Hysteresis, endogenous growth, and monetary policy

Sebastián Amador*

Abstract

I provide evidence of substantial hysteresis (i.e., a situation in which temporary shocks have long-run effects) from monetary shocks on two sources of endogenous growth; human capital and technological adoption. This contribution is the first to test for the presence of this phenomenon in direct measures of the supply-side potential of economies, instead of indirect measures, e.g., TFP. To estimate the effects of exogenous monetary policy shocks, I improve on the the trilemma identification by incorporating a mean-unbiased instrumental variable estimator. Results show substantial hysteresis in both human capital and technological adoption. Importantly, these are found to be asymmetric, as only contractionary shocks result in long lasting responses. I evaluate the aggregate importance of monetary hysteresis with a growth accounting exercise. Across the 17 countries in sample, the accumulated average cost of monetary hysteresis ranges between 1.2 and 9.6% of TFP, for human capital and the adoption of electricity, respectively.

1 Introduction

Most business cycle models assume economic activity fluctuates around an upward trend. The conventional view holds that the trend is determined by supply-side factors, such as technological advances, labor supply, and human capital. On the other hand, the cycle is influenced mainly by demand shocks and monetary policy. This has been the current dominant paradigm in macroeconomics, underpinning policy frameworks such as inflation targeting (Blanchard, 2018). However, this perspective would have to be reexamined in the presence of hysteresis; a situation in which temporary shocks have long-run effects.

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This alternative, popularized by Blanchard and Summers (1986), raised the possibility that negative demand shocks may leave permanent scars on potential output via hysteresis effects. This point of view was motivated from the fact that unemployment stabilized at a lower level after recessions in Europe during the 1980s.

Here I will define hysteresis as a situation in which a temporary demand shock has long-run effects on the productive potential of an economy. As monetary shocks operate through aggregate demand, this type of hysteresis would challenge the conventional view outlined above. This characterization can be justified in standard New Keynesian models, in which an expansionary monetary shock increases nominal marginal costs, but nominal rigidities keep prices from rising in the same proportion. This increases labor demand, which in turn stimulates aggregate output.

If indeed hysteresis is quantitatively important, standard stabilization policies would be inadequate, as they are often prescribed by models which ignore it. For instance, in most Dynamic Stochastic General Equilibrium (DSGE) models, demand factors have small transitory effects—or no effects at all—on the productive capacity of the economy. Moreover, the assumption of money neutrality in the long run is a central tenet of a large set of these models. Therefore, if nominal shocks are found to affect the productive potential of economies in the long-run, policy recommendations derived from these models would need to be reevaluated.

Alas, the jury is still out on whether sufficient hysteresis exists or not. Consider, Furlanetto, Lepetit, Robstad, Rubio-Ramírez, & Ulvedal (2020) and Benati & Lubik (2021). Both papers use Structural Vector Auto-Regressions (SVARs) that combine short and long-run identification as in Blanchard and Quah (1989). The first one finds evidence of hysteresis, while the second one does not. An additional important contribution, can be found in Jordà, Taylor, and Singh (2020), which focuses on hysteresis associated to monetary policy shocks. Using a panel database of 125 years and 17 advanced economies, they find effects of monetary policy that persist for at least a decade. Specifically, their show that a 100 basis points (bps) exogenous increase in the domestic interest rate leads to a five percent decline in GDP over a horizon of twelve years. They also investigate the origin of this effect by analyzing the individual components of output, finding that it appears to be driven by a reduced capital accumulation and lower Total Factor Productivity (TFP).

Given its importance, our understanding of hysteresis is insufficient. In particular, the COVID-19 pandemic has brought hysteresis into the center of policy debates, as it has been used to justify large stimulus packages. The logic of the argument is that—under sufficient hysteresis—shortfalls in aggregate demand would be costlier than excesses. Although overheating generated by excess demand may have short term costs (for instance higher inflation and increased asset prices), it would prevent any long-lasting scarring on productivity. Moreover, this stimulus could possibly even increase productivity and potential output. This boost to the supply side might eventually close the inflationary gap, thus compensating for any short-run inflationary costs (e.g., Mason, 2021a and 2021b).

Thus, three related questions emerge; (i) can monetary shocks affect the long-run productive potential of economies? (ii) if they do, through which channels? and (iii) is this phenomenon quantitatively important? The available evidence suggests hysteresis can be found on TFP (e.g., Jordà, Singh, and Taylor, 2020). However, the literature on productivity has found multiple biases in TFP estimates, originated in capacity utilization, markups, networks linkages, structural microeconomic elasticities of substitution and returns to scale, and the consequences of factor reallocation, and firm entry-exit dynamics. Additionally, to my knowledge there is no work identifying the channel through which mechanism this type of hysteresis operates, nor its aggregate importance.

To contribute in answering these questions, two objects of interest are estimated here. First, the response that temporary monetary shocks induce on the supply-side productive potential of economies. The relevance of this comes from the fact that if a substantial response is found long after impact, it would be evidence in favor of the presence of hysteresis. Second, a version of TFP without the effects monetary shocks had through supply-side productive potential factors. This would reveal the aggregate impact monetary hysteresis had on productivity through each source of endogenous growth. In combination these two objects will help in answering the three research questions presented above.

I focus here on hysteresis associated to human capital accumulation and technological adoption. This choice is justified by endogenous growth theory, which posits that the development[1] and adoption of new technologies, as well as investments in human capital, are key determinants of economic growth (Romer, 1994; Becker, 2009; Howitt, 2000). For this purpose, two data sources are employed; the stock of human capital derived from educational attainment from Barro and Lee (2013) and Lee and Lee (2016), and technological adoption as captured by 16 general purpose technologies from the Cross-country Historical Adoption of Technology (CHAT) dataset (Comin and Hobijn, 2009).

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[1] An alternative would be the accumulation of technological knowledge, measured by patents. However, these will be excluded from the analysis as they have been found to have a weak statistical relationship with productivity and output. For instance, patents explain less than 5% of the variance of output after 5 years (Alexopoulos, 2011), and less than 20% of patents result in commercial products (Geisler, 2000). Moreover, as Sanchis et al. (2015) show, patents have a heterogeneous effect on the productivity of countries. Thus, although is possible to obtain impulse response estimates of the effect monetary shocks have on the stock of patents, it is not clear how to compute the aggregate importance of this channel given its weak relationship to output and TFP. Estimates of the IRF of patents to monetary shocks (available by request), show the long-run effects of a contractionary shock are non-negative. This suggests patents do not explain the negative long-run effect monetary policy on TFP found in Jordà, Taylor, and Singh (2020).

As in Jordà, Schularick, and Taylor (2020), the open economy trilemma is exploited to identify exogenous monetary shocks. The main idea is that when a country pegs its currency to that of a base—while allowing free international movement of capital—it loses control over its domestic interest rate. This generates a correlation between the home and base interest rates, which can be used as an external instrument to obtain exogenous variation in domestic rates.

Econometrically, the approach employed is Local Projections Instrumental Variable (LP-IV), which has distinct advantages in the estimation of impulse response functions (IRF) at longer horizons. As shown formally by Jordà, Singh, and Taylor (2020) local projections estimate impulse responses consistently at any horizon (under some weak conditions on the truncation lag and the sample size). Other methods do not share this property (e.g., Lewis and Reinsel, 1985; Kuersteiner, 2005) and—as Jordà, Singh, and Taylor (2020) remark—this may explain why hysteresis effects were not found in previous work.

