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# What Drives Inflation and How? Evidence from Additive Mixed Models Selected by cAIC*

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**Abstract**

We analyze the forces that explain inflation using a large panel of 122 countries from 1997 to 2015. Models motivated by the economic theory are compared to a boosting algorithm, and non-linearities and structural breaks are explicitly considered. The boosting algorithm outperforms theory-based models. Further, we provide compelling evidence that the interaction of energy price and energy rents stand out among 37 explanatory variables. Other important determinants are demographic developments. Contrary to common belief, globalization and technology, public debt, central bank independence and transparency as well as countries' political characteristics, are less relevant. Exchange rate arrangements are more important than inflation-targeting regimes. Moreover, GDP per capita is more relevant than the output gap and credit growth is generally superior to M2 growth. Many predictors exhibit a structural break since the financial crisis. In particular, credit growth has lost its grip on the inflation process.

Keywords: Theories of Inflation, Longitudinal data, Additive Mixed Models, Model-based Boosting, Conditional Akaike Criterion

JEL classification: C14, C33, C52, E31

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# 1 Introduction

In the late 1970s and early 1980s, many countries experienced high inflation. A broad consensus emerged that this was unacceptable. Accordingly, policymakers worldwide adopted or were enabled to adopt policies designed to bring inflation down. As can be inferred from Figure 1, one of the most striking developments of the past two decades has been a steadily declining trend in inflation measured by consumer price index (CPI) and its volatility. In 1997, the average inflation was 21 %. By 2015 it had dropped to 5 %.

Many factors are believed to have contributed to this development. They range from stronger commitments to price stability, improved monetary policy, the emergence of the New Economy and the attendant acceleration of productivity growth, forces of globalization that increased competition and enhanced the flexibility of labor and product markets, the weakening influence of trade unions, disciplined fiscal policy, favorable exogenous circumstances, and even luck. All these factors likely played a role, and disentangling the relative contribution of each remains an important challenge.

However, the control of inflation has proven to be difficult. Since the inception of the financial turmoils in 2007, which set the stage for the global financial crisis (GFC) and the accompanying economic slump, numerous countries have faced inflation levels regarded to be uncomfortably low. Once the effective lower bound (ELB) to nominal short-term rates was reached, central banks were forced to adopt new measures to avert the danger of deflation. The result was a sizeable creation of monetary base. Despite considerable efforts to kick-start it, inflation has remained stubbornly low.

The general acceptance that the key objective of monetary policy should be price stability has aroused considerable interest in understanding the determinants of inflation. Empirical work in a cross-country setup is broad and diverse in its conclusions. Most of it addresses few potential sources for a limited number of countries or periods. Model comparisons are hardly made and non-linearities have often not been analyzed. Robustness checks with alternative estimation techniques are few and far between.

Empirical work that takes these shortcomings into account may help improve our understanding of what explains the inflation process over time and across countries. This offers the background to our paper, which identifies and quantifies various determinants of inflation, and motivates our extension of the empirical literature along several dimensions.

First, since the behavior of inflation has become increasingly difficult to understand,[1] we tested several models and variables based on abundant theoretical and empirical research. The explanatory variables were properly lagged to account for potential causal links.

Second, although the downward trend is a global phenomenon that had been noted years ago (Rogoff, 2003) research has typically focused on low-inflation (advanced) countries. For this reason, we base our analysis on not only as many theoretical explanations as possible but also the highest number of countries, including advanced countries, emerging market and developing economies (EMDEs), as well as low-income countries (LICs). To this end we pre-processed and analyzed an exceptionally large and comprehensive data set including annual observations of 37 explanatory variables for 122 countries during the period from 1997 to 2015.

Third, to properly consider the longitudinal structure of the data and the countries' heterogeneities, we recurred to mixed models whose variables were motivated by economic theory on the one hand and by a data-driven variable selection procedure on the other hand. Next, to allowing for a combination of countries with different characteristics, we extended the literature − which is focused on linear regressions, where inflation is regressed against a specific variable and control variables − by accounting for potential non-linear relationships between inflation and the regressors. For this purpose, we introduce additive mixed models to empirical research on inflation (which may find application in macroeconomic analyses in general) and provide the software implementation of conditional Akaike Information Criteria (cAIC) for additive mixed models with observation weights.

[1] Blanchard (2016) and Borio (2017) have even put into question economists' knowledge of its process.

The resulting assignment of cAIC to the models enabled us to compare several theories and the data-driven approach to one another.

We pose four questions: (i) What are the main drivers of inflation? (ii) What do the relationships look like? (iii) Are the estimates derived from data that preceded the GFC robust to events that have unfolded since then? (iv) Is an atheoretical approach superior to well-known economic theories?

We found clear answers. First, several variables, some more and others less, are consistently related to inflation across countries and over time. Second, several non-linearities are identified, which have implications for macroeconomic modeling. Third, the GFC has brought about various structural breaks. Fourth, the data-driven approach outperforms empirically the most compelling model informed from economic theory.

Specifically, the interaction of energy price and energy rents, whose effect has weakened after the GFC, unambiguously stands out among many potential determinants examined. Forces of globalization and technology, which are usually deemed to be crucial, are less important. The aging of society is also less relevant than energy prices and rents and is characterized by a disinflationary impact.

Another result relates to monetary variables. Models which include credit growth are superior to those which exhibit M2 growth. However, while M2 growth leads to higher inflation, the effect from credit growth has weakened after the financial crisis and may even have become negative. Turning to the real side of the economy, GDP per capita appears to be more important than GDP growth and the output gap, which is usually deemed of primordial importance in this context. Overall, a higher level of GDP per capita up to an income level of 50,000 USD raises inflation. In contrast, in low and middle-income economies, the association has dramatically changed after the financial crisis. The threshold is 10,000 USD; below this critical level, the association with inflation is weakly negative, whereas it becomes positive and strong beyond it. Unlike GDP per capita, the inflation-raising impact of GDP growth strengthened since the crisis. The output gap shows a positive non-linear relationship with inflation before and after the GFC.

Relating to monetary policy strategies, exchange-rate arrangements turn out to be more successful in explaining inflation than inflation targeting. Among institutional explanations, civil liberties reveal to be the most convincing, whereas the independence of central banks and their transparency as well as other political characteristics exhibit less empirical relevance. Fiscal variables present mixed evidence. The clearest result arises from the denomination of external debt. Here, the financial crisis also left its mark. Since then, the association between foreign currency debt and inflation has become positive and linear. Finally, past inflation exhibits a linear link with current inflation, which strengthened after the GFC.

The remainder of this paper is organized as follows. In Section 2 we review the literature and the ensuing explanatory variables underlying our empirical models. Section 3 presents the data. In Section 4 we lay out our estimation methods and the model selection procedure. The main findings are summarized in Section 5. Section 6 concludes the paper.

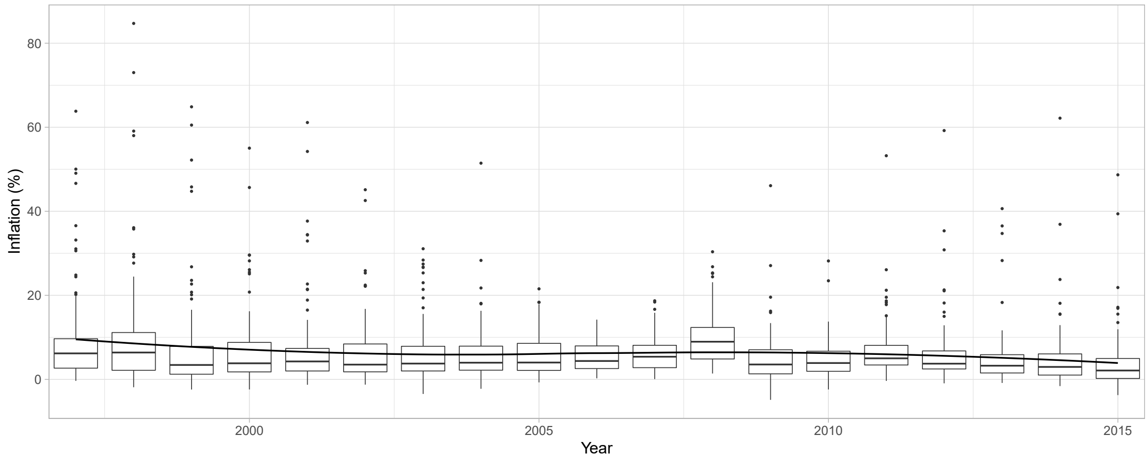


Figure 1: Truncated (99.5% percentile) distribution of inflation over time across 122 countries with a LOESS estimate.

# 2 Literature

In this section, we offer a brief survey of the most common explanations of inflation to derive testable implications.[2] We begin by one of the most established folk pearls of wisdom in monetary economics. Accordingly, inflation is said to be a monetary phenomenon. However, in criticizing the pure monetarist view, Kuttner (1990) noted that although some measure of money (possibly M2) may be the main determinant of inflation in the long run, it does not follow that only money matters in determining inflation over all horizons. A number of empirical studies show that the sources of inflation are quite diverse and include excess demand or slack, a country's institutional organization, the monetary policy strategy in place, fiscal imbalances, globalization and technology, demography, (shocks to) prices of natural resources, and past inflation. We discuss them in turn, present a selection of empirical studies on each of these topics, and explain the choice of variables for the empirical analysis.

## 2.1 Money, Credit, and Slack

### 2.1.1 Money

A key macroeconomic axiom is the quantity theory of money. It posits a proportional relation between the growth rate of money and inflation. Numerous studies confirm that sustained high growth rates of money in excess of its production of goods and services eventually produce high and rising inflation rates. For instance, Batini and Nelson (2001) show a relationship between inflation and money growth on U.K. and U.S. data for the period 1953–2001. Recent studies, for instance, Teles et al. (2016) confirm the quantity theory of money. However, the long-run link between money growth and inflation has weakened in low inflation countries, especially after the Great Inflation period. Gallegati et al. (2019), in a wavelet-based exploratory analysis covering 16 developed countries and spanning 140 years, documented a close relationship between excess money growth and inflation over time horizons between 16 and 24 years.

The quantity theory does not specify which definition of the money supply should be used in empirical tests. We account for the potential effect of money supply on inflation using the growth rate of M2 (*M2 Gr. (%)*).

[2] A comprehensive literature review is provided in the Literature Appendix B.

#### 2.1.2 Credit

In addition to money we also examine the effect of credit creation.[3] Two opposite effects are possible – an inflationary and a disinflationary one. On the one hand, an inflation-raising effect may arise from credit expansions that go hand in hand with money creation. On the other, domestic credit may proxy financial depth and, as such, contain information expected to be negatively related to inflation.[4] In addition, a credit expansion that leads to a build-up of investment and an expansion of production capacities put downward pressure on prices.

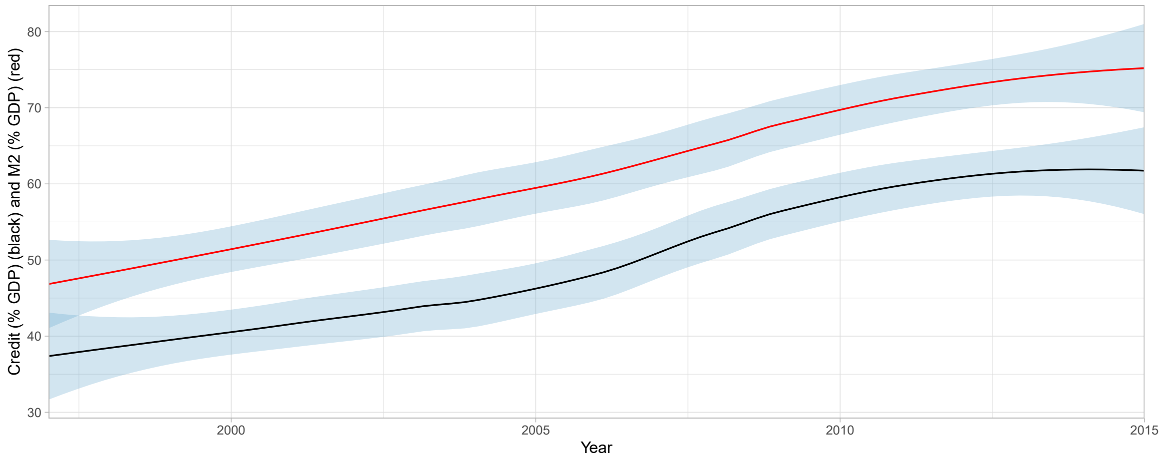


Figure 2: M2 (% GDP) and Credit (% GDP) over time with a LOESS estimate and 95% pointwise confidence intervals.

We employ two measures of domestic credit. The first refers to credit to the private sector in percent of GDP (*Credit (% GDP)*) and the second to its growth rate (*Credit (% GDP) Gr. (%)*).

Figure 2 plots the evolution of credit and M2 relative to GDP. Both have been trending upwards almost in parallel.

#### 2.1.3 Slack

Another central tenet of macroeconomics is that the real and nominal sides of the economy are linked through a Phillips curve relationship, in which inflationary pressures reflect the level of real economic activity and inflationary expectations. Over time, two specifications have arisen: the Traditional (or New Classical) and the New Keynesian Phillips curve. In the New Classical form, inflation is a function of lagged expected inflation and a contemporaneous measure of excess demand or slack, often measured by the output gap, defined as actual minus potential output. Inflation tends to rise if the gap is positive, while it tends to fall as long as the gap is negative. If the output gap is zero, inflation remains stable. In the New Keynesian model, current inflation is related to (rationally) expected future inflation, along with a measure of demand.

There is considerable evidence that the output gap is an important determinant of inflation.[5] However, inflation seems to have become less responsive to the domestic output gap measures than in the past. Blanchard (2016) found that a drop in the unemployment rate in the U.S. has less than a third as much power to raise inflation as it did in the mid-1970s.

[3] Schularick and Taylor (2012) uncovered a decoupling of money and credit in a sample of 14 advanced countries during the 20th century.

[4] See Calderón and Schmidt-Hebbel (2010).

[5] See, for instance, Coe and McDermott (1997), Deniz et al. (2016), Gross and Semmler (2017), and Jasova et al. (2019).

An important question is whether the financial crisis of 2008-2009 led to structural breaks. One point in case concerns the Phillips curve. The background is the missing disinflation which was observed in advanced economies in the aftermath of the financial crisis.[6] Several hypotheses have been advanced. Coibion and Gorodnichenko (2015) suggested that firms' inflation expectations moved countercyclically during the recession and recovery because they were overly influenced by oil prices, which increased from 2009 to 2011 – and extending their argument[7] – fell from 2014 through 2017. A second set of explanations focuses on special features of the financial crisis. Gilchrist et al. (2017) showed that financial distortions created an incentive for firms to raise prices in response to adverse financial or demand shocks to preserve internal liquidity and avoid accessing external finance. This strengthened the countercyclical behavior of markups and attenuated the response of inflation to output fluctuations. Another explanation refers to expectations. Mazumder (2018) found a stable Phillips curve for the euro area using short-term professional survey expectations data, and he attributes the weakening of inflation to a decline in expected inflation.

We calculate potential or trend output by a Hodrick-Prescott (HP) filter-based measure with a lambda set to 6.25. The resulting variable is denoted as *Out. Gap (%)*.

## 2.2 Institutions

The potentially numerous motives for authorities to inflate may be prevented by sound institutions. We split a country's institutional organization in five separate items—central bank independence, central bank transparency, political instability and orientation, civil rights, and economic growth.

### 2.2.1 Central Bank Independence

Rogoff (2003) argued that improved institutions and more sophisticated policymakers, not to mention a more sophisticated public, have played pivotal roles in the global reduction in inflation. Nevertheless, the fact that inflation has fallen even in countries with weak institutions, unstable political systems, and thinly staffed central banks raises the possibility that other factors have also been important. One fact that seems to have been on the rise throughout the world is the increased independence of central banks. As a consequence, central bank independence has received much attention in explaining cross-country differences in inflation rates.

However, the empirical evidence on the relationship between central bank independence and inflation is mixed. For instance, Dincer and Eichengreen (2014) provided a detailed analysis of the effect of central bank independence on inflation and its variability based on annual indices for more than 100 central banks. They found some, albeit statistically inconsistent, negative association with inflation. Recently, Baumann et al. (2021) accounted for possible reasons that motivate the decision of a country to adopt a certain degree of central bank independence and used a causal model that summarizes the economic process of inflation to inform their statistical analysis in which countries are treated as units in a panel setup. The authors reported only a weak causal link from independence to inflation, if at all.

We use the Dincer-Eichengreen index of de jure central bank independence ($CBI$), which ranges from 0 (most dependent) to 1 (most independent) available from 1998 to 2010. In addition, we measure the occurrence of turnovers at the headquarters of the central bank during the year ($TOR$) (Dreher et al., 2010). This proxy of de facto independence has the advantage of allowing us to exploit the whole data set, circumventing the limit other authors encountered due to the lack of long time series on central bank independence measures for a long list of countries.[8] In the interpretation of

[6] For recent reviews of papers on the apparent flattening of the U.S. Phillips curve in the 2000s, and especially since the financial crisis, see McLeay and Tenreyro (2019) and Hooper et al. (2019).

[7] See Stock and Watson (2019).

[8] For example, Catão and Terrones (2005) pointed to this circumstance in their panel that prevented them from evaluating their hypothesis on a broad cross-country basis.

results Lustenberger and Rossi (2020) pointed out that central bank independence and the turnover rate may measure two distinct dimensions of institutional independence.

### 2.2.2 Central Bank Transparency

One further fact that needs to be accounted for in the analysis of central bank independence is that its increase has been accompanied by greater transparency. Most central banks currently announce their objectives with quantitative targets, publish numerical macroeconomic forecasts and are open about their policy decisions, marking a departure from long-standing practice which valued confidentiality. This change is not only a reflection of accountability requirements that go hand in hand with increased central bank independence but also expresses the conviction within the central banks' community that greater transparency improves monetary policy effectiveness (Geraats, 2014).

Overall, the empirical literature documents beneficial effects from transparency. For example, Dincer and Eichengreen (2014) found that greater transparency is associated with lower average levels of inflation.

We measure central bank transparency (*CBT*) by the updated values of Dincer and Eichengreen that extend the observations reported in Dincer and Eichengreen (2014) by four more years until 2014.[9]

### 2.2.3 Political Instability and Orientation

Political instability adds another potentially important element to the analysis of institutions for inflation. Aisen and Veiga (2005) showed on a data set covering approximately 100 countries from 1960 to 1999 that a higher degree of political instability is associated with higher inflation, whereas higher degrees of economic freedom and democracy are associated with lower inflation. Maruf et al. (2017) uncovered, using the Panel maximum Likelihood method, a positive relationship between political instability and inflation, especially in oil-producing countries.

Various measures for political (in)stability have been applied. We rely on two. The first, *Pol. Stab.*, measures the percentage of cabinet members (veto players) dropping out in any given year. The variable ranges from 0 (most stable) to 1 (most unstable). The second is the party orientation with regard to their economic policy, *Pol. Orien.*, categorized into three classes: left, center, and right. Both variables are obtained from the World Bank's database of political institutions.

### 2.2.4 Civil Rights

Another arguably important institutional element is political rights which we approximate with three categorical variables taken from Freedomhouse.org (2015): political rights (*Pol. Rights*) taking on seven levels, civil liberties (*Civil Lib.*) also seven levels, and freedom status (*Fr. Status*) with three levels.

### 2.2.5 Growth

GDP and its growth rate, respectively, are considered important inflation-related factors that many authors have used. GDP per capita has been used as a proxy for institutional quality. Dollar and Kraay (2003) found that cross-country differences in institutions mirror the differences in the levels of GDP per capita. Calderón and Schmidt-Hebbel (2010) employed per capita income as a proxy of a more general group of institutional arrangements. Hielscher and Markwardt (2012) used GDP per capita to control for various structural disparities as differences in the financial sector, technologies, or optimal inflation.

We rely on two forms, real GDP per capita (*GDP pc (USD)*) and real GDP growth (*GDP Gr. (%)*).

[9] We downloaded the updated version of February 2017.

## 2.3 Monetary Policy Strategies

The next group of variables accounts for the effects on inflation associated with two monetary policy arrangements. The first relates to exchange rate arrangements, the second to adopting an explicit inflation targeting (IT) strategy.

### 2.3.1 Exchange Rate Regime

One rationale for adopting a fixed exchange rate framework is that it operates as a disciplinary tool for monetary authorities. Another benefit is that a fixed exchange rate signals enhanced credibility of lower future inflation. As a result, inflation should be lower in countries with fixed exchange rates.

Many studies include a dummy variable for the exchange rate regime as a (further) check on time-consistency issues. Overall, pegged regimes seem to yield lower inflation. Ghosh et al. (1997) found robust evidence of lower inflation under pegged regimes in a sample of 150 countries over 30 years. The negative relationship between fixed exchange rates and inflation is also reported in Cottarelli et al. (1998) and Husain et al. (2005). The reason seems to be a smaller money growth and higher credibility of the monetary system.

Exchange rate arrangements come in a variety of forms. For our analysis we extend the Reinhart-Rogoff classification. The resulting variable (*ERA*) distinguishes four categories: no separate legal tender, a crawling peg, managed floating, and free-floating.

### 2.3.2 Inflation Targeting

Inflation targeting (IT) is an operational framework for monetary policy aimed at achieving a numerical value (or range) for the inflation rate. A growing number of countries have adopted IT over the last two decades. At the start of 2012, some 27 central banks were considered full-fledged inflation targeters, and several others were in the process of establishing a full IT regime.[10]

A growing literature on the effects of IT on average inflation, inflation volatility, average growth, and its volatility has emerged. The evidence mostly concludes that IT is beneficial, lowering inflation, its volatility and inflation expectations (Truman 2003, Hyvonen 2004, Vega and Winkelried 2005, among others). However, Ball and Sheridan (2005) argued that IT makes no difference among industrial countries. More recent studies that include emerging markets tend to find stronger evidence of positive effects from IT.[11]

We created a binary variable, *Infl. Targ.*, that takes the value of 1 for countries that have adopted IT, and 0 otherwise. For its construction, we relied on various annual reports on Exchange Arrangements and Exchange Restrictions provided by the IMF.

