TFP Growth Regimes and the State-Dependence of the Slope of the Phillips Curve

Hanguo Huang *

November 9, 2022

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Abstract

What is the relationship between the long-run productivity growth and the short-run trade-off between inflation and economic slack? This paper studies the state dependence of the slope of the Phillips curve on the trend productivity growth. By merging two longitudinal databases, this paper presents estimates of the "average" New Keynesian Phillips curve for 17 advanced economies across TFP growth regimes since 1890. Following the latest state-of-art method, estimation of the New Keynesian Phillips curve using trilemma monetary shocks as instruments shows that the Phillips curve is *steeper (flatter)* in *high (low)* growth regime. The empirical finding is consistent with the following mechanism: the structural changes that contribute to higher productivity growth also result in more competitive market, increasing the price elasticity of demand so that the pass-through of marginal costs from short-run demand changes is higher, and vice versa. This mechanism is qualitatively consistent with the recent trends of flattening Phillips curve and productivity slowdown amid rising market concentration in major advanced economies. The policy implication is that structural reforms that can improve productivity and restore business dynamism help enhance the potency of monetary policy in the long run.

*Ph.D. candidate in Economics at the University of California, Davis.

"The connection between the slack in the economy with the level of unemployment and inflation was very strong if you go back 50 years, and it's got weaker and weaker and weaker to the point where it's a faint heartbeat that you can hear now." ...... At the end of the day, there has to be a connection because low (un)employment will drive wages up and ultimately higher wages will drive inflation (up).

—- Jerome Powell, July, 2019

1 Introduction

The trade-off between inflation and economic slack is traditionally inferred from the Phillips curve, and is at the core of monetary policy making. Recent episodes of high and fast-growing inflation rate bring the Phillips curve back to the public attention and policy debate. Thanks to the massive policy measures put forward by both fiscal and monetary authorities in the last couple of years, the pandemic recession turned out to be short, but the economy is now faced with a dilemma: stagflation. Although the Federal Reserves had taken increasingly bigger steps to raise interest rates, yet the inflation rate reached a four-decade high level of 9.1% in June 2022 and stays high till today. If the trade-off between inflation and economic slack is really weak, or in other words, the Phillips curve is almost flat, the contractionary monetary policy that aims to cool down the aggregate demand is more likely to push the economy towards recession without effectively bringing down the inflation rate.

It has been documented by many scholars that the slope of the Phillips curve has kept flattening over time, in terms of both reduced-form "Phillips correlation" and structural estimation.[1] The literature on "missing disinflation" puzzle during the Great Recession and "missing inflation" puzzle in the slow recovery thereafter have led some economists to go so far to declare that the Phillips curve is dead or at least "hibernating".[2] In the policy circle, policy makers also started to worry less about the inflation pressure from low unemployment due to the weak trade-off prior to the pandemic. The quota from the Federal Reserve Chairman Jerome Powell in his testimony before the House Financial Services Committee in July 2019 is one of the examples.

While the stylized fact of a flatter Phillips curve has been reasonably well established, the precise reasons for this change are not well understood. Anchoring of inflation expectations due to successful conduct of monetary policy and globalization are two possibilities in early discussions. Recent literature on the macroeconomic implications of the rising market power and declining business dynamism points to a new possibility. It has been shown that the impact of market concentration on the flattening of the Phillips curve can be quite sizable. The analyses along this vein either take market structure as given or abstract away the determination of market structure by long-run factors. However, we do observe that the declining business dynamism since the 1980s, and more strikingly, since the 2000s is accompanied by productivity slowdown among major advanced economies. Are these secular trends related?

[1] Among others, see Kuttner and Robinson (2010), Stock and Watson (2019).

[2] For brief discussions about the possible explanations, see Coibion and Gorodnichenko (2015) on the "missing disinflation" puzzle, see Ratner and Sim (2022) and Heise, Karahan, and Şahin (2022) on the "missing inflation" puzzle. See Hooper, Mishkin, and Sufi (2020) for a review on "hibernating" Phillips curve.

This paper attempts to provide an alternative explanation of the flattening Phillips curve and considers the slope change jointly with the secular trends of productivity slowdown amid declining business dynamism in major advanced economies. Is the flattening Phillips curve a by-product of the same structural changes that have led to the recent secular trends in both market structure and productivity growth? Are these events merely coincidentally observed in recent years? Or, have they been stably linked for a long time? If the latter is true, we should expect the slope of the Phillips curve to be state dependent on the trend productivity growth.

To identify the slope difference of the Phillips curve in periods of high versus low productivity growth, I rely on the long-run and cross-country variations. The reason for the coverage of a long history is twofold. For one thing, it usually takes decades for an economy to experience a full round of high and low productivity growth. For the other, we need multiple switches between two regimes or states to identify a robust state dependent relationship. Productivity growth in the modern economy experiences rises and falls constantly due to the changes in both long-run and short-run factors. My focus is on the low frequency component that describes the technological waves. Following the standard practice in the growth accounting literature, I assume that an economy is alternating between two "growth regimes": periods of high and low growth in trend productivity. Take the post-WW2 U.S. for example, the regime classification result in Kahn and Rich (2007) features a handful of regime switches over more than fifty years.

Furthermore, time series variations alone might not be rich enough for our purpose. In the single-country case, if two regime variables, say the level of inflation and the trend productivity growth, comove in the time horizon, then the time series variations will not allow us to separate the effects of different "state" variables. This is indeed the case for the post-WW2 U.S. economy prior to the Great Financial crisis. The low growth regime in the 1970s and early 1980s coincides with the "Great Inflation" era, and the high growth regime from mid-1990s to mid-2000s coincides with the "Great Moderation" era.[3] Existing literature has argued that the level of inflation may affect firm's pricing behavior, hence the slope of the Phillips curve may differ across growth regimes because of the difference in the inflation levels[4]. Therefore, it is quite data-demanding to study the growth regime dependence using the time series of a single country. In contrast, cross-country variations in the time path of growth regimes and other macro variables could provide important heterogeneity for us to identify the different roles played by different regime variables.

Fortunately, two new high-quality longitudinal databases meet the purpose of this study and are ready for public access. The first database is the *Long-Term Productivity Database* from Bergeaud, Cette, and Lecat (2016). They offer data on Total Factor Productivity per hour worked, Labor productivity per hour worked, capital intensity and GDP per capita for 23 economies since 1890.[5] The second one is the *Macrohistory Database* from Jordà, Schularick, and Taylor (2017). It captures rich macroeconomic and asset price dynamics for the near-universe of advanced economies since

[3]The growth regime classification for the US follows Fernald (2014) or Kahn and Rich (2007).

[4]Gabriel (2021) uses newly assembled data for 18 advanced economies between 1870 and 2020 and shows that the slope of wage Phillips curve is flatter in low inflation environment. Ramos-Francia and Torres (2008) estimate the hybrid New Keyneian Phillips curve for the low inflation sub-sample 1997-2006 in Mexico and find that prices on average remain fixed for a longer horizon.

[5]The data are available at http://www.longtermproductivity.com.

1870[6]. I use the *Long-Term Productivity Database* to classify growth regimes and merge the classification results with the *Macrohistory Database* to estimate the Phillips curve across regimes. The merged dataset consists of 17 advanced economies that are arguably close in technological advancement and economic institutions for the sample period between 1890 and 2012.

In terms of the empirical strategy to estimate the New Keynesian Phillips curve (NKPC), I rely on the latest state-of-art method of estimating structural forward-looking macroeconomic equations proposed by Barnichon and Mesters (2020). To deal with the endogeneity issues pervasive in the estimation of forward-looking macro equations, Barnichon and Mesters' approach consists of projecting the structural equation of interest on the space spanned by the present and past values of some well-chosen structural shocks. They argue that identified monetary policy shocks (Romer and Romer, 2004; Kuttner, 2001) are valid instruments to estimate the NKPC.

Different from their focuses on robust inference, this paper applies the two-step approach implied by their theoretical justification, and pays special attention to the exogeneity condition of valid instruments in a panel setting. In particular, the identified monetary policy shocks may still contain the information that the policy makers and the public know but the econometricians don't. Also, the monetary policy shocks may influence inflation through channels other than the domestic demand[7]. It is recommended that we control for as much information available to the agents as possible in the projection system. The identified monetary policy shocks used in this paper are based on trilemma mechanism proposed by Jordà, Schularick, and Taylor (2020). For peg countries that allow free capital mobility, base country's interest rate policy surprises can function as a source of natural experiments in domestic monetary policy.

The main empirical findings of this paper are as follows: first, growth regime classified using the cross-country variations over a long history is only weakly correlated with other regime variables such as output boom/bust, inflation level and credit boom, indicating that stratifying the data by productivity growth regime provides new and interesting perspectives. Second, estimation of the NKPC suggests that the Phillips curve is *steeper* in *high* productivity growth regime. The difference in slope estimates across regimes is quantitatively large, especially when we measure output gap using a low-pass HP filter. Third, monetary policy is subject to clear and different trade-offs between its nominal and real effects across productivity growth regimes. In response to contractionary monetary policy shocks, prices fall dramatically in high growth regime while they are almost muted in the low growth regime in the first four years. By contrast, output responses are relatively stronger in low growth regime. We don't find such clear trade-offs in the state-dependence analyses for other regimes.

To the best of my knowledge, this paper is the first to establish the empirical connection between the slope of the Phillips curve and the long-run productivity growth. The conventional wisdom is that short-run fluctuations and long-run growth are determined separately by assuming classical dichotomy. In a standard New Keynesian model with constant elasticity of substitution (CES) preferences and monopolistic competition, market structure and growth are irrelevant to firm's

[6]The data are available at https://www.macrohistory.net/database.

[7]see e.g., Razin and Binyamini (2007); Borio and Filardo (2007). The idea is that as an increasingly large proportion of the rise in domestic demand is satisfied through imports, rather than domestic production, increases in the domestic output gap will have smaller impact on domestic marginal costs, and hence on inflation.

pricing behavior, thus the slope of the Phillips curve. Recent literature starts to relax the standard assumptions to study the impact of the market concentration on the slope of the Phillips curve. Wang and Werning (2022) generalize the New Keynesian model by allowing for dynamic oligopolistic competition between any finite number of firms in each sector. Fujiwara and Matsuyama (2022) extend the canonical New Keynesian model by introducing endogenous entry and Homothetic Single Aggregator (HSA) demand systems. While both successfully demonstrate that market concentration flattens the Phillips curve, it remains unclear to us how these two events are related to the secular trend of productivity slowdown. Therefore, the empirical findings of this paper also have strong theoretical implications.

To explain the growth regime-dependence of the slope of Phillips curve, I propose a mechanism that links productivity growth, market structure, and the slope of the Phillips curve. Using a calibrated endogenous growth model with CES preferences and oligopolistic competition, I show that the structural changes that are attributed to higher productivity growth could also lead to more competitive market. If the price elasticity of demand rises with market competition, then the pass-through of marginal costs due to fluctuations in short-run demand will be larger, indicating a steeper Phillips curve, and vice versa. This mechanism is qualitatively in tune with the recent trends of flattening Phillips curve and productivity slowdown amid rising market concentration and markups in many advanced economies.

Related Literature. This paper relates to at least three broad strands of exisiting literature. First, this paper joins the discussion of state dependence of the efficacy of monetary policy. At the aggregate level, previous literature has well-recognized that monetary policy has asymmetric effects in the boom versus the slump. Tenreyro and Thwaites (2016) find that the effects of monetary policy are less powerful in recessions. And contractionary policy shocks are more powerful than expansionary shocks. Similar message is delivered by Barnichon and Matthes (2018). At the disaggregated level, leverage is another factor that affects the efficacy of monetary policies. Cloyne, Ferreira, and Surico (2020) work on the household mortgage indebtedness, and Ottonello and Winberry (2020) focus on the firm leverage. Jordà, Schularick, and Taylor (2020) conduct a comprehensive state dependence analysis using the *Macrohistory Database* and trilemma monetary shocks. They confirm that output response appears to be quite strong in booms, when inflation is above 2% and during mortgate credit boom, but considerably weaker in slumps, low inflation episodes and low growth in mortgage credit. This paper contributes to this literature by introducing a new source of state dependence, i.e., productivity growth regime, and shows that monetary policy faces different trade-offs between its nominal and real effects across growth regimes. The asymmetry of monetary policy effects constitutes the direct reason for the slope difference in the estimated NKPC across growth regimes.

Second, this paper links the recent studies on the declining business dynamism and productivity slowdown to the flattening Phillips curve. Akcigit and Ates (2021) summarize the ten trends related to the declining business dynamism in the U.S. since the 1980s. The entry rate of new businesses, the job reallocation rate, and the labor share have all been decreasing, yet the profit share, market concentration, and markups have all been rising, see the referrence therein for an extensive discussion. Some of these trends, if not all, have been examined to be also present in some other OECD countries. Calligaris, Criscuolo, and Marcolin (2018) find strong evidence that markups are increasing over the period 2001-2014 using Orbis data for 26 high-income economies. Bajgar et al. (2019) document a clear increase in industry concentration in Europe as well as in North America between 2000 and 2014. Calvino, Criscuolo, and Verlhac (2020) highlight that declines in business dynamism have been pervasive in many OECD countries and are driven by dynamics occurring at a disaggregated sectoral level, rather than reallocation across sectors. Koltay, Lorincz, and Valletti (2022) find an overall tendency towards oligopolistic structure and a sustained increase in aggregate profitability over the recent decades for European economies.

Efforts have been made to link these secular trends and study their causes and consequences. Aghion et al. (2019) propose a theory in which the driving force is falling overhead costs of spanning multiple products or a rising efficiency advantage of large firms. Akcigit and Ates (2019) use a general equilibrium model of endogenous firm dynamics to assess the relative importance of multiple potential mechanisms that can drive the observed trends in business dynamism, and their results highlight the dominant role of a decline in the intensity of knowledge diffusion from the frontier firms to the laggard ones. Bearing these trends in mind, this paper establishes new stylized facts linking the flattening Phillips curve with productivity slowdown, and presents a conceptual framework to rationalize the growth regime dependence of the slope of the Phillips curve through the changes in market structure due to structural changes. The proposed channel is also inspired by the extensive literature on innovation, growth and market competition, see Aghion, Akcigit, and Howitt (2014) and references therein.

In addition to the literature discussed above, my work builds on the vast literature on the Phillips curve. This strand of literature starts from Phillips (1958) and Samuelson and Solow (1960), followed by massive efforts to build theoretical models to rationalize the empirical relationship, e.g., Friedman (1968), Phelps (1967). After Lucas (1972), New Keynesian economists in particular started to incorporate sticky prices and wages into rational expectation models. Since then, the NKPC has gained popularity from its appealing theoretical micro-foundations and what appeared to be early empirical success (Mavroeidis, Plagborg-Møller, and Stock, 2014). More recent papers working on more flexible and robust estimation of the NKPC using time series data include Ball and Mazumder (2019), Stock and Watson (2019), Barnichon and Mesters (2020), and Del Negro et al. (2020). For the Phillips curve estimation using regional data, see Hazell et al. (2022) and the references therein. My paper applies Barnichon and Mesters (2020) method in a panel setting, and estimate the slope of the "average" NKPC for the group of advanced economies using trilemma monetary shocks as instruments.

The remainder of the paper proceeds as follows. The next section presents the baseline growth regime classification results using the regime-switching regression model. The section ends with a comparison between the growth regime and other regime variables considered in the literature. In Section 3, I provide more detail on the estimation procedure of the NKPC and present the estimation results across growth regimes. In Section 4, I show that the baseline results are robust to alternative regime classification methods, choices of output gap measure and projection horizons, and sample selections. Section 5 discusses the potential mechanism that could square with the empirical results. Section 6 concludes.

2 Growth Regime Classification

The first part of my empirical analysis is to classify growth regime for a wide group of advanced economies over a long history. In the growth accounting literature, scholars usually focus on the labor productivity growth, which can be decomposed into capital deepening, improvement in labor quality and growth in total factor productivity (TFP), see Fernald (2012). This paper classifies growth regimes based on the low frequency component of TFP growth for the following two reasons: first, TFP growth is mainly driven by the medium and long-run factors such as innovation and technological progress, which is the main focus on my study. Labor quality improvement is quite stable over time and is mainly driven by secular trends in labor supply. Capital deepening is mainly driven by capital accumulation, which varies mostly at business cycle frequency. Second, the growth regime classification by Fernald (2014) for the postwar U.S. economy shows that the main difference in labor productivity growth across growth regimes comes from the variations in TFP growth, while the contributions of capital deepening and labor quality are quite stable in both regimes over time.

To classify the growth regime, I incorporate the data from Bergeaud, Cette, and Lecat (2016). Their *Long Term Productivity Database* measures aggregate productivity for a rich panel of countries over a long period of time. In its version 2.4 published in August 2020, the database provides consistent measures of labor productivity, TFP, GDP per capita, capital intensity, and the average age of equipment capital stock for 23 countries dating back to 1890. Given the wide coverage of countries and sample periods, I am able to classify growth regime with different methods using their TFP measure, and then merge the classification results with Jordà-Schularick-Taylor *Macrohistory Database* to estimate the slope of the Phillips curve for 17 advanced economies over the sample period 1890-2012.

2.1 Baseline Classification: Regime-Switching Regression Model

Existing literature has proposed a couple of methods for detecting changes in trend productivity growth, both of which were first applied to study the U.S. experience. One is the regime-switching dynamic factor model proposed by Kahn and Rich (2007), the other is based on Bai and Perron (1998, 2003) test for multiple structural changes applied in Fernald (2014). My baseline classification method is closely related to Kahn and Rich (2007) in that I also assume that the trend component of TFP switches between high-growth and low-growth regimes with some probability at any point in time. However, instead of buliding more complicated models allowing for regime changes in both permanent and transitory components, I first filter out the cyclical component and then apply the regime-switching regression model to single series of trend TFP growth.

There are 17 countries in the merged dataset, the 3-digit ISO country codes are as follows: { AUS, BEL, CAN, CHE, DEU, DNK, ESP, FIN, FRA, GBR, ITA, JPN, NLD, NOR, PRT, SWE, USA}. Let's denote $S_{c,t}$ as the regime index for country c in year t. The trend TFP growth is assumed to be alternating between two average levels:

$$g_{c,t}^{\widetilde{TFP}} = \mu(S_{c,t}) + v_{c,t}, \quad v_{c,t} \sim N(0,1)$$

where $\widetilde{TFP}$ denotes the trend TFP estimated by low-pass HP filtering with a smoothing parameter of 100, and

$$\mu(S_{c,t}) = \begin{cases} \mu_{L,c} & \text{if } S_{c,t} = L \\ \mu_{H,c} & \text{if } S_{c,t} = H \end{cases}$$

with

$$\begin{aligned} Pr[S_{c,t} = L | S_{c,t-1} = L] &= q_{LL,c}; & Pr[S_{c,t} = H | S_{c,t-1} = L] &= 1 - q_{LL,c}. \\ Pr[S_{c,t} = H | S_{c,t-1} = H] &= q_{HH,c}; & Pr[S_{c,t} = L | S_{c,t-1} = H] &= 1 - q_{HH,c}. \end{aligned}$$

After estimating the model for each country, I calculate its probability of being in high-growth regimes $\Pr\{S_{c,t} = H\}$ over time, and then define the high-growth regime samples as $\{t_c : \Pr(S_{c,t} = H) \geq 0.5\}$, and the low-growth regime samples if otherwise.

