tau^w}{1 + \lambda_w} \lambda_t w_t L_t + \theta_w \beta \left((\pi_{ss}^w)^{1-\iota_w} (\pi_{W,t})^{\iota_w} \right)^{\frac{-1}{\lambda_{w,t+1}}} \pi_{W,t+1}^{\frac{1}{\lambda_w}} X_{2t+1}^w \tag{18}$$

$$\pi_{W,t} = \frac{w_t}{w_{t-1}} \pi_t (1 + g_t) \tag{19}$$

Capital Investment

$$k_{t+1}^u = \left[1 - S \left(\frac{\mathbb{I}_t}{\mathbb{I}_{t-1}} \frac{1 + g_t}{1 + g_{ss}} \right) \right] \mathbb{I}_t + (1 - \delta_k) \frac{k_t^u}{1 + g_t} \tag{20}$$

$$q_t = \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}}{\lambda_t (1 + g_{t+1})} \left(r_{t+1}^K u_{t+1} - a(u_{t+1}) + q_{t+1}(1 - \delta_k) \right) \right] \tag{21}$$

$$q_t \left[1 - S \left(\frac{\mathbb{I}_t}{\mathbb{I}_{t-1}} \frac{1 + g_t}{1 + g_{ss}} \right) - S' \left(\frac{\mathbb{I}_t}{\mathbb{I}_{t-1}} \frac{1 + g_t}{1 + g_{ss}} \right) \frac{\mathbb{I}_t}{\mathbb{I}_{t-1}} \frac{1 + g_t}{1 + g_{ss}} \right]$$
$$+ \beta \frac{\lambda_{t+1}}{\lambda_t} q_{t+1} \frac{1 + g_{t+1}}{1 + g_{ss}} \left(\frac{\mathbb{I}_{t+1}}{\mathbb{I}_t} \right)^2 S' \left(\frac{\mathbb{I}_{t+1}}{\mathbb{I}_t} \frac{1 + g_{t+1}}{1 + g_{ss}} \right) = 1 \tag{22}$$

Capital utilization rate

$$k_t = u_t \frac{k_t^u}{1 + g_t} \tag{23}$$

$$r_t^K = a'(u_t) \tag{24}$$

Production Technologies

$$y_t = k_t^\alpha L_t^{1-\alpha} \tag{25}$$

$$r_t^k = \alpha \frac{y_t}{k_t} \tag{26}$$

$$w_t = (1 - \alpha) \frac{y_t}{L_t} \tag{27}$$

Endogenous Growth

$$g_t = \log Z_t - \log Z_{t-1} = \mu_t + \eta \log(y_{t-1}/y_{t-1}^f) \tag{28}$$

Government

$$\frac{1 + i_t}{1 + i_{ss}} = \left(\frac{1 + i_{t-1}}{1 + i_{ss}} \right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi_{ss}} \right)^{\phi_\pi} \left(\frac{y_t}{y_t^f} \right)^{\phi_y} \right]^{1-\rho_R} \left(\frac{y_t/y_{t-1}}{y_t^f/y_{t-1}^f} \frac{1 + g_t}{1 + g_t^f} \right)^{\phi_{dy}} \epsilon_t^{mp} \tag{29}$$

Market Clearing

$$y_t = c_t + \mathbb{I}_t + a(u_t) \frac{k_t^u}{1 + g_t} + \left(1 - \frac{1}{\lambda_t^g} \right) y_t \tag{30}$$

Shocks

$$\log \lambda_t^g = (1 - \rho_g) \lambda^g + \rho_g \log \lambda_{t-1}^g + \epsilon_t^g; \quad \epsilon_t^g \sim N(0, \sigma_g) \tag{31}$$

$$\epsilon_t^{mp} \sim N(0, \sigma_r) \tag{32}$$

D.2. Steady State

$$1 = \beta \frac{1}{(1+g)} \frac{1+i}{\pi}$$

$$\lambda = \frac{(1+g) - h\beta}{c(1+g-h)}$$

$$mc = \frac{1}{1+\lambda_p}$$

$$\omega L^{1+\nu} = \frac{1+\tau^w}{1+\lambda_w} \lambda w L$$

$$\pi^w = \pi(1+g)$$

$$q = 1$$

$$u = 1$$

$$(1 - \frac{1-\delta_k}{1+g})k^u = \mathbb{I}$$

$$1 = \beta \left[\frac{1}{1+g} \left(r^K + (1 - \delta_k) \right) \right]$$

$$k = \frac{k^u}{1+g}$$

$$r^K = a'(1)$$

$$y = k^\alpha L^{1-\alpha}$$

$$r^k = \alpha \frac{y}{k}$$

$$w = (1 - \alpha) \frac{y}{L}$$

$$g = \mu$$

$$y = c + \mathbb{I} + \left(1 - \frac{1}{\lambda^g} \right) y$$

D.3. Approximate Equilibrium

We log-linearize the variables around the steady state as follows: for any variable x,

$$\hat{x}_t = \log \left(\frac{x_t}{x} \right)$$

where x is the steady state, except for the following variables

$$\hat{g}_{t+1} \equiv \log \left(\frac{1 + g_{t+1}}{1 + g} \right)$$

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$$\hat{i}_t = \log\left(\frac{1+i_t}{1+i_{ss}}\right)$$

Definition 2 (Approximate Equilibrium). An approximate competitive equilibrium in this economy with endogenous growth is defined as a sequence of 16 endogenous variables $\{\hat{\lambda}_t, \hat{g}_{t+1}, \hat{i}_t, \hat{\pi}_t, \hat{c}_t, \hat{\pi}_t^w, \hat{mc}_t, \hat{y}_t, \hat{L}_t, \hat{w}_t, \hat{k}_{t+1}^u, \hat{\mathbb{I}}_t, \hat{q}_t, \hat{r}_t^K, \hat{k}_t, \hat{u}_t\}$, which satisfy the following equations, for a given sequence of one exogenous shock $\{\hat{\epsilon}_t^{mp}\}$ and given sequence of flexible price allocations.