## 2.4 Public Finances

A well-established theory in macroeconomics is that governments running persistent deficits have sooner or later to finance those deficits with seigniorage. In the aftermath of the financial crisis, financial bailouts, stimulus spending, and lower tax revenues have resulted in public debts in advanced economies that have surpassed the peaks reached during World War I and the Great Depression (Reinhart and Rogoff, 2011). There are several theoretical channels for how public indebtedness may unleash inflation.

**Conventional view** According to the conventional view, an increase in public debt may cause inflation by inducing a positive wealth effect on households. Demand for goods and services rises and ultimately inflates the economy (Elmendorf and Mankiw, 1999).

[10] See Hammond (2012).

[11] See Samarina et al. (2014) and Deniz et al. (2016).

**Unpleasant Monetarist Arithmetic** The main result of the seminal paper on unpleasant monetarist arithmetic by Sargent and Wallace (1981) is that the effectiveness of monetary policy in controlling inflation depends critically on its coordination with fiscal policy.

**Fiscal Theory of the Price Level** A similar reasoning lies behind the fiscal theory of the price level (FTPL). Government debt not backed by expected future surpluses ensues in inflation, immediately or—depending on the maturity structure—in the future (Cochrane, 2001).

**Optimal Tax** A fourth explanation is based on the Theory of Optimal Taxation, according to which governments optimally equate the marginal cost of the inflation tax with that of output taxes.[12]

A large empirical literature examines the link between fiscal policy and inflation. Much of it focuses on the role of budget deficits. Deficit financing is generally insignificant. However, in high-inflation countries, there is a significant causality of fiscal deficits on inflation.

Rather than looking at inflation, several studies examine the link between money creation and deficits. For the U.S., Hamburger and Zwick (1981) found for the period after World War II that monetary growth was influenced by deficits, but only in specific episodes. Likewise, King and Plosser (1985) found little evidence of a connection between fiscal deficits and base money changes in a sample of 13 countries.

Campillo and Miron (1997) reported a positive and significant relationship between the public debt ratio and average inflation in a sample from 1973 to 1994, consistent with optimal taxation.

More recent research on the relationship between fiscal deficits and inflation has exploited both time and cross-sectional data dimensions. Again, the results are inconclusive. In a panel estimation on 32 countries, Karras (1994) did not find any inflationary impact of fiscal deficits. Fischer et al. (2002) investigated the relationship between inflation, money growth, seigniorage and fiscal deficits on data of 94 developing and developed countries during 1960–1995. According to their cross-sectional analysis fiscal deficits are significantly positively linked to seigniorage and inflation. Exploiting their panel data, they showed that in countries with high average inflation, fiscal deficits are the main drivers. However, this effect is no longer significant in low-inflation countries or high-inflation countries during low-inflation episodes. Catão and Terrones (2005) and Lin and Chu (2013), differently from the literature, modeled a non-linear relation between fiscal deficits and inflation. Their results are similar. The former report a positive association between deficits and inflation among high-inflation and developing country groups, but not among low-inflation advanced economies. The latter found a strong impact on inflation from fiscal deficits in high-inflation episodes, but only a weak impact in low-inflation episodes.

**Debt Management** A potentially important issue is also the public debt structure. In the models by Calvo (1988) and Missale and Blanchard (1994), higher levels of privately held government debt with a longer nominal maturity raise the incentive for a government to attempt surprise inflation. In this literature, foreign currency, inflation-indexed, or short-term debt are remedies against surprise inflation.

This topic has not been well examined in the empirical literature. Contributions are few and far between and mostly focused on advanced countries. Missale and Blanchard (1994) provided evidence in line with the theoretical model on some highly indebted European countries, and Mandilaras and Levine (2001) on a sample of 15 OECD countries.

Following the literature, we use different measures of fiscal stance. One captures the primary balance, *Prim. Bal. (% GDP)*. Another relates to debt growth (*Debt (% GDP) Gr. (%)*). As proxies for testing the implications of theories on public debt management, we use average maturity on new external debt (*Matur.*) as well as the percentage of external long-term public and publicly

[12] See Phelps (1973), Végh (1989), and Aizenman (1992).

guaranteed (PPG) debt contracted in multiple currencies for the low- and middle-income countries (*Denom. (%)*).

## 2.5 Globalization and Technology

Declining inflation in many countries over the past few decades simultaneously as rising global competition has led to a debate on the importance of globalization for domestic inflation. There are at least two lines of argument about how increased globalization may affect inflation in the literature. The first is due to Rogoff (2003) who argued that globalization reduces the inflation bias associated with discretionary monetary policy by closing the gap between the target level of output pursued by the central bank and the natural rate. The second line of thought holds that competition between currencies forces central banks to adopt best practices and keep inflation at bay in a more integrated world. This disciplining effect is related to financial globalization rather than real globalization (Wynne and Kersting 2007).

Empirical results are mixed. In a study on a cross-section of 114 countries based on 1973-88 averages, Romer (1993) found a robust negative relationship between openness, proxied by the ratio of imports to GDP, and inflation, but essentially no relationship between openness and inflation in the most developed countries. Bleaney (1999) reported, using 1989–98 averages, that the negative relationship between economic openness and inflation is not statistically significant. Campillo and Miron (1997) found in a slightly extended sample period (1973-94) of 62 countries that even for developed countries is greater openness associated with significantly lower inflation. Daniels et al. (2005) also reported a robustly negative effect of openness on inflation in a broad cross-section of countries.

The cited studies use a cross-section specification. The alternative is to exploit the time-series structure of the data and use panel estimation methods. Alfaro (2005) reported an inflation increasing effect of openness in a panel of 148 countries, whereas Sachsida et al. (2003) and Gruben and McLeod (2004), employing instrumental variable estimators to deal with endogeneity problems, documented an inflation-reducing effect of openness.

An important observation is that inflation has become increasingly globally synchronized (Ha et al., 2019). Recent research has highlighted a large and growing role of global factors in explaining movements in national inflation rates. Jasova et al. (2019) showed that both global and domestic output gaps are significant drivers of inflation in the pre-crisis (1994–2008) and post-crisis (2008–2017) periods, controlling for nonlinear exchange rate movements. The panel consists of 26 advanced and 22 emerging economies. However, after the crisis, the effect of the domestic output gap declines in advanced economies, whereas in emerging economies it is the effect of the global output gap that declines.

We use three openness variables. One refers to economic openness (*Trade Open. (% GDP)*) and reflects the sum of exports and imports divided by GDP (the most commonly used measure of openness). The second measures the openness in the capital account (*Fin. Open.*). Next, to their isolated effect, we also test the implication from their interactions. The third openness proxy is the KOF Globalization index (Gygli et al., 2019) which we denote as *KOF Global.*

In addition to globalization, a view embraced by several authors is that technological progress may be disinflationary by leading to declining prices of information and communications technology (ICT) products, by reducing entry barriers for new producers, and by lowering wage growth. Lv et al. (2019) found that both globalization and technology explain low inflation dynamics in the U.S. While the impact of globalization weakened, the effect of technology increased.

We examine the impact of technology by the ICT capital proxy of Jorgenson and Vu (2005) used by Jaumotte et al. (2013).[13] We denote this variable as *ICT Capital (%).*

[13]We thank Florence Jaumotte for sharing their index with us.

## 2.6 Demography

In an effort to understand the sources of the decline in inflation observed over the recent past, the adverse demographic trend has been invoked as a further possible driver. Mirroring theoretical ambiguity, the empirical evidence is inconclusive. Anderson et al. (2014), Yoon et al. (2014), Gajewski (2015), and Bobeica et al. (2017) find empirical evidence for aging to be associated with deflationary pressures. In contrast, Juselius and Takáts (2015) document that aging leads to more inflation. Similarly, Aksoy et al. (2015) estimated long-run effects of the changing age profile and found that dependent cohorts enhance the inflationary pressures in the long run.

To examine the role of demography two variables are used: the share of the population older than or equal to 65 (*Age 65 (%)*) and the share of population older than or equal to 75 (*Age 75 (%)*).

## 2.7 Natural Resources

The oil price is a well-known source of inflationary pressures in the world economy, and the change in the oil price is used as a control variable in several empirical studies. Cuñado and Pérez de Gracia (2003) found evidence of cointegration in the oil price-inflation relation in 11 of 15 European countries between 1960 and 1999. Typically, the impact of oil prices on long-term domestic inflation is more substantial among advanced countries than among developing countries. For instance, LeBlanc and Chinn (2004) showed that a 10 percentage points oil price increase boost inflation by 0.1–0.8 percentage points in the U.S. and the E.U. In Catão and Terrones (2005) a 1 percentage point increase in oil prices is estimated to raise advanced country inflation by near 0.2 percentage points. Ha et al. (2019) documented in exceptionally a large sample of countries of 141 EMDEs and 34 advanced economies over 1970-2018 that rapid changes in global inflation have occurred near turning points of the global business cycle or in the wake of sharp movements in global oil prices.

Feldkircher and Siklos (2019) investigated dynamics of inflation and short-run inflation expectations in a global vector autoregressive (GVAR) model encompassing 42 countries from 2001 to 2016. While the effects of the demand and supply shocks are short-lived for most countries, when global oil price inflation accelerates, effects on inflation and expectations are often more pronounced and last long. After the GFC the transmission between inflation and inflation expectations was largely unaffected in response to domestic demand and supply shocks, whereas the effects of an oil price shock on inflation expectations were reduced.

We consider two energy-related variables, both from the World Bank. The first is a weighted average of energy prices, including coal, crude oil, and gas (*En. Prices (USD)*). The second is the total of natural resources rents (in % of GDP). It is the sum of rents on oil, natural gas, coal, mineral, and forest, calculated as the difference between the price of a commodity and the average cost of producing it (*En. Rents (% GDP)*).

In the empirical analysis, we let the two variables interact. The rationale is based on the following testable hypothesis. In some countries earnings from natural resources, especially from fossil fuels and minerals, account for a sizable share of GDP. Rising rents can result from either a global commodity price increase due to a rise in world demand or reduced extraction or harvesting costs. In the first scenario, both energy prices and commodity rents increase, causing an increase in inflation in both exporting and importing countries. In the second, the demand-driven impact on inflation is concentrated in commodity-exporting countries with a contained effect on global inflation.

## 2.8 Past Inflation

In empirical studies past inflation is often controlled for.[14] Countries that experienced high inflation might be more aware of its negative consequences and oppose it more forcefully. A related effect

[14] See Campillo and Miron (1997), Kwon et al. (2009), Calderón and Schmidt-Hebbel (2010), Lin and Chu (2013), Alpanda and Honig (2014), Dincer and Eichengreen (2014).

that can be assessed by past inflation rates is inflation inertia, according to which inflationary shocks may translate into higher inflation expectations through wage and price contracts, which in turn materialize in terms of higher actual inflation.[15]

In the New Keynesian literature, there are four approaches establishing a link between past and current inflation. The first is the model by Gali and Gertler (1999) in which price reoptimization is done following a rule of thumb. The second is the indexation model proposed by Christiano et al. (2005), and the third the sticky information model of Mankiw and Reis (2002), which distinguishes between reoptimizing agents with adaptive expectations and those relying on past inflation as a proxy for expected inflation.

Bikai et al. (2016) used a Panel Vector Autoregressive approach on CEMAC countries (Economic and Monetary Community of Central Africa) and data from 1990 to 2014 to show that money supply and imported inflation are the two main sources of inflation. Nevertheless, money supply and imported inflation account for only 30% of the dynamics of inflation. 64% of it is determined by inflation itself.

Binder (2021) provided empirical support for the general premise of heterogeneous agent models with two types of private agents, distinguished by their expectations formation. In several papers, the two types are "credibility believers" and "adaptive expectations users." The former trust the central bank, expect future inflation to be near the central bank's inflation target and use a Phillips curve. The latter use only past inflation to forecast future inflation (Hommes and Lustenhouwer, 2019). Binder (2021) showed that forecasters who report to use the natural rate of unemployment to make forecasts resemble the "credibility believers" whereas the forecasters reporting not to rely on it are akin to the "adaptive expectations users" in the models of Goy et al. (2018) and others. The presence of these two types of agents can have implications for macroeconomic dynamics and policymaking. Goy et al. (2018) studied forward guidance at the ELB in a New Keynesian model with these two types, assuming that only the "credibility believers" respond to forward guidance. The smaller the share of "credibility believers," the less effective forward guidance is. Thus, the presence of "adaptive expectations users" helps resolve the forward-guidance puzzle in standard New Keynesian models with rational expectations (Del Negro et al., 2012).

In line with the literature, we account for the influence of inflation in the past. Specifically, we constructed a 3-year moving geometric average of inflation (*Past Infl. (%)*).

## 2.9 Economic Theories

Based on this literature survey, we set up eight economic theories and various testable models, which capture a diversity of country characteristics. In the literature, money and output-related variables are often part of the explanatory variables. For this reason, they are also included in each of our models. Because it is not straightforward which variables best reflect the development of money stock and GDP, each model includes either *M2 Gr. (%)* or *Credit (% GDP) Gr. (%)* in combination with either *GDP pc (USD)* or *GDP Gr. (%)*, extended by theory-specific explanatory variables. As a result, we obtained a range of four to 24 alternative specifications. This gave rise to an estimation of 98 model-specific variable combinations. The exact variable combinations of each economic model can be gleaned from the Table Appendix. In addition to variable compositions suggested by economic theory, we also predefined interactions of variables for which we assumed the existence of a mutual impact on inflation. This applies to *En. Prices (USD) and En. Rents (% GDP)* as well as *Trade Open. (% GDP) and Fin. Open.*

[15] See Lim and Papi (1997), Loungani and Swagel (2003), and Kamin and Klau (2003).

# 3 Data

Our aim is to cover as many countries as possible. This entails a trade-off between the number of countries and the completeness of the data set. We were able to collect annual data running from 1995 to 2015 for 124 countries for 21 explanatory variables and for the dependent variable from publicly accessible sources, mainly the IMF and the World Bank. For inflation, we finally relied on the IMF's change in the CPI due to data availability. Further, we derived growth rates from level variables, rolling averages from growth rate variables, and further transformations from level variables. As a result, 30 variables and the dependent variable resulted from this with missing information for some variables (2.8% of the observations). We imputed the missing observations by means of an EM-Algorithm on bootstrapped samples (Honaker et al., 2011). We limited the analysis to a single imputation instead of multiple imputed data sets due to the lack of theoretical background for averaging random effects.

The contemporaneous measurements of the resulting variables were replaced by their one- or two-year lagged counterpart according to theory and empirical results.[16] We excluded two countries with outliers from our sample since these countries heavily impaired model selection. This led to 122 countries spanning from 1997 to 2015. We refer to these data as the full sample.

In addition to the 30 variables, we also collected eight explanatory variables from various scientific publications and the World Bank that were not available across the whole time span from 1995 to 2015 or were only available for a subset of countries. Due to a non-compliance with the Missing At Random assumption, these predictors were not imputed. These variables are associated with the economic theories *Institutions, Monetary Policy Strategies, Public Finance* and *Globalization*. Their limited availability is one of the reasons for our two-stage selection procedure described in Section 4.4.

Finally, this gives rise to a classic longitudinal/panel data structure for a data set comprising 37 predictors and the World Bank's income classification. We provide summary statistics in the Appendix (cf. Figure A.1 and A.2). According to the World Bank's income classification, approximately 21% of the countries are low-income countries, 35% belong to the lower-middle-income category, 19% to the upper-middle-income category and 25% to the high-income category.

# 4 Methods

In this section we discuss the details of the statistical models and procedures underlying the analysis. First, we present the basic structure of additive mixed models (AMM) on which we rely to model annual inflation rates. To capture the country-specific correlation and the heterogeneity of countries, we specify these AMMs with either subject-specific random or fixed effects and country-specific weights. All estimated AMMs are compared by their cAIC. We discuss the cAICs' central pillars in the context of AMMs and present our contribution to its software implementation. We provide the details to model-based boosting for variable selection which we used as the starting point of our data-driven inflation modeling. We then present the two-stage model selection procedure that we developed. Finally, we add varying coefficients based on Hastie and Tibshirani (1993) to the AMMs that exhibit the lowest cAIC to tackle the question of a structural break during the financial crisis 2007/2008.

## 4.1 Additive Mixed Models

Mixed models are a natural choice for modeling longitudinal data and have been frequently applied, for example, in epidemiology.[17] However, to our knowledge, mixed models have not been applied to

[16] See Baumann et al. (2021) for details.
[17] See, e.g., Degruttola et al. (1991) and Pearson et al. (1994).

model inflation. In general, mixed models include (population) fixed and (subject-specific) random effects. When modeling macroeconomic data, a violation of the random effects assumption may arise which eventually leads to inconsistent estimators for the population fixed effects (Wooldridge, 2010). For this reason, we rely on the procedure proposed by Mundlak (1978) to check if the random effects assumption holds or if random effects have to be replaced by country-specific fixed effects. In general, the country-specific effects should act as surrogates for effects that have not been measured and induce heterogeneity between countries. Further, since non-linear relationships between the many predictors used in this paper and inflation cannot be excluded, we extend the mixed models in an additive manner by model terms which are functional forms of the predictors. This leads to the class of AMMs on which our main analysis is based.

The formal structure of the AMMs is as follows: 37 (metric and categorical) predictors and the dependent variable *inflation* (in percent), denoted by $\tilde{y}_{i,t}$, are given for $i = 1, \ldots, n = 122$ countries and for $t = 0, \ldots, T = 18$ consecutive years from 1997 to 2015 such that $\tilde{\boldsymbol{y}}_{\boldsymbol{i}} = (\tilde{y}_{i,0}, \ldots, \tilde{y}_{i,T})^\top$. The vector $\tilde{\boldsymbol{y}} = (\tilde{\boldsymbol{y}}_{\boldsymbol{1}}^\top, \ldots, \tilde{\boldsymbol{y}}_{\boldsymbol{n}}^\top)^\top$ has been transformed by the natural logarithm $\boldsymbol{y} := \ln(\tilde{\boldsymbol{y}} + 10.86)$ after shifting the support to values $\geq 1$ to avoid numerical instabilities. We chose the natural logarithm transformation to meet the distributional assumptions specified for $\boldsymbol{\epsilon_i}$ in (1).

The generic AMM used to explain $y_{i,t}$ by a set of predictors $A_{j,l}$ is given in Equation (1). Each of the eight economic theories is represented by a set $G_l := \{\{A_{1,l}\}, \{A_{2,l}\}, \ldots, \{A_{m_l,l}\}\}, l = 1, \ldots, 8$, containing $m_l := \mid G_l \mid$ sets of predictors $A_{j,l}$. Each $A_{j,l}$ is composed of disjunct subsets $B_{j,l}$ and $C_{j,l}$ of predictors with linear and non-linear effects, respectively, as well as pairs $D_{j,l}$ of variables in $B_{j,l}$ and pairs $E_{j,l}$ of variables in $C_{j,l}$ with linear and non-linear interaction effects, respectively. Non-linear effects $h$ of predictors $x \in C_{j,l}$ are estimated by univariate cubic P-splines (Eilers and Marx, 1996) with second-order difference penalties. Interaction effects $f(\cdot, \cdot)$ of pairs $(x, x^*)$ of variables in $E_{j,l}$ are modeled using penalized bivariate tensor-product splines. The assignment to $B_{j,l}$, $C_{j,l}$, $D_{j,l}$ and $E_{j,l}$ can be found in Tables A.1 and A.2 in the table Appendix. Each model $M_{j,l}$ corresponding to one $A_{j,l} \in G_l$ is of the following form:

$$y_{i,t} = \beta_0 + \eta_{i,t} + \boldsymbol{Z_{i,t}b_i} + \epsilon_{i,t}, \tag{1}$$

$$\eta_{i,t} = \sum_{x \in B_{j,l}} x_{i,t}\beta_x + \sum_{(x,x^*) \in D_{j,l}} (x_{i,t}x^*_{i,t})\beta_{(x,x^*)} + \sum_{x \in C_{j,l}} h_x(x_{i,t}) + \sum_{(x,x^*) \in E_{j,l}} f_{(x,x^*)}(x_{i,t}, x^*_{i,t}) \tag{2}$$

with $\boldsymbol{b_i} = (b_{i,0}, b_{i,1})^\top \overset{iid}{\sim} N(\boldsymbol{0}, \boldsymbol{G})$, where a random intercept $b_{i,0}$ and a random slope $b_{i,1}$ with design vector $\boldsymbol{Z_{i,t}} \equiv \boldsymbol{Z_t} = (1, t)$ and non-diagonal covariance $\boldsymbol{G}$ are (always) included to capture the serial within-country correlation. Further, $\boldsymbol{\epsilon_i} \sim N(\boldsymbol{0}, \boldsymbol{R_i})$ is assumed with $\boldsymbol{\epsilon_i} \perp\!\!\!\perp \boldsymbol{b_i}$, where $\boldsymbol{R_i}$ is a diagonal matrix with potentially heterogeneous country-specific variances $\sigma_i^2$ on its diagonal. The observation weights $w_i = \sigma^2/\sigma_i^2$ emerge implicitly and are contained on the diagonal of the matrix $\tilde{\boldsymbol{W}}_{\boldsymbol{i}}$ such that $\boldsymbol{R_i} = \sigma^2 \tilde{\boldsymbol{W}}_{\boldsymbol{i}}^{\boldsymbol{-1}}$. On a sample level, the error covariance structure is a block-diagonal matrix $\boldsymbol{R}$ with $\boldsymbol{R_i}$ on its diagonal.