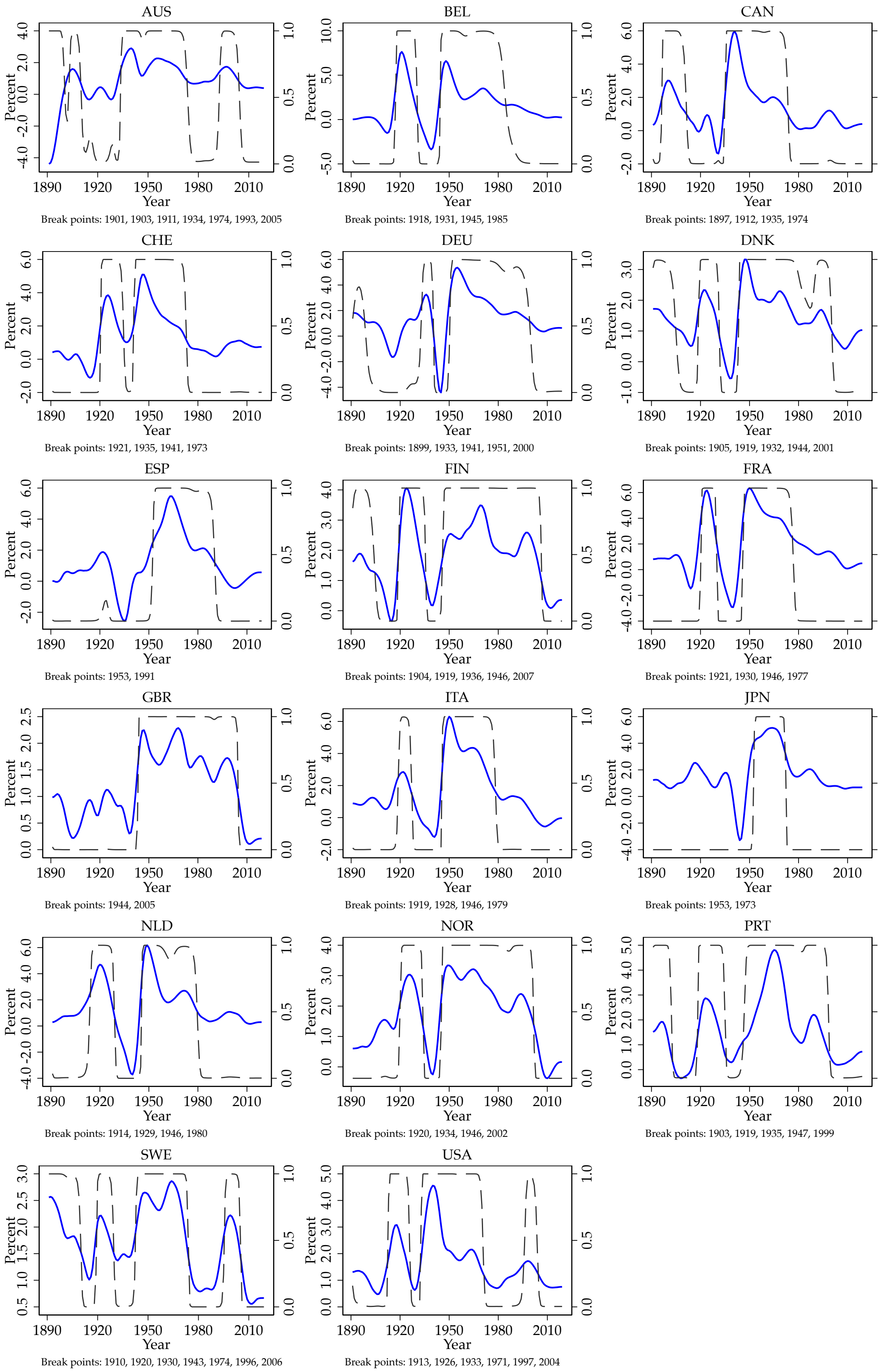
Since the estimates of average growth rates μ_L and μ_H may vary with the choice of sample period, sample selection matters for the detection of tuning points. As we shall see in the data, European countries experienced low productivity growth (some even experienced productivity loss) during two world wars, and productivity booms after the wars. If we exclude war periods, then the average growth rate in low-growth regimes will be estimated slightly higher, and more samples from normal years will be classified as in low-growth regimes. In the baseline results, I use the entire sample period to estimate the model and classify growth regimes.

Figure 1 collects the results of the regime classification for all 17 countries using regime-switching approach. The solid blue line shows each country's trend TFP growth over time (left axis), while the dashed grey line indicates its probability of being in high-growth regime (right axis) over the entire sample period of 1890-2019. The break points at the bottom of each chart list the tuning points of regime switches.

Let's take the U.S. economy as an example. Unlike most of the European countries, U.S. economy underwent productivity booms during war times. Between 1913 and 1926, TFP growth in the U.S. is relatively high. Thanks to a series of economic reforms to pull the economy out of the quagmire of the Great Depression, U.S. economy started another round of rapid technological progress from 1933 and sustained at about 2% annual growth for the decade after the second World War. Similar to the conclusions of Kahn and Rich (2007) and Fernald (2014), post-WW2 U.S. economy features high-low-high-low growth regimes alternating, with the recent short period of high-growth regime from mid-1990s to mid-2000s.

For the set of European countries, despite the closeness in the geographical environment and advancement in technology, we can still find some heterogeneities in their productivity growth profiles, especially in the post-WW2 period. Almost all of these countries suffered a lot from two world wars (1914-1919, 1939-1947) and the Great Depression in between (1929-1933) with low productivity growth or even productivity loss. Most rebounded quickly with fast productivity growth between wars and after the second world war, but the specific timing and phases of recovery differ across countries. In the post-WW2 period, some remained in high-growth regime

Figure 1. Regime-Switching Classification Results



Notes: Solid blue lines: trend TFP growth over time (left axis); dashed grey line: probability of being in high-growth regimes (right axis) over the entire sample period 1890-2019 including the war time.

for longer (eg. NOR, PRT, DEU, DNK, FIN, GBR, NLD), some lost growth momentum before 1990s and grew slowly thereafter (eg. BEL, CHE, ESP, FRA, ITA), while the others went through another high growth regime from mid-1990s to mid-2000s, similar to the U.S. (eg. AUS, SWE).

2.2 Growth Regime Versus Other Regimes

How do other regime variables correlate with TFP growth regime? If the regimes classified by another factor aligns closely with the growth regime, then it's hard to tell which regime variable is the relevant true state that matters for the relationship of interest. The other regime variables considered in this paper include output gap, inflation, and credit growth. I follow Jordà, Schularick, and Taylor (2020) and define these regime dummies as follows:

- Output boom: if a country's output gap is non-negative, where output gap is measured using HP filter with smoothing parameter equals 100.
- High inflation: if a country's inflation rate is greater or equal to 2% per year, excluding the hyperinflation periods when annual inflation rate exceeds 45%.
- Credit boom (total): if a country's 3-year mean changes in *total* credit over GDP is above its historic mean changes.
- Credit boom (mortgage): if a country's 3-year mean changes in *mortgage* credit over GDP is above its historic mean changes.
- Credit boom (non-mortgage): if a country's 3-year mean changes in *non-mortgage* credit over GDP is above its historic mean changes.

Table 1. Descriptive statistics by regimes

Regime dummies	*Panel A: Full sample*				*Panel B: Post-WW2 sample*			
	LG	HG	Total	ρ	LG	HG	Total	ρ
High TFP growth	0.00	1.00	0.58	1.00	0.00	1.00	0.66	1.00
Output boom	0.49	0.53	0.51	0.04	0.49	0.53	0.52	0.04
High inflation	0.48	0.65	0.58	0.17	0.70	0.75	0.73	0.06
Credit boom (total)	0.56	0.50	0.53	-0.06	0.51	0.49	0.49	-0.02
Credit boom (mortgage)	0.55	0.39	0.45	-0.16	0.55	0.35	0.42	-0.19
Credit boom (non-mortgage)	0.52	0.55	0.54	0.02	0.42	0.54	0.50	0.11

Notes: Full sample: 1890-2006 excluding world wars (1914-1919 and 1939-1947). Post-WW2 sample: 1948-2006. For each sample, the first two columns (LG/HG) list the means of regime dummies conditional on being in low/high TFP growth regime, the third column (Total) lists the unconditional means of regime dummies, and the last column (ρ) lists the correlation coefficients between each regime dummy and the TFP growth dummy.

Table 1 presents the conditional and unconditional means along with their correlation coefficients of regime dummies defined above for full sample (Panel A) and post-WW2 sample (Panel B). The first two columns of each panel compare the means conditional on TFP growth regimes. If the means of another regime dummy across two growth regimes turn out to be very close, then we are assured that the classification of these two regimes do not correlate systematically with one another. The correlation coefficient also delivers similar information.

It is evident that none of the other regimes aligns very well with the TFP growth regime, the pairwise correlation coefficients in absolute values are all below 0.2. Among the other five regime dummies, "Output boom" and "Credit boom (total)" correlate with the growth regime dummy the least. Take the output boom dummy for example. About equal fraction of the sample periods is in output boom conditional on growth regime, although it is slightly more likely to observe an output boom in high growth regime. The correlation coefficient between growth regime dummy and output boom dummy is very small, i.e., 0.04 for both sample results.

On the other hand, inflation regime correlates with growth regime relatively strongly in the full sample results. We tend to observe annual inflation rate above 2% more often in high growth regime (65%) than in low growth regime (48%). However, in the post-WW2 periods, both growth regimes saw high inflation quite often, and the difference in means is small. The non-mortgage credit boom dummy correlates with growth regime dummy relatively strongly in the post-WW2 sample results. It is more likely to observe non-mortgage credit boom in the high growth regime (54%) than in low growth regime (42%), while the difference is small in the full sample results. The mortgage credit growth regime is a little bit worrisome. In both panels, high growth regime is associated with lower probability (less than 40%) of observing high mortgage credit growth.

3 Phillips Curve Estimation and its Growth Regime Dependence

The second part of my empirical analysis is to estimate the slope of the Phillips curve and study its state dependence on the growth regimes. Although the Phillips curve was first introduced by Phillips (1958) to describe the empirical relationship between wage inflation and unemployment rate, macroeconomic models, especially the New-Keynesian models, have been using it to describe the relationship between the price inflation and output gap. It summarizes the firm's optimal price-setting condition facing nominal rigidity in the short run. Despite its theoretical foundation, the empirical estimation of the New Keynesian Phillips curve is notoriously challenging.

3.1 Identification Using Monetary Policy Shocks: A Two-Step Approach

Consider the hybrid New Keynesian Phillips curve (eg. Galí and Gertler, 1999) given by

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f E_t[\pi_{t+1}] + \lambda x_t + \epsilon_t^s \tag{1}$$

where π_t is inflation, $x_t \equiv y_t - y_t^n$ is the output gap which depends on the natural/potential level of output y_t^n and ϵ_t^s denotes the cost-push shocks. The parameters of interest γ_b, γ_f and λ are functions of deep structural parameters of an underlying model.

Despite decades of research, the estimation of Phillips curve is still notoriously difficult due to pervasive endogeneity issues (Barnichon and Mesters, 2020). To see this, let's re-write Equation (1) as follows

$$\pi_t = \gamma_b \pi_{t-1} + \gamma_f \pi_{t+1} + \lambda \hat{x}_t + \underbrace{\epsilon_t^s - \gamma_f(\pi_{t+1} - E_t[\pi_{t+1}]) - \lambda(\hat{x}_t - x_t)}_{u_t} \tag{2}$$

where $\hat{x}_t$ is some measure of output gap. We can see that there are three sources of endogeneity problems: (i) cost-push shocks (ϵ_t^s) can simultaneously affect inflation and output gap through the systematic response of monetary policy to inflation. In response to a negative cost-push shock that drives inflation up high (eg. oil price shock in 1970s), monetary policy may raise interest rates which will reduce the short-run output. (ii) measurement error in the output gap ($\hat{x}_t - x_t$) since the potential output is unobservable, and (iii) forecast error in inflation ($\pi_{t+1} - E_t[\pi_{t+1}]$).

Barnichon and Mesters (2020) argue that monetary policy shocks $\boldsymbol{\xi}^m_{t:t-H} \equiv (\xi^m_t, \xi^m_{t-1}, \cdots, \xi^m_{t-H})'$ are valid instruments to identify the Phillips curve in that they satisfy the following two conditions:

(i) Exogeneity: $E[u_t|\boldsymbol{\xi}^m_{t:t-H}] = 0$ holds if monetary policy shocks are orthogonal to the three sources of endogeneity problems;

(ii) Relevance: $E[\boldsymbol{\xi}^m_{t:t-H}(\pi_{t-1}, \pi_{t+1}, \hat{x}_t)]$ is of full column rank. That is, monetary policy shocks should be able to affect output gap and inflation.

One concern for the exogeneity of monetary policy shock is that policy markers respond to information beyond what has been considered when constructing the monetary policy shocks, eg. Greenbook forecasts for Romer and Romer (2004) shocks. It is often suggested that we add more macroeconomic controls as extra information set to clean the shocks. Another concern is that monetary policy shocks may affect inflation through channels other than the domestic output gap. This is particularly worrisome in our context where the monetary policy of the base country could also affect the global aggregation demand, e.g., U.S. in the post-WW2 era. The globalization-related view of the flattening Phillips curve suggests that as part of the domestic demand is satisfied through imports, if the rise in domestic demand due to expansionary monetary policy in the base country coincides with the rise in global demand, then the inflation pressure "leakage" will be small, inflation will be higher than if global demand is not sensitive to the monetary policy of the base country. So we should also control for the global business cycle effects.

Let's re-write Equation (2) h periods ahead, multiply both sides by the monetary policy shock ξ^m_t and take expectation conditional on extra information set $\boldsymbol{z}_t$,

$$E[\xi^m_t \pi_{t+h}|\boldsymbol{z}_t] = \gamma_b E[\xi^m_t \pi_{t+h-1}|\boldsymbol{z}_t] + \gamma_f E[\xi^m_t \pi_{t+h+1}|\boldsymbol{z}_t] + \lambda E[\xi^m_t \hat{x}_{t+h}|\boldsymbol{z}_t] + E[\xi^m_t u_{t+h}|\boldsymbol{z}_t]$$

Dividing both sides by $E[(\xi^m_t)^2|\boldsymbol{z}_t]$, and denoting the projection of variable w on monetary policy shock as $\mathscr{R}^w_h$, $w \in \{\pi, \hat{x}, u\}$, we get

$$\mathscr{R}^\pi_h = \gamma_b \mathscr{R}^\pi_{h-1} + \gamma_f \mathscr{R}^\pi_{h+1} + \lambda \mathscr{R}^{\hat{x}}_h + \mathscr{R}^u_h, \forall h = 0, 1, \cdots, H \tag{3}$$

where we assume that all variables are stationary and that the endogenous variables and residuals can be written as linear functions of monetary policy shocks. If monetary policy shocks are autocorrelated, then we also include their lags in $\boldsymbol{z}_t$. Under these assumptions, the exogeneity and relevance conditions can be restated in impulse response space as follows:

(i) Exogeneity: $\mathscr{R}^u_h = 0, \forall h = 0, 1, \cdots, H$

(ii) Relevance: $[\mathscr{R}^\pi_{h-1}, \mathscr{R}^\pi_{h+1}, \mathscr{R}^{\hat{x}}_h]^H_{h=0}$ is linearly independent

Equation (3) implies that to estimate the Phillips curve, we can take a **two-step approach**: (i) estimate the impulse response functions of inflation and output gap to the monetary policy shocks and obtain $\hat{\mathscr{R}}_h^{\pi}$ and $\hat{\mathscr{R}}_h^{\hat{x}}$ for $h = 0, \cdots, H$; (ii) use the estimated impulse response functions and run linear regression: $\hat{\mathscr{R}}_h^{\pi} = \gamma_b \hat{\mathscr{R}}_{h-1}^{\pi} + \gamma_f \hat{\mathscr{R}}_{h+1}^{\pi} + \lambda \hat{\mathscr{R}}_h^{\hat{x}} + e_h$, where e_h is a linear combination of estimation errors. To identify all three coefficients, rank condition requires that the dynamics of the impulse response functions have to be rich enough.

In empirical studies, $\gamma_b + \gamma_f = 1$ is often imposed and it is consistent with a vertical long-run Phillips curve and money neutrality in the long run (Barnichon and Mesters, 2020). A simple case study can be shown to demonstrate the improvement in the slope estimates with versus without imposing this restriction, especially when the rank condition fails. Take the simple three-equation New-Keynesian model with pure forward-looking NKPC for example. The theoretical impulse responses of inflation and output gap to monetary policy shocks are as follows:

$$\hat{\pi}_t = -\lambda \Lambda_\xi \xi_t$$
$$\hat{x}_t = -(1 - \beta\rho_\xi)\Lambda_\xi \xi_t$$

where Λ_ξ is a function of model parameters, ρ_ξ is the $AR(1)$ parameter (persistence) of the monetary policy shocks ξ_t, and $\hat{w}_t \equiv w_t - w_{ss}, w \in \{\pi, x\}$, is measured as the percentage (log) deviations from the steady state value.

We can immediately tell that the rank condition will fail for sure as

$$E_t \hat{\pi}_{t+1} = -\lambda \Lambda_\xi \rho_\xi \xi_t = \frac{\lambda \rho_\xi}{1 - \beta \rho_\xi} \hat{x}_t \propto \hat{x}_t$$

where the first equality holds because $E_t \xi_{t+1} = \rho_\xi \xi_t$.

Substituting into the pure forward-looking NKPC yields

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \lambda \hat{x}_t + \epsilon_t^s = \lambda \left(\frac{\beta \rho_\xi}{1 - \beta \rho_\xi} + 1 \right) \hat{x}_t + \epsilon_t^s$$

That is,

$$\hat{\pi}_t = \frac{\lambda}{1 - \beta \rho_\xi} \hat{x}_t + \epsilon_t^s$$

We cannot identify β and λ separately due to collinearity, and will over-estimate the slope coefficient if $\rho_\xi \neq 0$. Following the standard practice in the literature, let's calibrate $\beta = 0.99$ and set $\rho_\xi = 0.2$, we can calculate that the slope coefficient will be inflated by about 25%.

In this simple case, since $\gamma_b = 0, \gamma_f = \beta = 0.99$, then $\gamma_b + \gamma_f = 0.99 \approx 1$, the long-run restriction is very close to the truth. Imposing this restriction actually provides useful information to help identify the underlying parameters. Using the theoretical IRFs, I show in Appendix A that imposing the long-run restriction ($\gamma_b + \gamma_f = 1$), along with the range inequality constraints ($0 < \gamma_b, \gamma_f, \lambda < 1$), is able to get the slope parameter close to the true value. Therefore, in the empirical practice that follows, I draw my main conclusions based on the results with the restrictions imposed.

3.2 Step 1: Estimation of the Impulse Responses of Inflation and Output Gap

In the first step, I estimate the impulse response functions of inflation and output gap to monetary policy shocks using the merged dataset since *1890* (the start of the productivity data) in the spirit of Jordà (2005) and using the external instrument for exogenous monetary policy fluctuations based on trilemma mechanism (Jordà, Schularick, and Taylor, 2020). Compared with the local projection on the identified shocks directly, LP-IV is more robust to instrument problems and measurement errors, which is helpful in inference[8]. For the specification, I stay close to Jordà, Schularick, and Taylor (2020), but adjust the controls that are related to the response variables since they are no longer price and real output levels, but inflation and output gap.

The baseline local projection specification is as follows:

$$y_{c,t+h} - y_{c,t-1} = \alpha_{c,h} + \triangle i_{c,t}\beta_h + \boldsymbol{z}'_{c,t}\boldsymbol{\gamma}_h + u_{c,t+h}, \quad h = 0, 1, \cdots, H \tag{4}$$

using a longitudinal sample where $c = 1, \cdots, N$ and $t = 1, \cdots, T$.

The response variable $y_{c,t+h}$ is the inflation or output gap measured in percentage deviations relative to its initial value in year 0 computed as log change times 100. Inflation is measured by the first-difference of log CPI, and output gap is measured using Hodrick-Prescott (HP) filter with a smoothing parameter of 100. In Section 4, I show that the main conclusion holds qualitatively if we choose other measures of output gap.[9] The policy interest rate change $\triangle i_{c,t}$ will be defined as the one-year change in the short-term interest rate in year 0, and normalized to a 1 percentage point increase. The instrument variable is the base country's policy surprises conditional on a rich set of macroeconomic controls. For most countries, U.S. and U.K. serve as their base country, their policy surprises come from two seminal papers: Romer and Romer (2004) and Cloyne and Hürtgen (2016) for the post-WW2 period.

The macroeconomic variables $\boldsymbol{z}_{c,t}$ include the first-difference of the contemporaneous values, and up to 2 lags of the first-difference of the variables from the following list: log real consumption per capita; log real investment per capita; short-term interest rate (usually a 3-month government bond); long-term interest rate (usually a 5-year government bond); log real house prices; log real stock prices; and the credit to GDP ratio.[10] In addition, I control for the first-difference of the contemporaneous values of the log real GDP per capita (log CPI) and output gap (inflation) in the regression for inflation (output gap) response, respectively.[11] For both regressions, I also add up to 2 lags of the first-difference of the log real GDP per capita, output gap, log CPI and inflation. What's more, to partially address the "price puzzle" issue, I will interact all these controls with oil crisis dummy to allow the controls to take on a potentially different coefficient for the subsample period of oil crisis (1973-1980). To control for the global business cycle effects, it is crucial to add global GDP as one of the explanatory variables.[12]

Figure 2 presents the LP-IV estimates of the impulse responses of output gap and inflation to a 1

[8] I also check the LP results with monetary policy shocks as regressors, they differ mainly in magnitude as expected.

[9] Existing literature has proposed different measures of output gap, this paper will not take a stand.

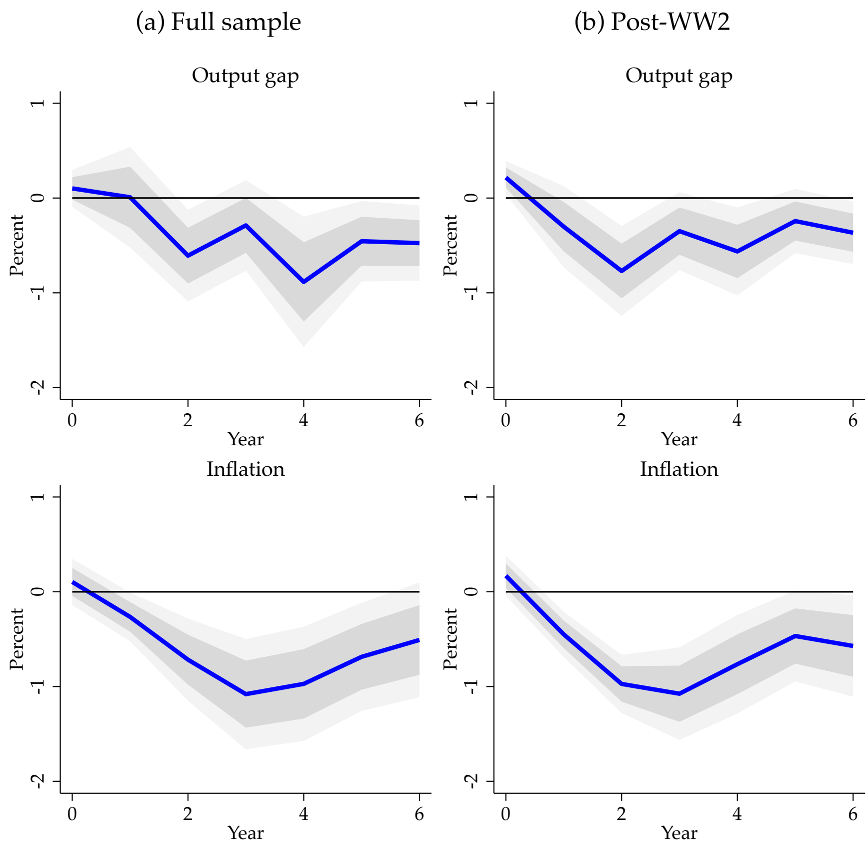
[10] The credit to GDP ratio is defined as the ratio of total loans to the nonfinancial private sector to GDP.