However, in exactly identified IV models such as Jordà, Schularick, and Taylor (2020), the finite sample moments of the estimator do not exist. This is problematic in small samples. To overcome this, I implement the Andrews and Armstrong (2017) mean-unbiased instrumental variable estimator of the structural parameters corresponding to the IRF. This estimator relies on knowledge about the sign of the first stage coefficient associated to the instrument. Fortunately, in the context of Jordà, Singh and Taylor (2020), this coefficient is know to be positive, from the trilemma of international finance. Under a peg and perfect mobility of capital, the correlation between the domestic interest rate and that of the peg will be positive due to arbitrage. This follows from the fact that if the base's interest rate increases (decreases), that of the domestic economy must also increase (decrease) in order to maintain the peg. As shown numerically by Andrews and Armstrong (2017), their unbiased IV estimator does not entail a cost in the form increased dispersion. Moreover, they show that their estimator is significantly less dispersed than two stage least squares least squares (2SLS) in finite samples.

To assess the aggregate importance of endogenous growth factors in monetary-originated hysteresis, a growth accounting exercise is performed. It consists on using the residuals from the first stage of the LP-IV (the exogenous shocks) and the estimated IRF to find the accumulated effect monetary shocks had on each endogenous growth factor during the entire sample. Then—using an aggregate production function—alternate versions of TFP are computed, excluding the effect monetary shocks had through each channel. In the case of human capital this is relatively straightforward. However, quantifying the aggregate impact of hysteresis associated to technological adoption presents unique challenges Although data is available for 16 general purpose technologies, to evaluate the aggregate impact of each one requires estimates of the output elasticity of each technology.

Thus, this paper focuses on the adoption of electricity. Several reasons motivate this choice. To begin, electricity is a general purpose technology, often regarded as characteristic of technological diffusion during the twentieth century. Moreover, numerous papers in economic history have studied this topic in the case of electricity (e.g., Crafts, 2002; Jalava & Pohjola, 2008; and Bakker et al., 2015). Additionally, the adoption of electricity coincides with a period in which most of the countries in the sample operated under fixed exchange rate regimes.

In sum, results show substantial hysteresis in the sources of endogenous growth, and that this phenomenon has significant costs in terms of aggregate productivity. Both technological adoption and human capital are negatively affected by monetary policy shocks, twelve years after impact. Both the magnitude of this result and its statistical significance are stronger in the case of technological adoption. Also, these findings are robust to possible violations of the exclusion restriction. In the case of technological adoption, hysteresis is also found when focusing only in the subset of high capital intensity technologies. Finally, these responses exhibit an high degree of asymmetry, as hysteresis is only present for contractionary shocks. This result matches prior research on both short and long-horizon asymmetries.

As for the impact of this phenomenon on aggregate productivity, it is found to be highly dependent on the asymmetric nature of the IRFs. When responses are symmetric, expansionary and contractionary monetary shocks cancel each other out over time (as they have mean zero). However, as only contractionary shocks exhibit substantial long-run effects, there is no "cancelling-out", and the costs of hysteresis are much higher. In the case of human capital, the accumulated cost monetary policy shocks had on over the period 1890-2010 is 0.2 and 1.2% of TFP for symmetric and asymmetric responses, respectively. On the other hand, the corresponding figures for the adoption of electricity are -1.2 and 9.6% of TFP. The magnitude of the cost is specially high in the case of the adoption of electricity. As percent of the total gains in productivity from the adoption of electricity, these losses are of about 10%. It is possible to conclude that delayed technological adoption is an important channel through which contractionary shocks leave hysteresis effects on productivity.

This paper contributes to the study of hysteresis and business cycles in several ways. First, up to my knowledge this is the first work to test for hysteresis in direct measures of supply-side productive-potential factors, unlike previous work, which uses indirect measures such as TFP or output per worker. This indirect measures can be problematic, as the literature has found multiple biases in TFP, originated in capacity utilization (Basu and Kimball, 1997; Basu, Fernald, and Kimball, 2006), markups, networks linkages, structural microeconomic elasticities of substitution and returns to scale, and the consequences of factor reallocation (Esfahani, Fernald, and Hobijn, 2020; Baqaee and Farhi, 2020a), and firm entry-exit dynamics (Baqaee and Farhi, 2020b). It must be noted that other works in this literature have failed to find hysteresis effects in measures of productivity. For instance, Furlanetto, Lepetit, Robstad, Rubio-Ramírez, & Ulvedal (2020) do not find long-run impacts of demand shocks on labor productivity. In contrast, my results suggest that in the long-run output productivity can be affected by demand shocks (contrary to the assumptions in Galí, 1999). Second, the time coverage of my sample also represents an improvement over recent works seeking to find hysteresis only in post-war data. Focusing on this period constrains the ability to infer about the long run, due to the shorter time-dimension of the panel, and the fact that it excludes epochs of rapid growth in productivity (such as the second industrial revolution; Atkenson & Kehoe, 2001; and the inter-war period; Field, 2006). By including this eras in a panel setting, my results benefit from increased cross-sectional and time-series variation on the dependent variable. Third, contrary to a literature finding schooling to be countercyclical (Dellas and Sakellaris, 2003; Méndez and Sepúlveda, 2012) I find negative hysteresis effects in human capital. A caveat is that in this paper the focus is not on the cycle, but on shocks orthogonal to it (monetary policy). These negative responses suggest that the interest rates affect schooling through ability-to-pay (public or private) rather than opportunity-costs considerations. Up to my knowledge, my results represent the first empirical work assessing the causal effect of monetary policy on aggregate human capital accumulation in the long-run. Fourth, the findings of this paper could have non-trivial consequences for the conduct and the analysis of monetary policy. For instance, as only contractionary shocks appear to have long-run impacts, this could limit the ability of central banks to "cancel out" the effects of contractionary policy by an increased expansionary stance in the future. Finally, the results presented here call for the development of a framework to analyze the trend and the cycle jointly. At least since Cooley and Prescott (1995), there has been interest in integrating the study of business cycles and growth. Moreover, as Ghironi (2018) points out, the slow recovery after the Global Financial Crisis highlighted the need for tools that overcome the artificial separation between trend and cycle. This necessity has been amplified by COVID-19 crisis, as currently there is significant concern about how a recovery would play, and how any permanent scarring might affect it.

This paper is related to several different literatures. First, the study of hysteresis, particularly regarding business cycles (a survey can be found in Cerra, Fatás, and Saxena, 2020). Second, the theoretical literature on hysteresis and endogenous growth. This body of work examines the hypothesis that the slowdown in productivity observed after the Great Recession was an endogenous result of the collapse of demand. In this context, the mechanisms that link demand and productivity are those of endogenous growth theory, specifically the development and adoption of new technologies and learning-by-doing (e.g., Anzoategui, Comin, Gertler, & Martinez, 2019; Benigno & Fornaro, 2018; Bianchi, Kung, & Morales, 2019; and Garga & Singh, 2020). Third, the literature on the causal effects of monetary policy (e.g., Ramey, 2016; Nakamura & Steinsson, 2018; and Jordà, Schularick, & Taylor, 2020). This paper is closely related to Jordà, Singh, and Taylor (2020), as it shares a significant portion of their methods and data.

The remainder of this paper is organized as follows. Section 2 describes the data, Section 3 presents the estimation methods, results, and robustness exercises for each object of interest. Finally, Section 4 concludes.