Assuming $\boldsymbol{\epsilon_i} \perp\!\!\!\perp \boldsymbol{b_i}$ further implies that the $\boldsymbol{b_i}$ have to be uncorrelated with all $x_{i,t}$ and $x^*_{i,t}$ included in the subsets of $A_{j,l}$ for all $t$. This assumption may seem unreasonable given the data and question under investigation. For this reason, we question the random effects assumption (i.e., $\mathbb{E}[\boldsymbol{b_i}|x_{i,t}, x^*_{i,t}] = \mathbb{E}[\boldsymbol{b_i}]$ for all $t$) and alternatively specified country-specific fixed effects to take the country-specific correlations into account. Specifically, we alternatively specified each $M_{j,l}$ as in (1) but without any distributional assumption for the country-specific parameters:

$$y_{i,t} = \eta_{i,t} + \boldsymbol{Z_{i,t}\gamma_i} + \epsilon_{i,t}, \tag{3}$$

where $\boldsymbol{\gamma}_i = (\gamma_{i,0}, \gamma_{i,1})^\top$. To decide if the random effects assumption under (1) or the country-specific fixed effects under (3) are more reasonable for each $M_{j,l}$, we follow Mundlak (1978), whose procedure enables us to derive a statistical test which examines if the time-invariant error components of the error in (1) might not be correlated with the time-varying regressors specified in (2). We test this hypothesis by specifying a further model $\bar{M}_{j,l}$ for each $M_{j,l}$ which is specified as the corresponding $M_{j,l}$ but with a linear predictor $\bar{\eta}_{i,t}$ that additionally encloses the time-averaged transformations of the regressors (i.e., $\bar{x}_i = \frac{1}{T+1}\sum_{t=0}^{T} x_{it}$) specified in (2). As a result, each $\bar{M}_{j,l}$ is of the form

$$y_{i,t} = \beta_0 + \bar{\eta}_{i,t} + \boldsymbol{Z_{i,t}b_i} + \epsilon_{i,t}, \tag{4}$$

$$\bar{\eta}_{i,t} = \eta_{i,t} + \sum_{x\in B_{j,l}} \bar{x}_i\bar{\beta}_{x_B} + \sum_{(x,x^*)\in D_{j,l}} \bar{x}_i\bar{\beta}_{x_D} + \bar{x}_i^*\bar{\beta}_{x_D^*} + \sum_{x\in C_{j,l}} \bar{x}_i\bar{\beta}_{x_C} + \sum_{(x,x^*)\in E_{j,l}} \bar{x}_i\bar{\beta}_{x_E} + \bar{x}_i^*\bar{\beta}_{x_E^*} \tag{5}$$

We test if all the parameters of the time-averaged transformations of the regressors are jointly zero, i.e., $H_0 : \bar{\beta}_{x_B} = \bar{\beta}_{x_D} = \bar{\beta}_{x_D^*} = \bar{\beta}_{x_C} = \bar{\beta}_{x_E} = \bar{\beta}_{x_E^*} = 0$ against the alternative $H_A$, that at least one of these parameters differs from zero based on a likelihood-ratio test. We obtained the conditional (cond.) log-likelihood as specified in Section 4.2 based on (4), $l_A$, and based on (1), $l_0$, which then enabled us to compute the test statistics

$$T_{LRT} = 2\sup_{H_A} l_A - 2\sup_{H_0} l_0 \tag{6}$$

This test statistics is asymptotically $\chi^2_{rank(L)}$ distributed where $L$ is the matrix of contrasts that varies with each $M_{j,l}$. When we could not reject $H_0$ at the 5%-significance level, we favored the specification under (1) over (3) for the corresponding $M_{j,l}$. We interpret the test result as an indication rather than a statement that provides definitive certainty for the choice between fixed and random effects.

In total, there are 98 ($= \sum_{l=1}^{8} m_l$) such AMMs for all predictor sets $A_{j,l}$ associated with each economic theory $G_l$. For each $G_l$ there is one set of models $\mathscr{M}_l$ which includes all corresponding $M_{j,l}$. We estimated these AMMs by (penalized) maximum likelihood with the `mgcv` package (Wood, 2011) and the `gamm4` package (Wood and Scheipl, 2017) as extensions to the statistical software `R` (R Core Team, 2020).

### 4.2 cAIC

Model selection based on the Akaike information criterion (AIC) is a common approach in econometrics. The criterion was initially introduced by Akaike (1973) and is composed of twice the maximized log-likelihood and a bias correction term, which, under certain regularity conditions, can be estimated asymptotically by two times the dimension of the unknown parameter vector specifying this log-likelihood (Saefken et al., 2018a). However, to apply this criterion to mixed models, two adaptations need to be made.

First, a joint Gaussian distribution of the random vectors $\boldsymbol{y}$ and $\boldsymbol{b}$ is assumed. This allows us to decide between two common views regarding the inference and predictions in mixed models. The distribution of $\boldsymbol{y}$ cond. on $\boldsymbol{b}$ leads to the cond. likelihood of $\boldsymbol{y}$ given $\boldsymbol{b}$, which then forms one component of our utilized cAIC. In contrast, when the random effects are integrated out, the marginal distribution of $\boldsymbol{y}$ emerges and thus provides the marginal likelihood. We demonstrate our reasoning for the conditional over the marginal view on the AIC later in this subsection.

Second, we consider the bias correction term for the conditional likelihood utilized in the cAIC. Following the introduction of the cAIC by Vaida and Blanchard (2005) the bias correction term is defined as

$$\text{BC} = 2tr(\boldsymbol{H}) \tag{7}$$

where $\boldsymbol{H}$ is the hat matrix projecting $\boldsymbol{y}$ onto $\hat{\boldsymbol{y}}$ where $\hat{\boldsymbol{y}}$ is a prediction vector for $\boldsymbol{y}$ with the random effects set to their predicted values. However, their proposal assumes known variance parameters and neglects the estimation uncertainty of these variance parameters. This estimation uncertainty can be taken into account whereby the bias correction term depends on the assumed cond. distribution of $\boldsymbol{y}$. For our Gaussian case, Liang et al. (2008) define

$$\text{cAIC} = -2\log f(\boldsymbol{y}|\boldsymbol{\theta}, \boldsymbol{b}) + 2\text{tr}\left(\frac{\partial \hat{\boldsymbol{y}}}{\partial \boldsymbol{y}}\right) \tag{8}$$

where $\boldsymbol{\theta}$ is defined as the vector of parameters in the model. Liang et al. (2008) approximate the trace of the derivatives of the estimated and predicted quantities numerically. However, this becomes computationally infeasible at a moderate sample size and a large quantity of models similar to in our case (Greven and Kneib, 2010). Greven and Kneib (2010) provide closed form expressions for these derivatives, circumventing the numerical approximations yielding an analytic representation of the cAIC which takes estimation uncertainty of the variance parameters into account. Saefken et al. (2018a) offer an efficient software implementation by means of the add-on package `cAIC4` (Saefken et al., 2018b).

The theoretical consideration underlying the derivation of the bias correction term introduced in (8) assumes independent and identically distributed errors across the subjects (countries in our case). As a result, the current software implementation in the `cAIC4` package originally provided for mixed models emerging from the `lme4` package (Bates et al., 2015) and the `gamm4` package (Wood and Scheipl, 2017) incorporates this assumption as well. However, in our case subject-specific error variances need to be modeled to capture the heterogeneity across countries, making the assumption of identically distributed errors inappropriate. The derived bias correction in (8) is thus no longer applicable since it disregards the additional parameters used for the estimation of $\boldsymbol{R}$ as defined in Section 4.1. To account for the estimation of a more complex error covariance structure in the bias correction, we incorporate the proposed extension of Overholser and Xu (2014). Since Overholser and Xu did not take into account the estimation uncertainty of $\boldsymbol{G}$, we implemented a working version that adds the number of unknown parameters $r$, which we used for the estimation of the error covariance matrix $\boldsymbol{R}$, to the bias correction term of (8) and obtained

$$\text{cAIC} = -2\log f(\boldsymbol{y}|\boldsymbol{\theta}, \boldsymbol{b}) + 2\left(\text{tr}\left(\frac{\partial \hat{\boldsymbol{y}}}{\partial \boldsymbol{y}}\right) + r\right). \tag{9}$$

We implemented Overholser and Xu's proposal for diagonal error covariance matrices into the `cAIC4` package and further extended the package for mixed and additive models estimated with the `mgcv` package (Wood, 2011). As a result, we provide, to our knowledge, the first software implementation for the estimation of the cAIC for mixed and additive models with non-identically distributed errors. This novel extension of `cAIC4` is made available to the CRAN repository for further applications. The proof of the asymptotic result of Overholser and Xu (2014) gives an upper bound for the bias correction term that can also be provided through derivations based on the partial derivative of the prediction vector $\hat{\boldsymbol{y}}$ for $\boldsymbol{y}$ with the random effects set to their predicted values.

We prefer the conditional over the marginal perspective on the AIC due to the mixed model representation of P-splines. To see the link in general, following Saefken et al. (2018a), we consider an additive model of the following form

$$\boldsymbol{y} = \boldsymbol{B}\boldsymbol{a} + \boldsymbol{\varepsilon}, \quad \boldsymbol{\varepsilon} \sim N(\boldsymbol{0}, \sigma^2\boldsymbol{I}) \tag{10}$$

where $\boldsymbol{B}$ is the design matrix containing the evaluations of predictors based on B-spline basis functions constructed from piecewise polynomials and $\boldsymbol{a}$ is the corresponding vector containing the basis coefficients. We can apply an eigenvalue decomposition to the quadratic penalty matrix $\boldsymbol{P} = \boldsymbol{D}^\top\boldsymbol{D}$ with column rank $k$, where $\boldsymbol{D}$ is the differences matrix such that $\boldsymbol{P} = \boldsymbol{V}\tilde{\boldsymbol{\Sigma}}\boldsymbol{V}^\top$. The $k$ eigenvectors in $\boldsymbol{V}$, which correspond to the $k$ positive eigenvalues, can be assigned to $\boldsymbol{V_1}$ while the remaining $d$ column vectors can be assigned to $\boldsymbol{V_0}$. We are then able to non-uniquely decompose the functional estimate $\boldsymbol{B}\boldsymbol{a}$ into two bases

$$\boldsymbol{B}\boldsymbol{a} = \boldsymbol{B}\boldsymbol{V_0}\boldsymbol{V_0}^\top\boldsymbol{a} + \boldsymbol{B}\boldsymbol{V_1}\boldsymbol{V_1}^\top\boldsymbol{a} = \boldsymbol{X}\boldsymbol{\beta} + \boldsymbol{Z}\boldsymbol{b} \tag{11}$$

yielding the common mixed model representation (Verbyla et al., 1999), where $\boldsymbol{\beta}$ specifies $d$ unpenalized parameters with the corresponding fixed effects design matrix $\boldsymbol{X}$ spanning the polynomial null space of $\boldsymbol{P}$, while $\boldsymbol{b}$ specifies $k$ penalized parameters corresponding to the random effects design matrix $\boldsymbol{Z}$ which spans its complement (Eilers et al., 2015), respectively. Currie et al. (2006) extended this representation for penalized functionals in higher dimensions. The specification under (11) differs from our generic mixed model (1) by different column ranks of the fixed and random design matrices and different dimensions of the corresponding parameter vectors, depending on the employed predictor sets $A_{j,l}$ as defined in Section 4.1. As a result, with $d = 2$ in our case, the marginal AIC would only take the fixed polynomial trend of degree one into account while the smooth deviation from this polynomial can now be taken into account in (9) as well. Thus, the cAIC, considered as a predictive measure in this context, accounts for the plausible assumption that the non-linear functional relation between the predictors and $\boldsymbol{y}$ estimated in our data set represents a more general relationship which is expected to hold also for new country observations.[18]

### 4.3 Model-based Boosting

To maximize predictive performance on out-of-sample data, we in addition also relied on a machine learning approach which could also be used for forecasting purposes. Specifically, we apply a model-based boosting algorithm which is purely driven by the data. It disregards the block by block segmentation of the predictors presented in Section 2, which was based upon the associated economic theories. For this reason, we next want to find an optimal prediction function $f^*$ for $\boldsymbol{y}$ through some prediction function $f$ which is found by minimizing the expected loss $\mathbb{E}_{Y,X}[\mathcal{L}(\boldsymbol{y}, f(\boldsymbol{x}))]$ (i.e., risk) through a gradient descent algorithm in function space (Hofner et al., 2014). We assume that $f$ is composed of a sum of functions of predictors and country-specific random effects which are all parameterized through different base learners. All predictors specified in Section 2 which are available in the full sample were collected in $\boldsymbol{x} := (\boldsymbol{x}_1, \ldots, \boldsymbol{x}_p)$. For the case of inflation, four kinds of base learners are specified. The first type are penalized least squares base learners which model all categorical predictors in $\boldsymbol{x}$. The second type are P-spline base learners which model all continuous predictors in $\boldsymbol{x}$. The third type are bivariate P-splines base learners allowing for the estimation of smooth interaction surfaces. We allow for the same bivariate interactions of predictors as we have done for the models specified by economic theory – *En. Prices (USD)* and *En. Rents (% GDP)* denoted by $f_{1,2}$ and *Trade Open. (% GDP)* and *Fin. Open.* denoted by $f_{3,4}$. The last type are random effect base learners for country-specific random intercepts, $f_{intercept}$, and country-specific random slopes, $f_{slope}$, with Ridge-penalized effects. We finally add a global intercept such that the following additive model results

$$\mathbb{E}[\boldsymbol{y}|\boldsymbol{x}] = \beta_0 + f_1 + \ldots + f_p + f_{1,2} + f_{3,4} + f_{intercept} + f_{slope} \tag{12}$$

The boosting algorithm minimizes the empirical risk which is given by

$$\mathcal{R} := \frac{1}{n} \sum_{i=1}^{n} \mathcal{L}(y_i, f(\boldsymbol{x_i})) \tag{13}$$

where $(y_i,\boldsymbol{x_i})$ is one out of $i = 1, \ldots, n$ realizations of $(\boldsymbol{y},\boldsymbol{x})$. The Huber-Loss, $\mathcal{L}$, was chosen because of its advantages in handling outliers compared with other approaches. The Huber-Loss is defined as

$$\mathcal{L}(\boldsymbol{y}, f; \delta) = \begin{cases} \frac{1}{2}(\boldsymbol{y} - f)^2 & \text{for } |\boldsymbol{y} - f| \leq \delta, \\ \delta(|\boldsymbol{y} - f| - \frac{\delta}{2}) & \text{for } |\boldsymbol{y} - f| > \delta \end{cases} \tag{14}$$

[18]See Greven and Kneib (2010); Saefken et al. (2018a).

and $\delta$ was chosen in each boosting iteration $m$ by

$$\delta_m = \text{median}(|y_i - \hat{f}_{m-1}|, i = 1, ..., n)$$

The utilized gradient boosting algorithm then starts with an initial function estimate $\hat{f}_{[0]}$ and proceeds in a stagewise manner. At each iteration $m$ it computes the negative gradient of the loss function and updates the current function estimate $\hat{f}^*_{[m]}$. Simultaneously, the algorithm descends along the gradient of the empirical risk $\mathcal{R}$ whereby only one base learner is selected at each iteration for updating the current function estimate. The decision when to stop the algorithm, $m_{stop}$, is crucial. However, it has been commonly suggested to enforce a stop of the algorithm before it converges to avoid overfitting and thus a suboptimal prediction (Bühlmann et al., 2007).

We employ a 10-fold bootstrap to find $m_{stop}$ by choosing the minimum out-of-sample risks averaged over all folds (Hothorn et al., 2018). To take the longitudinal structure of our data into account, this procedure was stratified by countries. To enforce variable selection, we decided to include only the base learners that were selected at least 1% of all $m_{stop}$ iterations. As a result, 14 out of the 34 base learners were selected. By stopping the algorithm before it converges, a shrinkage effect is imposed onto the effect estimates of the model. Therefore, we refitted the predictors associated with the 14 base learners collected in the predictor set $A_B$ as an AMM as specified in (3) and dubbed it $M_B$. We favored (3) over (1) due to the result of the testing procedure proposed by Mundlak (1978).

## 4.4 Selection Procedure

The model selection procedure is as follows: At a first stage, $\mathscr{S}_{fir}$, a winner model $M_l^*$ with the lowest cAIC among models $M_{j,l}$ in the set $\mathscr{M}_l$ is selected for each economic theory. At a second-stage $\mathscr{S}_{sec}$, $M_l^*$, $l = 1, \ldots, 8$ and $M_B$ are collected in the set $\mathscr{M}_P$. Some predictors associated with $\mathscr{M}_2$, $\mathscr{M}_3$, $\mathscr{M}_4$ and $\mathscr{M}_5$ are not imputed as these predictors are not available either across time and/or countries which makes a direct model comparison using the Likelihood and thus the cAIC invalid. As a result, if the predictor sets included in $M_2^*$, $M_3^*$, $M_4^*$ and $M_5^*$ are only available for a subsample of data, they are instead added to $\mathscr{M}^{''}$ to be compared to the AMM with the lowest cAIC in $\mathscr{M}_P$ later. The winner $M_P$ has the lowest cAIC in the set of models $\mathscr{M}_P$ and its cAIC is finally compared to each $M^{''} \in \mathscr{M}^{''}$ on the corresponding different data subsets to yield the overall winner $M^{**}$. If the computation of any AMM on any subset of the data fails, this AMM is assigned the highest cAIC in the given comparison. This can happen in particular for complex models on smaller subsets of the data. First- and second-stage selections are together labeled $\mathscr{S}_{sec}$. $M^{**}$ represents the model with the highest empirical relevance and provides the most reasonable set of inflation drivers.

The reasoning behind this two-stage approach is twofold. First, from a monetary economics perspective it is not known a priori which set of predictors has the most explanatory power for each economic theory ($G_l$). Second, the availability of specific predictor sets $A_{j,l}$ across time and countries enforces this procedure to ensure an admissible model comparison by means of the Likelihood and thus cAIC.

## 4.5 Varying Coefficient Models

After the model selection procedure, we additionally answered the important question of a structural break for the parameters comprised by $M_l^*$, $l = 1, \ldots, 8$ and $M_B$ through varying coefficient models. That is, we let each parameter interact with a two-level categorical variable $e_{i,t}$ such that (2) was replaced by

$$\tilde{\eta}_{i,t} = \sum_{x \in B_{j,l}} x_{i,t}\beta_x e_{i,t} + \sum_{(x,x^*) \in D_{j,l}} (x_{i,t}x^*_{i,t})\beta_{(x,x^*)} e_{i,t} + \sum_{x \in C_{j,l}} h_x(x_{i,t}) e_{i,t} + \sum_{(x,x^*) \in E_{j,l}} f_{(x,x^*)}(x_{i,t}, x^*_{i,t}) e_{i,t} \quad (15)$$

for each $M^*_l$, $l = 1, \ldots, 8$ and $M_B$. The first level of $e_{i,t}$ is considered when $t \leq 2007$ and the second level when $t > 2007$. Consequently, we obtain two simultaneous estimations of the same effect – one for each of the two levels. However, apart from the specification of (15), every model specification was identical to the model specification of the original $M^*_l$, $l = 1, \ldots, 8$ or $M_B$ respectively.

# 5 Results

The results of the AMMs presented in Section 4 are discussed in this section which is organized in two subsections. In the first, we present the results of $\mathscr{S}_{fir}$ as described in Section 4.4. Ordered by theory, we present the winning models, $M^*_l$, assessed by their cAIC and the resulting variables, discuss the linear links and plot the pattern of the variables that were estimated as P-splines together with their pointwise 95% confidence intervals (Wood, 2013). The empirical degree of non-linearity is assessed based on the effective degrees of freedom (EDFs; Wood (2017)) associated with each penalty specified in (2). The EDFs are reported along the y-axis. For example, an EDF equal to 1 indicates that the estimated $M_{j,l}$ penalized the corresponding smooth term to a linear relationship. To solve the identifiability issue of the AMMs specified in Section 4.1, all splines estimated incorporate a sum-to-zero constraint (e.g., $\sum_{i,t} \hat{h}_{GDPpc(USD)}(GDPpc(USD)_{i,t}) = 0$ for $M_{6,1}$). As a result, the corresponding effects can only be interpreted on a relative scale. In addition, for each model term enclosed by either (2) or (15) we performed a statistical test (Wood, 2013), where under the null the parameters associated with this model term are equal to zero. The order of magnitude of the p-value associated with this test is reported by means of asterisks.[19] Simultaneously, we evaluate the existence of structural breaks in the wake of the financial crisis and juxtapose the evidence of the pre-crisis period with that after the crisis. To this end, we applied the varying coefficient approach as defined in Section 4.5 in the Appendix. As discussed in Section 3 and 4.4, not all models could be estimated and compared on the full sample. The models included in $\mathscr{M}_1$, $\mathscr{M}_2$, $\mathscr{M}_6$, $\mathscr{M}_7$ and $\mathscr{M}_8$ were fitted on the maximum of observations possible.

For the estimates of institutional characteristics, $\mathscr{M}_2$, we fitted on 26 countries and for a time span from 2000 to 2012 at the first stage. However, we refitted $M^*_2$ on the full sample at the second stage since the predictors attached to its predictor set, $A_{16,2}$, are available for all 122 countries and all 19 points in time. The models examining monetary policy strategy variables, $\mathscr{M}_3$, were fitted on 30 countries and a time interval from 1997 to 2012. The models examining effects from public finance, $\mathscr{M}_4$, were fitted on 79 countries from 1997 to 2015. The AMMs enclosed by $\mathscr{M}_5$, that is globalization and technology, were fitted on 93 countries and from 1997 to 2012. Since the predictors, $A_{3,3}$, $A_{14,4}$ and $A_{20,5}$, are not available in the full sample, $M^*_3$, $M^*_4$ and $M^*_5$ were excluded from $\mathscr{S}_{sec}$.

In the second subsection, we describe the results of $\mathscr{S}_{sec}$ which were characterized by the addition of $M_B$ to the winners of $\mathscr{S}_{fir}$. Here, we identify the overall winning model, $M^{**}$, and describe its links to log inflation.