[11] This is equivalent to controlling the corresponding measure of potential output in the output gap regression.

[12] Global GDP is defined as the sum of all countries' real GDP measure adjusted for their PPP values.

percentage point increase in short-term interest rate. In Panel (a), the sample spans 1890-2006, but excludes two world wars (WW1: 1914-1919, WW2: 1939-1947) and short windows around the wars. In particular, We are end up with 1890-1908, 1921-1933, and 1948 -2006. Panel (b) reports the results for post-WW2 sample prior to the Great Financial crisis: 1948-2006. In Section 4, I extend the analysis to include more recent sample till 2012.

Figure 2. Impulse responses of inflation and output gap



Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Sample sizes are not harmonized in estimation. Output gap is measured using the HP filter with a smooth parameter of 100.

The impulse responses estimated using the full sample look quite similar to those using the post-WW2 sample. In response to a 1 percentage point increase in the policy rate, output gap decreases moderately for a peak response of 0.9% in the 4^{th} in the full sample results, and 0.8% in year 2 in the post-WW2 sample results, respectively. In comparison, the post-WW2 output gap responses have relatively shorter half-life. Inflation rate declines for a peak response of 1% in both cases and the peak response occurs in the 3^{rd} year. After reaching the peak response, impulse responses decay to zero slowly. Consistent with Jordà, Singh, and Taylor (2020), monetary policy effects last for a prolonged period of time.

3.3 Step 2: Estimation of Phillips Curve by Constrained NLS

In the second step, I run the following constrained NLS using the estimated impulse responses:

$$\hat{\mathscr{R}}_h^{\pi} = \gamma_b \hat{\mathscr{R}}_{h-1}^{\pi} + \gamma_f \hat{\mathscr{R}}_{h+1}^{\pi} + \lambda \hat{\mathscr{R}}_h^{\hat{x}} + e_h, \forall h = 0, \cdots, H \tag{5}$$

where I restricted all three coefficients to be between 0 and 1, i.e., $0 < \gamma_b, \gamma_f, \lambda < 1$. Because the range of the inverse logit function is the interval $(0,1)$, we can use the inverse logit function to set this restriction and estimate the coefficients using nonlinear least square (NLS) method. The initial values of the coefficients are set to match the empirical estimates reported in Barnichon and Mesters (2020) on U.S. Phillips curve, that is, $\gamma_b \approx 0.6, \gamma_f \approx 0.4$, and $\lambda \approx 0.3$.

Since the number of parameters to estimate is three, the effective sample size cannot go below 3. Given that we need to take leads for the IRFs of inflation on the right hand side, we need H to be at least 4. As is pointed out in the identification, rank condition requires the dynamics of the IRFs to be rich enough, it is more likely to fail when the sample size is small. However, H should not be too large because as h increases, the effect of monetary policy shocks tends to die out quickly, especially on output gap. Given all these concerns, I set H to be 6 in the baseline results. Section 4 shows the results for longer projection horizons. Because inflation last period is predetermined, it should be orthogonal to the shock this period so that $\mathscr{R}^{\pi}_{-1} = 0$.

Table 2 presents the constrained NLS estimates of the hybrid NKPC. The restricted estimates of λ range from 0.12 in the full sample results to 0.23 in the post-WW2 results. The latter is roughly in the same range as in Barnichon and Mesters (2020), and Stock and Watson (2019). To map the range of macro-level price stickiness to the micro-level frequency of price adjustment, I refer to the slope of the standard NKPC under Calvo (1983) pricing formulated as:

$$\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta}(\chi+\sigma) \tag{6}$$

where θ is the probability for the firm to be unable to reset price within the period, and $1-\theta$ is the probability of price adjustment; β is the discount factor; χ is the inverse Frisch elasticity of labor supply; σ is the elasticity of substitution. Under the standard calibration of these parameters where $\beta = 0.99$[13], $\chi = \sigma = 1$, the implied degree of price rigidity θ ranges from 0.72 to 0.79. That is, only a fraction of 21% to 28% of prices will adjust each quarter, prices are quite sticky.

Table 2. Estimation of the Phillips curve: $H = 6$

SAMPLE	UNRESTRICTED			RESTRICTED	
	γ_f	γ_b	λ	γ_f	λ
Full	0.51 (0.16)	0.53 (0.25)	0.07 (0.39)	0.50 (0.12)	0.12 (0.13)
Post-WW2	0.28 (0.20)	0.35 (0.19)	0.71 (0.40)	0.48 (0.15)	0.23 (0.21)

Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. All coefficients are constrained to be between 0 and 1 and estimated by NLS with $H = 6$. Coloumn "RESTRICTED" imposes an additional restriction: $\gamma_b + \gamma_f = 1$. Output gap is measured using the HP filter with a smooth parameter of 100.

For the unrestricted estimates, the full sample estimates are reasonably close to their unrestricted counterparts for both γ's and λ. However, the post-WW2 estimates for the lagged inflation (γ_b) and inflation expectation (γ_f) are relatively small. The lack of dynamics in the impulse responses of inflation fails the rank condition. Imposing the long-run restriction deflates the slope estimate by a factor of 3. Lastly, the backward-looking (γ_b) and forward-looking inflation expectations (γ_f)

[13] This corresponds to 2% annual real interest rate and is adjusted for a steady state growth rate of 2% per year.

are of similar importance in determining inflation dynamics, indicating that the hybrid NKPC is preferred to the purely forward-looking NKPC.

3.4 Growth Regime Dependence of the Slope of the Phillips Curve

In this section, I will stratify the sample by productivity growth regimes classified in Section 2.1 and apply the two-step approach to estimate the hybrid NKPC for each regime. To enlarge the sample size of each regime and avoid sample loss from taking first-difference and lags, I do not harmonize the sample sizes across horizons and keep the observations even if the value of the trilemma instrument equals zero.

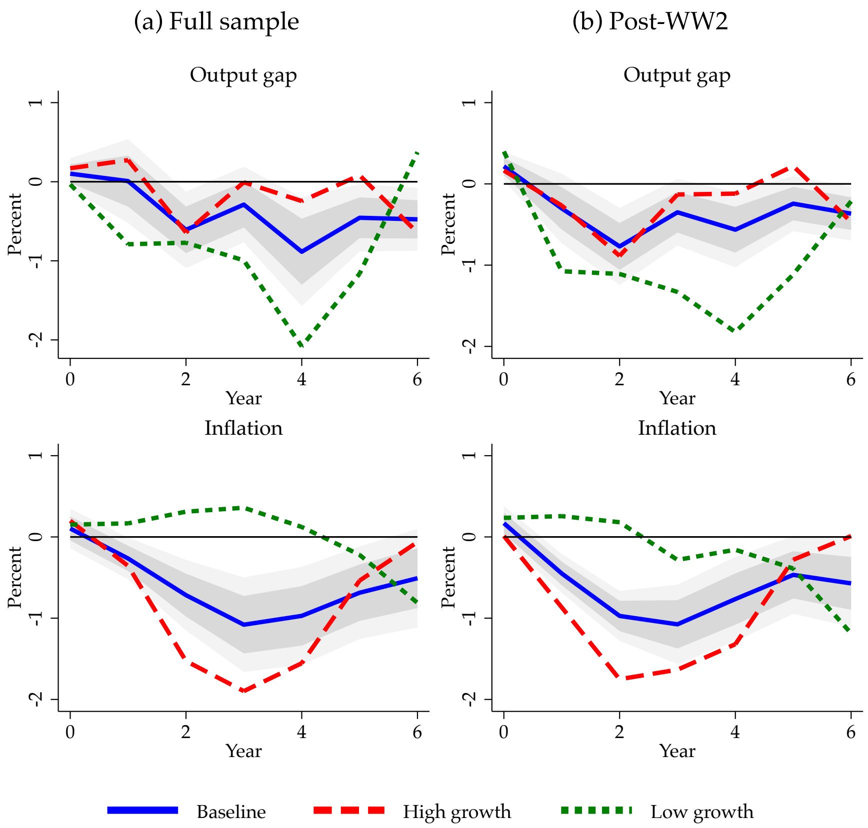
Figure 3 shows the impulse response of inflation and output gap estimated using LP-IV approach. The baseline non-state dependent estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates in the high growth regime are displayed with a red long-dashed line whereas estimates in the low growth regime are displayed with a green dashed line.

It is evident that monetary policy face different trade-offs between its ability to stablize inflation versus output across growth regimes. Inflation responses are almost muted in the low growth regime for a few years, especially in the full sample results, but output gap is much more responsive in low growth regime. The opposite is true in the high growth regime: contractionary monetary policy is very effective in controlling inflation with low cost of reduction in output gap. It's worth noting that the inflation responses in the low growth regime are slightly positive (not statistically significant though) for a few years. Given the significantly negative responses of output gap, the correlation between the IRFs of inflation and output gap is slightly negative, especially in the full sample results. After imposing the non-negativity constraint, the slope estimates for the low growth regime will be bounded by zero.

The constrained NLS estimates of the Phillips curve are presented in Table 3. In the full sample results, the restricted estimate of λ is bounded by zero, and the estimate of γ_b without imposing the long-run constraint is bounded by one. In contrast, the coefficient estimates are well behaved in high growth results. The slope estimate is much larger in magnitude than their counterparts in Table 2 for both regimes, and is statistically significant. The unrestricted estimates are quite close to the restricted ones.

As we've seen in Table 2, lack of dynamics in inflation after the WW2 renders serious challenge on the data to distinguish the effects of lagged and leading inflation terms, especially in the low growth regime. Despite this, both unrestricted and restricted estimates suggest that the Phillips curve is steeper in high growth regime. The restricted estimates suggest that λ ranges from 0.8 to 0.9 in high growth regime, which implies that the degree of price stickiness is approximately 0.54. That is, about half of the prices adjust each quarter, the price adjustment is more than twice as frequent as the average. Comparing the importance of two types of inflation expectation terms, I find that the backward-looking term plays a slightly more important role in inflation dynamics than the forward-looking term in low growth regime.

Figure 3. Asymmetric responses of inflation and output gap: regime-switching classification



Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates stratified by the high growth regimes are displayed with a red long-dashed line whereas estimates in the low growth regimes are displayed with a green dashed line. Sample sizes are not harmonized in estimation. Output gap is measured using the HP filter with a smooth parameter of 100.

Table 3. State dependence of the Phillips curve: regime-switching classification, $H = 6$

SAMPLE	BIN	UNRESTRICTED			RESTRICTED	
		γ_f	γ_b	λ	γ_f	λ
Full	growhi	0.49 (0.11)	0.56 (0.11)	0.83 (0.41)	0.47 (0.08)	0.89 (0.33)
Full	growlo	0.39 (0.07)	1.00 (.)	0.05 (0.03)	0.38 (0.07)	0.00 (.)
Post-WW2	growhi	0.30 (0.08)	0.58 (0.08)	1.00 (.)	0.39 (0.08)	0.80 (0.25)
Post-WW2	growlo	0.31 (0.16)	0.34 (0.43)	0.00 (.)	0.31 (0.25)	0.00 (0.10)

Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. All the coefficients are constrained to be between 0 and 1 and estimated by NLS with $H = 6$. Coloumn "RESTRICTED" imposes an additional restriction: $\gamma_b + \gamma_f = 1$. Output gap is measured using the HP filter with a smooth parameter of 100.

4 Robustness Checks and Further Results

In this section, I consider a number of robustness checks to see if the baseline results are robust to a variety of changes in the state-dependence analysis of the slope of the Phillips curve. The first set of robustness checks uses alternative growth regime classifications that are more intuitive without imposing any assumptions on the underlying process of trend TFP. Next, I show that my baseline conclusions survive at least qualitatively even if we choose other measures of output gap and longer projection horizons. Third, I consider alternative sample selection criteria: include more recent samples till 2012, and the subsample of European countries. Lastly, I compare the state dependent effects of monetary policy across different regimes to provide further evidence of the relevance and uniqueness of TFP growth regime. Below I will focus on the discussion of conclusions, with further detail and results shown in the Appendix.

4.1 Alternative Regime Classification Methods

Without taking a stand on which classification result makes more sense, it's worth checking if the baseline conclusion still holds when we classify growth regimes differently. In this part, a brief illustration of three alternative classification methods is followed by a discussion of regime classification results. Compared with the regime-switching approach, these simple methods share some *pros and cons*. Then I repeat the state-dependence analysis as in the previous section. Here are three alternative classfication methods sorted by complexity:

1. ***Above universal cutoff.*** We can simply define the high growth regime as the years when a country's trend TFP growth rate is above some universal cutoff level, i.e., $S_{c,t} = H$ if $g^{TFP}_{c,t} \geq \bar{g}$, and $S_{c,t} = L$ if otherwise, where $\bar{g}$ is fixed $\forall c, t$.

What level of $\bar{g}$ should we choose? One potential candidate is the sample average of trend TFP growth, which obviously depends on the sample period that we look at. Similar to the regime-switching approach, if we include more low growth periods in the sample (e.g., two world wars or more recent samples), the sample average TFP growth will be lower, and fewer observations will be classified to be in low growth regimes. Besides the common problem of the sensitivity to the choice of sample period, it is particularly a problem for this method that it tends to generate too many tuning points. This often occurs when a country's trend TFP growth rises above or falls below the cutoff level for a short period of time.

In the data, the average trend TFP growth over the period 1890-2018 for all countries is 1.47%. That is, if $g^{TFP}_{c,t} \geq 1.47\%$, then $S_{c,t} = H$ and the regime dummy equals one. Figure B.1 collects the classification results for all 17 countries in the merged dataset. The solid bule line shows each country's trend TFP growth over time (left axis), while the dashed grey line indicates the regime dummy (right axis). The universal cutoff level is displayed with a horizonal dashed red line.

Take the U.S. economy as an example. It is quite surprising to find that this simple method is able to pick up almost all the tuning points suggested by the regime-switching approach. The exact timing of the regime changes are quite close to my baseline results. The main difference lies in the starting point of the recent periods of high productivity growth. This simple method suggests that the U.S. economy has entered the high growth regime in 1994 and the regime lasts for a decade, while the regime-switching approach suggests that the recent high growth regime in the U.S. hasn't started until 1997, and it only lasts for 8 years.

On the other hand, we do find quite different classification results for a bunch of other countries. This simple approach tends to generate too many regime changes, making each regime shorter and more segamented. When the trend TFP growth fluctuates around the cutoff level, the method will treat the ups and downs as regime switches, e.g., Sweden (SWE) and Norway (NOR).

Since this method doesn't impose the assumption that the trend productivity growth varies around two average levels over time, it may provide some new insights as well. In the case of Japan, we get two distinct high growth regimes prior to WW2, one from 1912 to 1924, the other from 1933 to 1938; and the post-WW2 high growth regime also lasts for almost two decades longer, from 1950 to 1992, compared to what the regime-switching approach suggested, i.e., from 1953 to 1973.

Does the main conclusion still hold under this regime classification? The LP-IV estimates of the impulse responses are displayed in Figure B.2. The output gap responses are still stronger in low growth regime, especially at longer horizons. In the full sample results, the inflation responses are almost muted in low growth regime, but are quite significant in high growth regime. In the post-WW2 sample results, however, it seems that the inflation responses are stronger in low growth regime at longer horizons.

The estimates of the Phillips curve are shown in Table B.1. The full sample results are quite similar in both restricted and unrestricted case, and the slope coefficient in low growth regime is bounded by zero. The Phillips curve is steeper in high growth regime, the slope coefficient is not statistically significant though. In the post-WW2 sample results, the inflated unrestricted slope estimate for the low growth regime gets quite close to the estimate for the high growth regime, but the restricted estimates restore the stunning difference.

2. ***Above country-specific mean growth rate.*** Despite the closeness in the geographical, cultural and technological environment, countries still differ in their relative distances to the frontier and how fast they adopt new technologies, especially in the aftermath of two world wars. Some European countries recovered really quickly, e.g. Netherlands (NLD) achieved 4.6% and 4.9% growth rates in trend TFP after the two wars, while others grew relatively moderately[14]. The timing of regime changes might be similar across countries, but the level of trend TFP growth is less comparable. So it is reasonable to assume country-specific cutoff level when defining growth regimes, i.e., $S_{c,t} = H$ if $g^{TFP}_{c,t} \geq \bar{g}_c$, and $S_{c,t} = L$ if otherwise, where $\bar{g}_c$ is fixed for country c $\forall t$.

Using each country's sample average of trend TFP growth over the sample period of 1890-2019 as its cutoff level, the regime classification results are combined in Figure B.3. Compared with the universal cutoff, more sample periods will be classified as in low growth regime for the countries that achieve higher average trend TFP growth than 1.47%. That is, if $\bar{g} \leq g^{TFP}_{c,t} < \bar{g}_c$, $S_{c,t}$ will adjust from H to L, e.g., FIN, JPN, NOR, SWE, U.S., etc. The opposite is true if $\bar{g}_c \leq g^{TFP}_{c,t} < \bar{g}$, e.g. AUS, GBR, etc. It is evident that the problem of too frequent regime changes is still prevalent for some countries, e.g. JPN from 1934 to 1937, from 1977 to 1982, etc. The recent high growth regime in the U.S. is no longer self-evident any more.

Does the main conclusion still hold under this regime classification? The LP-IV estimates of the impulse responses are displayed in Figure B.4. The main conclusions remain the same, that is, in low growth regime, the output gap responses are relatively stronger while the inflation responses are relatively weaker. The coefficient estimates of the Phillips curve are shown in Table B.2. All specifications deliver qualitatively similar conclusions as my baseline results.

[14]The average trend TFP growth rate was 1.54% during the world war I (1917–1919), 2.51% from 1920 to 1922, 1.2% during the world war II (1939–1947), and 3.2% from 1948 to 1956.

3. ***Two percentiles with a medium high regime.*** The third classfication method tries to mitigate the problem of frequent regime changes shared in the previous two methods. Let's denote the two percentile levels as p_1 and p_2, $p_1 < 50 < p_2$ (eg. 45 and 55 percentiles). In the first step, I calculate the two percentiles of each country's trend TFP growth, denoted by $\bar{g}_{p_1,c}$ and $\bar{g}_{p_2,c}$. In the second step, I define the *raw* growth regimes as follows:

$$S_{c,t} = \begin{cases} L & \text{if } g_{c,t}^{TFP} < \bar{g}_{p_1,c} \\ M & \text{if } \bar{g}_{p_1,c} \leq g_{c,t}^{TFP} < \bar{g}_{p_2,c} \\ H & \text{if } g_{c,t}^{TFP} \geq \bar{g}_{p_2,c} \end{cases}$$

It is worth pointing out that a lot of the medium high growth regimes are short and temporary, and mostly occur when trend growth transitions from one growth regime to the other. So I take a recursive process in step 3 to reassign these transitional periods to their previous regime. For example, if the trend TFP growth changes from low (high) to high (low) growth regime, with less than 5 years in medium regime, then these transitional periods will be classified as low (high) growth regime. That is, if $S_{c,t} = M, S_{c,t-1} = L$, and $S_{c,t+x} = H$ where $x = 1, \cdots 5$, then $S_{c,t} = L$ after the adjustment. In this way, I essentially impose the rule that when regime switches from L to H, the trend TFP growth should exceed the higher percentile, and vice versa.

In step 4, to cope with the temporary rises and falls in trend TFP growth, I reassign these periods to the nearby regime. For example, in the middle of a long growth regime appears a few years (less than 5) of another growth regime, then the short regime will be re-classified to be the more populated regime. The last step deals with the high growth regime in which the trend TFP growth only exceeds the higher percentile slightly (lower than $g_{p_2,c} + \triangle$), where $\triangle$ is some small number. I adjust these sample to be in the medium high regime.

Which two percentiles should we choose? Considering the fact that medium high growth regimes are segmented and transitional, I prefer to choose two percentiles close to median not only to maximize the sample sizes of low and high growth regimes but also allow for a medium regime to absorb some less representative middle cases. Here I use each country's 45 and 55 percentiles of trend TFP growth over the sample period of 1890-2018 as the raw cutoff levels, and $\triangle = 0.1\%$. The classification results are shown in Figure B.5. Compared with the previous two methods, this method further refines the two representative regimes, the high growth regime subsample features slightly higher average trend TFP and is less segmented. In the state-dependence analysis, I group the low growth regime and medium high growth regime as one group, so the comparison is essentially high growth regime versus the rest non-high growth regimes.

The LP-IV estimates of the impulse responses are displayed in Figure B.6 and the corresponding estimates of the hybrid NKPC are summarized in Table B.3. We can see that the main results still hold in this case. Inflation responses are almost muted in the non-high growth regimes, and are stronger than the baseline in the high growth regime. The output gap responses are slightly stronger in low growth regime at longer horizons. The slope coefficients are quite close when using linearly detrended output gap as the forcing variable, but the difference is quite evident when I measure output gap using the HP filter.