2 Data

This section briefly describes the data sources of the two endogenous growth variables, and for macroeconomic controls. In order estimate long-run effects, long time series are required, preferably featuring a wide panel of countries to increase statistical power. Additionally, a set of shocks that share the same geographical and temporal coverage is required. Therefore, the sources were selected to maximize both the time series and panel dimensions. Four databases meeting these requirements are used in the subsequent analyses. All of them reaching back to at least 1890, and comprising 17 advanced economies (Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, and the United States). The first one is the Macrohistory database from Jordà, Schularick, and Taylor (2017), from which it is possible to obtain monetary policy shocks, systemic financial crisis indicators, and key macroeconomic controls (see section 2.1 for details). Second, the stock of human capital from Barro and Lee (2013) and Lee and Lee (2016). Third, technological adoption from the Cross-country Historical Adoption of Technology (CHAT) dataset (Comin and Hobijn, 2009). Finally, the long term productivity database of Bergeaud, Cette, and Lecat (2016), which covers the same 17 economies in the Macrohistory database. This source contains data on TFP, the capital stock, and hours worked. These databases are described in the following subsections.

2.1 Macrohistory database

The Macrohistory database (Jordà, Schularick, and Taylor, 2017; available online at `http://www.macrohistory.net/data/`) covers a period of 125 years and 17 advanced economies. It contains 45 nominal and real macroeconomic series, such as output, interest rates, inflation, credit, and other relevant controls for the analyses presented below. Importantly, from this data it is possible to derive exogenous monetary policy shocks by exploiting the trilemma of international finance (Obstfeld, Shambaugh, and Taylor, 2004, 2005; Shambaugh, 2004). The logic is that under free capital movement and a hard peg, the short-term interest rates in the home and base economies will be correlated due to arbitrage. This correlation—under the conditions described in Jordà, Schularick, and Taylor (2020)—will suffice for identification using instrumental variables. It is important to note that this identification strategy would be valid for the subsample of pegs, and invalid for the subsample of floats. This enables correcting for possible violations of the exclusion restriction using partial identification methods (Conley, Hansen, & Rossi, 2012; and van Kippersluis & Rietveld, 2018).

2.2 Human capital stock from educational attainment

Using a variety of sources, Barro and Lee (2012) and Lee and Lee (2016) construct long-run enrollment ratios, educational attainment, and human capital stock measures for a sample of 111 countries from 1820 to 2010, (available online at `https://barrolee.github.io/BarroLeeDataSet/DataLeeLee.html`). This data is available at intervals of five years, as it is based in censuses, which are commonly conducted at that frequency. In order to obtain accumulated IRF estimates, I use a linear interpolation to fill in the missing data. Since the goal of the paper is to estimate long-run effects, this doesn't substantially affect the results[2]. To measure the stock of human capital, this paper uses their estimates of educational attainment—measured in total years of education—for the total population aged 15-64. Additionally, the authors produce estimates of the stock of human capital, assuming a Mincerian log-linear relationship between years of education and human capital, that assumes imperfect substitutability between different skill types. Total labor input is modeled as a Constant Elasticity of Substitution (CES) aggregate of skilled and unskilled labor. Individuals with upper-level secondary schooling and above are classified as skilled, and everyone else as unskilled. Thus, human capital in year t and country i (omitting time and country subindices for simplicity) is given by:

$$E = [h_u^\rho + h_s^\rho]^{\frac{1}{\rho}} = \left[\left(\sum_a \sum_{j=1}^{4} e^{\theta_j^a dur_j^a} l_j^a \right)^\rho + \left(\sum_a \sum_{j=5}^{7} e^{\theta_j^a dur_j^a} l_j^a \right)^\rho \right]^{\frac{1}{\rho}} \tag{1}$$

where a corresponds to each age group (15-19, ..., 60-64), j denotes the different educational attainment

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[2] Alternatively, non-accumulated IRFs could be estimated using local projections. However, this complicates the estimation and interpretation of the results.

groups (1 = no formal education, 2 = incomplete primary, 3 = complete primary, 4 = lower secondary, 5 = upper secondary, 6 = incomplete tertiary, and 7= complete tertiary), ρ is the substitution parameter, and the elasticity of substitution between skilled and unskilled labor is given by $\sigma = \frac{1}{1-\rho}$. Note that this specification assumes perfect substitutability within each subgroup. This is forced on the calculation by the fact that estimating the elasticity of substitution between, say uneducated and incomplete primary workers is difficult. As in Lee and Lee (2016), the elasticity of substitution σ is set to 2, broadly in agreement with the available micro-evidence (Ciccone and Peri, 2005; Jones, 2014). The term dur_j^a represents the duration of educational level j for population group a, and l_j^a the fraction of the population in age-group a that has educational level j. Finally, θ_j^a stands for the marginal return to an additional year of schooling at level j. These marginal returns are assumed to be constant and equal to 10%; the world average rate of return (Caselli, 2005; Hall and Jones, 1999; Caselli and Ciccone, 2013). For uneducated workers, human capital stock is assumed to be constant and equal to one. Lee and Lee (2016) show how the evolution of human capital does not vary much with different values of the elasticity of substitution.

2.3 Cross-country historical adoption of technology

Comin and Hobjin (2004, 2009, and 2010) introduced historical data on the adoption of major technologies over the period 1750-2008 for over 150 countries. From this database, it is possible to construct a country-technology-year panel, which measures the evolution over time of the intensity of adoption of each technology in every country. As in Comin and Nanda (2019), I focus on a subset of 16 general purpose technologies, presented in Table 1. A potential issue is the heterogeneity among the different technologies. Some of them represent technical change embodied in capital goods (e.g., number of passenger cars in circulation), others are production technologies and are measured by output (e.g., tons steel produced in electric arc furnaces), and the remainder by the number of users (e.g., number of cellphone users). The solution is first to take logarithms of the per capita technology variables. This effectively removes the units, transforming each variable into a technology diffusion curve measured in percent (Comin and Hobijn, 2010). Second, as technologies at some point are fully adopted or become obsolete, the data is censored when the level of adoption becomes stable across countries. Finally, in the local projections specification below, country, technology, and technology-country fixed effects are included to account for adoption lags and specific constant unobserved factors.

A relevant characteristic of technologies is its capital intensity. The adoption of certain technologies is more costly than others, because of the relatively high cost of the capital goods which embody them, or due to the need for a expensive support infrastructure. As the effect of shocks is likely to be different depending on the capital intensity of each technology in this paper two sets of analyses are performed, the first one considering all technologies, and the second one taking into account only those exhibiting high capital intensity. As Comin and Nanda (2019) remark, capital intensity is a purely technological attribute, stable across time and space, thus facilitating the analysis (for details on how the capital intensity of each technology was obtain see Table 8 in Comin and Nanda, 2019).

Table 1: Description of technologies used

Technology	Measure	Capital intensity	Invention date
Railroad	Km of track installed	High	1825
Telegram	Number of telegrams sent	High	1835
Telephone	Number of telephones connected	High	1875
Electricity production	Kw/Hr produced	High	1882
Electric arc steel	Tons produced	High	1907
Blast furnace steel	Tons produced	High	1950
Cell phones	Number of users	High	1973
Ring spindle	Number in operation	Low	1779
Loom	Number in operation	Low	1785
Passenger cars	Number in operation	Low	1885
Commercial Vehicles	Number in operation	Low	1885
Tractors	Number in operation	Low	1903
Radio	Number in operation	Low	1920
TV	Number in operation	Low	1927
Computers	Number in operation	Low	1973
MRI machines	Number in operation	Low	1977

Source: Comin and Nanda (2019).