## 5.1 First Stage Selection

This subsection describes the results organized by economic theory. It first presents the winning model within the estimated model combinations and compares the empirical relevance of the vari-

[19] When $x$ corresponds to the EDF or the linear effect, $x^{***}$ corresponds to significance at the 0.1% level, $x^{**}$ at the 1% level, $x^*$ at the 5% level, $x^{\cdot}$ at the 10% level and no asterisks indicates no significance at the 10% level.

ables involved. The winning model is characterized by the lowest cAIC value. Table A.1 and A.2 in the Appendix display the results divided by theory. The first section lists the results for money, credit, and slack, $\mathscr{M}_1$, the second section those for institutions $\mathscr{M}_2$, the third for monetary policy strategies, $\mathscr{M}_3$, the fourth for public finance $\mathscr{M}_4$, the fifth for globalization and technology, $\mathscr{M}_5$, the sixth for demography, $\mathscr{M}_6$, the seventh for natural resources, $\mathscr{M}_7$, and the eighth for past inflation, $\mathscr{M}_8$. As can be gleaned from the p-values reported in the "p-value" column of Table A.1 and A.2, we specified country-specific fixed effects rather than random effects if the tested hypothesis specified based on the proposal of Mundlak (1978) in Section 4.1 was significant at the 5% level.

The subsequent discussion focuses on whether the effects are linear or not, based on the EDF values. Three figures plot the results for three different periods of observations. A left-hand panel plots the results for the whole sample, a middle panel those relating to the pre-crisis, and a right-hand panel those for the post-crisis period.

#### 5.1.1 Money, Credit, and Slack

**Overall** AMMs that include M2 growth exhibit higher empirical relevance than those that include credit growth, while the models that include output gap are more relevant than those that account for GDP growth. However, the output gap is less relevant than GDP pc.

**Winning Model** $M_{6,1}$ is the winning model. It exhibits GDP pc and credit growth. There is evidence of a linear and positive association between credit growth and log inflation. A one percentage point increase leads to a rise in log inflation of 0.022* (approximately 2.2 percent increase in inflation). The estimated effect after the GFC (0.136**) has strengthened relative to the pre-crisis period (0.0178). In contrast, GDP pc affects inflation in a non-linear way, as seen in Figure 3. An increase up to 50'000 USD is associated with a sharp increase in log inflation and peters out at this income value.

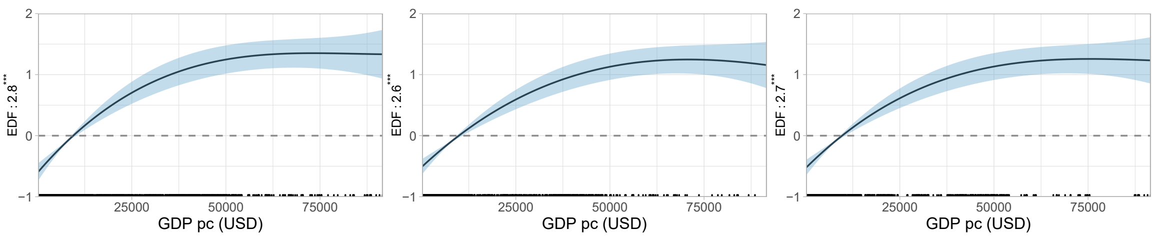


Figure 3: The estimate $\hat{h}_{GDP\ pc\ (USD)}(GDP\ pc\ (USD))$ results from the winning model $M_{6,1}$ specified under (2) and (15). The corresponding EDFs are reported along the y-axis. The ticks on the x-axis indicate the ranges of strong (dense ticks) and weak (sparse ticks) data support of the GDP pc (USD) variable.

#### 5.1.2 Institutions

**Overall** In all cases models with credit growth are more relevant than the models with M2 growth. GDP growth does better than GDP pc in 10 out of 12 cases. The freedom status variable bears also empirical relevance. However, these results are derived from a reduced sample size of 26 countries and a period from 2000 to 2012.

**Winning Model** The winning model is $M_{16,2}$ which features civil liberties next to credit growth and GDP pc. Due to the full-sample availability of civil liberties, we refitted the winning model on the full sample. The results are as follows: In the winning model, all variables show evidence of a weak linear relationship with log inflation. In particular, credit growth (Figure 4) affects log inflation in a linear way. However, after the GFC, as indicated by missing asterisks of the EDFs, it cannot be told if the effect differs from zero. Estimated across the entire time span, the transition from no civil liberties to higher civil liberties is associated with an increasing impact on log inflation ($0.01^{*}$ at most). However, before the crisis, this effect was positive (0.12 at most) and turned negative afterwards ($-0.2^{*}$ at most). GDP pc exerts a significant negative effect ($-0.00001^{***}$) across the entire period.

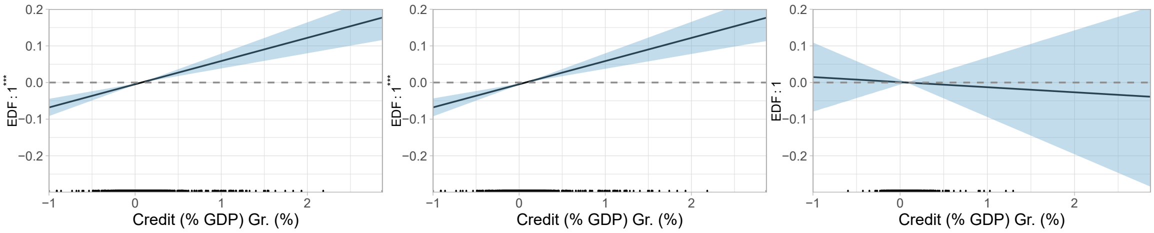


Figure 4: The estimate $\hat{h}_{Credit\ (\%GDP)\ Gr.(\%)}(Credit\ (\%GDP)\ Gr.(\%))$ results from the winning model $M_{16,2}$ specified under (2) and (15). The corresponding EDFs are reported along the y-axis. The ticks on the x-axis indicate the ranges of strong (dense ticks) and weak (sparse ticks) data support of the Credit (% GDP) Gr. (%) variable.

### 5.1.3 Monetary Policy Strategies

**Overall** Models including exchange-rate arrangements (ERA) do better than those with inflation targeting. Credit growth and M2 growth do equally well in terms of empirical relevance, whereas GDP growth outperforms GDP pc in four out of four cases.

**Winning Model** $M_{3,3}$ is the winning model. According to it, ERA are important next to credit and GDP growth. The transition from a situation with no legal tender, actually a fixed-exchange-rate regime, to managed floating leads to a rise in log inflation ($0.052^{*}$). This effect is slightly weaker (0.031) for a transition to a crawling-peg and weakest for the transition to free-floating (0.002). No structural changes could be estimated for ERA due to singularities. Credit growth displays a positive linear relationship with log inflation (Figure 5). This holds before the crisis but vanishes after that, although estimated with high uncertainty. GDP growth also exhibits a linear effect ($1.059^{***}$) which has slightly strengthened after the crisis ($1.439^{***}$).

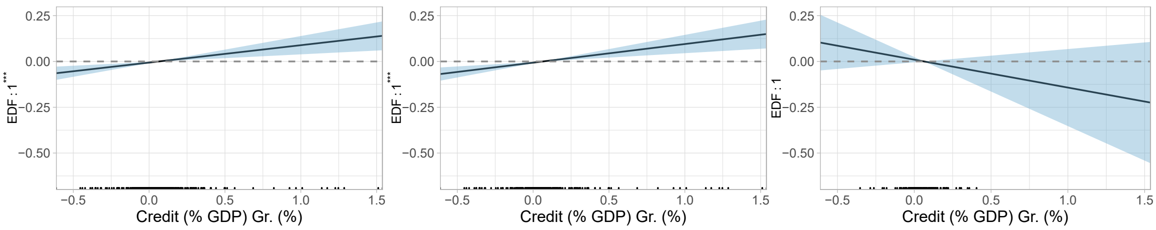


Figure 5: The estimate $\hat{h}_{Credit\ (\%GDP)\ Gr.(\%)}(Credit\ (\%GDP)\ Gr.(\%))$ results from the winning model $M_{3,3}$ specified under (2) and (15). The corresponding EDFs are reported along the y-axis. The ticks on the x-axis indicate the ranges of strong (dense ticks) and weak (sparse ticks) data support of the Credit (% GDP) Gr. (%) variable.

### 5.1.4 Public Finance

**Overall** Models with M2 growth do better than those with credit growth in seven out of eight comparisons. Models with GDP pc turn out to be better than the models that include GDP growth.

Debt denomination (Denom. (%)) plays a dominant role while the maturity structure (Matur.) is less relevant.

**Winning Model** $M_{14,4}$ is the winner. Figure 6 summarizes the estimations which exhibit some non-linearities. It includes M2 growth, GDP pc, and debt denomination. M2 growth exhibits a positive linear link with log inflation. In contrast, GDP pc (USD) reveals a clear non-linear link (panel d). While the effect varies somehow below a threshold of 10,000 USD, it strongly increases beyond this income level. This pattern arises after the crisis (panel f). Debt denomination exhibits a cubic association with log inflation over the entire period (panel g). Beyond a share of public and publicly guaranteed external long-term debt denominated in a foreign currency of 20%, a further issuance reduces log inflation. The comparison between the pre-crisis period summarized in panel h with the post-crisis period (panel i), shows a clear break. Since then, increasing the share of foreign-currency debt linearly boosts log inflation. Due to data availability, this evidence is obtained for observations of low and middle-income countries where an effect may be more likely than in advanced countries. However, the results after the crisis contrast with theoretical predictions from the time-inconsistency literature. One possible explanation is that the more debt is issued in a form that protects investors from unexpected inflation, the higher the level of inflation required to reduce the inflation-sensitive part of the debt.

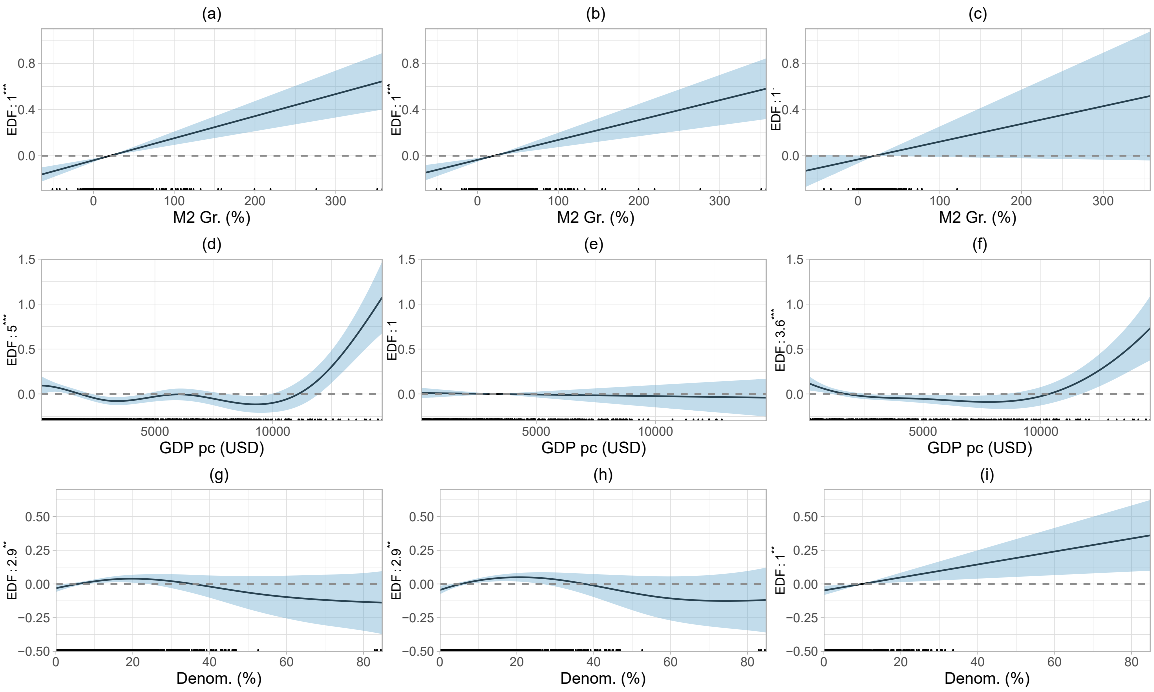


Figure 6: The three variables displayed result from the winning model $M_{14,4}$ specified under (2) and (15). The corresponding EDFs are reported along the y-axis. The ticks on the x-axis indicate the ranges of strong (dense ticks) and weak (sparse ticks) data support of the variables.

### 5.1.5 Globalization and Technology

**Overall** Models with GDP growth are superior to models that exhibit GDP pc in eight out of nine comparisons. Credit growth stands out in comparison with M2 growth in eight out of eight cases.

**Winning Model** The winning model is $M_{20,5}$ which features information and communication technology capital over the total capital stock (ICT Capital) next to credit and GDP growth. When ICT Capital is increased by one unit, log inflation rises by $4.088^{***}$ c.p. on average (approximately 4.1 percent increase in inflation). The effect weakens when separated into the pre-crisis ($2.537^{***}$) and the post-crisis ($2.748^{***}$) era. As illustrated in Figure 7 credit growth reveals a linear link with log inflation over the whole sample period and in the pre-crisis period but disappears subsequently. In contrast, while GDP growth hardly affected log inflation before the crisis (0.123), it has boosted inflation ($1.581^{***}$) thereafter, leading to inflation rising relationship over the whole period ($0.083^{***}$).

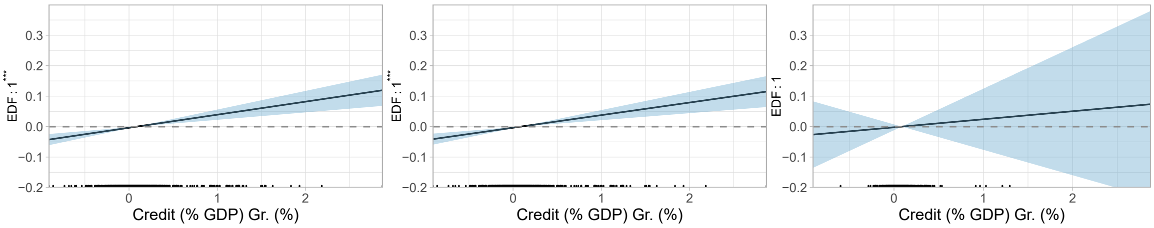


Figure 7: The estimate $\hat{h}_{Credit\ (\%GDP)\ Gr.(\%)}(Credit\ (\%GDP)\ Gr.(\%))$ results from the winning model $M_{20,5}$ specified under (2) and (15). The corresponding EDFs are reported along the y-axis. The ticks on the x-axis indicate the ranges of strong (dense ticks) and weak (sparse ticks) data support of the Credit (% GDP) Gr. (%) variable.

### 5.1.6 Demography

**Overall** AMMs with credit growth fare better than those with M2 growth in three out of four cases. This also holds for the models featuring the share of the population older than or equal to 65 (Age 65 (%)) compared to those exhibiting the share of population older than or equal to 75. Models that include GDP pc are superior to the models with GDP growth in three out of four cases.

**Winning Model** $M_{4,6}$ exhibits the variable combination that best explains a relationship between demography and log inflation. It includes Age 65 (%) next to credit growth and GDP pc. Age 65 (%) exerts a significant (at all levels) negative effect on log inflation. If this share increases by one percentage point, log inflation decreases on average by $0.039^{***}$. This effect is of similar magnitude before the crisis ($-0.032^{***}$) but weakens afterward ($-0.022^{***}$). From Figure 8 which displays the non-linear estimates of GDP pc, we can infer a similar non-linearity over the whole sample period as for GDP pc in the winning model $M_{6,1}$ illustrated in Figure 3. However, in contrast to $M_{6,1}$, where the non-linearity holds up in all three (sub)periods, the effect changes from quadratic before the crisis to linear after the crisis. Note that we observe higher values of GDP pc after the crisis than before. Credit growth exhibits a positive linear association ($0.023^{*}$) across the whole sample. Before the crisis the effect is similar to the overall observation ($0.025^{***}$) but strengthens ($0.085^{***}$) after that.

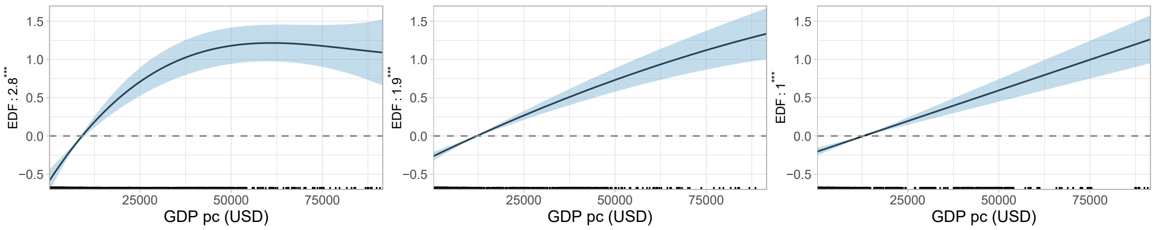


Figure 8: The estimate $\hat{h}_{GDP\ pc\ (USD)}(GDP\ pc\ (USD))$ results from the winning model $M_{4,6}$ specified under (2) and (15). The corresponding EDFs are reported along the y-axis. The ticks on the x-axis indicate the ranges of strong (dense ticks) and weak (sparse ticks) data support of the GDP pc (USD) variable.

### 5.1.7 Natural Resources

**Overall** In three out of four comparisons, AMMs that include credit growth instead of M2 growth yield a better result. Models with GDP pc are superior to those that contain GDP growth (in two out of three cases).

**Winning Model** $M_{12,7}$ results as the winning model. It is composed of credit growth, GDP pc, and the interaction of energy prices with energy rents. From Figure 9 we can infer non-linear relationships. An acceleration in credit growth in the range between 0 and 150% (panel a) pushes log inflation non-linearly. The effect is positive and linear before the crisis (panel b) but becomes negative and non-linear in the post-crisis period (panel c). Turning to GDP pc (panels d-f), the relationship with log inflation is again similar to Figure 3. It is cubic throughout. Panels g-i illustrate the bivariate interaction effects between energy prices and energy rents using contour plots. They show the joint relationship between energy prices on the x-axis, energy rents on the y-axis, and log inflation. The passage from a blue to a red area denotes mounting inflationary pressure. Conversely, the passage from a red to a blue area indicates a decrease in inflation. The black contour (iso-effect value) lines indicate the strength of the effects, which can only be interpreted on a relative scale, as discussed at the beginning of this section. Along the same iso-effect line, the interaction effect does not change. From panel g, a non-linear interaction effect between energy prices and rents can be inferred. When energy prices are below 75 USD while rents are high (above 25), the strongest impact on log inflation arises from an increase in energy prices. The effect from rising energy prices beyond 75 USD is still positive but weakens sharply. When energy rents hover below 25, an energy price increase still boosts log inflation, but by a much smaller magnitude than when rents are high. In the pre-crisis period, the relationship remains non-linear (panel h). The post-crisis still exhibits a non-linear interaction as long as energy prices are below 50 USD, but disappears beyond this level. While an increase in energy prices still leads to more log inflation, a change in energy rents leaves log inflation unaffected for any value of energy prices above 50 USD (c.p.).

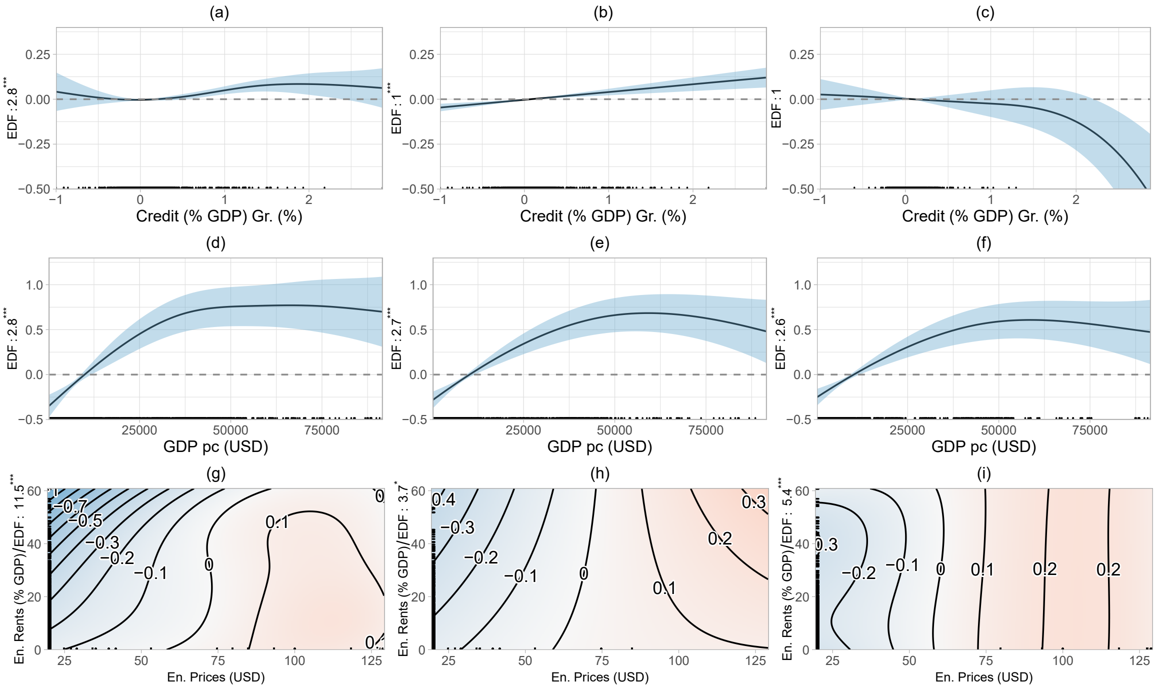


Figure 9: The three variables displayed result from the winning model $M_{12,7}$ specified under (2) and (15). The corresponding EDFs are reported along the y-axis. The ticks on the x-axis indicate the ranges of strong (dense ticks) and weak (sparse ticks) data support of the variables.

#### 5.1.8 Past Inflation

**Overall** AMMs that feature M2 growth strictly outperform AMMs that exhibit credit growth. No clear picture emerges from the comparison of AMMs that include GDP pc with models that include GDP growth.