4.2 Alternative Measures of Output Gap

By definition, $y_t \approx y_t^n + x_t$, that is, the (log) real output y_t can be decomposed into a trend component y_t^n, and a cyclical component x_t. Since y_t^n is unobservable, different ways of estimating the trend component will yield different measures of output gap. If one attibutes more variations in real output to long-run forces that change potential output, then less variations are left to the business cycle factors that affect output gap. In other words, if potential output is estimated to be more volatile or less smoothed, then output gap will be less volatile.

Does monetary policy have long-run effects on output? The conventional wisdom is that monetary policy only affects output in the short-run due to the existence of nominal or real rigidities, but money is neutral in the long run. In this case, monetary policy shocks should not affect potential output, but only the output gap. The IRFs of output gap should be exactly the same as the IRFs of output. However, Jordà, Singh, and Taylor (2020) challenge this widely accepted benchmark and find empirically that monetary policy shocks have effects on output, capital and TFP over a horizon of more than a decade!

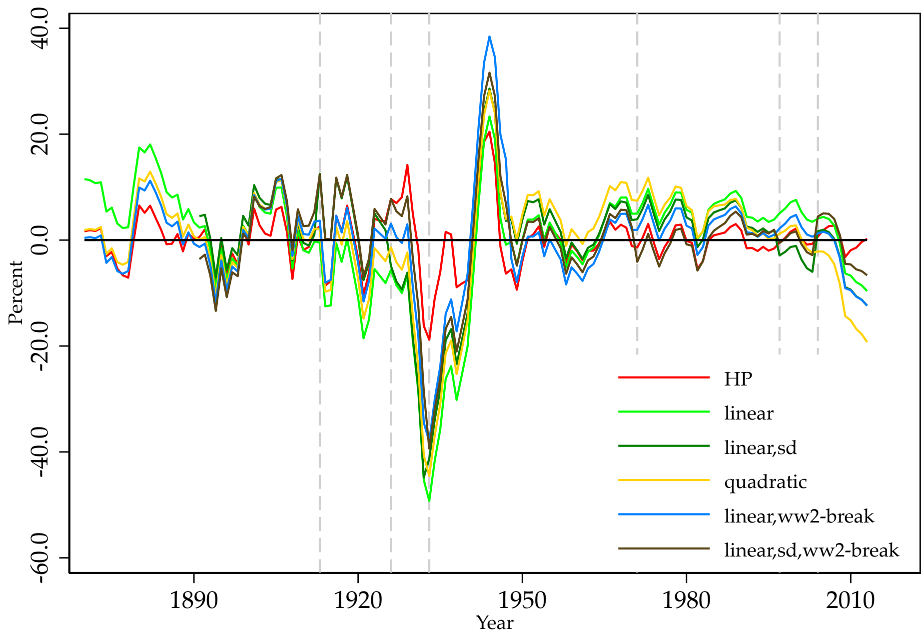
Therefore, the extent to which potential output responds to the monetary policy shocks distinguishes some measures of output gap from the others. The simplest way of estimating the potential output is to fit a linear trend over the entire sample period. The resulting residual gives us the linearly detrended measure of output gap, x_{linear}. In the context of TFP growth regimes, it is natural to incorporate the non-linearity by allowing the growth rate of the trend component to be regime-dependent, the resulting residual $x_{linear,sd}$ should be less volatile than x_{linear}.

On the other extreme is the output gap measure using the HP filter. Depending on the degree of smoothness, the trend component can be estimated to be more or less smoothed. In the baseline results, I follow Jordà, Schularick, and Taylor (2020) and set the smoothing parameter to be 100. Compared to the previous two output gap measures, the output gap using the HP filter, denoted as x_{hp}, is least volatile because the trend component is time-varying and comoves with output more closely. So we would expect that the IRFs of x_{hp} would look relatively dwarfed in magnitude.

Figure 4 plots the time series of different measures of output gap for the U.S. from 1890 to 2013. Apart from x_{hp},x_{linear} and $x_{linear,sd}$, I also consider the quadratically detrended output gap x_{qt} and two linearly detrended output gap measures that allow the coefficients to take on different values before and after the WW2 when estimating the linear trend(s). The main takeaway is threefold: first, all these measures of output gap comove together most of the time; second, x_{hp} is relatively less volatile than most of the other measures most of the time, whereas x_{linear} and x_{qt} are the most volatile measures; third, huge structural changes occur during the Great Depression and WW2. Allowing for coefficients to take on different values before and after the WW2 essentially adjusts the linearly detrended measures towards x_{hp}.

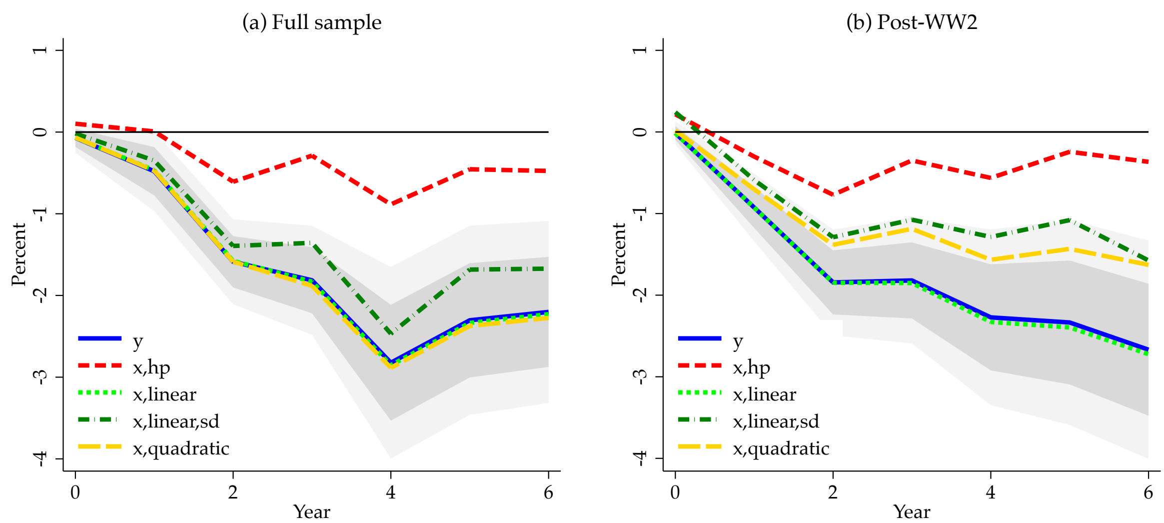
Figure 5 shows the IRFs of output and different measures of output gap to monetary policy shocks using LP-IV approach. In both panels, the LP-IV estimates of the output responses are displayed with a solid blue line and 68% and 90% confidence bands in grey. Various types of dashed colored lines show the estimated IRFs of different measures of output gap. Among these output gap measures, it is expected that the IRFs of x_{linear} will overlap with the IRFs of output conditional

Figure 4. Different measures of output gap for the U.S.



Notes: "HP": output gap using HP filter with a smoothing parameter of 100; "linear": linearly detrended output gap; "linear, sd": growth regime-dependent linearly detrended output gap; "ww2-break": the coefficients in the linear trend regression can take on different values before and after the WW2; "quadratic": quadratically detrended output gap. The break points are the tuning points of TFP growth estimated using the regime-switching approach. See text.

Figure 5. IRFs of output and different measures of output gap



Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. LP-IV estimates of the IRFs of output are displayed with a solid blue line and 68% and 90% confidence bands in grey. Dashed lines are IRFs of different measure of output gap, relative to the IRFs of output, the controls also include up to 2 lags of the first-difference of output gap. Sample sizes are not harmonized across horizons.

on the same set of macroeconomic controls $\boldsymbol{z}_{c,t}$. The minor difference in the graph is due to the controls related to output gap. In contrast, the IRFs of x_{hp} get dampened the most. The IRFs of x_{qt} are very close to the IRFs of the linearly detrended output gap x_{linear} in the full sample results, while the IRFs of the output gap assuming regime-dependent average growth rates in trend ($x_{linear,sd}$) lie closely to the IRFs of x_{linear}. Panel (b) delivers quite similar results, except that the IRFs of x_{qt} and $x_{linear,sd}$ lies between the IRFs of x_{linear} and x_{hp}. In summary, x_{linear} and x_{hp} represent two extreme cases.

In Table 4, I collect the estimates of the hybrid NKPC using three alternative measures of output gap. The differences in the slope estimates are quite consistent with what we've noticed from Figure 5. In the full sample results, the output gap measures assuming constant linear trend and quadratic trend yield quite small slope estimates, while the measure assuming growth regime-dependent linear trends fall in between. Across all measures of output gap, both restricted and unrestricted estimates confirm that the Phillips curve is steeper in the high growth regime.

Table 4. Estimation of the Phillips curve: Alternative measures of output gap

SPEC	BIN	UNRESTRICTED			RESTRICTED	
		γ_f	γ_b	λ	γ_f	λ
Panel A: Full sample						
linear	growhi	0.45 (0.15)	0.30 (0.23)	0.65 (0.43)	0.53 (0.11)	0.31 (0.19)
linear	growlo	0.47 (0.15)	0.48 (0.42)	0.00 (.)	0.47 (0.13)	0.00 (.)
linear, sd	growhi	0.41 (0.11)	0.39 (0.12)	0.93 (0.31)	0.50 (0.10)	0.60 (0.23)
linear, sd	growlo	0.19 (0.41)	0.94 (0.70)	0.05 (0.07)	0.28 (0.28)	0.03 (0.06)
quadratic	growhi	0.45 (0.15)	0.29 (0.24)	0.67 (0.46)	0.53 (0.11)	0.33 (0.20)
quadratic	growlo	0.39 (0.91)	0.45 (1.34)	0.02 (0.11)	0.16 (0.49)	0.04 (0.07)
Panel B: Post-WW2 sample						
linear	growhi	0.37 (0.28)	0.30 (0.35)	0.43 (0.52)	0.51 (0.14)	0.13 (0.15)
linear	growlo	0.39 (0.14)	0.48 (0.32)	0.00 (.)	0.38 (0.13)	0.00 (.)
linear, sd	growhi	0.15 (0.07)	0.76 (0.05)	0.87 (0.12)	0.23 (0.06)	0.78 (0.12)
linear, sd	growlo	0.26 (0.30)	0.52 (0.42)	0.08 (0.16)	0.28 (0.27)	0.04 (0.14)
quadratic	growhi	0.31 (0.24)	0.32 (0.23)	0.66 (0.49)	0.49 (0.13)	0.22 (0.19)
quadratic	growlo	0.37 (0.30)	0.49 (0.41)	0.00 (0.12)	0.36 (0.13)	0.00 (.)

Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. All coefficients are constrained to be between 0 and 1 and estimated by NLS with $H = 6$. Coloumn "RESTRICTED" imposes an additional restriction: $\gamma_b + \gamma_f = 1$. Column "SPEC" specifies the measure of output gap. In Column "BIN", "growhi" stands for high growth regime; "growlo" stands for low growth regime. Regimes are calssified by "regime-switching" approach. See text.

4.3 Alternative Choices of Projection Horizon

In the baseline results, I chose 6 as the projection horizon for the IRFs estimated in Step 1, which is also the number of observations for the regression in Step 2. In this part, I will extend the projection horizon (denoted as H) and utilize more periods of IRFs in the second step estimation. Table B.4 and Table B.5 display the estimates of the Phillips curve in the second step using the impulse responses of inflation and output gap estimated for $H = 9$ and 12 in the first step, which are plotted in Figure B.7 and B.8, respectively.

The main takeaway here is twofold: first, the main conclusions associated with the state dependence of the slope of the Phillips curve still hold. That is, the Phillips curve is steeper in high growth regime. Second, the more periods of impulse responses we include in the second step regression, the flatter the Phillips curve is estimated to be. The output gap responses decay quickly after the sixth year, especailly in the low growth regime. Inflation responses differ quite substantially across two regimes: in the high growth regime, inflation declines quickly in the first three years and almost recovers in the sixth year, then falls again with smaller peak response thereafter. In the low growth regime, however, it takes a couple of years for the inflation to fall and the peak response occurs in the sixth or seventh year. The inertia in inflation response is also coupled with smaller peak response.

4.4 Sample Selections

1. ***Including more recent samples.*** The baseline results include the sample periods prior to the Great Financial Crisis to avoid the zero lower bound by which the conduct of monetary policy is constrained. In this part, I extend the sample period to include more recent samples till 2012, the latest year that the trilemma instrument estimates are available in the *Macrohistory Database*.

Figure B.9 plots the impulse responses of inflation and output gap estimated using LP-IV approach. With 6 more years of data, the estimated impulse responses look quite close to the baseline results. The IRFs in the high growth regime are almost the same since almost all countries are in low growth regime after 2006, except for Finland (FIN), it enters low growth regime in 2007. The IRFs of output for low growth regime change slightly with a smaller peak response. In Table B.6, we find very similar point estimates as those in Table 3, although the slope coefficients in the low growth regime are bounded by zero in the full sample results due to the “price puzzle”.

2. ***The subsample of European countries.*** Considering the similarities within the group of European countries in various other dimensions beyond the economic development, I conduct the same analysis using the subsample of European countries. The results are displayed in Figure B.10 and Table B.7. In the full sample results, things are qualitatively similar to their counterparts in the baseline. In the post-WW2 sample results, the inflation responses show little difference across growth regime, but the output gap responses are much stronger in the low growth regime. The slope estimates deliver qualitatively the same conclusion.

4.5 State Dependence Analysis: Growth Regime vs. Other Regimes

Although the descriptive analysis in Section 2.2 shows only weak correlation between the TFP growth regime and other regime dummies, there remain concerns about how and to what extent the TFP growth regime differs from other regimes in terms of the monetary policy effects. In this section, I conduct similar state dependence analyses as in Jordà, Schularick, and Taylor (2020) and compare the asymmetric responses of output and price levels to monetary policy shocks under the stratifications based on inflation level, credit growth (both mortgage and non-mortgage), and trend TFP growth. This helps us visualize how differently trend TFP growth matters for the transimission of monetary policy. The LP-IV specification and IRFs are displayed and discussed in Appendix C with more detail.

Compared with the inflation regimes and credit growth regimes, the rich panel data at hand suggest that the stratification based on the trend TFP growth shows different state dependent effects of montary policy. The main takeaway is as follows: monetary policy is subject to clear and distinct trade-offs between its nominal effect on prices and real effect on output across TFP growth regimes. We don't find such trade-offs in the state dependence analyses based on inflation regime (Figure C.1) or credit growth regimes (C.2). In particular, Figure C.3 shows that output response is relatively stronger in low growth regime than in high growth regime. In contrast, the price response is almost muted in low growth regime for the first 4 years after the policy change, but the price is very responsive in high growth regime. Such clear and distinct trade-offs between the nominal and real effects of monetary policy suggest that agents might face different degrees of price rigidity across TFP growth regimes.

5 Theoretical Explanations

So far the empirical estimation of the slope of the NKPC using the merged panel data on 17 advanced economies over a century suggests that the short-run tradeoff between inflation and output gap depends on the productivity growth regimes. In particular, the Phillips curve is steeper when the trend productivity growth is faster. Since the growth regimes are classified based on trend growth in TFP, and NKPC summarizes firm's optimal pricing behavior when faced with short-run nominal rigidities, my empirical finding implies that the long-run technological development matters for the firm's pricing behavior in the frictional short run. This, to the best of my knowlege, remains a gap in the macroeconomic theories.

In this section, I propose one potential channel through which the slope coefficient will exhibit the observed growth regime dependence. The proposed mechanism bridges the recent literature on endogenous growth, market structure and the slope of the Phillips curve. On the one hand, it has been successfully established by recent studies that rising market concentration flattens the slope of the Phillips curve, see e.g., Wang and Werning (2022), and Fujiwara and Matsuyama (2022). On the other hand, market structure and productivity growth are interdependent in the endogenous growth framework. To match my empirical findings, I argue that structural changes that contribute to higher productivity growth historically also lead to more competitive market, and vice versa. That is, productivity boom (slowdown) is often accompanied by lower (higher) market concentration and markups.

To illustrate the mechanism, let me start from the standard NKPC. Under the assumptions of CES preference and monopolistic competition as in Dixit and Stiglitz (1977), and price adjustment costs à la Rotemberg (1982), the NKPC is formulated as

$$\lambda = \frac{e-1}{\phi_R} \times \frac{\partial mc}{\partial x}$$

where e is the price elasticity of demand, ϕ_R denotes the degree of price adjustment costs and $\frac{\partial mc}{\partial x}$ captures the sensitivity of marginal cost with respect to output gap.[15]

Under the assumptions of CES preference and monopolistic competition, each firm is atomic and

[15]The Calvo (1983) assumption of staggered price-setting leads to $\lambda = \kappa(\theta) \times \frac{\partial mc}{\partial x}$ as in equation (6). If $\kappa(\theta) = \frac{e-1}{\phi_R}$, it will be equivalent to the NKPC under Rotemberg (1982) assumption.

too small to affect the price or output of the entire market, and the price elasticity of demand is determined solely by the elasticity of substitution between products/varieties, which is assumed to be constant. Therefore, market structure is irrelevant to the slope of the Phillips curve.

In general, the sensitivity of λ with respect to the trend growth in productivity g is given by

$$\frac{\partial \ln \lambda}{\partial \ln g} = \underbrace{\frac{e}{e-1}\frac{\partial \ln e}{\partial \ln g}}_{\text{real rigidity}} - \underbrace{\frac{\partial \ln \phi_R}{\partial \ln g}}_{\text{nominal rigidity}} + \frac{\partial}{\partial \ln g}\ln\left(\frac{\partial mc}{\partial x}\right) \tag{7}$$

The three terms on the right hand side represent three potential channels through which the slope of the Phillips curve might exhibit growth regime dependence: the first term captures the "real rigidity" channel through the price elasticity of demand given the form of market competition and preference system; the second term captures the "nominal rigidity" channel through the price adjustment costs, and the last term captures the channel through the marginal cost variations with respect to demand conditions.

My proposed mechanism breaks the irrelevance through the "real rigidity" channel by linking the price elasticity of demand to the market structure and endogenizing the market structure by firm entry and exit in the long run. In particular, the long-run forces that determine firm's innovation incentive and profitability will also affect the number of firms operating in the economy, thus the slope of the Phillips curve through the change in the price elasticity of demand.

There are at least two approaches in the literature to establish the linkage between the price elasticity of demand (e) and the market structure, or the number of firms (N) in the symmetric case: one relies on oligopolistic competition, and the other relies on non-CES preferences. For the first approach, Smulders and Klundert (1995, 1997) build an endogenous growth model featuring CES preference and oligopolistic competition. Different varieties are imperfect substitutes with a constant elasticity of substitution $\epsilon > 1$, and the number of firms/varieties is perceived as fixed in the short-run but is endogenously determined by the zero-profit condition in the long run. The perceived price elasticity of demand is increasing in the number of the firms, i.e., $e'(N) > 0$, so if N increases when the economy transitions to high growth regime, then this mechanism can qualitatively explain the observed fact.

In Appendix D, I calibrate their model along the balanced growth path and conduct a simple comparative statics analysis based on two structural changes proposed in the literature to explain the productivity boom in the mid-1990s and the productivity slowdown in mid-2000s. One is the decline in the overhead costs due to the arrival of new Generous Purpose Technology (GPT), e.g., Information and Communication Technlogy (ICT), see Aghion et al. (2019). The other is the rise in the research productivity as new GPT frees out the research resources in the overly-crowded tranditional sector and reallocates them into the booming sectors. Anzoategui et al. (2019) and Bloom et al. (2020) point out that the decline in R&D efficiency has led to the recent low growth regime prior to the Great Financial crisis.

The comparative statics anaylsis shows that a fall in the overhead costs and a simultaneous rise in the research productivity result in a new long-run equilibrium with higher growth and more competitive market. In contract to Aghion et al. (2019), the decline in the overhead costs or rise in the process efficiency alone attracts more firms to enter but discourages innovation as each firm's market share is lower. Meanwhile, the rise in research productivity encourages firms to invest more in firm-specific knowledge, and the increase in the fixed R&D costs is roughly offset by the increase in profits, leaving the number of firms almost unchanged. With both structural changes in action, the model is able to link growth to more competition.

However, the model is unable to generate quantitatively large enough change in the slope. To see this, let's take Bertrand competition for example. The perceived price elasticity of demand is formulated as $e = \epsilon - (\epsilon - 1)\frac{1}{N}$, and the "real rigidity" channel can be simplified as

$$\frac{e}{e-1}\frac{\partial \ln e}{\partial \ln g} = \frac{1}{N-1}\frac{\partial \ln N}{\partial \ln g}$$

If N is not so small, then this mechanism only plays a secondary role.