2.4 Long term productivity database

The Long Term Productivity (LTP) database (Bergeaud, Cette, and Lecat, 2016; available online at `http://www.longtermproductivity.com`) includes data on TFP per hour worked, for the 16 countries in our sample, from 1890 to 2015. The advantages of using TFP are that (1) the data is available for a long time period, allowing for long-run analysis, (2) it is expressed in terms of purchasing power parity, and (3) assumptions are consistent across countries and time for the construction of the series. Thus, these estimates allow for level and growth rate comparisons across countries. TFP is computed as the ratio of GDP to an aggregation of the two considered production factors, capital K, and labor L. The capital stock is computed by the perpetual inventory method from gross capital formation data on machinery, equipment, and buildings, each with is own depreciation assumptions (for details see subsection 2.2 in Bergeaud, Cette, and Lecat, 2016). Assuming a Cobb-Douglas production function, then $TFP_t^{LTP} =$

$\frac{GDP_t}{K_{t-1}^{\alpha} L_t^{\beta}}$, where $\alpha + \beta = 1$. The parameters α and β represent output elasticities with respect to different factors. Thus, these can be estimated by their share of their remuneration on total income. As in the sample labor costs represent around two thirds of income, it is assumed that $\alpha = 0.3$.

3 Results

To identify the causal effect of monetary policy on the two sources of endogenous growth, I follows the identification strategy of Jordà, Schularick, and Taylor (2020). The logic is that under free capital movement and a hard peg, the short-term interest rates in the home and base economies will be correlated due to arbitrage. This correlation—under the conditions described in Jordà, Schularick, and Taylor (2020)—will suffice for identification using instrumental variables. The following subsections present first some empirical results on hysteresis, second the effects of a monetary shock on human capital, third, the response of technological adoption to a monetary shock, and finally growth accounting estimates of the aggregate importance of endogenous growth mechanisms on productivity.

3.1 Empirical results on monetary hysteresis

In this subsection I reproduce the results of Jordà, Singh, and Taylor (2020). There are two main reasons to reproduce their findings here. First, they show the response of GDP and its components (TFP, capital stock, hours worked) to a monetary shock. In particular, I am interested in attributing these responses to a particular endogenous growth mechanism. Thus, presenting the responses provides valuable information that disciplines the analysis. Second, I incorporate the Andrews and Armstrong (2017) mean-unbiased IV estimator to the econometric approach of Jordà, Singh, and Taylor (2020). This this exercise will help verify if the results hold under this new estimation procedure.

The empirical specification used in Jordà, Singh, and Taylor (2020) to estimate the IRF to a trilemma-based monetary shock is described by

$$y_{j,t+h} - y_{j,t-1} = \alpha_{j,h} + \hat{\Delta} i_{j,t} \beta_h + \mathbf{x}_{j,t} \gamma_h + u_{j,t+h} \tag{2}$$

$$\Delta i_{j,t} = \kappa_j + z_{j,t} \lambda_p + z_{j,t}^{f} \lambda_f + \mathbf{x}_{j,t} \zeta + \nu_{j,t} \tag{3}$$

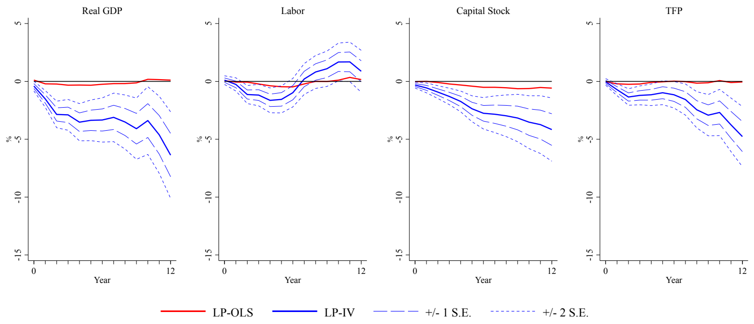
for $h = 1, ..., H$; $j = 1, ..., J$; $t = t_0, ..., T$, where $y_{i,t+h}$ is the outcome variable (in this Subsection;

GDP, TFP, capital stock, and hours worked) for country j observed in period $t+h$. The term $\alpha_{j,h}$ captures country fixed effects for horizon h, $\hat{\Delta} i_{j,t}$ is the instrumented change in the 3-month government bond nominal interest rate (a proxy of the monetary policy rate). The trilemma instrument is defined as $z_{j,t} \equiv k_{j,t}(\Delta i_{b(j,t)} - \hat{\Delta} i_{b(j,t)})$, where $\Delta i_{b(j,t)}$ is the change in the short-term nominal interest rate of country j's base and $\hat{\Delta} i_{b(j,t)}$ is the portion of $\Delta i_{b(j,t)}$ that is predictable using the base's macroeconomic aggregates. According to Jordà, Singh, and Taylor (2020), $\hat{\Delta} i_{b(j,t)}$ can be interpreted as what would be prescribed by a policy rule. The term $k_{j,t} \in [0,1]$ corresponds to a measure of capital mobility from Quinn, Schindler, and Toyoda (2011). Macroeconomic controls are collected in $\mathbf{x}_{j,t}$, which includes; real GDP, consumer price index, short term interest rate, long term interest rate, total credit as percent of GDP, investment as percent of GDP, government expenditure as percent of GDP, population, housing price index, stock price index, "world" GDP (the sum of the GDP of the 17 economies in the sample), and a dummy variable for systemic financial crises. All variables are in differences, except for interest rates and the financial crisis dummy. Natural logarithms are used whenever appropriate. Contemporaneous terms and two lags are included, except for the dependent variable and the interest rate.

Instead of employing usual two-step IV methods, I use the Andrews and Armstrong (2017) estimator. This work derives mean-unbiased estimators for the structural parameter of a IV model with a single endogenous regressor when the sign of the first-stage coefficient associated to the instrument is known. Fortunately, in the context of Jordà, Singh and Taylor (2020), this coefficient is know to be positive, from the trilemma of international finance. Under a peg and perfect mobility of capital, the correlation between the domestic interest rate and that of the peg will be positive due to arbitrage. This follows from the fact that if the base's interest rate increases (decreases), that of the domestic economy must also increase (decrease) in order to maintain the peg. This estimator is unique in the single instrument case, and its based on the reduced-form and first-stage regression coefficients. Importantly, unbiasedness does not come at the cost of reduced efficiency; Andrews and Armstrong (2017) numerically show how the unbiased estimator is less dispersed two-stage least squares.

Figure 1 presents instrumental variable (LP-IV) and OLS (LP-OLS) estimates of Equation 2, for GDP, TFP, the capital stock, and hours worked. In all instances, the LP-OLS estimates are always close to zero, while the LP-IV exhibit negative responses for all variables in the long-run. The only exception is hours worked, where there is no evidence of hysteresis. In sum, these results match the ones presented in Jordà, Singh, and Taylor (2020).

Figure 1: Response to a 100 bps trilemma shock - Real GDP and Solow Decomposition - Full sample (1890-2015)



Source: Author's calculations.
Note: Response to a 100 bps shock in the domestic interest rate. LP-IV estimates in blue, LP-OLS estimates in red, 1 S.E. and 2 S.E. bands computed using clusters at the country level. World war periods are excluded.

Although this exercise shows some evidence of hysteresis, it may be implausible to assume that the responses to monetary shock are symmetric (i.e., equal for contractionary and expansionary shocks). This assumption is important, as asymmetry can impact the aggregate impact of hysteretic phenomena. For instance, if only contractionary shocks have long-run impacts, this could limit the ability of policymakers to "run the economy hot" might have a long-run benefit through hysteresis.