**Winning Model** The winning model is $M_{2,8}$ and includes past inflation together with M2 growth and GDP pc. There is evidence of a positive linear effect ($0.001^{***}$) from past inflation estimated over the whole sample period. While the relationship did not change, the strength of the effect increased somewhat since the crisis ($0.011^{***}$) compared with the preceding period ($0.001^{***}$). As seen in the left panel of Figure 10, there is a quadratic relationship between M2 growth and log inflation in the whole sample, but with evidence for a linear relationship in the region with the most data support. The uneven distribution of the data should limit the interpretation of the effects in areas without any data support. An acceleration of M2 growth below a level of 100% raises inflation. Beyond 100%, the impact becomes highly uncertain. In contrast, before the crisis, the center panel suggests that M2 Gr.(%) impacted log inflation linearly. After the crisis, the effect strengthened slightly. In contrast, GDP pc exhibits a positive and linear effect over the whole period ($0.00002^{***}$), before ($0.00002^{***}$), and after the crisis ($0.00002^{***}$).

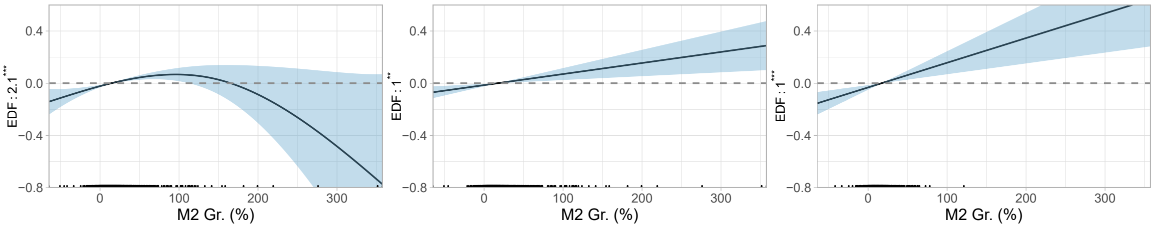


Figure 10: The estimate $\hat{h}_{M2\ Gr.\ (\%)}(M2\ Gr.\ (\%))$ results from the winning model $M_{2,8}$ specified under (2) and (15). The corresponding EDFs are reported along the y-axis. The ticks on the x-axis indicate the ranges of strong (dense ticks) and weak (sparse ticks) data support of the M2 Gr. (%) variable.

We do not explicitly examine how people form their inflation expectations. However, the importance of past inflation suggests the existence of (at least a share of) "adaptive expectations users" in practice.

## 5.2 Second Stage Selection

In $\mathscr{S}_{fir}$, discussed in Section 5.1, we derived the winning model for each economic theory. In this subsection, we discuss the derivation of the overall winning model, $M^{**}$. This required a second stage selection because the winning model of the first stage for four of the theories examined was obtained from a lower number of countries and a reduced period. This applies to theories associated with institutions, monetary policy strategies, public finance, and globalization and technology ($\mathscr{M}_2$, $\mathscr{M}_3$,$\mathscr{M}_4$ and $\mathscr{M}_5$). Their Likelihood and thus their cAICs cannot be directly compared with the AMMs from the other theories – $\mathscr{M}_1$, $\mathscr{M}_6$, $\mathscr{M}_7$, $\mathscr{M}_8$ – and the AMM selected by the boosting algorithm, $M_B$. However, since some AMMs comprised by $\mathscr{M}_2$, $\mathscr{M}_3$, $\mathscr{M}_4$ and $\mathscr{M}_5$ contain $M_{j,l}$ associated with predictor sets $A_{j,l}$ that are also available for the full sample, these $M_{j,l}$ can be refitted on the full sample, in case they were selected during $\mathscr{S}_{fir}$. This is the case for $M_2^*$. As a result, $M_2^*$ has been refitted on the full sample and was added to the comparison of the AMMs that were already estimated during the first stage comparison (i.e., $M_{6,1}, M_{20,5}, M_{4,6}$ and $M_{12,7}$). We next present $M_B$ and compare its cAIC against the cAIC of the first-stage winners.

**AMM Selected by the Boosting Algorithm** The boosting algorithm selected the set of predictors $A_B$ which can be inferred from the last subsection of Table A.2. This subsection also includes separating all selected predictors into disjoint subsets, informing which predictors were modeled (non-)linearly and/or through a bivariate interaction. For the boosting algorithm we added more predictors to those exhibited in the AMMs presented in Section 5.1. These additional variables are domestic credit level by the financial sector in percent of GDP (Credit Fin. (% GDP)) and its growth rate (Credit Fin. (% GDP) Gr. (%)). The remaining additional variables are M2 (% GDP), Credit (% GDP), Debt (% GDP), En. Price Gr. (%), En. Rents Gr. (%), GDP (USD), and GDP pc Gr. (%).

Figure 11, 12 and 13 present the non-linear effect estimates included in $M_B$. Past inflation (Figure 11, panel a-c) suggests such a pattern across the whole sample but with high uncertainty when assessed over the whole sample period. However, in the range where most observations lie ($< 250\%$), the relationship is linear with a positive slope. The same observation holds for the pre- and post-crisis period. The bivariate interaction of energy prices and rents (panel d) confirms the results from the estimation of $M_{12;7}$ illustrated in Figure 9, at least over the entire sample. In the pre-crisis period, the interplay between energy prices and rents weakens (panel e). An increase in energy prices beyond 75 USD would lower log inflation, irrespective of the value of energy rents. Below energy prices of 75 USD, a rise in energy prices would increase log inflation and still for any level of energy rents. On the other hand, if energy rents rise, there is hardly any effect on log inflation, regardless of the level of energy prices. Finally, in the post-crisis era (panel f), the impact of the interaction of energy prices and rents vanishes completely. When interpreting these results, it has to be kept in mind that $M_B$ estimates the univariate effects of energy prices and rents in contrast to $M_{12,7}$, which estimates their interaction.

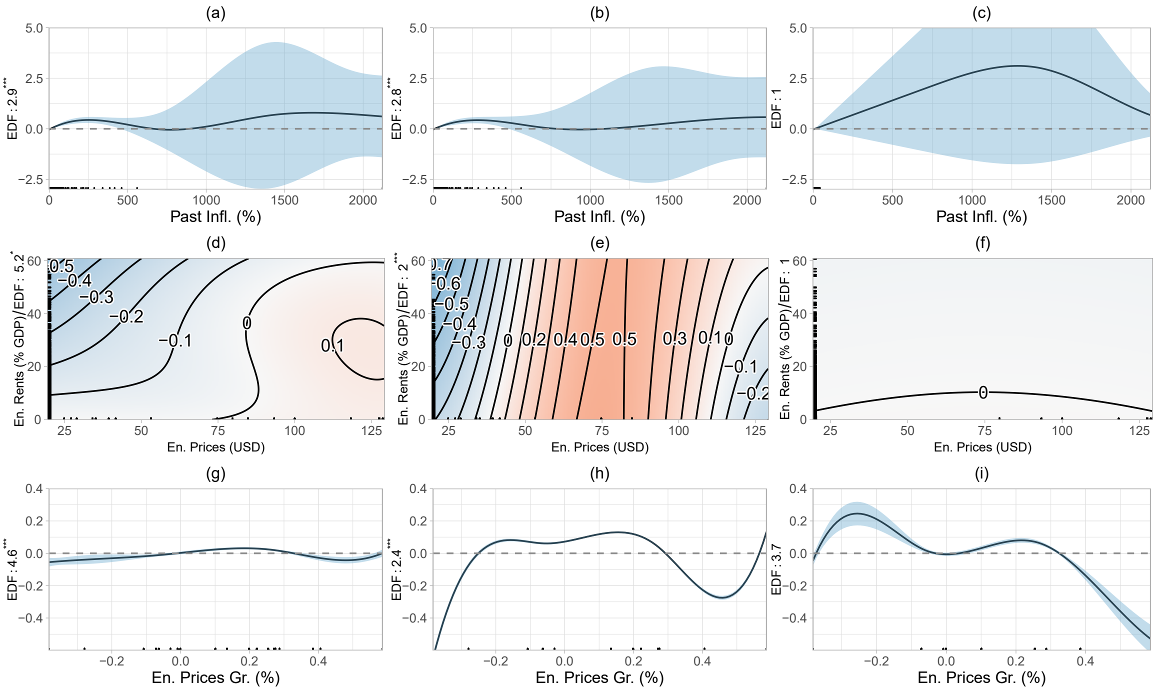


Figure 11: The first out of three plots that displays the estimated non-linear effects from $M_B$.

Panels g, h, and i display the results of energy price growth. Over the whole sample, the relationship is highly non-linear (panel g). For a growth rate of energy prices below 20% a rise in the growth rate increases log inflation. Beyond a growth rate of 20% a further energy price rise has an inflation abating effect, followed again by an acceleration above 50%. The evidence for the pre-crisis period can be seen in panel h and in the post-crisis period in panel i. Note that the variation for the energy price variable (and its growth) results exclusively from the time variation and not from the cross-country variation, as we have identical energy prices for each country in the estimation. The resulting uneven distribution of the data weakens the reliability of the effects in areas without any data support.

Figure 12 summarizes the results of financial openness, energy prices, and credit. As long as values of financial openness hover below 0.6, an increase in openness lowers log inflation but increases it beyond this threshold (panel a). This pattern also holds before the crisis (panel b) but turns linear (panel c) after the crisis. Energy prices show again a strong non-linear relationship (panel d). Below 80 USD, a rise in energy prices is conducive to inflation, although subject to high uncertainty. Afterward, the effect turns negative. The evidence preceding the crisis (panel e) suggests that energy prices were associated with lower inflation, especially beyond 80 USD. However, this changed dramatically after the crisis (panel f) where energy price boosts below 80 USD are linked with continuously higher log inflation and stagnation afterward. For credit the relationship is also non-linear but positive and strong for values below 50 over the whole sample (panel g). When separating into the pre- (panel h) and the post-crisis period (panel i), the effect does not differ from zero.

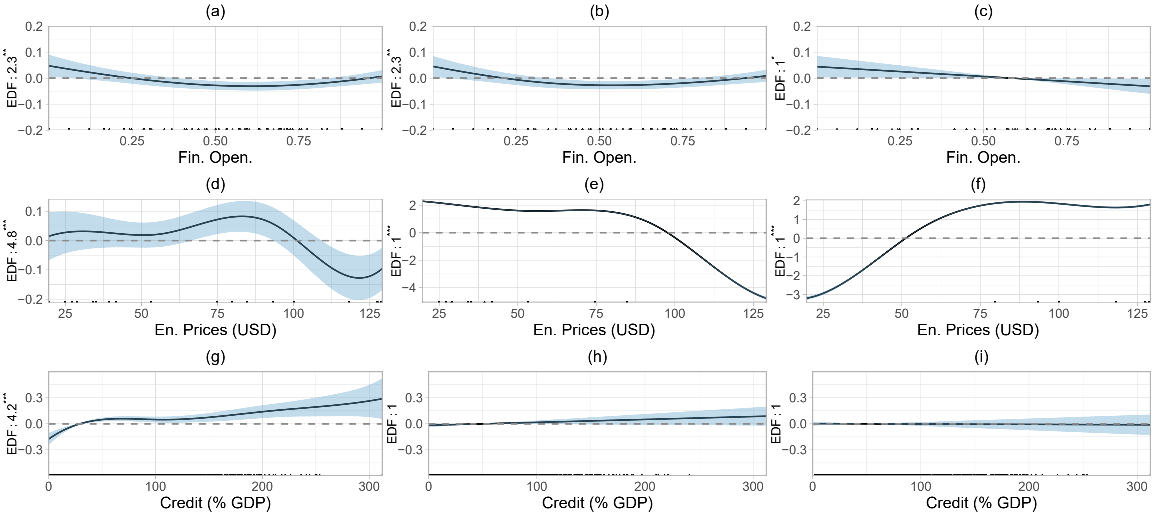


Figure 12: The second out of three plots that displays the estimated non-linear effects from $M_B$.

The last non-linear effects comprised by $M_B$ are shown in Figure 13 and relate to the output gap whose pattern suggests a cubic relationship with log inflation. Log inflation is boosted by a widening gap between -5% and 20% and followed by a negative effect (although subject to increasing uncertainty). This pattern holds over the whole sample and in the period preceding the crisis. However, after the crisis, the relationship has changed, becoming negative for output gap values below -5% and positive after that.

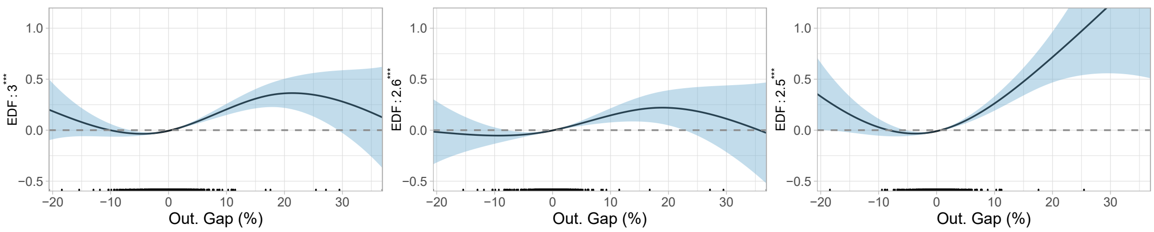


Figure 13: The third out of three plots that displays the estimated non-linear effects from $M_B$.

Finally, all linearly estimated effects of $M_B$ are insignificant at the 10% level. One exception is M2 growth ($0.0005^*$), whose impact weakens before the crisis (0.0004) but turns stronger ($0.003^{***}$) after the crisis. The second exception is trade openness which exhibits a negative impact on log inflation ($-0.001^*$) across the whole sample but turns insignificant when separated into a pre- and post-crisis effect.

**Overall Winner** As seen in Table A.1 and A.2 in the Appendix the comparison among theory-based winning models yields $M_{12,7}$ as the best model. However, the lowest cAIC overall is exhibited by $M_B$. Since both AMMs feature variables associated with natural resources, we conclude that these variables play a key role in the inflation (disinflation) process. In particular, the interaction of prices and rents of natural resources exhibited in $M_B$ and $M_{12,7}$ seems to have particularly high explanatory power. The empirical relevance is higher when energy rents and prices interact than when they enter as two separate univariate terms. Moreover, their interacting effects are highly non-linear. The boosting algorithm supports this interaction and shows the importance of energy prices and their growth rate as additional univariate drivers of inflation. Finally, we computed the cAIC for models that do not contain any economic variable at all (that is, they exhibit no effects other than for time and country-level) and found a substantially higher cAIC for these models compared to every other model included in the first and second stage selection. Consequently, it can be inferred that model compilation based on economic theory significantly improves the goodness-of-fit.

Summarizing the evidence of the pairwise comparisons on a meta-level yields that credit growth outperforms M2 growth and GDP pc outperforms GDP growth.

# 6 Conclusions

We contribute to the literature on what determines inflation and how by estimating a large quantity of macro, institutional and political models in a sample of 122 countries at different stages of development from 1997 to 2015. Both the comprehensive cross-country data set and the covered period are of particular interest for three reasons. First, this period is characterized by a negative inflation trend that prompted central banks in advanced countries even to take countermeasures. Second, exploiting data from a large set of heterogeneous countries helps mitigate potential selection biases. Third, observations following the GFC allow for the examination of potential structural changes.

The methodical innovation to the empirical literature on inflation is the use of additive mixed models selected by cAIC with which we identify model winners from among eight economic theories. Additive mixed models present various features particularly suitable for our data set. In particular, they enable us to account for country heterogeneities and potential non-linearities. Overall, we estimated 108 models and 37 explanatory variables.

Three general results emerge from the analysis. First, we identified both linear and non-linear effects, adding new insights into the evolution of inflation. Second, there is compelling evidence that corroborates the importance of some variables suggested in the literature; other variables that have been reported to be important in previous research are less relevant. Third, we uncovered several structural breaks since the GFC.

From among the eight theories, the winning model includes energy prices and energy rents, whose interplay exhibits non-linear associations with inflation. The boosting algorithm outperforms all theoretically motivated models in terms of explanatory power and suggests a particular role for energy prices, whereas energy rents by themselves do not seem to be as important. The effect of the interplay between these two variables appears to have weakened after the crisis.

Globalization and technology are less relevant. Information and communication technology capital has the highest empirical power from the variables that proxy globalization and technology. Its relationship with inflation is positive and was not affected by the GFC. Demographic developments turned out to be important, although less than energy prices and rents. The graying of society exerted a linear downward pressure on inflation, which weakened after the crisis.

Another finding is that credit growth is more often part of the winning model than M2 growth. Credit creation is linearly related to inflation. While credit expansion tends to raise inflation, this pattern seems to have weakened or even turned negative since the crisis. This suggests the existence of excess production capacities built up in preceding decades. In contrast, the positive link of M2 growth with inflation has strengthened since the crisis. The fact that credit growth is more important than M2 growth is arguably because M2 growth may strongly fluctuate over interest-rate cycles and at times become negative.

The next results relate to real GDP per capita, which appears to be more important than GDP growth and the output gap. In the literature, GDP per capita has been used as a proxy for the quality of a country's institutions. Accordingly, a higher institutional quality lowers inflation. We find the opposite. A higher level of GDP per capita below 50,000 USD raises inflation. This association has not changed over time. However, when estimated on 80 low and middle-income countries, results look quite different. In contrast to GDP per capita, the inflation-raising impact of real GDP growth has strengthened since the crisis.

The evidence with respect to monetary policy strategies is straightforward. Exchange-rate arrangements are more successful in explaining inflation than inflation targeting. Countries' political setup and in particular central bank independence and transparency, which in academic papers and public debates rank high, exhibit only a weak association with inflation. Civil liberties, in contrast, are associated with lower inflation since the financial crisis.

The most persuasive evidence comes from the denomination of external debt from the long list of theoretical explanations establishing a causal link between public debt or its management and inflation. Increasing its share displays an interesting non-linear pattern: A share below 20% raises inflation while a higher share exerts downward pressure. The financial crisis had a strong impact. Since then, the association has become positive and linear.

Finally, past and current inflation exhibit a linear association whose effect strengthened after the crisis.

The results have a bearing on monetary policy. The empirical importance of energy prices (and rents) has implications for when and how central banks need to respond to oil price shocks. Another challenge to monetary policy-making arises from the link between past and current inflation in a low-inflation environment. One way to lift inflation has been the stimulus of credit creation. However, there is little evidence that this policy was successful. It cannot be excluded that it even backfired. A promising tool to boost inflation is higher GDP per capita level. This suggests that economic policies geared towards growth should be more promising than monetary policies aimed at enhancing credit growth. Another result relates to the output gap. While in monetary theory and policy it is considered a key variable in the determination of inflation, it plays a minor role compared to GDP per capita.

The analysis could be extended along several dimensions. For instance, different explanatory variables related to institutional characteristics may be envisaged for a larger set of countries. Further, the separation of countries according to their stage of economic development may inform about the possible difference in the inflation process across countries. For forecasting purposes, the variables selected by our machine learning modeling approach could provide a starting point. Methods explicitly dedicated to the estimation of potential outcomes (Tinbergen, 1930; Wright, 1934) could also contribute to a more in-depth understanding of the causal links between the predictors uncovered in this paper and inflation along the lines of Baumann et al. (2021). From a statistical perspective regarding the cAIC, an avenue for future research is the provision of an analytic solution for the bias correction term for a more general error covariance structure.