My empirical estimate of the slope coefficient in the baseline for the post-WW2 sample increases by a factor of 3.5 from 0.23 on average to 0.8 in high growth regime. Given the parameter calibration $\epsilon = 6$ and initial equilibrium number of firms $N \approx 5$, a back-of-the-envelope calculation implies that the price elasticity of demand has to increase by a factor of 3 from 5 on average to 15 in high growth regime. However, in the calibrated model, e is at most $\epsilon = 6$, which corresponds to a 25% increase in the slope even if the number of firms goes from 5 to infinity.[16]

Alternatively, the non-CES homothetic preference system is also able to introduce state-dependence into the slope of the Phillips curve through the "real rigidity" channel. One such preference uses the translog expenditure function proposed by Feenstra (2003), and another features exponential love-of-variety. For both preference specifications, the symmetric price elastcity of demand is formulated as $e = 1 + \gamma N$, where $\gamma > 0$ is a free parameter, and N is the number of available varieties (Bilbiie, Ghironi, and Melitz, 2019). Unlike the previous approach, non-CES preference system is able to generate much larger variations in the slope of the Phillips curve. We can show that

$$\frac{e}{e-1}\frac{\partial \ln e}{\partial \ln g} = \frac{\partial \ln N}{\partial \ln g}$$

which is $N-1$ times the magnitude in the previous case. Given the same initial values for e and N, to match my empirical results, we need the number of firms to increase by a factor of 3.5 from 5 on average to 17.5 in high growth regime. From here we can infer that models with more flexible non-CES preference under monopolistic competition or oligopolistic competition are potentially able to generate even larger effect on the slope coefficient through this channel.[17]

Besides the plausible support in theory, the sample correlation between trend productivity growth and markups also confirms my conjunction that *high* trend growth is associated with *lower* markups at least for post-1980 sample. By incorporating the markup measures from De Loecker and Eeckhout (2018) since 1980, I find that the average markup ratio for the advanced economies in my sample is 1.208 in the high growth regime, and 1.265 in the low growth regime.

[16] e goes from 5 to 6 as N increases from 5 to infinity, percentage change in the slope is $\frac{\epsilon - e}{e-1} = 25\%$.

[17] Wang and Werning (2022) build a model that features non-CES preference (e.g. Kimball) and oligopolistic competition with Calvo pricing. They show that going from monopolistic competition to an oligopolistic competition with $N = 3$ divides the slope of the Phillips curve by four.

Although I mainly rely on the "real rigidity" channel to explain the growth regime dependence of the slope of the Phillips curve, other channels are by no means less important nor less promising. In terms of the "nominal rigidity" channel, empirical evidence on the price adjustment costs alone is quite rare. Survey studies that look at the frequency and duration of price changes reflect both nominal and real rigidities.[18] It would be helpful to empirically distinguish one from the other, and study how technological changes affect the price adjustment costs. Regarding the sensitivity of marginal costs with respect to demand changes, globalization-related views suggest that this term has been decreasing due to the increasing fraction of imports as shares of GDP in advanced economies since 1970s. But its state-dependence on growth regime is not clear to us.[19] There still remain a number of gaps in this topic that would benefit from future research.

6 Conclusions

What is the relationship between the long-run productivity growth and the short-run trade-off between inflation and economic slack? This paper investigates the state dependence of the slope of the Phillips curve on the trend productivity growth. By merging the Bergeaud-Cette-Lecat *Long-Term Productivity Database* with Jordà-Schularick-Taylor *Macrohistory Database*, this paper stratifies the sample based on the level of the trend TFP growth for 17 advanced economies over more than a century. The rich cross-country variations, together with the long sample period, enables us to distinguish the different roles played by different regime variables, and productivity growth regime is shown to provide new perspectives, especially in terms of the asymmetric monetary policy effects. Monetary policy faces clear and different trade-offs between its nominal and real effects across growth regimes. Following the latest state-of-art method of estimating structural forward-looking macroeconomic equations proposed by Barnichon and Mesters (2020), empirical estimation of the slope of the NKPC suggests that the Phillips curve is *steeper* in *high* productivity growth regime.

To explain these findings, this paper proposes a mechanism that bridges the literature on endogenous growth, market structure and the slope of the Phillips curve. In a calibrated endogenous growth model with CES preference and oligopolistic competition, an exogenous fall in overhead costs and a simultaneous rise in research productivity could lead to higher trend growth and more competitive market populated with more varieties/firms. If the price elasticity of demand rises with market competition, then the pass-through of marginal costs due to short-run demand changes will be larger, indicating a steeper Phillips curve, and vice versa. This mechanism is qualitatively in tune with the recent trends of flattening Phillips curve and productivity slowdown amid rising market concentration and markups in many advanced economies. Quantitatively, however, an endogenous growth model with non-CES preference and oligopolistic competition should be a good path to pursue for future research.

The policy implications of my paper are at least twofold. First, when the potency of monetary policy to steer inflation is limited in low productivity growth regime, central banks should be more

[18]see Nakamura and Steinsson (2013) and references therein for an extensive discussion.

[19]The relationship between trade openness and economic growth is ambiguous from both theoretical and empirical point of view. See Silajdzic and Mehic (2018) for an extensive discussion.

alert to negative supply shocks and take decisive actions to rein in inflation before expectation de-anchors. Second, good growth perspectives and active business dynamism enhance the potency of monetary policy, therefore, structural reforms that can improve productivity and restore business dynamism not only help alleviate supply constraints but also improve the potency of monetary policy in the long run. Such structural reforms include more strict enforcement of antitrust laws to reduce the market power of big firms, competition-enhancing policies to reduce entry barriers and growth-enhancing policies to foster more efficient R&D.

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Appendices

A Phillips Curve Estimation Using Theoretical IRFs

The simple three-equation New-Keynesian model (e.g., Gali, 2015, Chapter 3) yields the following theoretical IRFs to monetary policy shocks:

$$\hat{\pi}_t = -\lambda\Lambda_\xi \xi_t$$
$$\hat{x}_t = -(1-\beta\rho_\xi)\Lambda_\xi \xi_t$$

where $\hat{y}_t = y_t - y_{ss}, y \in \{\pi, x\}$, is measured by the percentage deviations from the steady state, and

$$\Lambda_\xi = \frac{1}{(1-\beta\rho_\xi)[\sigma(1-\rho_\xi)+\phi_y]+\lambda(\phi_\pi - \rho_\xi)}$$

β is the discount factor, σ is the elasticity of substitution, ρ_ξ is the AR(1) parameter of the monetary policy shock, ϕ_π and ϕ_y are the weight parameters in the monetary policy rule for inflation gap and output gap. λ is the slope of the Phillips curve, and it is a function of deep model parameters as well,

$$\lambda = \frac{(1-\theta)(1-\beta\theta)}{\theta}(\chi+\sigma)$$

where θ is the probability of price adjustment each period, χ is the Frisch elasticity of labor supply. Given the following calibrations: $\beta = 0.99, \sigma = 1, \chi = 1, \theta = 0.8, \phi_\pi = 1.5, \phi_y = 0$, and $\rho_\xi = 0.2$, we have $\Lambda_\xi = 1.2873$ and the coefficients of the "hybrid" NKPC are $\gamma_b = 0, \gamma_f = \beta = 0.99$, and $\lambda = 0.104$.

Consider a one-period innovation in monetary policy shock,

$$\xi_t = \rho_\xi \xi_{t-1} + \epsilon_t^\xi$$

and $\epsilon_0^\xi = 1, \epsilon_t^\xi = 0, \forall t \neq 0$ or $\xi_t = \rho_\xi^t, \forall t \geq 0$. The theoretical IRFs can be derived as follows:

$$\mathscr{R}_h^\pi = \frac{E[(\pi_{t+h} - \pi_{t-1})\xi_t]}{E[\xi_t^2]} = \frac{E[(\pi_{t+h} - \pi_{ss} - (\pi_{t-1} - \pi_{ss}))\xi_t]}{E[\xi_t^2]} = \frac{E[(\hat{\pi}_{t+h} - \hat{\pi}_{t-1})\xi_t]}{E[\xi_t^2]} = -\lambda\Lambda_\xi \rho_\xi^h$$

where $E[\hat{\pi}_{t-1}\xi_t] = 0$ by the timing assumption.

Similarly, we can derive the IRFs of output gap and get

$$\mathscr{R}_h^x = -(1-\beta\rho_\xi)\Lambda_\xi \rho_\xi^h$$

Notice that

$$\mathscr{R}_h^\pi = \frac{\lambda}{1-\beta\rho_\xi}\mathscr{R}_h^x$$

and

$$\mathscr{R}_{h+1}^\pi = \frac{\lambda\rho_\xi}{1-\beta\rho_\xi}\mathscr{R}_h^x \propto \mathscr{R}_h^x$$

If we simply regress $\mathscr{R}_h^\pi$ on $\mathscr{R}_{h-1}^\pi$, $\mathscr{R}_{h+1}^\pi$ and $\mathscr{R}_h^x$, we will have perfect collinearity problem.

The series of monetary policy shock ξ_t and the theoretical IRFs of inflation $\mathscr{R}_t^\pi$ and output gap

$\mathscr{R}_t^x$ are presented in Table A.1. We can see that as h increases, the IRFs revert back to zero exponentially. So the horizon over which we run regression (with no constant term) in the second step should not be too large, here I choose $H = 5$.

Table A.1. Theoretical IRFs to monetary policy shock

h	ξ_h	$\mathscr{R}_h^\pi$	$\mathscr{R}_h^x$	$\mathscr{R}_{h-1}^\pi$	$\mathscr{R}_{h+1}^\pi$
0	1	-0.13388	-1.03244	0	-0.02678
1	0.2	-0.02678	-0.20649	-0.13388	-0.00536
2	0.04	-0.00536	-0.04130	-0.02678	-0.00107
3	0.008	-0.00107	-0.00826	-0.00536	-0.00021
4	0.0016	-0.00021	-0.00165	-0.00107	-0.00004
5	0.00032	-0.00004	-0.00033	-0.00021	-0.00001

The unrestricted OLS estimates of the Phillips curve using the theoretical IRFs shows that γ_b is essentially zero, the expected inflation term is omitted due to perfect collinearity, and the slope coefficient is estimated to be 0.1297, which is approximately 25% larger than the true value. If we impose the long-run restriction that $\gamma_b + \gamma_f = 1$, the point estimate is 1 for γ_f, approximately zero for γ_b, but the slope coefficient is omitted due to perfect collinearity.

To estimate the coefficients that match their ranges in theoretical models, I further constrain three coefficients to be between 0 and 1, i.e., $0 < \gamma_b, \gamma_f, \lambda < 1$. Because the range of the inverse logit function is the interval $(0,1)$, we can use the inverse logit function to set this restriction and estimate the coefficients using nonlinear least square (NLS) method.

The coefficient estimates without imposing the long-run restriction depend on the initial values we choose for the coefficients when running the nonlinear least square method. The point estimate of γ_b is always approximately zero, whereas the point estimate of γ_f will rest at its initial value, suggesting that there're insufficient variations in the "data" – theoretical IRFs – to identify all three coefficients. For example, if we choose the initial value of γ_f to be approximately 0, or the logit function to be some large negative number (say -20), then the point estimate of λ remains at 0.1297. But if the initial value of γ_f is set to be 0.5, or the logit function to be at 0, then the point estimate of λ is 0.1167, closer to the true value. And if we instead choose the initial value of γ_f to be approximately 1, or the logit function to be some large positive number (say 20), then λ is estimated to be 0.1037, which is almost at the true value.

Alternatively, we can impose the long-run restriction $\gamma_b + \gamma_f = 1$ to improve the point estimates. After imposing the long-run restriction, the slope estimate becomes 0.1037, and γ_f is bounded by 1. What's more, if we knew and imposed the true long-run restriction $\gamma_b + \gamma_f = 0.99$ under this calibration, we could actually recover the true coefficients.

B Robustness Checks

B.1 Alternative Growth Regime Classification Methods

1. *Above universal cutoff.* Figure B.1 shows the regime classification results for the cutoff level $\bar{g} = 1.47\%$, which is the sample average of trend TFP growth over the entire sample period. Figure B.2 plots the estimated IRFs of inflation and output gap in the first step. Table B.1 summarizes the corresponding estimates of the Phillips curve for high and low growth regimes.

2. *Above country-specific mean growth rate.* Figure B.3 shows the regime classification results with the country-specific sample averages of the trend TFP growth over the entire sample period. Figure B.4 plots the estimated IRFs of inflation and output gap in the first step. Table B.2 summarizes the corresponding estimates of the Phillips curve for high and low growth regimes.

3. *Two percentiles with a medium high regime.* Figure B.5 shows the regime classification results with the country-specific 45 and 55 percentiles of the trend TFP growth over the entire sample period. Figure B.6 plots the estimated IRFs of inflation and output gap in the first step. Table B.3 summarizes the corresponding estimates of the Phillips curve for high and low growth regimes.

B.2 Phillips Curve Estimation with Longer Projection Horizons

Table B.4 and Table B.5 display the estimates of the Phillips curve in the second step using the impulse responses of inflation and output gap estimated for $H = 9$ and 12 periods in the first step, which are plotted in Figure B.7 and B.8, respectively.

B.3 Sample Selections

1. ***Include more recent samples.*** Figure B.9 plots the estimated IRFs of inflation and output gap in the first step if we include the more recent sample till 2012. Table B.6 summarizes the corresponding estimates of the Phillips curve for high and low growth regimes in the second step.

2. ***The subsample of European countries.*** Figure B.10 plots the estimated IRFs of inflation and output gap in the first step if we only include the subsample of European countries: BEL, DEU, DNK, EPS, FIN, FRA, ITA, NLD, PRT, SWE, NOR, CHE. Table B.7 summarizes the corresponding estimates of the Phillips curve for high and low growth regimes in the second step.

C State Dependence Analysis: TFP Growth Regimes vs. Other Regimes

Following Jordà, Schularick, and Taylor (2020), in this section I conduct state dependence analyses for the monetary policy effects across different regimes by estimating the impulse responses of price and real output using local projection with the trilemma monetary shocks as external instrument. The baseline LP-IV specification follows equation (4) except that the response variables are real GDP per capita and log CPI, and the macroeconomic control variables on the right hand side do not include variables related to output gap nor inflation.

C.1 Inflation Regimes

First, let me present the state dependence of the impulse response functions by stratifying the data by the level of inflation for the sample period starting from 1890. I use an annual 2% CPI inflation rate cutoff to define high/low inflation after excluding a few hyperinflation periods (greater than 45% annual rate, occured e.g., in Germany after the first world war).

Figure C.1 shows the asymmetric impulse responses of real GDP per capita and price level to a 1 percentage point increase in short-term interest rate for the baseline (solid blue line), low inflation state (dashed green line) and high inflation state (long dashed red line). The analysis is conducted using both the full sample (1890-2006 excluding world wars) and post-WW2 sample (1948-2006). The response of output to monetary policy is relatively stronger when the inflation is above 2%. The full sample results show more significant difference between two states, and it takes longer time for the monetary policy to have real effects when the inflation is below 2%.

The response of price level to monetary policy changed somehow after the WW2, and the difference between two states became less observable. In the full core sample results, we find almost no effect on the price level for the first three years when the inflation is below 2%, while in the post-WW2 sample, the effect in low inflation state is even stronger than that in high inflation state for the first two years. Put two pairs of impulse responses together, we don't find the typical tradeoff between the output and price responses implied by nominal ridigity story.

C.2 Credit Growth Regimes

Next, let's turn to the state dependence of the impulse responses by stratifying the data based on the mortgage credit growth for the sample periods starting from 1890. The high mortgage / non-mortgage credit growth regime is when a country's 3-year mean changes in mortgage / non-mortgage credit over GDP (y_{it}) is above its historic mean changes, i.e., $y_{it} > \bar{y}_i$ or $y_{it} - \bar{y}_i > 0$.

Figure C.2 Panel A shows the asymmetric impulse responses of real GDP per capita and price level to a 1 percentage point increase in short-term interest rate for the baseline (solid blue line), low mortgage credit growth state (dashed green line) and high mortgage credit growth state (long dashed red line). The left panel shows the results for the full sample (1890-2006 excluding world wars), whereas the right panel shows the results for the post-WW2 sample (1948-2006). The main takeaway is twofold: one, the price responses show little asymmetry in both regimes relative to the baseline, especially after the second world war; two, the effect of interest rates on output differs a lot depending on whether mortgage credit growth is fast or slow, monetary policy has much stronger real effects when the mortgage credit grows faster. In response to the same 1% interest rate increase, the decline in output is about 3 percentage points higher 4 years after the intervention.

Figure C.2 Panel B shows the asymmetric impulse responses of output and price level to a 1 percentage point increase in short-term interest rate for the baseline (solid blue line), low non-mortgage credit growth state (dashed green line) and high non-mortgage credit growth state (long dashed red line). Things are quite the opposite with the non-mortgage credit stratification. On the one hand, the output responses show little asymmetry in both regimes relative to the baseline at least for the first three years after the policy change, the regime-specific impulse responses lie within the 90% confidence bands of the baseline. On the other hand, the effect of interest rates on price differs a bit depending on whether non-mortgage credit growth is fast or slow, especially in the full sample results. In response to the same 1% interest rate increase, the decline in price is about 2.5 percentage points higher 4 years after the intervention.

C.3 TFP Growth Regimes

Now let's switch to the main focus of this paper concerning how the monetary policy may have different effects in times of high growth and low growth in productivity. Figure C.3 shows the asymmetric impulse responses of real GDP per capita and price level to a percentage point increase in short-term interest rate for the baseline (solid blue line), low growth regimes (dashed green line) and high growth regimes (long dashed red line). The growth regimes are classified by the baseline regime-switching approach.

The output response to monetary policy is relatively stronger in low growth regime than in high growth regime. In terms of magnitude, in the full sample results, at the end of year 4, in response to 100 bps increase in short-term interest rate, output declines by approximately 2.3% in the baseline, 2.5% in low growth regime and 1.0% in high growth regime. The post-WW2 sample delivers similar results with slightly smaller magnitude, output decreases by 1.9% in the baseline and low growth regime, and 0.8% in high growth regime.

In contrast, price response is almost muted in low growth regime for the first 4 years after the change in monetary policy, while price responds quite strongly in high growth regime. In the full sample results, price level drops by more than 5% at the end of year 4, and in post-WW2 sample results, price level drops by more than 4%. Unlike the previous discussion about inflation regimes or credit growth regimes, there seems to be a tradoff between output and price level responses when we stratify the data by growth regimes.

In relation to the correlation among different regime dummies, we do observe that the asymmetric responses of output look qualitatively similar to those when we stratify the data based on mortgage credit growth, whereas the asymmetric responses of price look qualitatively similar to those when we stratify the data based on inflation. In particular, the TFP growth regime dummy correlates positively with the inflation regime dummy (esp. for the full sample) but negatively with the mortgage credit growth regime dummy, and we observe that the effect of interest rates on output is stronger in *low* TFP growth regime and *high* mortgage credit growth regime, while the effect on price is weaker/muted in *low* TFP growth regime and *low* inflation regime. But all of these regimes differ in the combination of nominal and real effects of monetary policy.

D An Endogenous Growth Model with CES Preference and Oligopoly

The basic model follows from Smulders and van de Klundert (1995, 1997) in discrete time. It combines elements from endogenous growth theory and industrial organization literature on innovation. The exercise here is to use their model and show that the long-run forces that change the trend growth rate along the balanced growth path may alter the number of firms in the market, which will affect firm's perceived price elasticity of demand.

There are two sectors in the economy: a high-tech sector with differentiated products and a traditional sector with a homogenous good. The traditional sector is competitive while the high-tech sector is oligopolistic, with a finite number of imperfectly substitutable product types. The number of firms/brands N is determined in the long run by free entry condition. Agents have rational expectations and perfect foresight. Time is discrete and infinite.

D.1 Households

The representative household's preferences are given by

$$U = E_t \sum_{s=0}^{\infty} \beta^s \frac{C_{t+s}^{1-\sigma}}{1-\sigma} \tag{8}$$

Consumers trade off future consumption for present consumption according to a CRRA utility function with elasticity of intertemporal substitution $1/\sigma$ and discount factor β. The final consumption good is a composite good, according to equation (9), of the homogeneous good Z and the differentiated good X, with η representing the expenditure share of X-goods:

$$C_t = X_t^{\eta} Z_t^{1-\eta}, \quad 0 < \eta < 1 \tag{9}$$

The X-goods is a bundle of N varieties which are imperfect substitutes with constant elasticity of substitution ϵ:

$$X_t = \left(\sum_{j=1}^{N} x_{jt}^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}}, \quad \epsilon > 1 \tag{10}$$

Besides consumption, households supply labor inelastically for a nominal wage rate of W_t, and the total labor supply is denoted as $\bar{L}$. The period budget constraint is

$$P_t^C C_t + Q_{t+1} B_{t+1} \leq B_t + W_t L + T_t \tag{11}$$

where P_t^C is the ideal price index for the final consumption good, B_{t+1} represents purchases of one-period bonds that will mature in period $t+1$ at a price of $Q_{t+1} \equiv \frac{1}{1+i_{t+1}}$, W_t is the nominal wage rate, and T_t is a lump-sum componet of income (which may include, among other things, the dividends from ownership of firms).