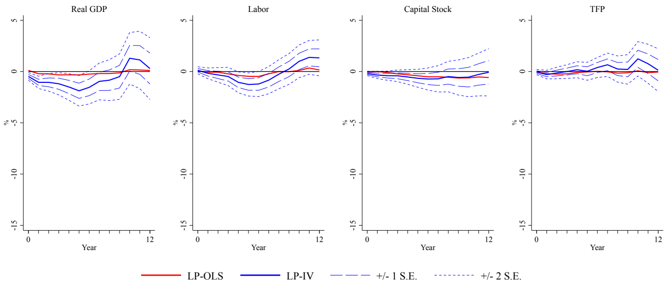
Figure 2 modifies the estimated in Figure 1 to allow for a different response after contractionary and expansionary shocks, following Jordà, Singh, and Taylor (2020). For expansionary shocks, the trilemma instrument $z_{j,t}$ is modified to include only loosening shocks ($z_{j,t}$ is replaced by zero whenever $z_{j,t} > 0$ or $\Delta i_{j,t} > 0$) and only tightening shocks ($z_{j,t}$ is replaced by zero whenever $z_{j,t} < 0$ or < 0). My results match those of Jordà, Singh, and Taylor (2020), as strong evidence of hysteresis is only present in the case of contractionary shocks. This suggests central banks cannot boost the supply side of the economy using expansionary policy. The fact that productivity is shown to be affected by monetary policy in the long-run is particularly puzzling. In the remainder of this Section, I will explore the origins of this result.

3.2 Effects of a monetary shock on human capital accumulation

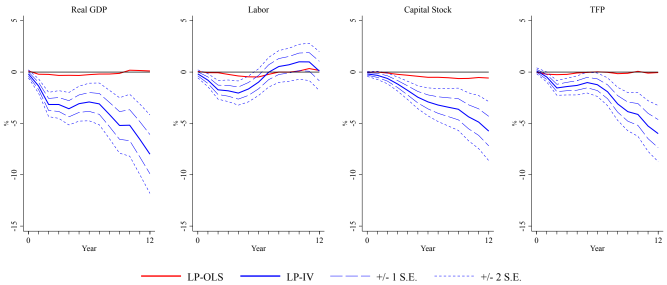
In order to test for the presence of hysteresis in human capital, I use the per capita stock from Barro and Lee (2013) and Lee and Lee (2016) computed from educational attainment measured in total years of education (for details see Subsection 2.2). This variable assumes a Mincerian log-linear relationship between years of education and human capital, that allows for imperfect substitutability between different skill types. The local projections estimate of the IRF to a trilemma shock estimated is given by:

Figure 2: Asymmetric response to a 100 bps trilemma shock - Real GDP and Solow Decomposition - Full sample (1890-2015)

(a) Expansionary Shock



(b) Contractionary Shock



Source: Author's calculations.
Note: Response to a 100 bps shock in the domestic interest rate for contractionary and expansionary shocks.This figure modifies estimates in Figure 1 to allow for a different response after contractionary and expansionary shocks, following Jordà, Singh, and Taylor (2020). For expansionary shocks, the trilemma instrument $z_{j,t}$ is modified to include only loosening shocks ($z_{j,t}$ is replaced by zero whenever $z_{j,t} > 0$ or $\Delta i_{j,t} > 0$) and only tightening shocks ($z_{j,t}$ is replaced by zero whenever $z_{j,t} < 0$ or < 0). LP-IV estimates in blue, LP-OLS estimates in red, 1 S.E. and 2 S.E. bands computed using clusters at the country level. World war periods are excluded.

$$E_{j,t+h} - E_{j,t-1} = \alpha_{j,h} + \hat{\Delta} i_{j,t} \beta_h + \mathbf{x}_{j,t} \gamma_h + \nu_{j,t+h} \tag{4}$$

following notation from Equations 2 and 3, where $E_{j,t}$ stands for human capital for country j and year t (from Equation 1). The controls used in $\mathbf{x}_{j,t}$ are; real GDP, consumer price index, short term interest rate, long term interest rate, total credit as percent of GDP, investment as percent of GDP, government expenditure as percent of GDP, population, housing price index, stock price index, "world" GDP (the sum of the GDP of the 17 economies in the sample), and a systemic financial crisis dummy. All variables are in differences, except for interest rates and the financial crisis dummy. Natural logarithms are used whenever appropriate. Contemporaneous terms and two lags are included, except for the dependent variable and the interest rate. Government expenditure as a share of GDP is a key addition in the controls, due to the large share of education spending that is publicly funded in the set of countries in the sample.

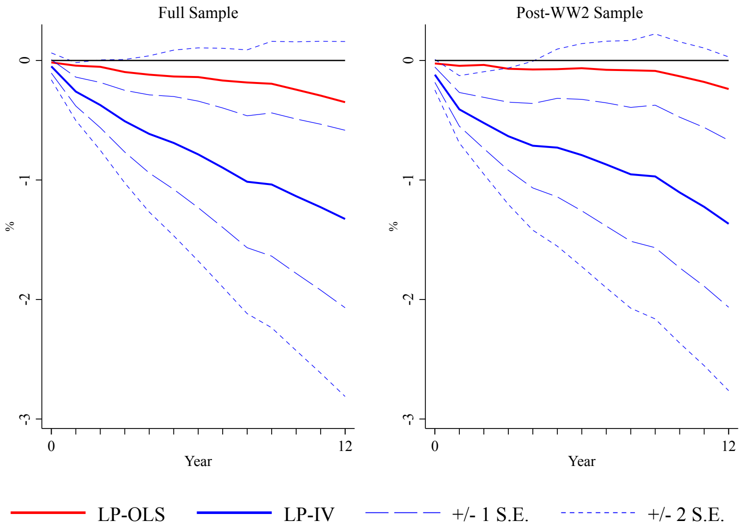
Figure 3 presents LP-IV and LP-OLS estimates of Equation 4 for the per capita human capital stock. The effect of an exogenous 100 bps increase in the domestic short-term interest rate is followed by an accumulated reduction in per capital human capital 12 years later of about 1.3% for both the full and post-WW2 samples. Figure 4 shows full sample estimates allowing for an asymmetric response (as in Figure 2). As before, hysteresis effects are only present for contractionary shocks.

Interestingly, these negative responses are contrary to what would be expected from the literature finding schooling to be countercyclical in advanced economies after WW2 (e.g., Dellas and Sakellaris, 2003; Méndez and Sepúlveda, 2012). However, the IRF estimates presented here correspond to exogenous monetary policy shocks, so they need not to be similar to those capturing the effect of the business cycle. Up to my knowledge there is no empirical work assessing the effect of monetary policy on the accumulation. Some theoretical work suggests that the effect of an exogenous increase in nominal rates has negative effects on human capital investment (Chu, Ning, and Zhu, 2017). This finding is surprising, as (i) education is free or heavily subsidized in several of these countries, and (ii) Jordà, Singh, and Taylor (2020) find no significant long-term effects of trilemma shocks on labor supply, as measured by hours worked. This suggests that the interest rate affects schooling through ability-to-pay (public or private) rather than opportunity-costs considerations.