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# A Table Appendix

| | $B_{j,l}$ | $C_{j,l}$ | $D_{j,l}$ | $E_{j,l}$ | p-value | cAIC |
|---|---|---|---|---|---|---|
| $A_{1,1}$ | M2 Gr. (%) | Out. Gap (%), Year | | | 1.00 | -1155.98 |
| $A_{2,1}$ | GDP Gr. (%) | M2 Gr. (%), Year | | | 1.00 | -1117.81 |
| $A_{3,1}$ | GDP pc (USD) | M2 Gr. (%) | | | 0.00 | -1280.26 |
| $A_{4,1}$ | Out. Gap (%) | Credit (% GDP) Gr. (%), Year | | | 0.92 | -1170.79 |
| $A_{5,1}$ | GDP Gr. (%) | Credit (% GDP) Gr. (%), Year | | | 1.00 | -1133.39 |
| $A_{6,1}$ | Credit (% GDP) Gr. (%) | GDP pc (USD) | | | 0.00 | **-1300.80** |
| $A_{1,2}$ | M2 Gr. (%), CBT | GDP Gr. (%) | | | 0.98 | -393.34 |
| $A_{2,2}$ | M2 Gr. (%), GDP pc (USD) | CBT | | | 0.37 | -391.92 |
| $A_{3,2}$ | Credit (% GDP) Gr. (%), CBT | GDP Gr. (%) | | | 0.88 | -395.57 |
| $A_{4,2}$ | CBT, GDP pc (USD) | Credit (% GDP) Gr. (%), Year | | | 0.16 | -395.85 |
| $A_{5,2}$ | Pol. Orien., Pol. Stab., M2 Gr. (%) | GDP Gr. (%), Year | Pol. Orien. : Pol. Stab. | | 1.00 | -401.33 |
| $A_{6,2}$ | Pol. Orien., Pol. Stab., GDP pc (USD) | M2 Gr. (%), Year | Pol. Orien. : Pol. Stab. | | 1.00 | -397.20 |
| $A_{7,2}$ | Pol. Orien., Pol. Stab., Credit (% GDP) Gr. (%) | Year, GDP Gr. (%) | Pol. Orien. : Pol. Stab. | | 1.00 | -402.67 |
| $A_{8,2}$ | Pol. Orien., Pol. Stab., GDP pc (USD) | Credit (% GDP) Gr. (%), Year | Pol. Orien. : Pol. Stab. | | 1.00 | -399.27 |
| $A_{9,2}$ | M2 Gr. (%), Pol. Rights | GDP Gr. (%), Year | | | 1.00 | -399.52 |
| $A_{10,2}$ | Pol. Rights, GDP pc (USD) | M2 Gr. (%), Year | | | 1.00 | -397.78 |
| $A_{11,2}$ | Pol. Rights, Credit (% GDP) Gr. (%) | GDP Gr. (%), Year | | | 1.00 | -401.72 |
| $A_{12,2}$ | Pol. Rights, GDP pc (USD) | Credit (% GDP) Gr. (%), Year | | | 1.00 | -400.48 |
| $A_{13,2}$ | Civil Lib., M2 Gr. (%) | GDP Gr. (%), Year | | | 1.00 | -389.19 |
| $A_{14,2}$ | Civil Lib., GDP pc (USD) | M2 Gr. (%), Year | | | 1.00 | 203.39 |
| $A_{15,2}$ | Civil Lib., Credit (% GDP) Gr. (%) | GDP Gr. (%), Year | | | 1.00 | -393.18 |
| $A_{16,2}$ | Civil Lib., GDP pc (USD) | Credit (% GDP) Gr. (%), Year | | | 1.00 | **-413.58**/ -1115.99 |
| $A_{17,2}$ | Fr. Status, M2 Gr. (%) | GDP Gr. (%), Year | | | 1.00 | -405.67 |
| $A_{18,2}$ | Fr. Status, GDP pc (USD) | M2 Gr. (%), Year | | | 0.99 | -403.87 |
| $A_{19,2}$ | Fr. Status, GDP pc (USD) | Credit (% GDP) Gr. (%), Year | | | 0.75 | -405.45 |
| $A_{20,2}$ | Fr. Status, Credit (% GDP) Gr. (%) | GDP Gr. (%), Year | | | 1.00 | -407.99 |
| $A_{21,2}$ | M2 Gr. (%), CBI, TOR | GDP Gr. (%), Year | TOR : CBI | | 1.00 | -396.04 |
| $A_{22,2}$ | CBI, TOR, GDP pc (USD) | M2 Gr. (%), Year | TOR : CBI | | 0.99 | -392.48 |
| $A_{23,2}$ | Credit (% GDP) Gr. (%), CBI, TOR | GDP Gr. (%), Year | TOR : CBI | | 1.00 | -398.46 |
| $A_{24,2}$ | CBI, TOR, GDP pc (USD) | Credit (% GDP) Gr. (%), Year | TOR : CBI | | 0.53 | -395.28 |
| $A_{1,3}$ | ERA, GDP Gr. (%) | M2 Gr. (%), Year | | | 1.00 | -386.56 |
| $A_{2,3}$ | ERA | M2 Gr. (%), GDP pc (USD), Year | | | 1.00 | -368.36 |
| $A_{3,3}$ | ERA, GDP Gr. (%) | Credit (% GDP) Gr. (%), Year | | | 1.00 | **-390.12** |
| $A_{4,3}$ | ERA, Credit (% GDP) Gr. (%) | GDP pc (USD), Year | | | 1.00 | -367.31 |
| $A_{5,3}$ | Infl. Targ., GDP Gr. (%) | M2 Gr. (%), Year | | | 1.00 | -381.05 |
| $A_{6,3}$ | Infl. Targ. | GDP pc (USD), M2 Gr. (%), Year | | | 1.00 | -363.80 |
| $A_{7,3}$ | Infl. Targ., GDP Gr. (%) | Credit (% GDP) Gr. (%), Year | | | 0.30 | -384.77 |
| $A_{8,3}$ | Infl. Targ., Credit (% GDP) Gr. (%) | GDP pc (USD), Year | | | 0.52 | -363.59 |
| $A_{1,4}$ | Debt (% GDP) Gr. (%) | M2 Gr. (%), GDP Gr. (%), Year | | | 1.00 | -127.18 |
| $A_{2,4}$ | Debt (% GDP) Gr. (%) | M2 Gr. (%), GDP pc (USD), Year | | | 1.00 | -176.95 |
| $A_{3,4}$ | Credit (% GDP) Gr. (%), Debt (% GDP) Gr. (%) | GDP Gr. (%), Year | | | 0.81 | -121.38 |
| $A_{4,4}$ | Credit (% GDP) Gr, Debt (% GDP) Gr. (%) | GDP pc (USD), Year | | | 1.00 | -137.40 |
| $A_{5,4}$ | M2 Gr. (%) | Prim. Bal. (% GDP), GDP Gr. (%), Year | | | 1.00 | -133.08 |
| $A_{6,4}$ | Prim. Bal. (% GDP) | M2 Gr. (%), GDP pc (USD), Year | | | 1.00 | -177.66 |
| $A_{7,4}$ | Prim. Bal. (% GDP), Credit (% GDP) Gr. (%) | GDP Gr. (%), Year | | | 1.00 | -119.48 |
| $A_{8,4}$ | Prim. Bal. (% GDP), Credit (% GDP) Gr. (%) | GDP pc (USD), Year | | | 1.00 | -144.61 |
| $A_{9,4}$ | Matur. | M2 Gr. (%), GDP Gr. (%), Year | | | 1.00 | -120.76 |
| $A_{10,4}$ | Matur. | M2 Gr. (%), GDP pc (USD), Year | | | 1.00 | -176.68 |
| $A_{11,4}$ | Credit (% GDP) Gr. (%), Matur. | GDP Gr. (%), Year | | | 1.00 | -115.07 |
| $A_{12,4}$ | Credit (% GDP) Gr. (%), Matur. | GDP pc (USD), Year | | | 1.00 | -133.05 |
| $A_{13,4}$ | | Denom. (%), M2 Gr. (%), GDP Gr. (%), Year | | | 1.00 | -138.57 |
| $A_{14,4}$ | | Denom. (%), M2 Gr. (%), GDP pc (USD), Year | | | 1.00 | **-262.59** |
| $A_{15,4}$ | Credit (% GDP) Gr. (%) | Denom. (%), GDP Gr. (%), Year | | | 1.00 | -138.64 |
| $A_{16,4}$ | Credit (% GDP) Gr. (%) | Denom. (%), GDP pc (USD), Year | | | 1.00 | -159.66 |

Table A.1: (1/2) Allocation of the predictor set $A_{j,l}$ of the model $M_{j,l}$ to $B_{j,l}$,$C_{j,l}$, $D_{j,l}$ and $E_{j,l}$. The cAIC value for the AMM with the lowest cAIC is printed in bold. For $A_{16,2}$, the first value indicates the cAIC value obtained on the subsample while the second one indicates the value obtained from refitting the model on the full sample.

| | $B_{j,l}$ | $C_{j,l}$ | $D_{j,l}$ | $E_{j,l}$ | p-value | cAIC |
|---|---|---|---|---|---|---|
| $A_{1,5}$ | M2 Gr. (%), GDP Gr. (%) | Fin. Open., Trade Open. (% GDP), Year | | | 1.00 | -861.16 |
| $A_{2,5}$ | Trade Open. (% GDP), GDP Gr. (%) | M2 Gr. (%), Fin. Open., Year | Trade Open. (% GDP) : Fin. Open. | | 1.00 | -862.49 |
| $A_{3,5}$ | GDP Gr. (%), | M2 Gr. (%), Year | Fin. Open. : Trade Open. (% GDP) | | 1.00 | -868.87 |
| $A_{4,5}$ | Fin. Open., Trade Open. (% GDP) | M2 Gr. (%), GDP pc (USD), Year | | | 1.00 | -835.10 |
| $A_{5,5}$ | Fin. Open., Trade Open. (% GDP), M2 Gr. (%) | GDP pc (USD), Year | Trade Open. (% GDP) : Fin. Open. | | 0.80 | -835.97 |
| $A_{6,5}$ | M2 Gr. (%) | GDP pc (USD), Year | Fin. Open. : Trade Open. (% GDP) | | 1.00 | -841.52 |
| $A_{7,5}$ | GDP Gr. (%), Fin. Open., Trade Open. (% GDP) | Credit (% GDP) Gr. (%) | | | 0.01 | -1052.44 |
| $A_{8,5}$ | GDP Gr. (%), Fin. Open., Trade Open. (% GDP) | Credit (% GDP) Gr. (%) | Fin. Open. : Trade Open. (% GDP) | | 0.05 | -1056.61 |
| $A_{9,5}$ | GDP Gr. (%), Fin. Open., Trade Open. (% GDP) | Credit (% GDP) Gr. (%) | | | 0.00 | -1052.44 |
| $A_{10,5}$ | GDP pc (USD), Fin. Open., Trade Open. (% GDP) | Credit (% GDP) Gr. (%) | | | 0.00 | -1016.03 |
| $A_{11,5}$ | Trade Open. (% GDP) | Credit (% GDP) Gr. (%), Fin. Open., GDP pc (USD) | Trade Open. (% GDP) : Fin. Open. | | 0.01 | -1017.63 |
| $A_{12,5}$ | GDP pc (USD), Fin. Open., Trade Open. (% GDP) | Credit (% GDP) Gr. (%) | | | 0.01 | -1016.03 |
| $A_{13,5}$ | GDP Gr. (%) | KOF Global., M2 Gr. (%), Year | | | 1.00 | -860.21 |
| $A_{14,5}$ | | GDP pc (USD), KOF Global., M2 Gr. (%), Year | | | 0.91 | -810.54 |
| $A_{15,5}$ | GDP Gr. (%) | KOF Global., Credit (% GDP) Gr. (%) | | | 0.03 | -1062.65 |
| $A_{16,5}$ | GDP pc (USD), KOF Global. | Credit (% GDP) Gr. (%) | | | 0.02 | -1026.54 |
| $A_{17,5}$ | GDP Gr. (%) | ICT Capital (%), M2 Gr. (%), Year | | | 0.59 | -794.95 |
| $A_{18,5}$ | M2 Gr. (%), GDP pc (USD) | ICT Capital (%), Year | | | 0.63 | -819.88 |
| $A_{19,5}$ | GDP pc (USD), ICT Capital (%) | Credit (% GDP) Gr. (%) | | | 0.00 | -1041.86 |
| $A_{20,5}$ | GDP Gr. (%), ICT Capital (%) | Credit (% GDP) Gr. (%) | | | 0.00 | **-1083.88** |
| $A_{1,6}$ | Age 65 (%), GDP Gr. (%) | M2 Gr. (%), Year | | | 1.00 | -1127.62 |
| $A_{2,6}$ | Age 65 (%), GDP pc (USD) | M2 Gr. (%), Year | | | 0.08 | -1105.93 |
| $A_{3,6}$ | Age 65 (%), GDP Gr. (%) | Credit (% GDP) Gr. (%), Year | | | 1.00 | -1142.30 |
| $A_{4,6}$ | Age 65 (%), Credit (% GDP) Gr. (%) | GDP pc (USD) | | | 0.04 | **-1308.49** |
| $A_{5,6}$ | Age 75 (%), GDP Gr. (%) | M2 Gr. (%), Year | | | 1.00 | -1116.97 |
| $A_{6,6}$ | M2 Gr. (%), GDP pc (USD) | Age 75 (%) | | | 0.00 | -1278.86 |
| $A_{7,6}$ | Age 75 (%), GDP Gr. (%) | Credit (% GDP) Gr. (%), Year | | | 1.00 | -1132.36 |
| $A_{8,6}$ | Age 75 (%), GDP pc (USD) | Credit (% GDP) Gr. (%) | | | 0.00 | -1264.68 |
| $A_{1,7}$ | GDP Gr. (%) | En. Prices (USD), En. Rents (% GDP), M2 Gr. (%), Year | | | 1.00 | -1273.53 |
| $A_{2,7}$ | GDP Gr. (%) | En. Prices (USD), En. Rents (% GDP), M2 Gr. (%), Year | | En. Prices (USD) / En. Rents (% GDP) | 1.00 | -1304.82 |
| $A_{3,7}$ | GDP Gr. (%) | M2 Gr. (%), Year | | En. Prices (USD) / En. Rents (% GDP) | 1.00 | -1266.08 |
| $A_{4,7}$ | En. Prices (USD), En. Rents (% GDP), GDP pc (USD) | M2 Gr. (%) | | | 0.00 | -1289.50 |
| $A_{5,7}$ | En. Prices (USD), En. Rents (% GDP), GDP pc (USD) | M2 Gr. (%) | | | 0.00 | -1289.50 |
| $A_{6,7}$ | En. Prices (USD), En. Rents (% GDP), GDP pc (USD) | M2 Gr. (%) | | | 0.00 | -1289.50 |
| $A_{7,7}$ | GDP Gr. (%) | En. Prices (USD), En. Rents (% GDP), Credit (% GDP) Gr. (%), Year | | | 1.00 | -1317.56 |
| $A_{8,7}$ | GDP Gr. (%) | En. Prices (USD), En. Rents (% GDP), Credit (% GDP) Gr. (%), Year | | En. Prices (USD) / En. Rents (% GDP) | 1.00 | -1321.54 |
| $A_{9,7}$ | GDP Gr. (%) | Credit (% GDP) Gr. (%), Year | | En. Prices (USD) / En. Rents (% GDP) | 1.00 | -1351.89 |
| $A_{10,7}$ | En. Prices (USD), En. Rents (% GDP), GDP pc (USD) | Credit (% GDP) Gr. (%) | | | 0.00 | -1279.86 |
| $A_{11,7}$ | En. Rents (% GDP), Credit (% GDP) Gr. (%), GDP pc (USD) | En. Prices (USD) | | | 0.00 | -1468.50 |
| $A_{12,7}$ | | Credit (% GDP) Gr. (%), GDP pc (USD) | | En. Prices (USD) / En. Rents (% GDP) | 0.00 | **-1544.34** |
| $A_{1,8}$ | GDP Gr. (%) | M2 Gr. (%), Past Infl. (%) | | | 0.00 | -1283.38 |
| $A_{2,8}$ | Past Infl. (%), GDP pc (USD) | M2 Gr. (%) | | | 0.00 | **-1294.65** |
| $A_{3,8}$ | GDP Gr. (%) | Credit (% GDP) Gr. (%), Past Infl. (%), Year | | | 1.00 | -1150.11 |
| $A_{4,8}$ | GDP pc (USD), Past Infl. (%) | Credit (% GDP) Gr. (%), Year | | | 1.00 | -1132.82 |
| $A_B$ | Debt (% GDP) Gr. (%), Debt (% GDP), Trade Open. (% GDP), M2 Gr. (%) | Past Infl. (%), Year, En. Prices (USD), En. Price Gr. (%), Credit (% GDP), Out. Gap (%), Fin. Open. | | En. Prices (USD) / En. Rents (% GDP) | 0.00 | **-1700.26** |

Table A.2: (2/2) Allocation of the predictor set $A_{j,l}$ of the model $M_{j,l}$ to $B_{j,l}$,$C_{j,l}$, $D_{j,l}$ and $E_{j,l}$. The cAIC value for the AMM with the lowest cAIC is printed in bold. The model complexity of $M_{9,5}$, $M_{12,5}$, $M_{5,7}$ and $M_{6,7}$ had to be reduced (i.e. fewer model parameters) due to non-convergence during the optimization of the initially intended AMM.

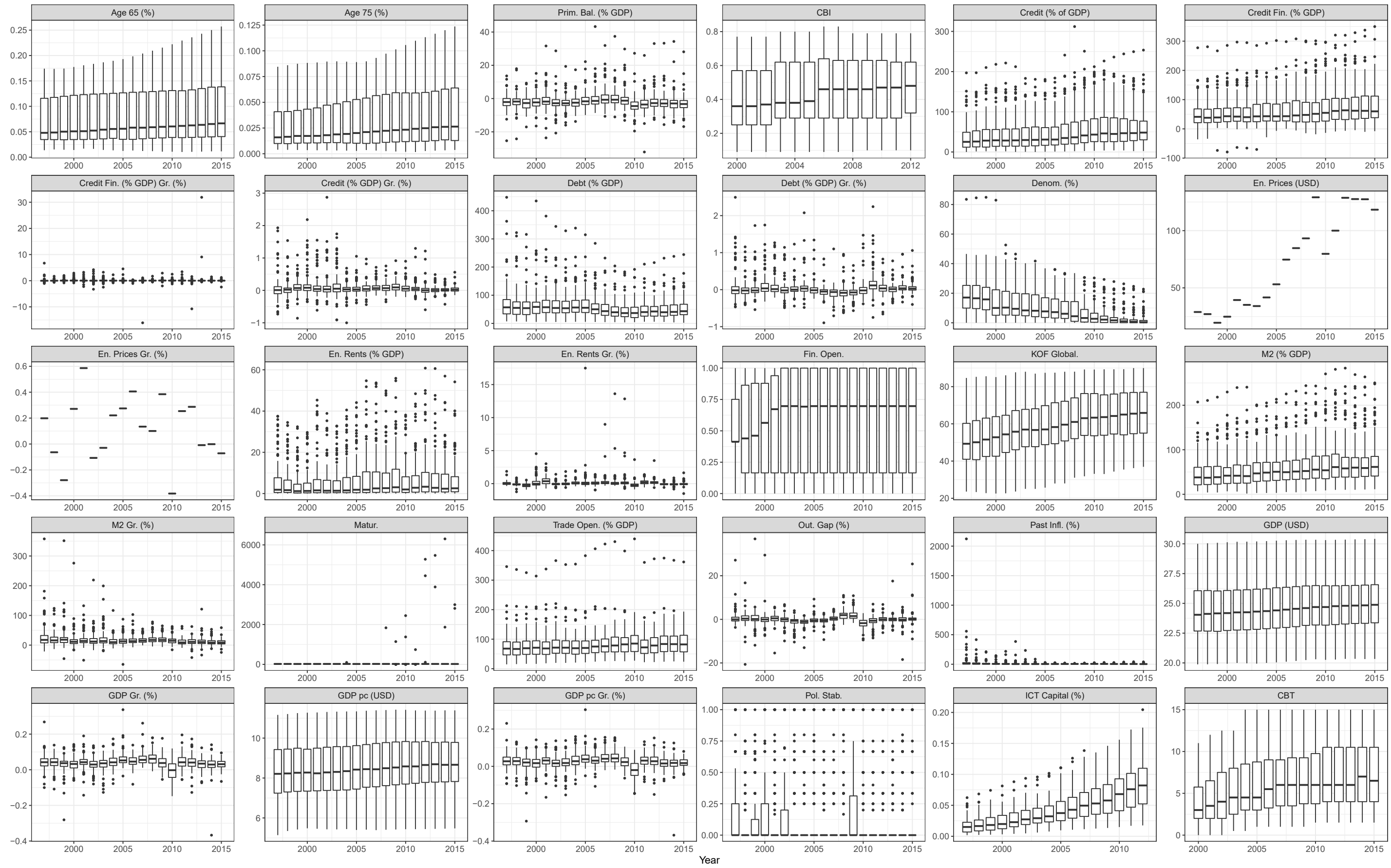


Figure A.1: Descriptive statistics for all metric predictors comprised by the data set. The variables GDP (USD) and GDP pc (USD) have been transformed by the natural logarithm for visualization.

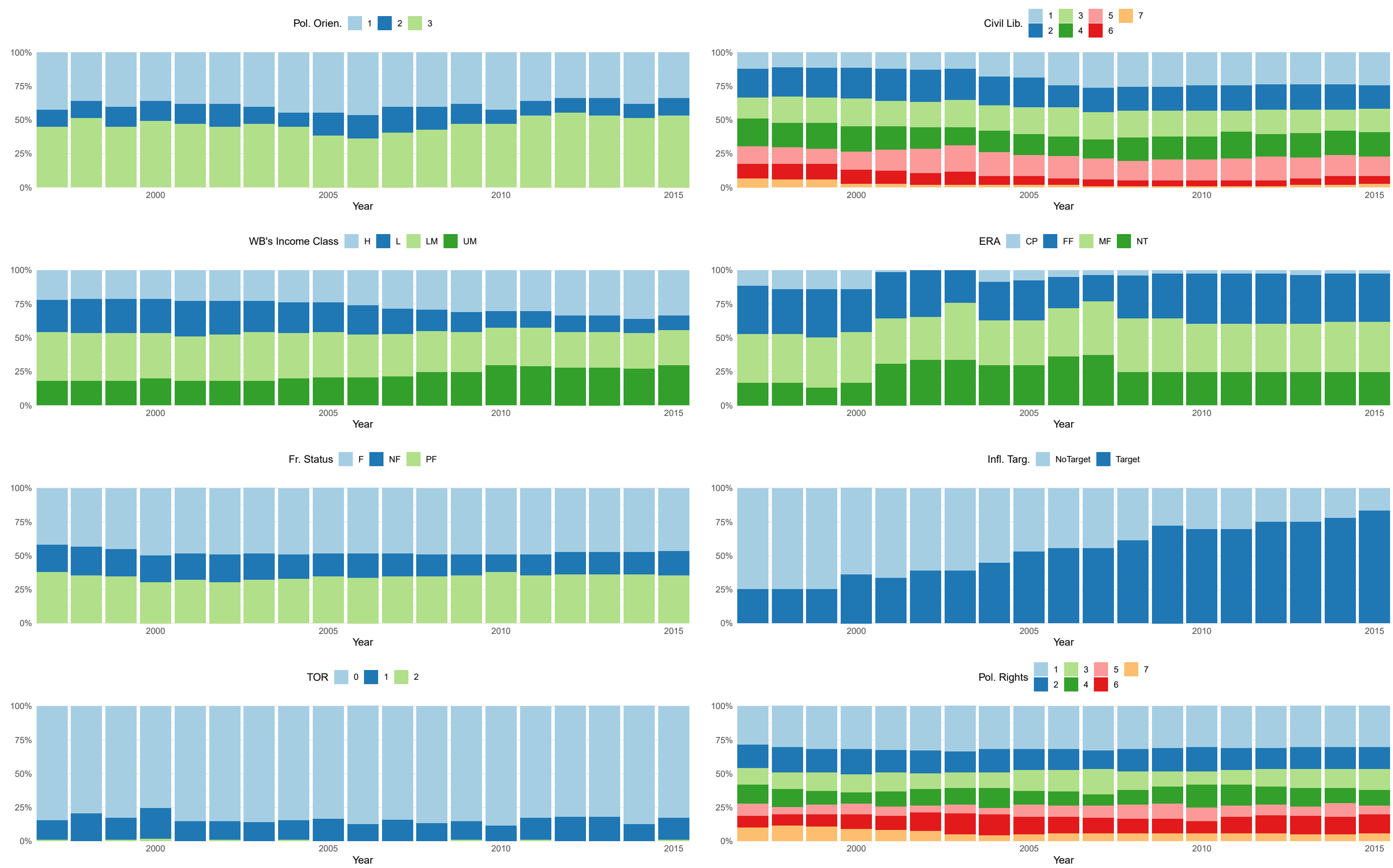


Figure A.2: Descriptive statistics for all categorical predictors comprised by the data set and the World Bank's income classification.