Proposition 1. *Consumer behavior can be summarized by the following optimality conditions:*

i. The optimal consumption / savings decision is described by

$$Q_{t+1} = \beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{P_t^C}{P_{t+1}^C} \right] \tag{12}$$

ii. The optimal composition of sectoral goods satisfies:

$$X_t = \eta \frac{P_t^C}{P_t^X} C_t \tag{13}$$

$$Z_t = (1-\eta) \frac{P_t^C}{P_t^Z} C_t \tag{14}$$

iii. The optimal composition of differentiated goods satisfies:

$$x_{jt} = X_t \left(\frac{p_{jt}^x}{P_t^X} \right)^{-\epsilon} \tag{15}$$

or

$$x_{jt} = \eta C_t \left(\frac{P_t^X}{P_t^C} \right)^{-1} \left(\frac{p_{jt}^x}{P_t^X} \right)^{-\epsilon} \tag{16}$$

iv. The price indices

$$P_t^C = \left(\frac{P_t^X}{\eta} \right)^{\eta} \left(\frac{P_t^Z}{1-\eta} \right)^{1-\eta} \tag{17}$$

$$P_t^X = \left(\sum_{j=1}^{N} \left(p_{jt}^x \right)^{1-\epsilon} \right)^{\frac{1}{1-\epsilon}} \tag{18}$$

$$P_t^X X_t = \sum_{j=1}^{N} p_{jt}^x x_{jt} \tag{19}$$

D.2 Firms

The homogenenous good Z is produced subject to a linear technology using labor only. By choice of units, one unit of labor is required to produce one unit of Z:

$$Z = L_{Zt} \tag{20}$$

Perfect competition implies that the price of the homogeneous good equals the wage rate, i.e.,

$$P_t^Z = W_t \tag{21}$$

Each of the differentiated product $j \in \{1, \cdots, N\}$ is produced by one manufacturer, using labor and knowledge as inputs. The production and management of each variety/brand requires its own product/firm-specific knowledge h_{jt}. The technology to produce differentiated products is given by

$$x_{jt} = h_{jt} L_{xjt} \tag{22}$$

where L_{xjt} is production labor time and h_{jt} is labor productivity.

The law of motion of firm-specific knowledge is formulated as

$$h_{j,t+1} - h_{jt} = \xi \left(h_{jt}^{1-\alpha} H_t^{\alpha} \right) L_{rjt} \tag{23}$$

Firms can employ labor L_{rjt} to conduct in-house R&D activities to accumulate new firm-specific knowledge. The knowledge base in R&D activities is represented by the term $h_{jt}^{1-\alpha}H_t^{\alpha}$ in equation (23), where $H_t \equiv \frac{1}{N}\sum_{j=1}^{N} h_{jt}$ is the average knowledge level in the economy and $0 < \alpha < 1$ represents the degree of knowledge spillover. In particular, innovation mainly bases on own firm-specific knowledge, but may subject to diminishing returns as $1-\alpha < 1$. Furthermore, research may benefit from spillover from the knowledge developed for other products and from generally applicable public knowledge as indicated by H_t.

Besides labor costs for production L_{xjt} and R&D activities L_{rjt}, firms also have to incur a fixed overhead cost L_f for any level of production every period, which captures the costs of management, marketing and coordination. Her period profit flow is given by

$$D_{jt} = p_{jt}^{x} x_{jt} - (L_{xjt} + L_{rjt} + L_f)W_t \tag{24}$$

Each producer in the high-tech sector maximizes her firm value by choosing L_{xjt}, L_{rjt} and p_{jt}^{x}, taking as given the demand from the final sector for consumption, the aggregates $\Upsilon_t \equiv \{P_t^C, N, H_t, C_t\}$, the production function (22), and the law of motion of firm-specific knowledge (23).

Let's denote the value of the firm j as $V_t^j(\cdot) \equiv V^j(h_{jt};\Upsilon_t)$ such that

$$V^j(h_{jt};\Upsilon_t) = \max_{L_{xjt}, L_{rjt}, h_{j,t+1}, p_{jt}^{x}} \quad D_{jt} + E_t\left[Q_{t,t+1} V^j(h_{j,t+1};\Upsilon_{t+1})\right] \tag{25}$$

subject to equation (16), (22), and (23). Note that with oligopolistic competition at the sector level, P_t^X is a function of own price p_{jt}, price of other varieties $p_{-j,t}$, and the number of varieties N.

Proposition 2. *Differentiated goods producer's optimization problem can be summarized by the following optimality conditions:*

i. Optimal pricing rule

$$p_{jt}^{x} = \frac{e_{jt}}{e_{jt}-1}\frac{W_t}{h_{jt}}$$

ii. Optimal investment in R&D activities:

$$W_t = \Psi_{jt}\xi h_{jt}^{1-\alpha}H_t^{\alpha} \tag{26}$$

where Ψ_{jt} denotes the marginal cost/shadow price of h_{jt}.

iii. No-arbitrage condition between investing in capital market versus creating new knowledge:

$$\Psi_{jt} = E_t\left\{Q_{t,t+1}\left[p_{j,t+1}^{x}\left(1-\frac{1}{e_{j,t+1}}\right)L_{x,j,t+1} + \Psi_{j,t+1}(1+\xi(1-\alpha)h_{j,t+1}^{-\alpha}H_{t+1}^{\alpha}L_{r,j,t+1})\right]\right\} \tag{27}$$

D.3 Symmetric Balanced Growth Equilibrium

Assuming perfect foresight of agents and symmetry across firms, we may drop the subscript j. Each firm has the same level of productivity and firm-specific knowledge which consequently equals the average knowledge level: $h_{jt} = H_t$. The economic growth comes from the accumulation of firm-specific knowledge, let $g_t = H_t/H_{t-1} - 1$ be the growth rate of knowledge. Assume constant number of varieties N along the balance growth path.

Proposition 3. *The general equilibrium balanced growth path for a given number of varieties N where $g_{t+1} = g_t = g$ and $\pi_t^x \equiv \frac{p_t^x}{p_{t-1}^x} - 1 = \pi^x, \pi_t^C \equiv \frac{P_t^C}{P_{t-1}^C} - 1 = \pi^C, \forall t$, can be characterized as follows:*

i. Growth rates are related:

$$g \equiv g_H = g_X = \frac{1}{\eta} g_C = \frac{1}{\eta} g_Y = \frac{1}{\eta} g_w = \frac{1}{1-\eta}(\pi^C - \pi^x) = g_W - \pi^x \tag{28}$$

ii. Constant markup pricing:

$$p_t^x = \frac{e}{e-1}\frac{W_t}{H_t} \tag{29}$$

where $e \equiv e(\epsilon, N)$ defined as

$$e^B \equiv \epsilon - (\epsilon - 1)\frac{1}{N}$$

for Bertrand (price) competition, and

$$e^C \equiv \frac{\epsilon}{1 + (\epsilon - 1)\frac{1}{N}}$$

for Cournot (quantity) competition.

iii. Labor allocations L_Z, L_x, L_r are constant over time.

$$L_r = \frac{g}{\xi} \tag{30}$$

$$L_x = \frac{\eta(e-1)}{e-\eta}\left(\frac{L}{N} - L_f - L_r\right) \tag{31}$$

$$L_Z = \frac{1-\eta}{\eta}\frac{e}{e-1} N L_x \tag{32}$$

iv. "Preference" line (supply of savings) summarizes the household's intertemporal choice:

$$r_x = \rho + (\sigma\eta + 1 - \eta) g \tag{33}$$

where $r_x \equiv E_t[i_{t+1}] - \pi_{ss}^x$, and $\rho \equiv \frac{1}{\beta} - 1$.

v. "Technology" line (demand for savings) summarizes the firm's investment decision:

$$r_x = \left(\frac{e(1-\eta)}{e-\eta} - \alpha\right) g + \xi \frac{\eta(e-1)}{e-\eta}\left(\frac{L}{N} - L_f\right) \tag{34}$$

vi. The interaction between "Preference" line and "Technology" line yields the short-run equilibrium (SRE) line along which the demand and supply of savings are equalized:

$$g = \frac{\xi b\left(\frac{L}{N} - L_f\right) - \rho}{(\sigma - 1)\eta + \alpha + b} \tag{35}$$

where $b = 1 - \frac{e(1-\eta)}{e-\eta} = 1 - \frac{1-\eta}{1-\eta/e}$.

vii. Increasing concentration (smaller N) is conducive to growth.

With entry and exit of firms in the differentiated goods sector, (35) is no longer a complete characterization of the long-run equilibrium. A positive net present value of profits induces entry of new firms until no firm can earn a profit by entering the market. This endogenizes the number of firms. To make a solution tractable, it is assumed that new firms have the same structure and productivity as incumbent firms, and that there is no sunk cost of entry.

Profits in the equilibrium along the balanced growth path are defined as

$$D_{jt} = p_t^x x_t - W_t(L_x + L_f + L_r) = W_t\left(\frac{1}{e-1}L_x - L_f - L_r\right)$$

Substituting in the expressions for L_x and L_r, we find the zero-profit condtion implies

$$D_{jt} = W_t\left[\frac{\eta}{e-\eta}\frac{L}{N} - \frac{e}{e-\eta}(L_f + L_r)\right] = \frac{w_t}{e-\eta}\left[\eta\frac{L}{N} - e(L_f + \frac{g}{\xi})\right] = 0 \iff g = \xi\left(\frac{\eta}{e}\frac{L}{N} - L_f\right) \tag{36}$$

Note that e is increasing in N, so g **is decreasing in** N. Intuitively, a higher rate of innovation (g) implies higher fixed R&D costs ($w_t L_{rt}$ is independent of x_t), so that there is less room for firms. Under free entry, growth is higher and the number of firms in the market is smaller relative to the short-run equilibrium with fixed N.

Proposition 4. *The general equilibrium balanced growth path with entry and exit in the long run is characterized by the interaction between the short-run equilibrium (SRE) line (35) and the zero-profit (ZP) line (36) in the $g-N$ space. This equilibrium is stable when the SRE line is flatter than the ZP line or the ZP line cuts the SRE line from above. See Smulders and Klundert (1995) and references therein.*

D.4 Calibration and Comparative Statics Analysis

The model is calibrated in such a way that the main statistics are kept close to their post-WW2 sample averages if applicable. σ in the utility function is inversely related to the elasticity of intertemporal substitution (EIS), and the range for EIS is still quite debatable in the literature. I follow the results from Attanasio and Weber (1995) that EIS is between 0.1 and 0.5, which implies $\sigma \in [2,10]$, and I choose $\sigma = 8$. σ only affects the SRE line, higher σ flattens out the SRE line quite significantly, and increases the sensitivity of number of firms with respect to shifts in ZP line. The value of ϵ governs the elasticity of substitution between differentiated products, and is also related to price elasticity of demand and markup ratio. I choose $\epsilon = 6$ so that the gross markup is 1.25 on average. $1-\eta$ is the expenditure share of homogeneous products that don't experience much technological progress, and I refer to the share of the primary sector in the economy, around 5%. α measures the knowledge spillover, and I set it to 0.9 following Kung (2015). The discount factor β is set to 0.99[20], and the labor supply L is normalized to be 100. L_f and ξ are the two treatment variables I will consider later. When choosing f and ξ, I target the quarterly growth rate of knowledge g to be 0.54%, which corresponds to a 2.04% average annual growth rate in the

[20]For post-WW2 sample, the average growth rate is set to be the same as TFP growth rate, which is about 2.04% on average. The real short-term interest rate is about 2.2%, so quarterly calibration of $\beta = 1/(1+r^*)(1+g) \approx 0.99$.

post-WW2 sample[21]. One such pair of (f, ξ) is (2.05,0.0035).

Table D.1. Parameter calibration

Parameter	Description	Value
β	discount factor	0.99
σ	inverse of EIS	8
ϵ	elasticity of substitution between varieties	6
η	share of differentiated goods sector	0.95
α	knowledge spillover	0.9
L	labor supply	100
L_f	overhead labor	2.05
ξ	research productivity	0.0035

This paper focuses on the two structural changes that recent literature has pointed out to explain the reasons behind the productivity boom in mid-1990s: fall in the overhead costs (L_f) and rise in the efficiency of R&D (ξ). Figure D.1 presents three cases of comparative statics: a one-time fall in overhead costs L_f in Panel (a), a one-time increase in research productivity ξ in Panel (b) and both changes in Panel (c). Under the current calibration, the SRE line (in blue) is almost invariant to the change in L_f, and the new long-run equlibrium in Panel (a) features lower growth and more firms. The intuition is simple: lower overhead costs L_f encourage more firms to enter the market. However, this lowers the market share of existing firms, discouraging them from innovation, therefore, growth declines.

On the contrary, the research productivity mainly affects the equilibrium growth rate, while the number of products/firms stay more or less the same. The new equilibrium in Panel (b) exhibits much higher growth with almost the same number of firms. The intuition is as follows: more efficient research encourages existing firms to invest more in firm-specific knowledge. However, high rate of innovation also implies higher fixed R&D costs, leaving less room for firms. The latter effect is less prominent under current calibration.

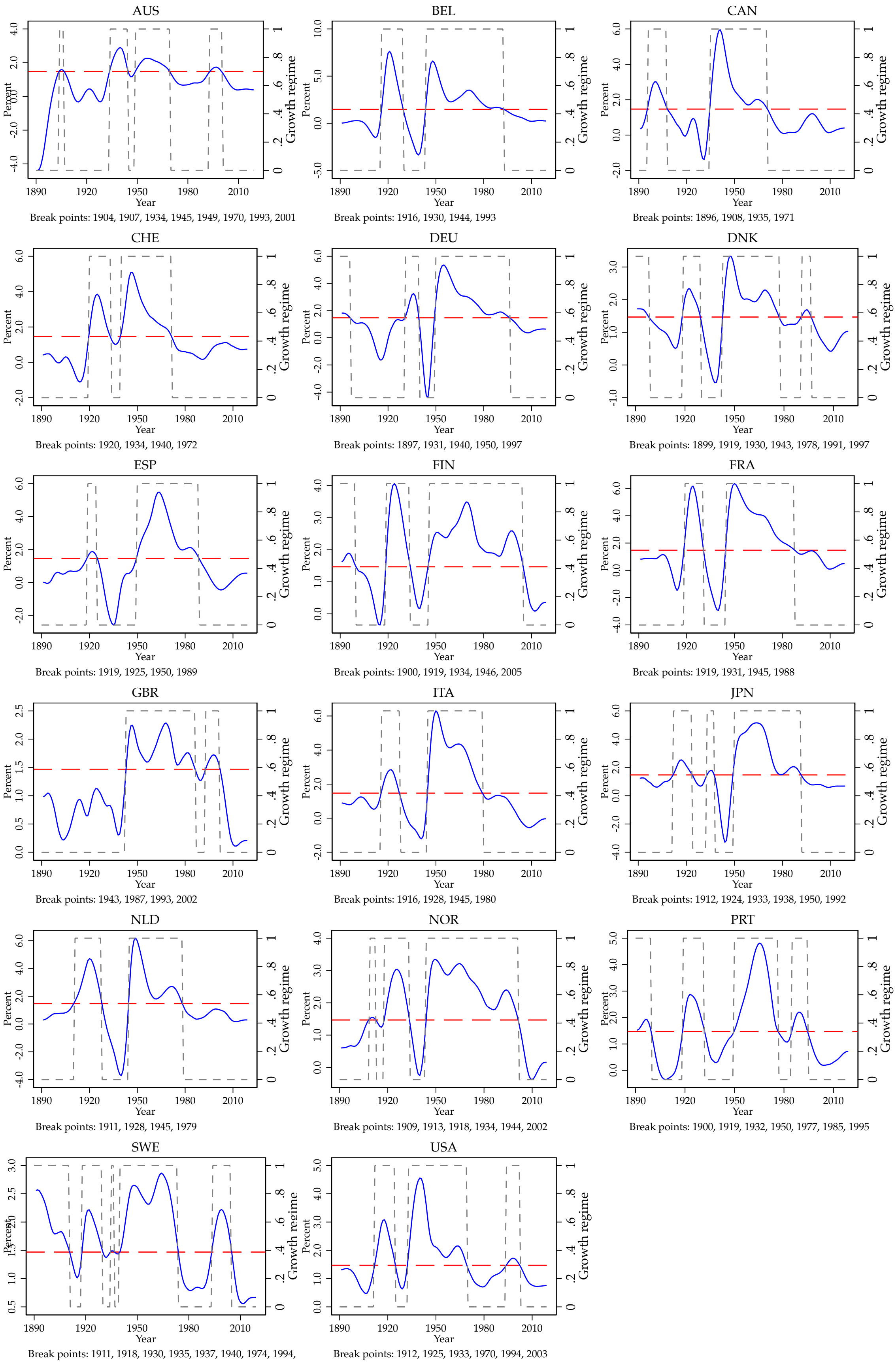
In Panel (c), both changes occur simultaneously and I change the parameters in such a way that the growth rate along the new balanced growth path is targeted at 2.61%, the average trend TFP growth rate in the post-WW2 sample. The number of firms increases from 5 to almost 9, and the implied slope of the Phillips curve should be steeper.

Qualitatively, this model is able to generate correct predictions on the Phillips curve: a fall in overhead costs and a simultaneous rise in research productivity lead to higher growth and steeper slope, the impact on the slope of the Phillips curve is quantitatively small though. The limit of this mechanism is restricted by the range of e. Even if $N \to \infty$, $e \to \epsilon$, the percentage change in $\frac{e-1}{\phi_R}$ term amounts to 25%[22], whereas the empirical estimate for the high growth regime after the WW2 can be more than twice the magnitude of the average slope.

[21] TFP growth in this model is η fraction of the knowledge growth rate g.

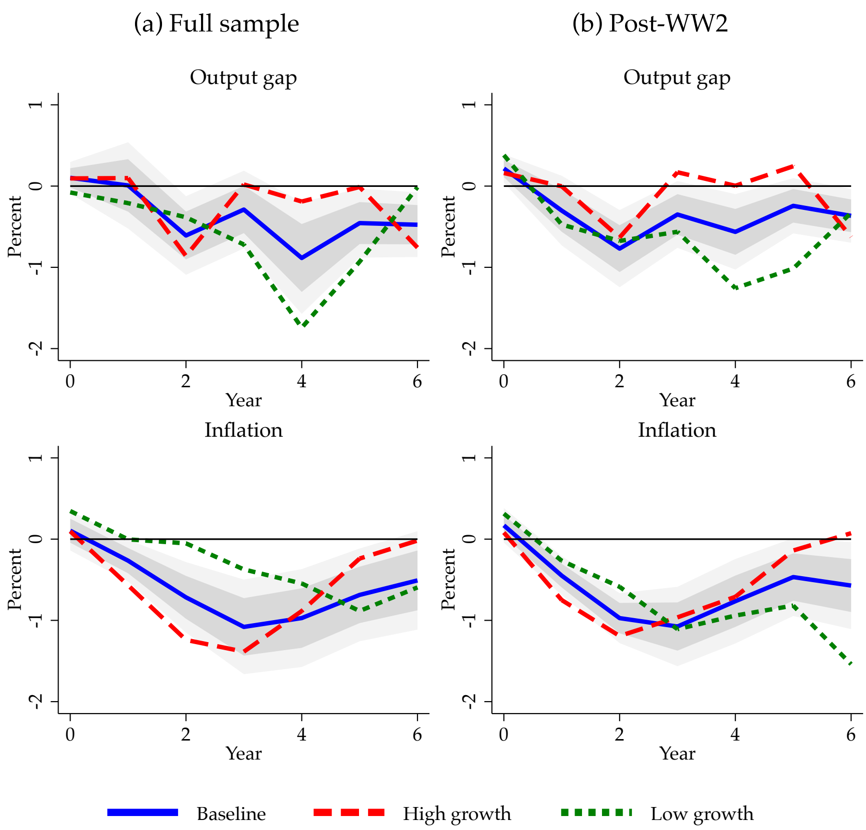
[22] When $\epsilon = 6$ and $N = 5$, $e = \epsilon - (\epsilon - 1)\frac{1}{N} = 5$. Percentage change in $\frac{e-1}{\phi_R}$ in the extrem case is equal to $\frac{\epsilon - e}{e-1} = 0.25$.

Figure B.1. Regime classification results: above universal cutoff



Notes: Solid blue lines: trend TFP growth over time (left axis); dashed grey lines: regime dummy (right axis), equals 1 in high regime, 0 in low regime; red dashed lines: sample average. Sample period: 1890-2019.