3.3 Effects of a monetary shock on technological adoption

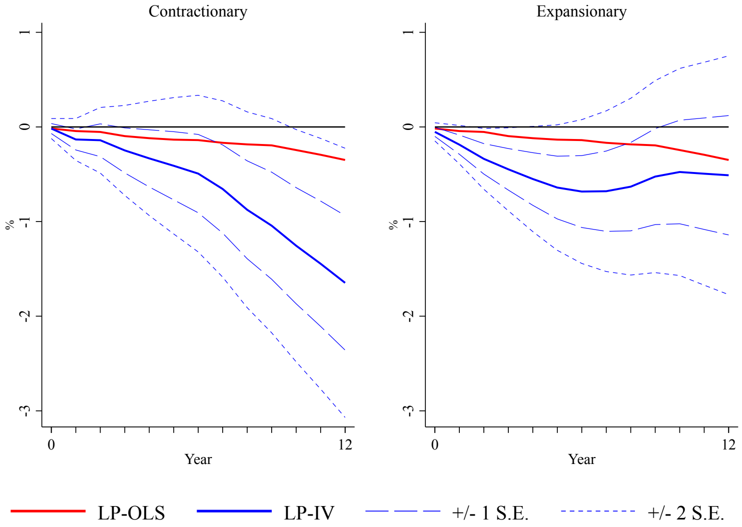
Estimating the response of technological adoption is significantly more challenging than the other

Figure 3: Response of the stock of human capital to a 100 bps trilemma shock



Source: Author's calculations.
Note: Response to a 100 bps shock in the domestic interest rate. LP-IV estimates in blue, LP-OLS estimates in red, 1 S.E. and 2 S.E. bands computed using clusters at the country level. World war periods are excluded.

Figure 4: Asymmetric response of the stock of human capital to a 100 bps trilemma shock



Source: Author's calculations.
Note: Response to a 100 bps shock in the domestic interest rate for contractionary and expansionary shocks.This figure modifies estimates in Figure 3 to allow for a different response after contractionary and expansionary shocks, following Jordà, Singh, and Taylor (2020). For expansionary shocks, the trilemma instrument $z_{j,t}$ is modified to include only loosening shocks ($z_{j,t}$ is replaced by zero whenever $z_{j,t} > 0$ or $\Delta i_{j,t} > 0$) and only tightening shocks ($z_{j,t}$ is replaced by zero whenever $z_{j,t} < 0$ or < 0). LP-IV estimates in blue, LP-OLS estimates in red, 1 S.E. and 2 S.E. bands computed using clusters at the country level. World war periods are excluded.

exercises presented in here. The main issue is that the 16 general purpose technologies in the data are measured in different units. For instance, it is not clear how to compare kilometers of railroad track to number of tons of steel produced in electric arc furnaces (see Table 1). A solution for this problem is presented here, inspired by Comin and Nanda (2019). First, the dependent variable will be divided by the population of each country, and will be used in natural logarithms. This effectively removes the units, transforming each variable into a technology diffusion curve (Comin and Hobijn, 2010). Second, as technologies at some point are fully adopted or become obsolete, the data is censored when the level of adoption becomes stable across countries. Finally, in the local projections specification below, fixed effects account for differences in the adoption path across technologies and countries, as follows:

$$\tau_{j,c,t+h} - \tau_{j,c,t-1} = \varrho_{c,h} + \eta_{j,h} + \omega_{jc,h} + \hat{\Delta} i_{j,t} \beta_h + \mathbf{x}_{c,t} \gamma_h + \nu_{j,c,t+h} \tag{5}$$

where $\tau_{j,c,t}$ is a per capita measure of the adoption in logarithms for technology j, country c, and time t; $\varrho_{c,h}$, $\eta_{j,h}$ and $\omega_{jc,h}$ stand for country, technology, and technology-country fixed effects, respectively. The rest of the notation is the same as in Equation 4. The fixed effects terms control for country, technology, and country-technology specific lags in adoption and constant unobserved factors. The resulting interpretation of the impulse response estimates, $\{\hat{\beta}_h\}_{h=0}^{12}$, is the average response across the 16 technologies and 17 countries to trilemma shocks. The controls in $\mathbf{x}_{j,t}$ are; real GDP, consumer price index, short term interest rate, long term interest rate, total credit as percent of GDP, investment as percent of GDP, government expenditure as percent of GDP, population, housing price index, stock price index, "world" GDP (the sum of the GDP of the 17 economies in the sample). All variables are in differences, except for interest rates, and natural logarithms are used whenever appropriate. Contemporaneous terms and two lags are included, except for the dependent variable and the interest rate.

Figure 5 presents the response of average technological adoption for the sixteen technologies in Table 1. For both samples there is a negative significant effect on technological adoption after 12 years, of X% for the full sample and X% for the post-WW2 sample. Figure 6 presents estimates for the full sample allowing for an asymmetric response to contractionary and expansionary shocks. As before, the evidence of hysteresis is strong only in the case of contractionary shocks.

In sum estimates suggest that there is significant hysteresis in technological adoption from monetary shocks. The fact that the response is larger for capital intensive technologies suggests this effect occurs through cost of capital channels. The relatively large effect might explained by complementarities in technological adoption (Buera, Hopenhayn, Shin, and Trachter, 2012). If these complementarities are substantial, the gains from adoption would be increasing in the number of firms that already adopted, thus amplifying the effect of monetary policy.

3.4 Aggregate importance of endogenous growth mechanisms in monetary hysteresis

In this section I evaluate the aggregate importance of monetary hysteresis with a growth accounting exercise. This calculation will approximate the long-run impact that each shock has on TFP and output through the sources of endogenous growth. The reader should bear in mind that these estimates may be subject to several sources of amplification or attenuation not accounted for here[3]. The goal is obtaining a estimate of TFP without the effect monetary shocks had on human capital and technological adoption. Assume the aggregate production function is of the form (omitting country subindices):

$$Y_t = A_t \tau_t^{\eta} {K_t}^{\alpha} (E_t L_t)^{1-\alpha} \tag{6}$$

were Y_t is real GDP, A_t is TFP, τ_t is an index representing the intensity of adoption of an specific technology, η is the output elasticity of technology τ, K_t the aggregate capital stock, E_t is human capital from Equation 1, and L_t aggregate hours worked. Applying log-differences, Equation 6 would be transformed into:

$$\Delta \log Y_t = \Delta \log A_t + \eta \Delta \log \tau_t + \alpha \Delta \log K_t + (1-\alpha) \Delta \log E_t + (1-\alpha) \Delta \log L_t \tag{7}$$

In this last expression, the growth rate of output will be a sum of the growth rates of TFP, technological adoption, the capital stock, human capital, and hours worked, weighted when appropriate by the capital and labor shares of income. For all countries and all periods it will be assumed that $\alpha = 0.3$, as in Bergeaud, Cette, and Leccat (2016).