# B Literature Appendix

In this Appendix we offer a more comprehensive overview of the most common explanations of inflation, beginning with one of the most established pearls of wisdom in monetary economics. It postulates a relationship between long-run monetary growth and long-run inflation. This is the background underlying the belief that inflation is generally a monetary phenomenon. Traditional monetarists support the strict view that non-monetary factors are irrelevant in determining inflation. According to the P*-model that tends to support the traditional monetary view, inflation results from monetary growth; demand and supply shocks have no roles to play.

However, in criticizing the pure monetarist view, Kuttner (1990) noted that although some measure of money (possibly M2) may be the main determinant of inflation in the long run, it does not follow that only money matters in determining inflation over all horizons. In this vein a number of empirical studies show that the sources of inflation are quite diverse and include a country's institutional organization, the monetary policy strategy in place, fiscal imbalances, effects of globalization and technology, demographic changes, (shocks to) prices of natural resources, as well as past inflation. We will discuss them in turn and present a selection of empirical studies.

## B.1 Money, Credit, and Slack

### B.1.1 Money

A key macroeconomic axiom is the quantity theory of money. It posits a proportional relation between inflation and the growth rate of money (but no effect of a permanent increase in money growth on output and velocity). Numerous studies confirm that sustained high growth rates of a nation's stock of money in excess of its production of goods and services eventually produce high and rising inflation rates. For instance, Batini and Nelson (2001) show a relationship between inflation and money growth on UK and US data for the period 1953-2001. Studies involving international cross-sections of countries are, among others, De Grauwe and Polan (2005) and Assenmacher-Wesche and Gerlach (2007). De Grauwe and Polan (2005) control for the level of inflation and report long-run (1969-1999) cross-section evidence of a strong (although not proportional) positive relationship between the long-run growth rate of money and the rise in CPI inflation for 159 countries. However, this link is practically completely due to the presence of high-inflation or hyperinflation countries. Recent studies, for instance, Hillinger et al. (2015), and Teles et al. (2016) confirmed the quantity theory of money in countries with low inflation. However, the long-run link between money growth and inflation has weakened in low inflation countries, especially after the Great Inflation period. Gallegati et al. (2019), in a wavelet-based exploratory analysis covering 16 developed countries and spanning 140 years, documented a close relationship between excess money growth and inflation over time horizons between 16 and 24 years.

### B.1.2 Credit

Another variable that is related to money is credit creation. The reason for distinguishing between money supply and credit growth is given by the decoupling of the two since the 1980s (Schularick and Taylor (2012). In previous work (Calderón and Schmidt-Hebbel (2010)), domestic credit to the private sector to GDP has been seen as a proxy of financial depth and, as such, containing information that is expected to be negatively related to inflation.[20] First, financial depth may be seen as a measure of the institutional quality of a country. Second, the more developed financial markets are, the easier it is for a government to finance temporary (and sustainable) deficits through borrowing from national residents, making it less likely to incur in seigniorage-based revenue. Third, a financial sector's opposition to inflation could have an additional price-dampening effect. Posen (1995) argues that the opposition to inflation from the financial sector, which reflects the financial sector's distaste for inflation and its ability to express that distaste, is a significant predictor of inflation. In addition, a credit expansion that leads to a build-up of investment and capacities for production put downward pressure on prices. By contrast, an inflation-raising effect may arise from credit expansion that go hand in hand with money creation.

### B.1.3 Slack

A further central tenet of macroeconomics is that the real and nominal sides of the economy are linked through a Phillips curve relationship, in which inflationary pressures reflect the level of real economic activity and inflationary expectations. Two specifications have arisen over time: the Traditional (or New Classical) and the New Keynesian Phillips curve. In the New Classical form, inflation is a function of lagged expected inflation and a contemporaneous measure of excess demand, often measured by the output gap, defined as actual minus potential output. The parameter on excess demand indicates the degree to which prices are flexible. According to this form, inflation tends to rise if the gap is positive, while it tends to fall if the gap is negative. If the output gap is zero, inflation remains stable.

The New Keynesian approach predicts that there should be a short-run Phillips Curve that relates some measure of economic activity to inflation.[21] This approach posits that deviation of an economy's actual output from its potential level as a result of excess demand in an overheated economy (positive output gap) engineers inflation. [22] Empirical support for

[20] Other authors, for example, Dincer and Eichengreen (2014), measured financial depth by the ratio of M2 to GDP.

[21] See, for instance, Gali and Gertler (2007).

[22] Actually, the literature has developed a third approach – the Hybrid Phillips curve, according to which inflation depends on currently expected future inflation as well as lagged realized price changes, together with contemporaneous economic slack. The impulse-response pattern of inflation

the output (unemployment) gap model is provided by a number of studies.[23] However, inflation seems to have become less responsive to measures of the domestic output gap than in the past, as documented by Roberts (2006). The Phillips Curve has become less steep. Blanchard (2016) found that a drop in the unemployment rate in the U.S. has less than a third as much power to raise inflation as it did in the mid-1970s. A number of recent papers have pointed out that inflation can be approximated (and forecast) by statistical processes unrelated to the amount of slack in the economy. Dotsey et al. (2018) is representative of the papers that have documented this. Some commentators have interpreted the empirical disconnect between inflation and various measures of slack as evidence that the Phillips curve has weakened or even disappeared (Ball and Mazumder (2011).[24]

An important question is whether the financial crisis of 2008-2009 led to structural breaks. One point in case concerns the Phillips curve.[25] The background is the missing disinflation that was observed in advanced economies in the aftermath of the financial crisis. Several hypotheses have been advanced. Coibion and Gorodnichenko (2015) suggest that firms' inflation expectations moved countercyclically during the recession and recovery because they are overly influenced by oil prices, which increased from 2009 to 2011 – and extending their argument[26] – fell from 2014 through 2017. A second set of explanations focuses on special features of the financial crisis. Gilchrist et al. (2017) show that financial distortions created an incentive for firms to raise prices in response to adverse financial or demand shocks to preserve internal liquidity and avoid accessing external finance. This strengthened the countercyclical behavior of markups and attenuated the response of inflation to output fluctuations. Another explanation refers to expectations. Unlike the literature discussed above, which focuses on the U.S., Mazumder (2018) finds a stable Phillips curve for the euro area using short-term professional survey expectations data. He attributes the weakening of euro area inflation to a decline in expected inflation. Ball and Mazumder (2020) find that Friedman's half-century-old Phillips curve fits the behavior of core inflation in the euro area.

To test this theory, it is necessary to estimate potential or trend output in order to define the gap between actual and potential output. Therefore, any test of the gap model is a joint test of the estimated gap and the impact of the gap on inflation. Unfortunately, estimating trend or potential output is more an art than a science. There are many different methods, and no one is trouble-free. Stock and Watson (2019) recently proposed as a measure of slack real activity variables that are bandpass filtered or year-over-year changes instead of gaps.

## B.2 Institutional variables

The soundness of institutions in place is considered a prevention to the potentially numerous motives for authorities to inflate.[27] The institutional organization of a country can be split in four separate items—central bank independence, central bank transparency, political stability, and economic growth.

### B.2.1 Central Bank Independence

Rogoff (2003) argues that improved institutions and more sophisticated policymakers, not to mention a more sophisticated public, have played pivotal roles in the global reduction of inflation. Still, the fact that inflation has fallen everywhere—even in countries with weak institutions, unstable political systems, and thinly staffed central banks—raises the possibility that other factors have also been significant. Rogoff (2019) pointed to the influx of inexpensive Chinese imports and the rise of computers. But if one looks at the timing of when different countries succeeded in bringing down inflation, there is little question that the most important role must be assigned to the rise of central bank independence (CBI) throughout the world as a remedy for the time-inconsistency problem in monetary policy. Dincer and Eichengreen (2014) found that CBI has tended to increase over time in more open economies. In line with this argument, one aspect that has received much attention in explaining cross-country differences in inflation rates is the degree of CBI.

Since the seminal work of Kydland and Prescott (1977) and Barro and Gordon (1983), CBI is considered an institutional necessity for credible monetary policy geared toward price stability. This proposition has been widely analyzed with various independence measurements.[28] However, the cross-country empirical evidence on the relationship between the degree of CBI and inflation is mixed, largely depending on the choice of sample countries. On the one hand, a robust and significant inverse relationship has been found.[29] On the other hand, this result has been questioned.[30] Recently, Dincer and Eichengreen (2014) provided a detailed analysis of the effect of CBI on inflation and its variability during the period from 1998 to 2010 based on annual indices for more than 100 central banks. They found some negative, albeit statistically inconsistent, association between CBI and inflation.

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to output gap changes in the New Keynesian Phillips curve is opposite to those postulated by the New Classical approach. See Carlin and Soskice (2015).

[23] See, for instance, Coe and McDermott (1997), Clark and McCracken (2006), Deniz et al. (2016), Gross and Semmler (2017), and Jasova et al. (2019).

[24] See Stock and Watson (2019) and McLeay and Tenreyro (2019) for a different view.

[25] McLeay and Tenreyro (2019) and Hooper et al. (2019) provided reviews on the apparent flattening of the Phillips curve in the 2000s, and especially since the financial crisis recession. These studies focus on the U.S.

[26] See Stock and Watson (2019).

[27] See Cukierman (1992), Campillo and Miron (1997), Aisen and Veiga (2008), Calderón and Schmidt-Hebbel (2010).

[28] See Arnone et al. (2006) for a survey.

[29] See, among others, Grilli et al. (1991), Cukierman (1992), Alesina and Summers (1993), Loungani and Sheets (1997), Panagiotidis and Triampella (2006).

[30] See, among others, Posen (1995), Eijffinger and de Haan (1996), Fuhrer (1997), Campillo and Miron (1997), King and Ma (2001), Hayo and Hefeker (2002), Klomp and de Haan (2010).

Several possible reasons why a robust negative relation of independence with inflation is wanting have been proposed. One is the inaccuracy in measurements. Several of the indices that have been constructed to capture the degree of central bank independence rely on the wording of the law. This de jure measurement may be different from actual (de facto) independence, particularly in emerging and developing countries (Cukierman (1992)). Applying latent variable analysis to explicitly deal with measurement errors, Brumm (2002) concluded that the negative relation can be restored across countries.

A second explanation for the ambiguity in empirical studies is that the literature does not distinguish appropriately between central bank independence and conservatism.[31] According to Rogoff (1985), the inflation bias depends on the combination of both. If this is not taken properly into account, estimates may be distorted.

A third explanation is given by the lack of data. Earlier studies were based on pure cross-sections of countries. Crowe and Meade (2008) found a significant negative relationship between both legal and actual independence, the latter measured by the turnover rate of central bank governors,[32] and inflation in a sample of 56 countries after exploiting the time dimension of the data. However, they were unable to identify a significant link in the pure cross-section of the data set. One reason for this result might be that exploiting the time dimension of the data may diminish possible omitted variable biases which were identified in a meta-regression analysis of previous studies by Klomp and de Haan (2010). Following Brumm (2002) and de Haan et al. (2003) on the panel data set provided by Crowe and Meade (2008), Posso and Tawadros (2013) also found evidence that higher independence is conducive to lower inflation.

This evidence notwithstanding, the literature has little to say about what conditions support the effect of independence on inflation. As pointed out by Hielscher and Markwardt (2012), while many studies include a range of control variables, there is very little analysis into the interaction between them. Hielscher and Markwardt (2012) showed in a cross-section of 69 countries that higher independence does not necessarily improve the inflation performance. What is crucial is not only a sufficiently large increase in independence, but also a high quality of political institutions. Recently, Baumann et al. (2021) accounted for possible reasons that motivate the decision of a country to adopt a certain degree of CBI and use a causal model that summarizes the economic process of inflation to inform their statistical analysis in which countries are treated as units in a panel setup. The authors report only a weak causal link from independence to inflation, if at all.

#### B.2.2 Central Bank Transparency

One additional fact that needs to be accounted for in the analysis of central bank independence is that its increase has been accompanied by greater transparency to the point of becoming a key feature of modern monetary policymaking.[33] Most central banks announce their objectives with quantitative targets and publish numerical macroeconomic forecasts, marking a departure from long-standing practice which valued confidentiality. This change is partly a reflection of increased independence, which has been accompanied by formal accountability requirements. But foremost, central banks have become more transparent with the aim to make monetary policy more effective (Geraats (2014)).

Central banks have also become much more open about their policy decisions and some among them even give explicit guidance about upcoming policy moves (forward guidance). The move toward the provision of more information on future policy plans has become a prominent feature in monetary policy in countries where the effective lower bound (ELB) constraint has been binding following the deflationary pressures in the aftermath of the financial crisis. However, some central banks such as the Reserve Bank of New Zealand started to give explicit guidance about upcoming policy moves long before the financial crisis.

Overall, the empirical literature documents beneficial effects from transparency. Sterne et al. (2002) used the survey data collected by Fry et al. (2000) to find a statistically significant, inverse relationship between average inflation and transparency across 82 countries after controlling for a number of other factors, including central bank independence. Crowe and Meade (2007) reported, in contrast, that while the relationship between transparency and average monthly inflation is inverse, it is not significant in their sample of 40 countries. Dincer and Eichengreen (2014) found that greater transparency is associated with lower average levels of inflation after controlling for openness, financial depth, and past inflation.

#### B.2.3 Political Instability and Orientation

Political instability adds another potentially important element to the analysis of institutions for inflation. It may capture a number of effects. For example, high turnover rates of political incumbents may increase inflation as the political focus shifts to short-term gains, neglecting their associated long-term costs. Carmignani (2003) argues that political instability generates uncertainty about the future course of economic policies. The political framework of a country also determines its ability to collect taxes. Politically unstable countries tend to use inflation to increase their revenue since their tax system is more likely to suffer from tax evasion or a larger amount of underground activity.

According to Cukierman et al. (1992), political instability induces the use of revenues from money creation (seigniorage). The model prediction was tested on cross-section data for 79 countries after controlling for other variables. The outcome was that political instability significantly contributed to explaining the fraction of government revenue derived from seignorage. Aisen and Veiga (2005) showed on a data set covering around 100 countries from 1960 to 1999 that a higher degree of political

[31] See Berger et al. (2001), Hayo and Hefeker (2002).

[32] See Lustenberger and Rossi (2020) for possible differences between legal independence measures and the turnover rate.

[33] Dincer and Eichengreen (2014) documented that all central banks covered had a higher degree of transparency in 2010 compared to 1998. Still, central banks differ considerably in the extent to which they are transparent in various respects. Countries with higher per capita income, deeper financial markets, more open economies, stronger political institutions, and more flexible exchange rate regimes raise the transparency levels of their central bank.

instability is associated with higher inflation whereas higher degrees of economic freedom and democracy are associated with lower inflation. Similarly, Aisen and Veiga (2008) used the system-GMM estimator for linear dynamic panel data models on a sample covering 160 countries from 1960 to 1999 and found that higher political instability and social polarization were associated with more volatile inflation. Telatar et al. (2010) analyzed the role of the political and institutional environment in dynamic panel data estimations on a sample of 39 countries from 1983 to 2002, reporting an adverse effect of political instability on inflation. This is initially observed only for developed and low-inflation economies. However, when political freedom is taken into account, political instability turns out to be significant only for high-inflation countries. In a sample of 25 countries in South Asia, the Middle East, and the Sub-Saharan African region, Maruf et al. (2017) uncover a positive relationship between political instability and inflation, especially in oil-producing countries, in the period 1984-2014.

One problem in estimating the effect of political instability on inflation is (potential) collinearity with other independent variables. More stable countries tend, for instance, to have a higher per capita output growth (Alesina et al. (1996)). Dincer and Eichengreen (2014) found that central bank independence and transparency respond to similar economic and institutional variables such as political stability. To tackle the resulting endogeneity problem, they use political stability as an instrument for transparency.

### B.2.4 Growth

GDP and its growth rate are considered important inflation-related factors by many authors. In Campillo and Miron (1997) the level of GDP is included to control for country size effects while log of income per capita (in 1980) controls for various effects. Dollar and Kraay (2003) found that cross-country differences in institutions mirror the differences in the levels of GDP per capita. Calderón and Schmidt-Hebbel (2010) used per capita income as a proxy of a more general group of institutional arrangements. In Hielscher and Markwardt (2012) GDP per capita controls for various structural disparities as differences in the financial sector, technologies or optimal inflation.

## B.3 Monetary Policy Strategies

The next group of variables accounts for the effects on inflation associated with two monetary policy arrangements. The first relates to exchange rate arrangements, the second to the adoption of an explicit inflation targeting strategy.

### B.3.1 Exchange Rate Regime

Another important element in the debate of driving forces of inflation is the flexibility in exchange rate arrangements adopted by countries. Under floating exchange rates disequilibria in the balance of payments are adjusted by the exchange rate. Under a pegged system the adjustments rest on central bank interventions in the currency markets. One rationale for adopting a fixed exchange rate framework is that it operates as a disciplinary tool for monetary authorities, limiting their ability to expand the monetary base at the risk of causing a balance of payments crisis (Mohanty and Bhanumurthy (2014)). Another benefit is that a fixed exchange rate signals enhanced credibility of lower future inflation because countries that have pegged their currencies face costs in terms of credibility losses if they abandon the peg. As a result, inflation should be lower in countries with fixed exchange rates because this regime is likely to have been chosen precisely by those suffering from excessive inflation in the past.

Many studies include a dummy variable for the exchange rate regime as a (further) check on time-consistency issues. Ghosh et al. (1997) found robust evidence of lower inflation under pegged regimes in a sample of 150 countries over 30 years. The negative relationship between fixed exchange rates and inflation is also reported in Cottarelli et al. (1998) and Husain et al. (2005). The reason seems to be a smaller money growth and a higher monetary credibility. Similarly, Bleaney (1999) found that floating exchange rates are significantly associated with inflation rates at least 10 percent a year higher than pegged exchange rate regimes in the post-Bretton Woods era to 1998.[34]

### B.3.2 Inflation Targeting

Inflation targeting (IT) is an operational framework for monetary policy aimed at achieving a numerical value (or range) for the inflation rate. A growing number of countries have adopted IT over the last two decades. Starting in the early 1990s with a handful of advanced economies, by the late 1990s and early 2000s, central banks in emerging economies began adopting IT. Emerging market countries, in particular, were searching for a nominal anchor that did not have the instability associated with fixed exchange rate regimes. By 2006 eight advanced economies and 13 emerging market countries had adopted it (Batini and Laxton (2007)). At the start of 2012, some 27 central banks were considered fully-fledged inflation targeters, and several others were in the process of establishing an IT regime (Hammond, 2012). IT's perceived benefits include both lower inflation and inflation variability, while retaining enough flexibility to respond to macroeconomic shocks to stabilize output.

A growing body of literature on the effects of IT on average inflation, inflation volatility, average economic growth, and its volatility has emerged. The evidence mostly concludes that IT is beneficial in terms of lowering inflation, its volatility and inflation expectations.[35] However, Ball and Sheridan (2005) argued that IT makes no difference among industrial countries.

[34] Ilzetzki et al. (2019) provide a history of anchor or reference currencies, exchange rate arrangements, and a new measure of foreign exchange restrictions for 194 countries and territories from 1946 to 2016.

[35] See Truman (2003), Hyvonen (2004), Vega and Winkelried (2005), among others.

Its apparent success in the period of global disinflation, when inflation experienced a reversion toward the mean, seems to be sample-dependent.

Brito and Bystedt (2010) emphasized that the key for finding any effect of IT on inflation is the choice of the control group. Using the GMM systems estimator as opposed to the commonly used difference-in-differences estimator employed in Ball and Sheridan (2005), Brito and Bystedt (2010) report weaker support for the effect of IT on average inflation, inflation volatility, and growth volatility, and provide evidence that average growth is lower under IT. Surveying the literature, Ball (2010) concluded that the evidence of beneficial effects of IT in emerging economies, while stronger than in advanced countries, is not yet conclusive.

More recent studies that include emerging markets tend to find stronger evidence of positive effects from IT.[36] Mishkin and Schmidt-Hebbel (2007) find that the largest inflation reduction is experienced by emerging market economies and converging-to-target ITs. Samarina et al. (2014) emphasized the importance of distinguishing countries by economic development. No effect of IT in advanced economies but a significant inflation-reducing effect in emerging and developing countries is found.

Alpanda and Honig (2014) argued that not all emerging economies are the same and that IT may work better in some economies than in others. In particular, since central banks differ in their degree of independence, this may interact with an IT regime to produce different macroeconomic outcomes. Therefore, it is possible that when this distinction is not made, conclusive results for the effects of IT in a subset of countries are weakened by the inclusion of countries for which IT has no effect. When differentiating the impact of IT based on the degree of central bank independence, they find large effects in emerging economies with low independence of the central bank. This suggests that an independent central bank is not a prerequisite for countries to experience significant declines in inflation after the adoption of IT. One channel through which IT lowers inflation more in countries with low central bank independence is by reducing budget deficits.

## B.4 Public Finances

Another important topic in the literature is the impact of fiscal imbalances.[37] Public deficits and debt have been extensively discussed as potential sources of price instability. Given the limits on domestic and foreign borrowing, monetization is the residual form of deficit financing. A well-established theory in macroeconomics is that governments running persistent deficits have sooner or later to finance those deficits with money creation (seigniorage). Across centuries and countries, a common way in which sovereigns have paid for high debt is by high and even hyperinflation. In the aftermath of the financial crisis financial bailouts, stimulus spending, and lower revenues have resulted in public debts in advanced economies that have surpassed the peaks reached during World War I and the Great Depression (Reinhart and Rogoff (2011)). The question is whether expanding public debts is inflationary. There are several theoretical channels for how public indebtedness may unleash inflation.