Figure B.2. Impulse responses of inflation and output gap: above universal cutoff



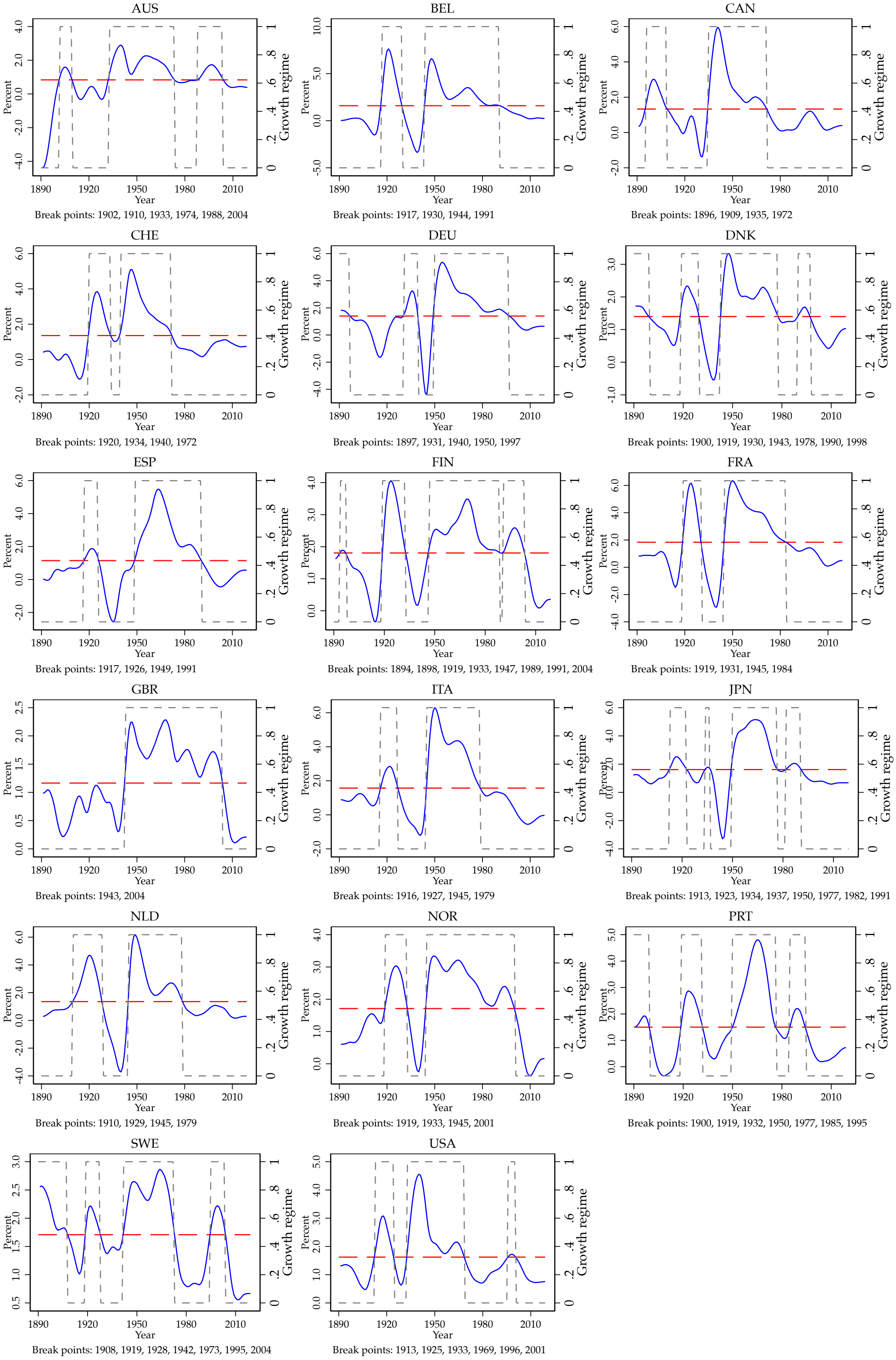
Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates stratified by the high (low) growth regime are displayed with a red long-dashed (green dashed) line. Output gap is measured using the HP filiter with a smoothing parameter of 100. Sample sizes are not harmonized across horizons.

Table B.1. Estimation of the Phillips curve: above universal cutoff

SAMPLE	BIN	UNRESTRICTED			RESTRICTED	
		γ_f	γ_b	λ	γ_f	λ
Full	growhi	0.51 (0.17)	0.55 (0.16)	0.28 (0.41)	0.48 (0.12)	0.35 (0.30)
Full	growlo	0.50 (0.29)	0.66 (0.48)	0.00 (.)	0.39 (0.47)	0.07 (0.19)
Post-WW2	growhi	0.47 (0.16)	0.58 (0.15)	0.65 (0.37)	0.44 (0.12)	0.67 (0.32)
Post-WW2	growlo	0.20 (0.31)	0.22 (0.42)	0.50 (0.46)	0.40 (0.27)	0.01 (0.21)

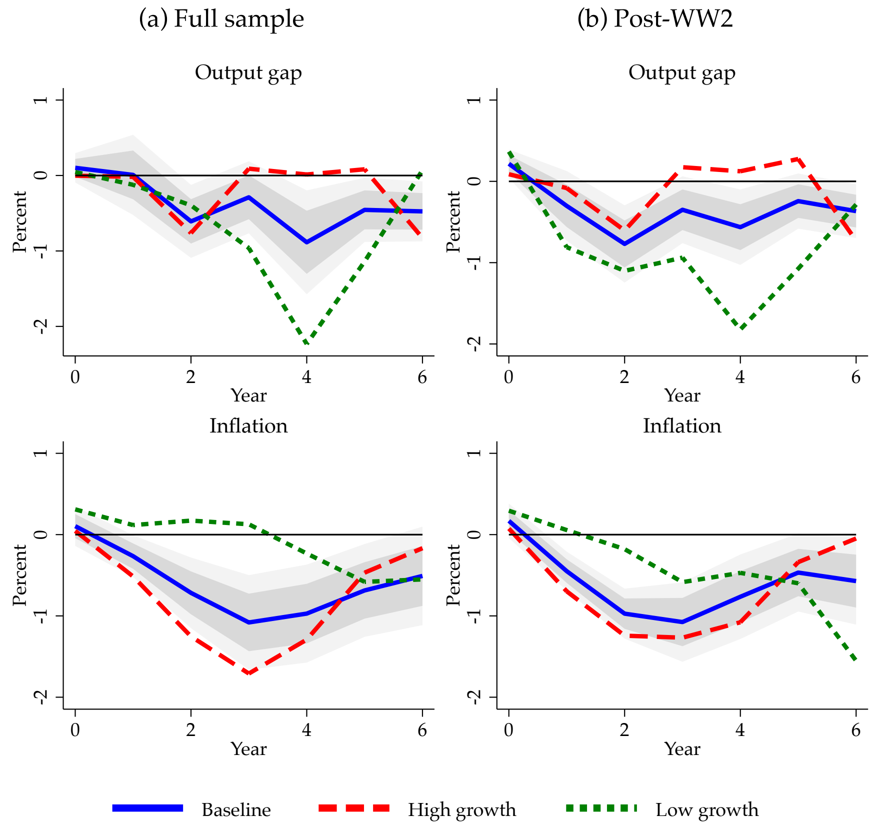
Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. All coefficients are constrained to be between 0 and 1 and estimated using NLS with $H = 6$. Coloumn "RESTRICTED" imposes an additional restriction: $\gamma_b + \gamma_f = 1$. In Column "BIN", "growhi" stands for high growth regime; "growlo" stands for low growth regime. Output gap is measured using the HP filiter with a smoothing parameter of 100. See text.

Figure B.3. Regime classification results: above country-specific mean growth rate



Notes: Solid blue lines: trend TFP growth over time (left axis); dashed grey lines: regime dummy (right axis), equals 1 in high regime, 0 in low regime; red dashed lines: country-specific average. Sample period: 1890-2019.

Figure B.4. Impulse responses of inflation and output gap: above country-specific mean growth



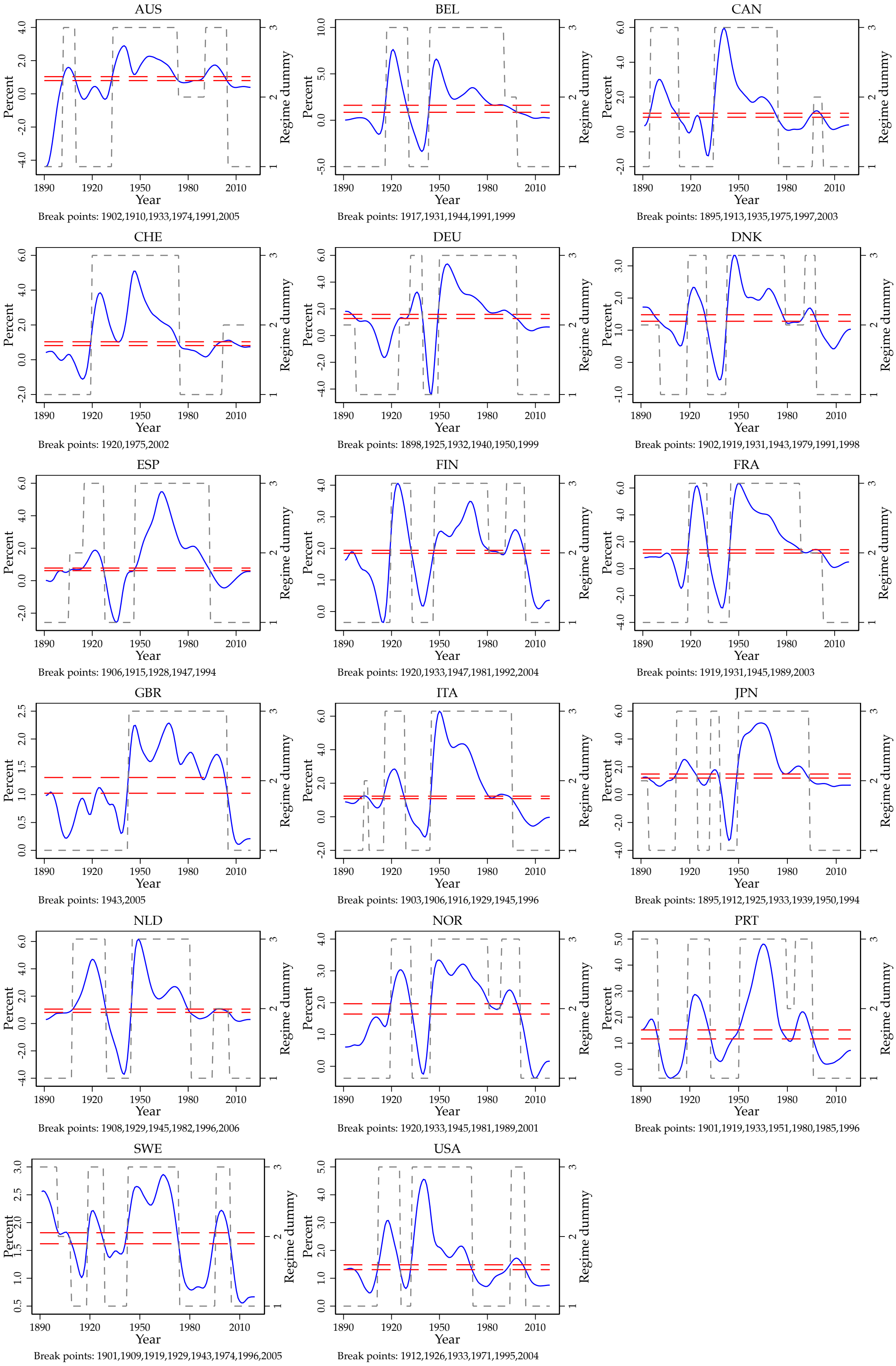
Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates stratified by the high (low) growth regime are displayed with a red long-dashed (green dashed) line. Sample sizes are not harmonized across horizons. Output gap is measured using the HP filiter with a smoothing parameter of 100.

Table B.2. Estimation of the Phillips curve: above country-specific mean growth

SAMPLE	BIN	UNRESTRICTED			RESTRICTED	
		γ_f	γ_b	λ	γ_f	λ
Full	growhi	0.54 (0.20)	0.57 (0.17)	0.04 (0.58)	0.46 (0.15)	0.22 (0.49)
Full	growlo	0.60 (0.21)	0.64 (0.40)	0.00 (.)	0.56 (0.19)	0.00 (.)
Post-WW2	growhi	0.42 (0.18)	0.66 (0.17)	0.59 (0.47)	0.38 (0.14)	0.62 (0.43)
Post-WW2	growlo	0.19 (0.24)	0.40 (0.41)	0.13 (0.15)	0.23 (0.24)	0.04 (0.12)

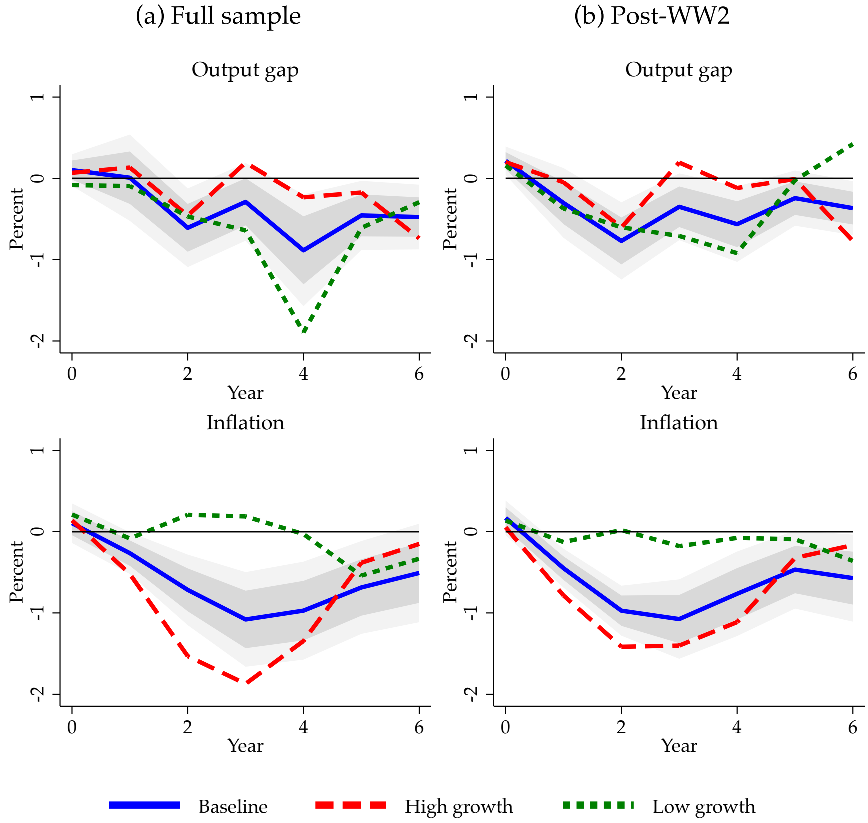
Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. All coefficients are constrained to be between 0 and 1 and estimated using NLS with $H = 6$. Coloumn “RESTRICTED” imposes an additional restriction: $\gamma_b + \gamma_f = 1$. In Column “BIN”, “growhi” stands for high growth regime; “growlo” stands for low growth regime. Output gap is measured using the HP filiter with a smoothing parameter of 100. See text.

Figure B.5. Regime classification results: 45 and 55 percentiles with a medium high regime



Notes: Solid blue lines: trend TFP growth over time (left axis); dashed grey lines: regime dummy (right axis), 3 for high regime, 2 for medium high regime, 1 for low regime; red dashed lines: country-specific 45 and 55 percentiles. Sample period: 1890-2019.

Figure B.6. Impulse responses of inflation and output gap: 45 and 55 percentiles



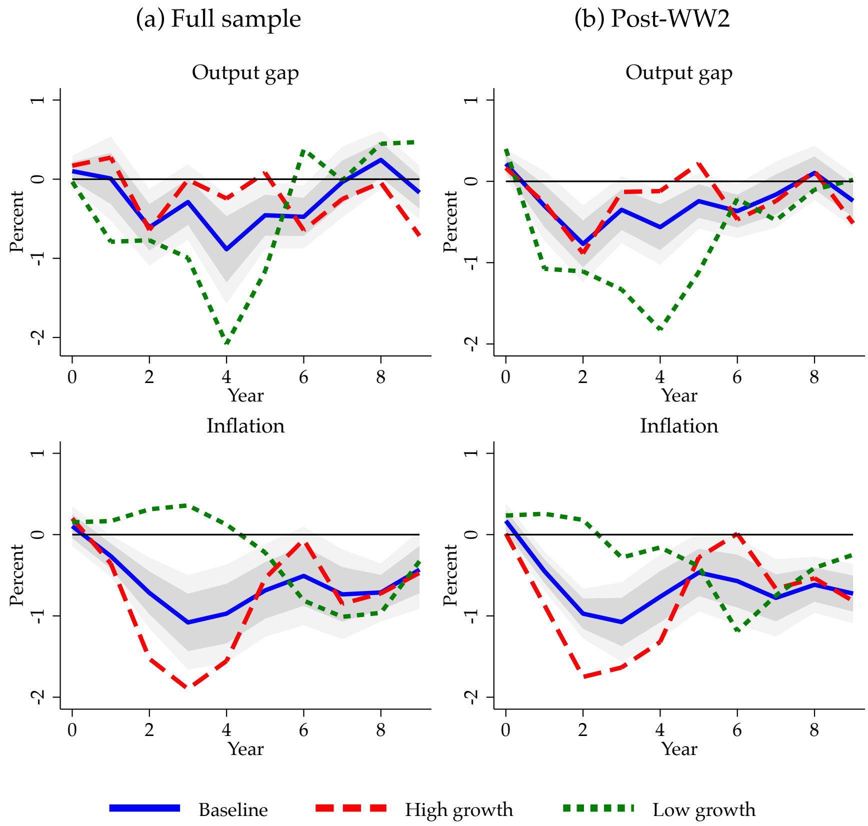
Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates stratified by the high (low) growth regime are displayed with a red long-dashed (green dashed) line. Sample sizes are not harmonized across horizons. Output gap is measured using the HP filiter with a smoothing parameter of 100. The low regime here also includes the medium high growth regime. See text.

Table B.3. Estimation of the Phillips curve: 45 and 55 percentiles

SAMPLE	BIN	UNRESTRICTED			RESTRICTED	
		γ_f	γ_b	λ	γ_f	λ
Full	growhi	0.56 (0.17)	0.56 (0.18)	0.12 (0.79)	0.50 (0.14)	0.30 (0.67)
Full	growlo	0.40 (0.38)	0.00 (.)	0.00 (.)	0.50 (0.30)	0.00 (.)
Post-WW2	growhi	0.49 (0.16)	0.54 (0.16)	0.61 (0.50)	0.47 (0.12)	0.64 (0.41)
Post-WW2	growlo	0.00 (0.26)	0.00 (.)	0.14 (0.08)	0.28 (0.53)	0.03 (0.14)

Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. All coefficients are constrained to be between 0 and 1 and estimated using NLS with $H = 6$. Coloumn "RESTRICTED" imposes an additional restriction: $\gamma_b + \gamma_f = 1$. In Column "BIN", "growhi" stands for high growth regime; "growlo" stands for low growth regime, which also includes the medium high growth regime. Output gap is measured using the HP filiter with a smoothing parameter of 100. See text.

Figure B.7. Impulse responses of inflation and output gap: $H = 9$



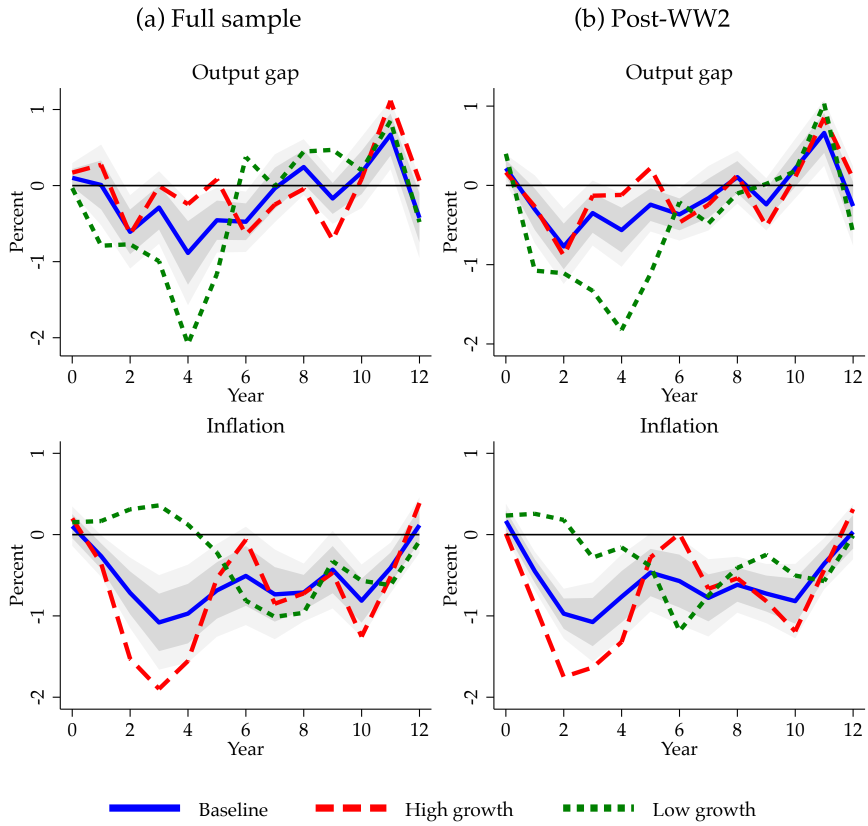
Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates stratified by the high (low) growth regime are displayed with a red long-dashed (green dashed) line. Sample sizes are not harmonized across horizons. Output gap is measured using the HP filiter with a smoothing parameter of 100.

Table B.4. Estimation of the Phillips curve: $H = 9$

SAMPLE	BIN	UNRESTRICTED			RESTRICTED	
		γ_f	γ_b	λ	γ_f	λ
Full	growhi	0.53 (0.18)	0.55 (0.17)	0.12 (0.51)	0.49 (0.14)	0.22 (0.42)
Full	growlo	0.50 (0.06)	0.76 (0.07)	0.00 (.)	0.42 (0.09)	0.00 (.)
Post-WW2	growhi	0.35 (0.18)	0.56 (0.15)	0.67 (0.45)	0.41 (0.13)	0.54 (0.35)
Post-WW2	growlo	0.51 (0.22)	0.50 (0.22)	0.00 (.)	0.51 (0.18)	0.00 (.)

Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. All coefficients are constrained to be between 0 and 1 and estimated using NLS with $H = 9$. Coloumn "RESTRICTED" imposes an additional restriction: $\gamma_b + \gamma_f = 1$. In Column "BIN", "growhi" stands for high growth regime; "growlo" stands for low growth regime. Output gap is measured using the HP filiter with a smoothing parameter of 100. See text.