Note that by construction $\Delta \log A_t$ will exclude any change in productivity originated in changes in technological adoption or human capital. From Equation 15, the change in standard Solow-residual TFP ($\tilde{A}_t$) would be given by:

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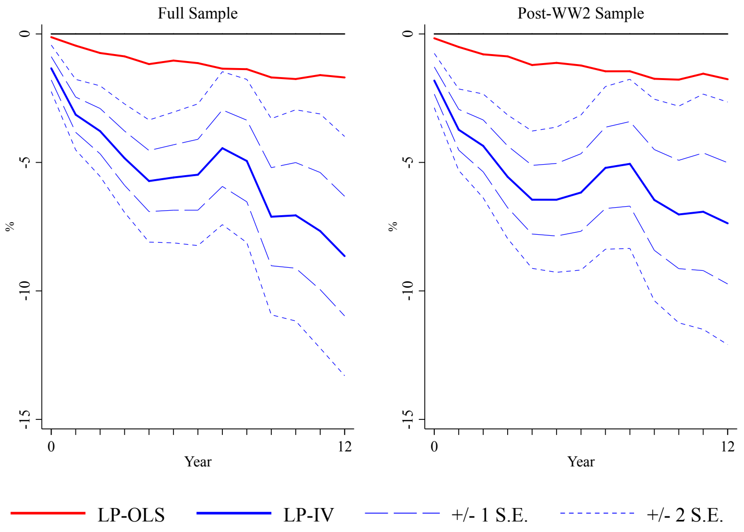
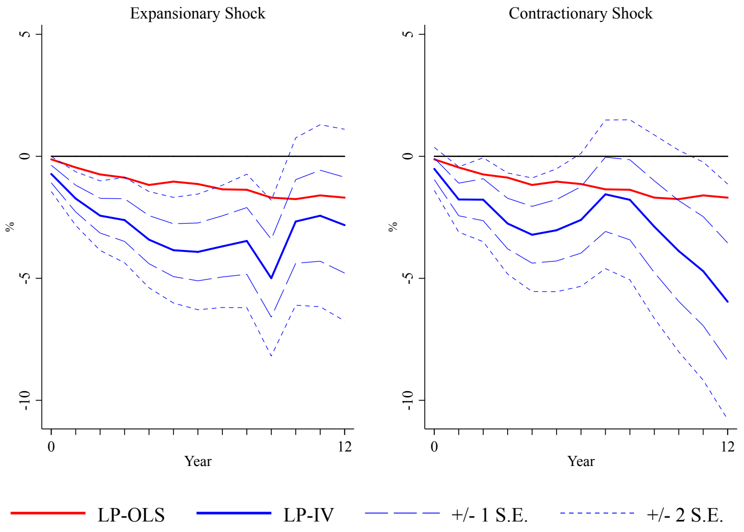
[3] Baqaee and Farhi (2020a and 2020b) show that non-linearities have major consequences on the aggregate impact of these shocks how in the presence of inefficiencies, networks linkages, structural microeconomic elasticities of substitution and returns to scale, and factor reallocation (Esfahani, Fernald, and Hobijn, 2020; Baqaee and Farhi, 2020a), and firm entry-exit dynamics (Baqaee and Farhi, 2020b). Additionally, technological adoption can generate significant amplification in the presence of coordination failures (Buera, Hopenhayn, Shin, and Trachter, 2021).

Figure 5: Response of the technological adoption to a 100 bps trilemma shock



Source: Author's calculations.
Note: Response to a 100 bps shock in the domestic interest rate. LP-IV estimates in blue, LP-OLS estimates in red, 1 S.E. and 2 S.E. bands computed using clusters at the country level. World war periods are excluded.

Figure 6: Asymmetric response of the stock of human capital to a 100 bps trilemma shock



Source: Author's calculations.
Note: Response to a 100 bps shock in the domestic interest rate for contractionary and expansionary shocks.This figure modifies estimates in Figure 3 to allow for a different response after contractionary and expansionary shocks, following Jordà, Singh, and Taylor (2020). For expansionary shocks, the trilemma instrument $z_{j,t}$ is modified to include only loosening shocks ($z_{j,t}$ is replaced by zero whenever $z_{j,t} > 0$ or $\Delta i_{j,t} > 0$) and only tightening shocks ($z_{j,t}$ is replaced by zero whenever $z_{j,t} < 0$ or < 0). LP-IV estimates in blue, LP-OLS estimates in red, 1 S.E. and 2 S.E. bands computed using clusters at the country level. World war periods are excluded.

$$\Delta \log A = \Delta \log \tilde{A}_t + \alpha \Delta \log \tau_t + (1-\alpha)\Delta \log E_t \tag{8}$$

where $A_t = \frac{Y_t}{K_t^{\alpha} L_t^{1-\alpha}}$. Note that from Equation 8 it is possible to obtain the growth rate of TFP excluding the contribution of τ_t and E_t as a residual. From this growth rates it is possible to recover a TFP index, $\tilde{A}_t$. The percent difference between A_t and $\tilde{A}_t$ can be interpreted as the share of TFP owing to the adoption of τ_t and human capital accumulation.

Importantly, if the fraction of $\Delta \log \tau_t$ and $\Delta \log E_t$ associated to monetary shocks was observed, we could compute a version of TFP excluding them. Fortunately, this can be approximated by the local projection IRF estimates of the previous subsections. For instance, the portion of the growth rate of human capital that is associated to monetary policy shocks, denoted $\Delta \log E_t^{\hat{i}}$, can be obtained for each country-year from multiplying the first difference of the impulse response IV estimates of Equation 4 by the corresponding lags of monetary policy shocks from the first stage (Equation 3). Then, growth of the alternative version of TFP—excluding the effect trilemma shocks had through human capital—would be given by $\Delta \log A_t^{\neg(E^{\hat{i}})} = \Delta \log A_t - \Delta \log E_t^{\hat{i}}$. Again, TFP indices for $A_t^{\neg(E^{\hat{i}})}$ and $A_t^{\neg(\tau^{\hat{i}})}$ can derived from these growth rates. Finally to assess the aggregate cumulative long-run impact of trilemma shocks on human capital, it suffices to compute $\frac{A_T - A_T^{\neg(E^{\hat{i}})}}{A_T^{\neg(E^{\hat{i}})}}$ and $\frac{A_T - A_T^{\neg(\tau^{\hat{i}})}}{A_T^{\neg(\tau^{\hat{i}})}}$, where T is the end of the sample. Additionally, it is possible to produce estimates for $A_t^{\neg(E^{\hat{i}})}$ and $A_t^{\neg(\tau^{\hat{i}})}$ using both the symmetric and asymmetric IRFs.

Two important caveats should be noted before presenting the results. First, the use of Equation 1 implies that $\Delta \log E_t^{\hat{i}}$ is interpreted as percent of human capital. Following Bergeaud, Cette, and Lecat (2018) we modify the results so they are compatible with the long-run. If we assume that in the $\frac{K}{L}$ is constant, an increase of 1 year in the average educational attainment leads to an increase in productivity of $(1-\alpha) \times \theta$. On the other hand, if we assume $\frac{K}{Y}$ a similar increase would increase productivity by θ. The second case corresponds to a situation in which physical capital can adjust to changes in educational attainment, and can be seen as the long-term returns to schooling (for details see Bergeaud, Cette, and Lecat, 2016). Second, it is not clear that the aggregate production function approach is compatible with the CHAT technological adoption data. Although data is available for 16 general purpose technologies, to evaluate the aggregate impact of each one requires estimates of the output elasticity of each technology. Thus, this paper focuses on the adoption of electricity. Several reasons motivate this choice. To begin, electricity is a general purpose technology, often regarded as characteristic of technological diffusion during the twentieth century. Moreover, numerous papers in economic history have studied this topic in the case of electricity (e.g., Crafts, 2002; Jalava & Pohjola, 2008; Bakker et al., 2015; and Bergeaud, Cette, & Lecat, 2018). Additionally, the adoption of electricity coincides with a period in which most of the countries in the sample operated under fixed exchange rate regimes. In the sample, 61% of the country-year observations are under a currency peg, and in 59% there was a peg while electricity was being adopted[4]. In particular, I follow the approach of Bergeaud, Cette, and Lecat (2018), who performed a similar growth accounting exercise in the same sample. They provide and IV estimate of the output elasticity of electricity. Growth accounting regressions often suffer from endogeneity and reverse causality effects. This can be explained by the fact that the adoption of new technologies is likely to be positively correlated with the business cycle, and with productivity enhancing developments in management, finance, and industrial organization. Their instrument is the weighted sum of technological adoption in all other countries weighted by the logarithm of their distance, which is correlated to the adoption of electricity. The diffusion of new technologies often occurs through international trade, which is in turn closely related to the distance between trading partners (Madsen and Farhadi 2016). Thus, it is assumed that $\eta = 0.08$ (the IV estimate of the output elasticity of electricity in Bergeaud, Cette, & Lecat, 2018).