Consumption Euler Equation

$$(\mathbb{E}_t\hat{\lambda}_{t+1} - \hat{\lambda}_t - \hat{g}_{t+1}) + \hat{i}_t - \mathbb{E}_t\hat{\pi}_{t+1} = 0 \tag{33}$$

$$\hat{\lambda}_t = \frac{1+g}{1+g-h\beta}\left[\hat{g}_t - \left(\frac{1+g}{1+g-h}(\hat{c}_t + \hat{g}_t) - \frac{h}{(1+g)-h}\hat{c}_{t-1}\right)\right] \tag{34}$$
$$+ \mathbb{E}_t\frac{h\beta}{(1+g)-h\beta}\left[\left(\frac{1+g}{1+g-h}(\hat{c}_{t+1} + \hat{g}_{t+1}) - \frac{h}{(1+g)-h}\hat{c}_t\right)\right]$$

Price-Setting

$$\hat{\pi}_t = \frac{\beta}{1+\iota_p\beta}\mathbb{E}_t\hat{\pi}_{t+1} + \frac{\iota_p}{1+\iota_p\beta}\hat{\pi}_{t-1} + \kappa_p\hat{mc}_t \tag{35}$$

where $\kappa_p = \frac{(1-\theta_p\beta)(1-\theta_p)}{\theta_p(1+\iota_p\beta)}$.
Wage-Setting

$$\hat{\pi}_t^w = \frac{\beta}{1+\iota_w\beta}\mathbb{E}_t\hat{\pi}_{t+1}^w + \frac{\iota_w}{1+\iota_w\beta}\hat{\pi}_{t-1}^w + \kappa_w[-\hat{\lambda}_t + \nu\hat{L}_t - \hat{w}_t] \tag{36}$$

where $\kappa_w \equiv \frac{(1-\theta_w)(1-\beta\theta_w)}{\theta_w(1+\iota_w\beta)(1+\nu(1+\frac{1}{\lambda_w}))} > 0$

$$\hat{\pi}_t^w = \hat{w}_t - \hat{w}_{t-1} + \hat{\pi}_t + \hat{g}_t \tag{37}$$

Capital Investment

$$\hat{k}_{t+1}^u = \frac{\mathbb{I}}{k^u}\hat{\mathbb{I}}_t + \frac{1-\delta_k}{1+g}\left[\hat{k}_t^u - \hat{g}_{t+1}\right] \tag{38}$$

$$\hat{q}_t = \left[\mathbb{E}_t\hat{\lambda}_{t+1} - \hat{\lambda}_t - \hat{g}_{t+1}\right] + \frac{r^K}{r^K + (1-\delta_k)}\hat{r}_{t+1}^K + \frac{1-\delta_k}{r^K + (1-\delta_k)}\mathbb{E}_t\hat{q}_{t+1} \tag{39}$$

$$\hat{q}_t - S''\left(\hat{\mathbb{I}}_t - \hat{\mathbb{I}}_{t-1} + \hat{g}_t\right) + \beta S''\left(\hat{\mathbb{I}}_{t+1} - \hat{\mathbb{I}}_t + \hat{g}_{t+1}\right) = 0 \tag{40}$$

parametrize S'' from Smets and Wouters (2007), or Justiniano et al. (2013) to be between 3 and 5.
Capital utilization rate

$$\hat{k}_t = \hat{u}_t + \hat{k}_t^u - \hat{g}_t \tag{41}$$

$$\hat{r}_t^K = \frac{a''(1)}{a'(1)}\hat{u}_t \tag{42}$$

Production Technologies

$$\hat{y}_t = \alpha\hat{k}_t + (1-\alpha)\hat{L}_t \tag{43}$$

$$\hat{r}_t^k = \hat{y}_t - \hat{k}_t \tag{44}$$

$$\hat{w}_t = \hat{y}_t - \hat{L}_t \tag{45}$$

Endogenous Growth

$$\hat{g}_t = \hat{\mu}_t + \eta(\hat{y}_{t-1} - \hat{y}_{t-1}^f) \tag{46}$$

where η is the hysteresis elasticity

Government

$$\hat{i}_t = \rho_R \hat{i}_{t-1} + (1 - \rho_R)\left[\phi_\pi \hat{\pi} + \phi_y(\hat{y}_t - \hat{y}_t^f)\right] + \phi_{dy}\left[(\hat{y}_t - \hat{y}_{t-1}) - (\hat{y}_t^f - \hat{y}_{t-1}^f) + (\hat{g}_t - \hat{g}_t^f)\right] + \hat{\epsilon}_t^{mp} \tag{47}$$

Market Clearing

$$\frac{1}{\lambda^g}\hat{y}_t = \frac{c}{y}\hat{c}_t + \frac{\mathbb{I}}{y}\hat{\mathbb{I}}_t + \frac{a'(1)k}{y}\hat{u}_t \tag{48}$$