Figure B.8. Impulse responses of inflation and output gap: $H = 12$



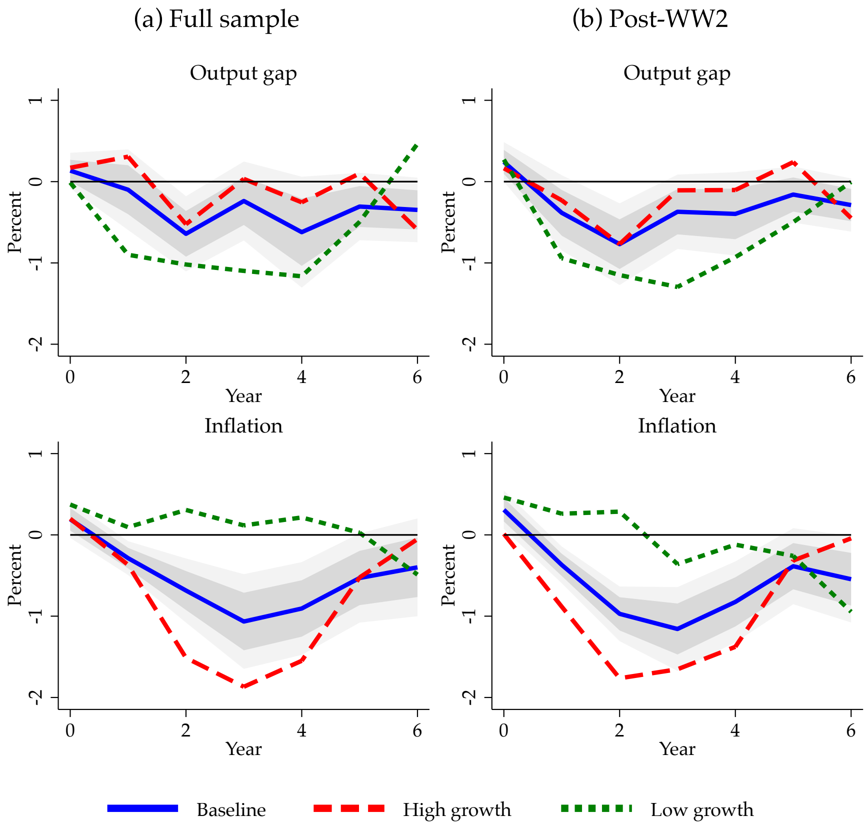
Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates stratified by the high (low) growth regime are displayed with a red long-dashed (green dashed) line. Sample sizes are not harmonized across horizons. Output gap is measured using the HP filiter with a smoothing parameter of 100.

Table B.5. Estimation of the Phillips curve: $H = 12$

SAMPLE	BIN	UNRESTRICTED			RESTRICTED	
		γ_f	γ_b	λ	γ_f	λ
Full	growhi	0.50 (0.15)	0.57 (0.15)	0.00 (.)	0.47 (0.12)	0.00 (.)
Full	growlo	0.49 (0.14)	0.59 (0.14)	0.00 (.)	0.45 (0.12)	0.00 (.)
Post-WW2	growhi	0.39 (0.18)	0.63 (0.14)	0.35 (0.35)	0.38 (0.13)	0.37 (0.30)
Post-WW2	growlo	0.47 (0.19)	0.56 (0.19)	0.00 (.)	0.46 (0.16)	0.00 (.)

Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. All coefficients are constrained to be between 0 and 1 and estimated using NLS with $H = 12$. Coloumn "RESTRICTED" imposes an additional restriction: $\gamma_b + \gamma_f = 1$. In Column "BIN", "growhi" stands for high growth regime; "growlo" stands for low growth regime. Output gap is measured using the HP filiter with a smoothing parameter of 100. See text.

Figure B.9. Impulse responses of inflation and output gap: include more recent samples



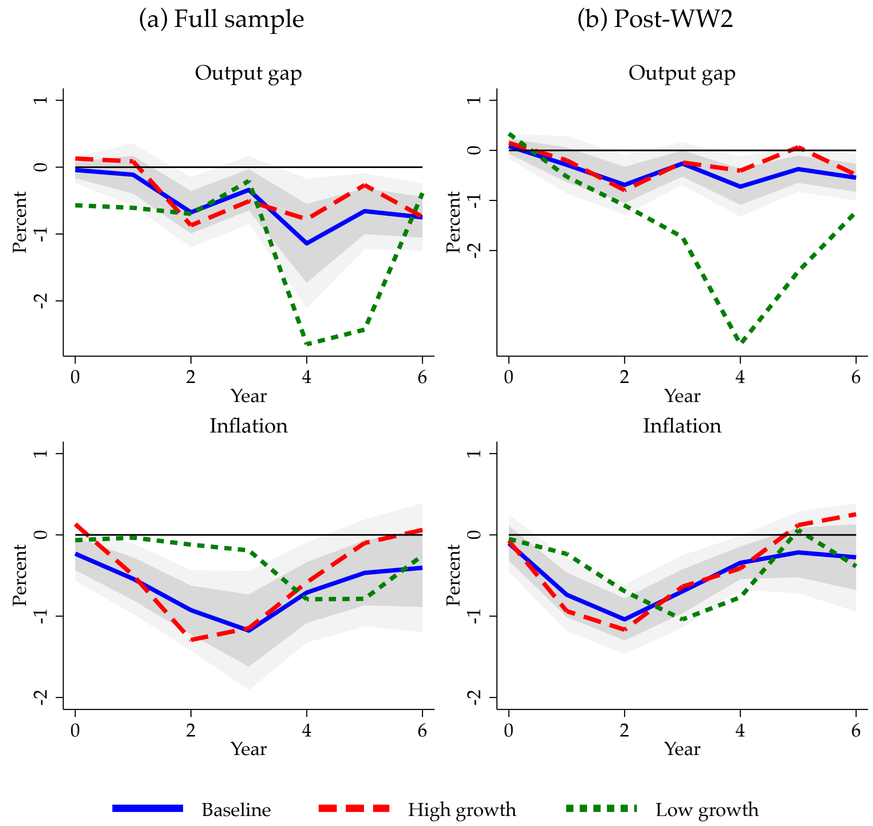
Notes: Full sample: 1890-1908, 1921-1933, and 1948-2012. Post-WW2 sample: 1948-2012. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates stratified by the high (low) growth regime are displayed with a red long-dashed (green dashed) line. Regimes are calssified by "regime-switching" approach. Sample sizes are not harmonized across horizons. Output gap is measured using the HP filiter with a smoothing parameter of 100.

Table B.6. Estimation of the Phillips curve: include more recent samples

SAMPLE	BIN	UNRESTRICTED			RESTRICTED	
		γ_f	γ_b	λ	γ_f	λ
Full	growhi	0.52 (0.10)	0.55 (0.10)	0.91 (0.41)	0.49 (0.08)	0.98 (0.36)
Full	growlo	0.29 (0.37)	0.00 (.)	0.00 (.)	0.38 (0.32)	0.00 (.)
Post-WW2	growhi	0.33 (0.08)	0.58 (0.08)	1.00 (.)	0.38 (0.08)	0.96 (0.27)
Post-WW2	growlo	0.25 (0.44)	0.27 (0.70)	0.04 (0.24)	0.28 (0.42)	0.09 (0.22)

Notes: Full sample: 1890-1908, 1921-1933, and 1948-2012. Post-WW2 sample: 1948-2012. All coefficients are constrained to be between 0 and 1 and estimated by NLS with $H = 6$. Coloumn "RESTRICTED" imposes an additional restriction: $\gamma_b + \gamma_f = 1$. In Column "BIN", "growhi" stands for high growth regime; "growlo" stands for low growth regime. Output gap is measured using the HP filiter with a smoothing parameter of 100. Regimes are calssified by "regime-switching" approach. See text.

Figure B.10. Impulse responses of inflation and output gap: European countries



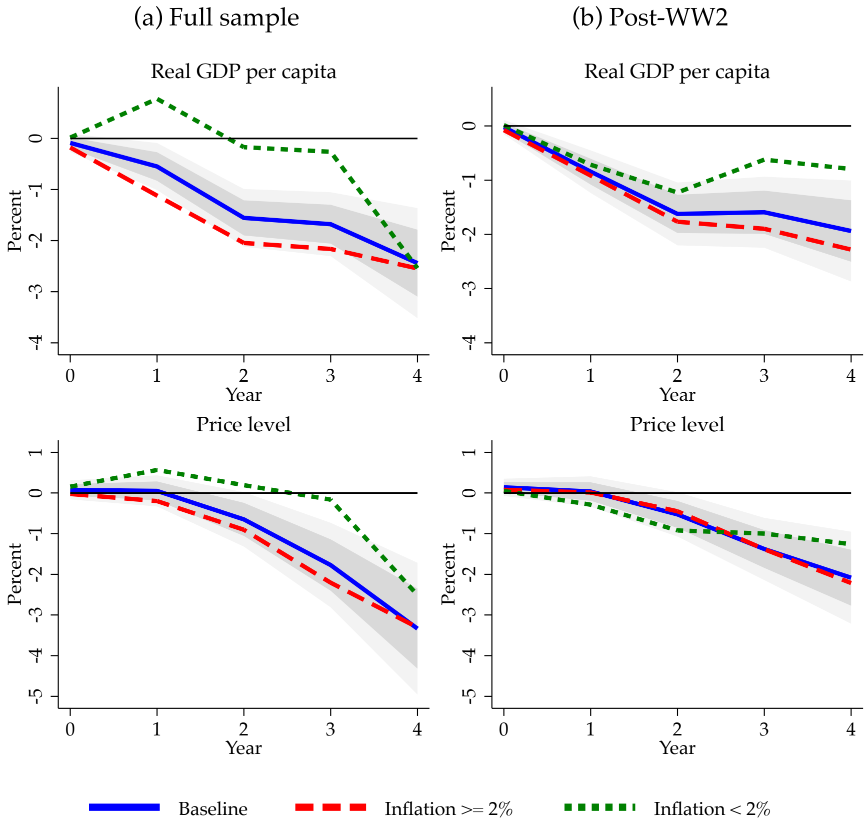
Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. Only European countries are included. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates stratified by the high (low) growth regime are displayed with a red long-dashed (green dashed) line. Sample sizes are not harmonized across horizons. Output gap is measured using the HP filiter with a smoothing parameter of 100. Regimes are calssified by "regime-switching" approach.

Table B.7. Estimation of the Phillips curve: European countries

SAMPLE	BIN	UNRESTRICTED			RESTRICTED	
		γ_f	γ_b	λ	γ_f	λ
Full	growhi	0.49 (0.17)	0.22 (0.29)	0.65 (0.46)	0.57 (0.13)	0.33 (0.21)
Full	growlo	0.17 (0.12)	0.31 (0.21)	0.20 (0.06)	0.32 (0.12)	0.11 (0.03)
Post-WW2	growhi	0.47 (0.09)	0.14 (0.09)	1.00 (.)	0.59 (0.13)	0.56 (0.26)
Post-WW2	growlo	0.45 (0.33)	0.49 (1.64)	0.01 (0.48)	0.46 (0.22)	0.00 (.)

Notes: Full sample: 1890-1908, 1921-1933, and 1948-2006. Post-WW2 sample: 1948-2006. Only European countries are included. All coefficients are constrained to be between 0 and 1 and estimated by NLS with $H = 6$. Coloumn "RESTRICTED" imposes an additional restriction: $\gamma_b + \gamma_f = 1$. In Column "BIN", "growhi" stands for high growth regime; "growlo" stands for low growth regime. Output gap is measured using the HP filiter with a smoothing parameter of 100. Regimes are calssified by "regime-switching" approach. See text.

Figure C.1. The impulse responses of output and price level by inflation regimes

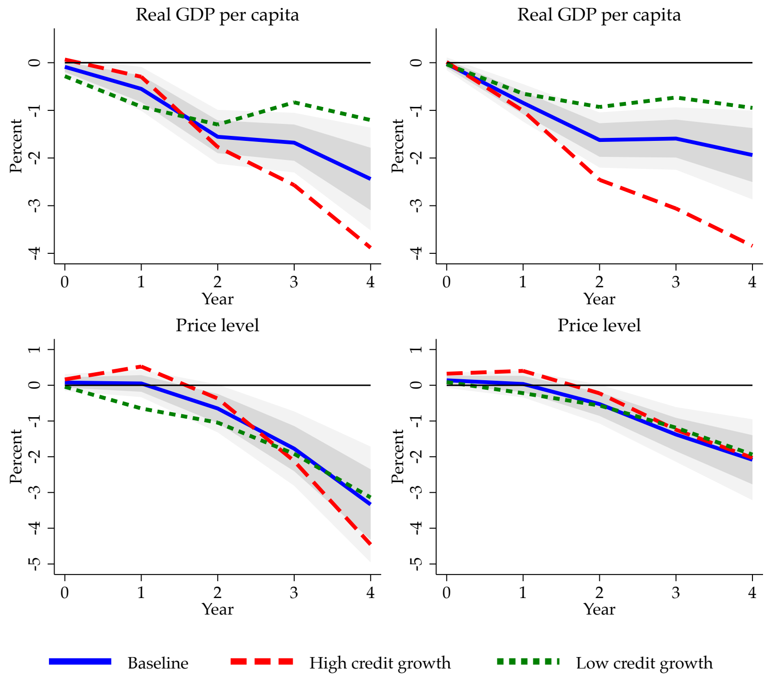


Notes: Full sample: 1890-2006 excluding world wars (1914-1919 and 1939-1947). Post-WW2 sample: 1948-2006. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates stratified by the high inflation regime are displayed with a red long-dashed line whereas estimates in the low inflation regime are displayed with a green dashed line. Sample sizes are not harmonized when estimating IRFs.

Figure C.2. The impulse responses of output and price level by credit growth regimes

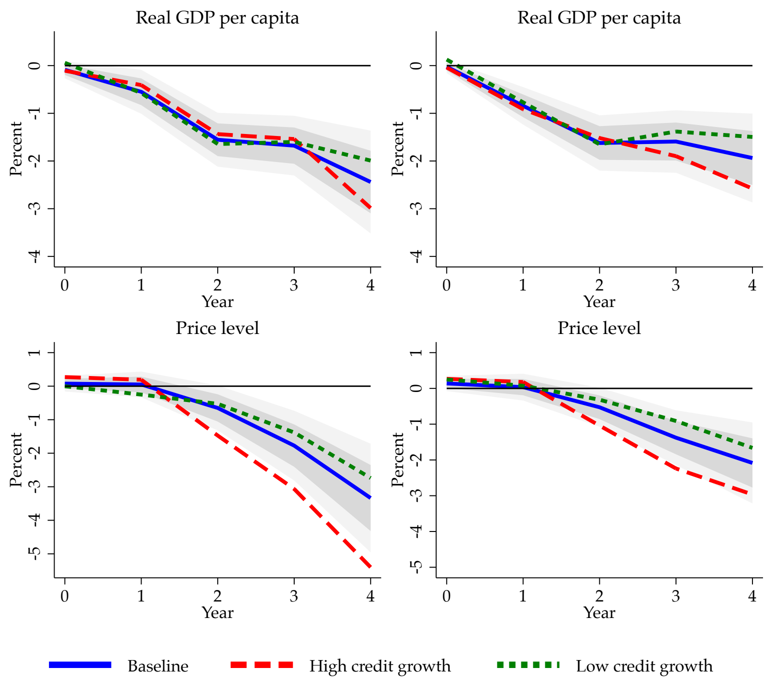
A. Mortgage credit

(a) Full sample (b) Post-WW2



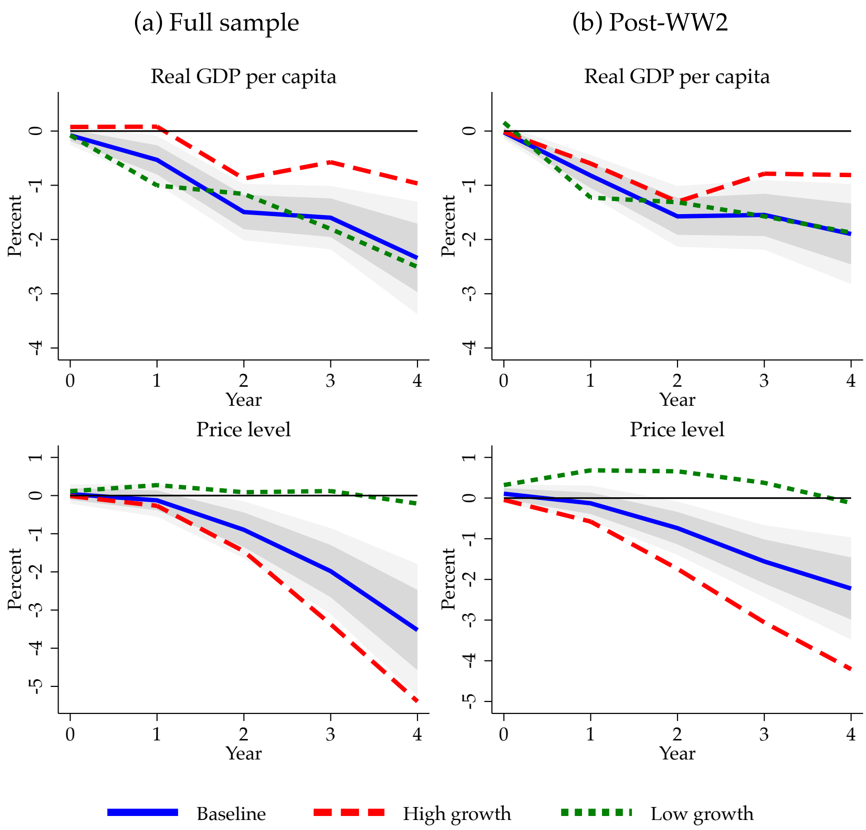
B. Non-mortgage credit

(a) Full sample (b) Post-WW2



Notes: Top panel stratifies by mortgage credit growth, bottom panel stratifies by non-mortgage credit growth. Full sample: 1890-2006 excluding world wars (1914-1919 and 1939-1947). Post-WW2 sample: 1948-2006. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates stratified by the high credit growth regimes are displayed with a red long-dashed line whereas estimates in the low credit growth regimes are displayed with a green dashed line. Sample sizes are not harmonized.

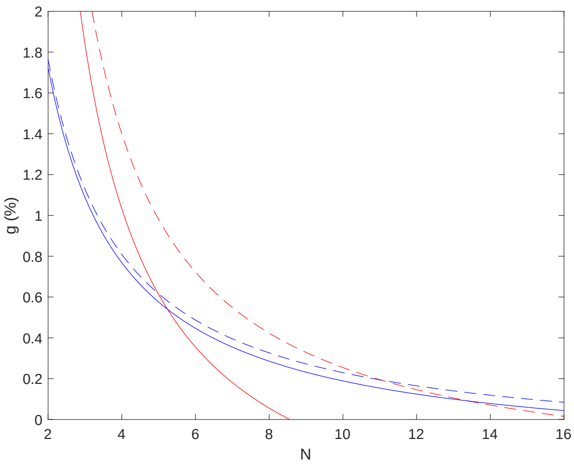
Figure C.3. The impulse responses of output and price level by trend TFP growth regimes



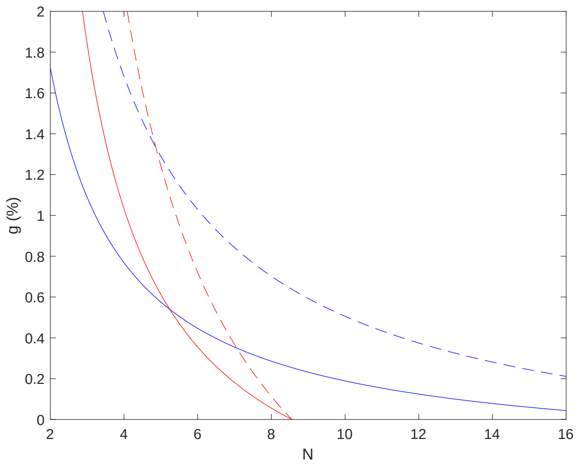
Notes: Full sample: 1890-2006 excluding world wars (1914-1919 and 1939-1947). Post-WW2 sample: 1948-2006. Baseline non-state dependent LP-IV estimates are displayed with a solid blue line and 68% and 90% confidence bands in grey area. Estimates stratified by the high TFP growth regimes are displayed with a red long-dashed line whereas estimates in the low TFP growth regimes are displayed with a green dashed line. Sample sizes are not harmonized.

Figure D.1. Comparative Statics

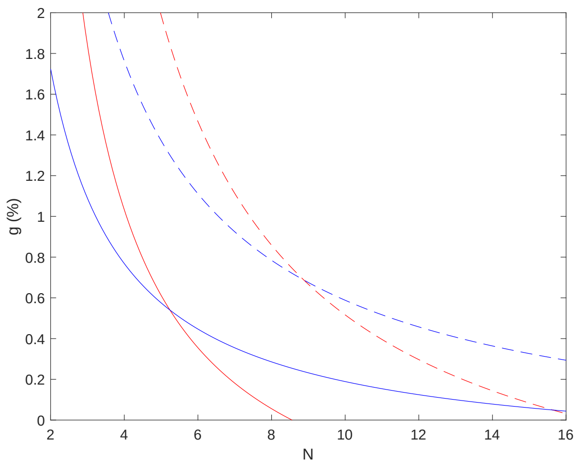
(a) Overhead costs $L_f \downarrow$



(b) Research productivity $\xi \uparrow$



(c) Both $\xi \uparrow$ and $L_f \downarrow$



Notes: Number of firms N on the x-axis, growth rate of knowledge g in the y-axis. In Panel (a), overhead costs L_f falls from 2.05 to 1 unit. In Panel (b), research productivity ξ rises from 0.0035 to 0.0071. The ZP line is in red and the SRE line is in blue, and solid lines describe the initial equilibrium and dashed lines describe the new equilibrium after the parameter changes.