The chosen value of η is fairly conservative. To illustrate this point, consider a plausible lower bound derived from Hulten's Theorem (Hulten, 1978). This results states that in efficient economies (and under mild assumptions), the aggregate effect of a technological shocks to an individual firm or sector is proportional to their sales as a share of GDP. As sales include intermediate inputs, if all firms in the economy were affected uniformly by a technology shock of the same size, the aggregate effect would be larger than 100%. This result is explained by the fact that the productivity gains in intermediate inputs would further enhance the productivity of final goods. However, as shown by Baqaee and Farhi (2019), this approximation excludes important features, most importantly complementarities in production. As the electricity sector is likely to have large complementarities in the production of final goods, the value of η is likely to be much higher that 4%; that is, the sales share of electricity in the GDP of the United States. Consequently, the sales share over GDP of the electricity sector would be a suitable lower bound for the effects.

Tables 2 and 3 present the accumulated contribution to TFP from human capital accumulation and the adoption of electricity, respectively. Figure 7 presents versions of TFP with and without the contributions of electricity and human capital for the United States and the United Kingdom. Overall, human capital

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[4] The measures of technological adoption are censored when they stop increasing. The implicit assumption is that when the intensity of adoption stops increasing the technology is fully adopted. See section 2 for details.

Table 2: Accumulated Effect of Human Capital on TFP

Country	Human Capital
USA	122.74
UK	78.06
Belgium	104.51
Denmark	79.85
France	106.57
Germany	111.31
Italy	92.88
Netherlands	73.55
Norway	137.69
Sweden	107.37
Switzerland	121.63
Canada	89.65
Japan	101.4
Finland	112.45
Portugal	74.09
Spain	65.5
Australia	75.12

Source: Author's Calculations.
Note: All values correspond to 2010.

and the adoption of electricity had large positive effects on the productivity of the countries in sample. Note that the magnitudes are similar for both endogenous growth mechanisms.

Tables 4 and 5 compare TFP estimates with and without the accumulated effect monetary shocks had on human capital and the adoption of electricity, respectively. The columns corresponding to the symmetric IRFs show smaller effects, even showing some negatives, suggesting TFP was higher due to the effect monetary policy had on the endogenous growth variables. However, when using asymmetric IRFs, the effects monetary shocks had through human capital accumulation and the adoption of electricity are negative in all cases. These results suggest that these asymmetries result in unambiguously positive costs associated to monetary hysteresis on the sources of endogenous growth.

4 Conclusion

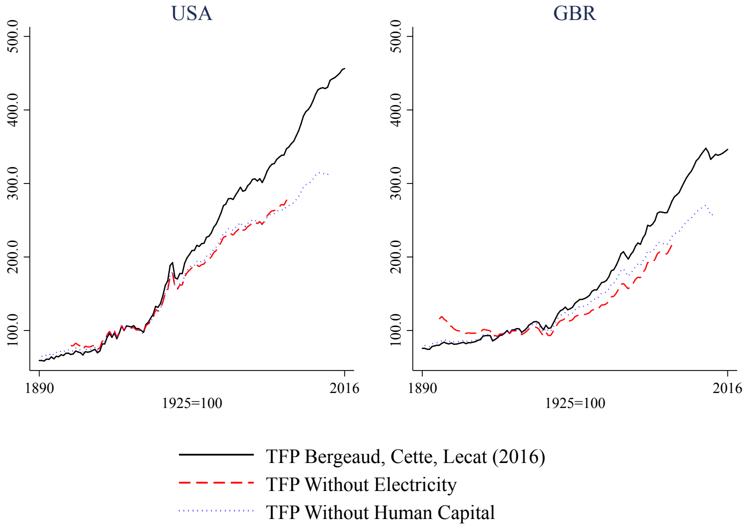
I provide evidence suggesting that temporary monetary shocks can generate substantial hysteresis on the sources of endogenous growth. These estimates run counter to the conventional view, which holds that demand shocks do not affect the long-run, supply-side productive potential of economies. Since this phenomenon is found to be quantitatively important, standard stabilization policies based on this conventional view should be revised. Accounting for this type of hysteresis is likely to have major

Table 3: Accumulated Effect of the Adoption of Electricity on TFP

Country	Full Adoption Year	Percent
USA	1993	69.97
UK	1993	58.77
Belgium	1999	97.91
Denmark	1996	96.15
France	2001	126.03
Germany	1991	85.2
Italy	2001	112.7
Netherlands	2001	75.43
Norway	2000	97.99
Sweden	2001	88.22
Switzerland	2001	65.04
Canada	2000	65.99
Japan	1999	107.26
Finland	2001	153.36
Portugal	2001	151.87
Spain	2001	96.55
Australia	2001	74.84

Source: Author's Calculations. Note: The year of full adoption is determined by censoring observations after the measure of technological adoption stops increasing.

Figure 7: Total Factor Productivity excluding contribution of electricity and human capital accumulation



Source: Author's calculations.

Table 4: Effect of Monetary Shocks on TFP through Human Capital

Country	Symmetric	Asymmetric
USA	-	-
UK	-.12	1.05
Belgium	-1.06	1.56
Denmark	-.64	.35
France	-.45	.85
Germany	.61	1.52
Italy	-1.42	-1.2
Netherlands	-.09	.86
Norway	.31	.88
Sweden	.58	2.02
Switzerland	.74	1.66
Canada	-1.39	1.52
Japan	3	3.22
Finland	-.35	.33
Portugal	.85	1.53
Spain	1.05	1.14
Australia	1.57	2.27

Source: Author's Calculations.
Note: All values correspond to 2010.

Table 5: Effect of Monetary Shocks on TFP through Adoption of Electricity

Country	Full Adoption	Symmetric	Asymmetric
USA	1993	-	-
UK	1993	-.42	4.34
Belgium	1999	-12.31	9.2
Denmark	1996	-6.67	4.5
France	2001	-11.31	11.92
Germany	1991	1.59	8.14
Italy	2001	-12.17	15.7
Netherlands	2001	-2.59	8.29
Norway	2000	2.17	4.68
Sweden	2001	4.69	16.07
Switzerland	2001	5.2	8.03
Canada	2000	-6.75	8.43
Japan	1999	17.34	16.67
Finland	2001	-5.94	11.55
Portugal	2001	-6.51	9.09
Spain	2001	3.27	13.95
Australia	2001	10.63	10.58

Source: Author's Calculations. Note: The year of full adoption is determined by censoring observations after the measure of technological adoption stops increasing.

implications for optimal policy and welfare. Importantly the responses of human capital and technological adoption are found to be asymmetric, as only contractionary shocks affect them in the long run. This implies excessively tight money has costs in the form of decreased human capital accumulation and delayed technological adoption. Future research should focus on micro-founding these behaviors, in order to better understand the mechanisms involved and any relevant policy trade-offs. Another important issue is the extent to which the hysteretic results presented in this section can be explained by coordination failures. Buera, Hopenhayn, Shin, and Trachter (2021) develop a quantitative model that features complementarity in firms's technological adoption decisions. In this environment, the gains to adoption are larger in the presence of complementarities. This often results in coordination failures, that may substantially amplify or attenuate the effects of distortions and policies.

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