**Conventional view** Traditional analysis of the fiscal impact on inflation focuses mostly on Keynesian aggregate demand considerations, public wage spill-overs to private sector wages, and taxes affecting marginal costs and private consumption. According to the conventional view, an increase in public debt may cause inflation by inducing a positive wealth effect on households. Demand for goods and services raises and ultimately inflates the economy (Elmendorf and Mankiw (1999)).

**Unpleasant Monetarist Arithmetic** Following Milton Friedman, the most widely accepted school of thought on inflation is that it is always and everywhere a monetary phenomenon. This is based on the quantity theory of money which posits that inflation is determined solely by the change in the relative supply of money and goods. Following this logic, disinflation policy in many countries is framed with the objective of constraining monetary growth to be in line with the expansion in nominal income and not to accommodate imprudent fiscal policies. However, given that current money demand should depend on expectations about future inflation, a purely monetary effort at reducing inflation may not be successful. Theoretically, once an account is taken of forward-looking expectations, multiple equilibrium paths for inflation can coexist. Under such circumstances, money supply alone may not be sufficient to pin down the time path of inflation.

Against this background, attention has increasingly been paid to the role of fiscal policy in determining inflation. The main result of the seminal paper by Sargent and Wallace (1981) is that the effectiveness of monetary policy in controlling inflation depends critically on its coordination with fiscal policy. In their model, tighter monetary policy could lead to higher inflation under certain circumstances, even when the traditional relation between money and the price level holds. Given the limits on domestic and foreign borrowing, monetization is the residual form of deficit financing. With the demand for government bonds given and in the absence of changes in future fiscal policy, a part of government obligations has to be covered by seigniorage at some point in the future. In line with this argument, Friedman (1994) expressed the view that expansionary fiscal policy had generated inflation in the U.S. by encouraging overly expansionary monetary policy.

**Fiscal Theory of the Price Level** A similar reasoning lies behind the fiscal theory of the price level (FTPL). The FTPL identifies the wealth effect of government debt as an additional channel of fiscal influence on inflation. It posits that increased government debt adds to household wealth (defying Ricardian Equivalence) and, hence, to the demand for goods and services, ushering in price pressures.[38]

[36] See Batini and Laxton (2007), Mishkin and Schmidt-Hebbel (2007), Gonçalves and Salles (2008), Lin and Ye (2009), Abo-Zaid and Tuzemen (2012), Samarina et al. (2014), and Deniz et al. (2016).

[37] See, for example, Montiel (1989) and Bruno and Fischer (1990).

[38] Cochrane (2011) argues that the current high levels of U.S. debt may lead to higher inflation through the FTPL.

Debates on the coherence of the theory (Buiter (1999) and Niepelt (2004)) have spawned an extensive literature.[39] The implications of rising public debt for inflation are observationally similar between the Sargent-Wallace framework and the FTPL. Nonetheless, there is an important theoretical distinction between the two (Leeper and Yun (2006)). Under FTPL, an increase in government debt raises the wealth of bond holders while not reducing those of others. Long-term bond prices rise, boost aggregate demand and push up the price level. Money supply, which is endogenous in this regime, increases in accommodation of the higher money demand. The price level is the factor equilibrating the nominal value of future discounted primary surplus and the nominal value of public debt. Under the Sargent-Wallace framework an increase in government debt not fully backed by future real primary surpluses increases concerns about monetization of public debt, raising inflation expectations, and thereby reducing bond demand and increasing long-term interest rates. This will, in turn, reduce money demand and push up the price level even without a contemporaneous increase in the money supply.

**Optimal Tax** A fourth explanation based on a fiscal view is based on optimal tax considerations. Most economists acknowledge that differences in monetary and fiscal policies among countries are the main reasons behind the inflation variability they sustain. However, this explanation leads to a much deeper and fundamental question, which is why countries differ on the way they conduct fiscal and monetary policies. One of the many attempts that have been made to answer this question is based on the idea that structural features of a specific economy determine its government's ability to collect taxes. This view implies that countries' abilities to tax is technologically constrained by their stage of development and structure of their economies. As tax collecting costs are high and tax evasion pervasive, countries might use the inflation tax more frequently.

One interpretation is that governments in poor countries might find it optimal to rely more heavily on seigniorage instead of output taxes to finance their expenditures. According to the Theory of Optimal Taxation, governments optimally equate the marginal cost of the inflation tax with that of output taxes.[40] Edwards and Tabellini (1991) and Cukierman et al. (1992) failed to find evidence that this theory applies to developing countries. The empirical failure of the Theory of Optimal Taxation motivated the use of theoretical and empirical models focusing on the role played by political and institutional variables discussed above.

**Debt Management** An important issue in the discussion about the possible implications of public debt is its structure. Ever since emerging economies started issuing debt in global markets, the currency composition of debt has become a central element of the policy debate. During the 1990s, the perception was that governments found it difficult to place debt denominated in local currency, a phenomenon Eichengreen et al. (2002) termed the original sin. The predominant concern was related to the economic vulnerabilities associated with high levels of debt-dollarization. Over the last decade, this has changed as governments from emerging countries have increasingly issued local currency debt. But this switch may come at a price. In the models by Calvo (1988) and Missale and Blanchard (1994), higher levels of privately held government debt with a longer maturity raise the incentive for a government to attempt surprise inflation. In this literature, foreign currency, inflation-indexed, or short-term debt are remedies against surprise inflation.

More recently, Arellano and Ramanarayanan (2012) argued that the problem of debt maturity choice involves a trade-off between hedging and disciplining properties.[41] While short-term debt provides the right incentives, long-term debt is useful for hedging consumption. Similarly, Ottonello and Perez (2019) proposed a model in which a government that lacks commitment chooses debt and monetary policy weighs two opposite incentives. On the one hand, debt in local currency provides insurance through state contingencies created by movements in the real exchange rate and inflation. On the other hand, high levels of debt in local currency induce governments to dilute the value of their debt by generating costly inflation or keeping the real exchange rate excessively depreciated. This time-inconsistency problem prompts debt managers to tilt their debt portfolios toward foreign currency at the expense of forgoing the hedging properties of the local currency debt.

Finally, the structure of debt also plays a role in the FTPL literature, where government debt not backed by expected future surpluses ensues in inflation, immediately or, depending on the maturity structure, in the future (Cochrane, 2001).

**Empirical Evidence** A large body of empirical literature examines the link between fiscal policy and inflation. Much of it focuses on the role of budget deficits. Despite the theoretical view that fiscal deficits are inflationary, empirical studies have yet to provide a strong and statistically significant connection between fiscal deficits and inflation across a broad range of countries and inflation rates. While there is widespread consensus that hyperinflations are caused by fiscal imbalances, at more-moderate inflations the evidence of a link is murkier. Empirical studies of developing countries generally indicate that the inflationary effect of deficit financing is insignificant, but do find a significant causality of fiscal deficits on inflation in high-inflation countries.[42]

Rather than looking at inflation, several studies examine the link between money creation and deficits. For the U.S., Hamburger and Zwick (1981) found that after World War II the monetary growth was influenced by deficits, but only in specific episodes. Likewise, King and Plosser (1985) showed that whether deficits can predict monetary growth depends on what other variables are used in the forecasting exercise. Their conclusion is that there is no evidence of a link between monetary growth and deficits in the U.S. Likewise, in a comprehensive analysis of the determinants of seigniorage in the U.S.

[39] See, among others, Leeper (1991), Sims (1994), Canzoneri et al. (2001), Cochrane (2001), Woodford (2001), De Graeve and Queijo von Heideken (2015).

[40] See Phelps (1973), Végh (1989), and Aizenman (1992).

[41] This is the main message from the Fiscal Insurance Theory of debt management. See Missale (1997) and Missale (2012).

[42] See Lin and Chu (2013) for a review of the empirical literature.

during the postwar period 1953–1982 and 12 other countries, King and Plosser (1985) found little evidence of a significant causality running from fiscal deficits to changes in base money and inflation in both single equation OLS regressions and VARs.[43]

More recent research on the relationship between fiscal deficits and inflation has exploited both time and cross-sectional dimensions of data. Again, results are inconclusive. While Karras (1994) found that deficits are not inflationary in a panel estimation in 32 countries, Cottarelli et al. (1998) found a significant impact of fiscal deficits on inflation in industrial and transition economies by using a dynamic panel data model. Fischer et al. (2002) expanded the analysis to a data set of 94 developing and developed countries during 1960–1995 to investigate the relationship between inflation, money growth, seigniorage and fiscal deficits. According to their cross-sectional analysis fiscal deficits are significantly positively linked to seigniorage and inflation. Exploiting their panel data, they showed that in countries with high average inflation, fiscal deficits are the main drivers. However, this effect is no longer significant in low-inflation countries or high-inflation countries during low-inflation episodes.

In short, empirical studies have encountered difficulties in uncovering a statistically significant and strong relationship between budget deficits and inflation. An important reason is the use of data samples with a disproportionately high weight on advanced countries or economies with historically low inflation (Catão and Terrones (2005)). Countries that have well-established institutions that curb fiscal profligacy, central banks that are credibly committed to low inflation, and deep financial markets arguably have great latitude in managing their intertemporal budget constraints (Canzoneri et al. (2001)).

Another factor that makes it difficult to uncover any fiscal deficit-inflation relationship among developing countries is inadequate modeling. Catão and Terrones (2005) argued that the fixed effects estimator combined with specifications that do not account for differences in the size of the inflation tax base imparts a downward bias on the relevant cross-country estimates. Hence, unlike previous studies, Catão and Terrones (2005) modeled inflation as non-linearly related to fiscal deficits through the inflation tax base and estimate this relationship as intrinsically dynamic, using panel techniques that explicitly distinguish between short- and long-run effects of fiscal deficits. The sample consists of 107 countries over the 1960–2001 period. It results that the inflationary effect of deficits on inflation depends on the financial depth of a country, the inflation tax base, and the credibility of monetary authorities. Fiscal deficits are inflationary in high-inflation and developing countries, but not in low-inflation and advanced countries. Developing countries with less efficient tax collection, political instability, and limited access to external borrowing tend to have a lower relative cost of seigniorage and thus a higher inflation tax. Reflecting the ambiguous mood in the empirical literature, several cross-country studies on the determinants of inflation do not even include fiscal balances in their regressions, implicitly or explicitly, assuming that fiscal balances play no role or that their effects are indirectly captured by other variables.[44]

Lin and Chu (2013) applied the dynamic panel quantile regression (DPQR) model under the autoregressive distributional lag (ARDL) specification to analyze the deficit inflation relationship in 91 countries spanning from 1960 to 2006. They reported budget deficits having a strong effect on inflation in high-inflation episodes and weakly in low-inflation episodes. Castro et al. (2003) found that the extent of debt monetization in OECD countries is negatively associated with the degree of central bank independence. Kwon et al. (2009) applied a dynamic fixed-effect estimator and a fist-difference GMM estimator on data from 71 countries from 1962 to 2004 and show that debt growth leads to inflation in indebted developing countries, but less so in other developing countries. In advanced countries a growing debt is less inflationary.

A considerable amount of literature has also examined whether the behavior of inflation over time and especially its relation to other taxes is consistent with the principles of optimal taxation.[45] Campillo and Miron (1997) analyzed whether differences in average inflation rates across countries are consistent with optimal tax considerations. On the one hand, optimal tax suggests that countries with higher expenditure ratios should have higher levels of all taxes, including inflation. On the other hand, these considerations imply that holding expenditures constant, inflation should be higher in countries where the demand for money is relatively inelastic. Differences in this elasticity might occur because of differences in the sophistication of the banking system, since highly developed banking systems provide good substitutes for money and therefore more elastic money demand. Campillo and Miron (1997) reported a positive and significant relationship between the public debt ratio (measured in 1975) and average inflation in a sample 1973-1994. This holds for the whole sample, for high-income and other countries. According to Campillo and Miron (1997) the evidence is consistent with the view that inflation has been used as it should be from an optimal tax perspective.

This result does not seem to be robust to the sample period. By using debt and inflation data that span the entire post-1960 period, specifically including the important inflation starts that occurred in the 1960s and early 1970, Boschen and Weise (2003) showed that the positive correlation between the average debt ratio and the average inflation is smaller and not statistically significant.

Empirical contributions to the debt management literature on time-inconsistency issues are few and far between and mostly focused on advanced countries. Missale and Blanchard (1994) provided evidence in line with the theoretical model on some highly-indebted European countries and Mandilaras and Levine (2001) on a sample of 15 OECD countries. Aizenman and Marion (2011) argued that U.S. policymakers have a strong incentive to inflate the debt, similar to the period after World War II when inflation reduced the debt by about 40 percent within a decade. However, they also pointed to some important differences with the current situation. On the one hand, the shorter debt maturities today reduce the temptation

[43] Seigniorage has been important for many developing countries that have experienced high inflation. As an example, Sargent et al. (2009) reported that seigniorage frequently raised revenues of more than 5 percent of GDP for Argentina and Brazil during their high-inflation years, with occasional higher spikes. In the case of low-inflation economies, however, this number is always very small.

[44] See Romer (1993), Lane (1997), Campillo and Miron (1997), Loungani and Swagel (2003).

[45] See Mankiw (1987), Poterba and Rotemberg (1990), Grilli et al. (1991).

to inflate, while the larger share held by foreigners would increase it. Similarly, Hilscher et al. (2014) estimated that higher inflation would unlikely lower the real value of U.S. debt significantly. The reasons are expectations of modest inflation and short maturities of publicly held debt. The conclusion that arises is that the interaction between financial repression and long maturities of debt allows for significant effects of inflation.

The quantitative analysis of the model by Ottonello and Perez (2019) based on a panel of 18 countries shows that the presence of the trade-off between the hedging motive of local-currency nominal debt and its distortionary incentive motive, which gives rise to inflationary costs and real exchange rate distortions can indeed account for the observed degree of original sin in emerging economies, as well as its dynamic patterns.

## B.5 Globalization and Technology

### B.5.1 Globalization

Declining inflation in many countries over the past few decades at the same time as rising global competition has led to a debate on the importance of globalization for domestic inflation. As highlighted by Greenspan et al. (2005) globalization is likely an essential element in explaining low inflation. In the literature there are at least two lines of argument about how increased globalization may have affected inflation in the long run. The first is due to Rogoff (2003) who argued that globalization reduces the inflation bias associated with discretionary monetary policy. In a more competitive world brought about by globalization, deregulation, and less government involvement in the economy monetary policy has smaller effects on real activity, and central banks have less incentive to inflate. Globalization also has permanent effects on the inflation rate by closing the gap between the target level of output pursued by the central bank and the natural output rate. Similarly, Romer (1993) argued that more open economies have steeper Phillips curves so that their policymakers face a larger output-inflation trade-off. This is because an unanticipated monetary expansion causes real exchange rate depreciation, raising costs for households and businesses. The larger the share of imported goods—the more open the economy—the greater the increase in inflation. Thus, if the temptation to pursue expansionary policy is an important determinant of inflation, it would be lower in more open economies, resulting in lower average inflation.

The second line of thought associated with globalization and its effects on inflation, and holds that in a more integrated world, competition between currencies forces central banks to adopt best practices and keep inflation at bay. However, this disciplining effect is related to financial globalization, rather than real globalization (Wynne and Kersting (2007)).

In his empirical study on a cross-section of 114 countries based on 1973-88 averages, Romer (1993) found a robust negative relationship between openness, proxied by the ratio of imports to GDP, and inflation. More specifically, while Romer (1993) found that the basic correlation is robust to conditioning on other variables (development level of a country, CBI, and political stability) essentially no relationship between openness and inflation is reported for the most developed countries. Average inflation in the richest countries tends to be low regardless of how open they are. This suggests that these countries have largely solved the time-consistency problem, leading to higher inflation in less advanced economies. Similarly, Badinger (2009) found that the relationship between openness and inflation disappears in OECD countries. Bleaney (1999) reported, using 1989-98 averages, that the negative relationship between economic openness and inflation is not statistically significant.

The two main follow-up studies that look at the same period as Romer (1993), are Lane (1997) and Terra (1998).[46] By conditioning on country size, per capita income, and central bank independence the relationship between openness and inflation becomes statistically significant and negative even for the advanced economies. However, the relationship can be lessened by controlling for development and indebtedness. Campillo and Miron (1997) used a slightly extended sample period (1973-94) of 62 countries and also conditioned on a wider set of variables (prior inflation experience, optimal tax considerations, and time-consistency issues in areas other than monetary policy). Their finding is that even for developed countries, greater openness is associated with significantly lower inflation.[47] In this vein, Daniels et al. (2005) and Badinger (2009) reported a robustly negative effect of openness on inflation in a broad cross-section of countries (except for OECD countries).

The cited studies used a cross-section specification. The alternative is to exploit the time-series structure of the data and use panel estimation methods.[48] Alfaro (2005) reports an inflation increasing effect of openness in a panel of 148 countries. However, Wynne and Kersting (2007) argued that the evidence noted by Alfaro (2005) seems to rest entirely on her use of annual data. Taking five-year averages (like Gruben and McLeod (2004)), a negative relationship between openness and inflation is re-established. In contrast to Alfaro (2005), Sachsida et al. (2003) and Gruben and McLeod (2004) employed instrumental variable estimators to deal with endogeneity problems. Both author pairs found evidence of an inflation-reducing effect of openness. Sachsida et al. (2003) confirmed that Romer's findings were not limited to a certain group of countries or a specific time frame.

Catão and Terrones (2005) control for openness measured as the ratio of exports plus imports to GDP in their above-mentioned study on deficits and inflation. The results are not only dependent on the estimation procedure, but also on the country group. Only for the advanced country group does openness yield a statistically significant negative coefficient,

[46] Lane (1997), however, emphasized a different channel through which openness and inflation may be related, namely the degree of imperfect competition and price rigidity in the non-traded sector.

[47] By contrast, central bank independence turns out to be unimportant in developed and developing countries. Campillo and Miron (1997) concluded that it is mainly structural factors—openness, political stability, and tax policy—and not institutional characteristics of an economy, particularly the degree of central bank independence and exchange rate arrangements, that drive differences in inflation across countries.

[48] However, Romer (1993) argues that this would likely yield biased estimates because changes in openness within countries are caused by changes in trade policy and other macroeconomic factors that could also affect inflation through other channels.

confirming that the openness-inflation results are sample-specific, as argued by Terra (1998) and Bleaney (1999). Dincer and Eichengreen (2014) also control for openness (also measured by the sum of exports and imports to GDP) in GMM estimates of inflation. The coefficient is weakly significant or insignificant with negative sign. Lotfalipour et al. (2013) showed in a static panel that countries that are exposed to oil price shocks have a positive relationship between openness and inflation.

In short, there are many ways in which increased openness can lead to a lower price level. However, as pointed out by Wynne and Kersting (2007), it is important to keep in mind that most of these are one-time effects, implying a transitory impact on inflation. Nevertheless, these one-time effects may take a long time to play out, so that the temporary effects may last quite a long time.

An important observation is that inflation has become increasingly globally synchronized (Ha et al. (2019)). Recent research has highlighted a large and growing role of global factors in explaining movements in national inflation rates. Ciccarelli and Mojon (2010) found in their seminal paper that 70% of the variance of national inflation rates in 22 OECD countries can be explained by a common global factor. Parker (2018) confirmed that global inflation factors could explain a large share of the variance of national inflation rates of advanced economies but not of middle-income and low-income economies. Jasova et al. (2019) used a New-Keynesian Phillips curve framework that controls for nonlinear exchange rate movements for a panel of 26 advanced and 22 emerging economies. Both global and domestic output gaps are significant drivers of inflation in pre-crisis (1994–2008) and post-crisis (2008–2017) periods. However, after the crisis, the effect of the domestic output gap declined in advanced economies, whereas in emerging economies, the global output gap declined. Forbes (2019) showed that inflation models should control for changes in the global economy and allow for key parameters to adjust over time. Global factors (global commodity prices, global slack, exchange rates, and producer price competition) can affect inflation after controlling for the standard domestic variables.

Empirical research on the relevance of globalization for domestic inflation has not produced a clear picture. Given the weak empirical evidence for the U.S., Ball (2006) argued that there is little reason to think that globalization has influenced domestic inflation significantly. Calza (2009) came to a similar conclusion in tests of the proposition that globalization has led to greater sensitivity of domestic inflation to the global output gap in the euro area. However, other empirical studies provide evidence of a relationship between globalization and inflation. Borio and Filardo (2007) found that the weighted average foreign output gap has a significant positive effect on domestic inflation in OECD countries which has trended upwards. Chang and Tsai (2015) uses panel causality analysis applied on 21 OECD countries from 1970 to 2010 to examine causal linkages between globalization and inflation, concluding that globalization has had a significant effect in some major countries. According to Manopimoke et al. (2015) a global output gap replaced the domestic output gap as the key driving variable for inflation in 17 advanced and emerging countries, particularly since 2000. Zhang et al. (2015) showed that the global output gap significantly affects the dynamics of inflation in China.

But there have also been opposing conclusions. Using a time-varying VAR, Bianchi and Civelli (2015) investigated whether global economic slack replaced the domestic output gap in driving inflation as globalization increased. The authors concluded that globalization has not yet induced changes in openness large enough to justify significant changes in inflation dynamics. Busetti et al. (2019) estimated a Phillips curve type relationship in the euro area using an expectile regression approach, extended to capture time-varying effects to find that the domestic and the foreign output gaps drive core inflation, although the domestic component exhibits stronger effects.

Andrews et al. (2018) explored the implications of the global value chain (GVC) integration and market contestability for inflation using a range of industry-level and micro-data sources. As a result, rising participation in GVCs has placed downward pressure on producer price inflation, by increasing the ability of firms to substitute domestic inputs with cheaper foreign equivalents. In addition, the authors reported an increasing trend in mark-ups, particularly in the services sectors. They concluded that stalling globalization, stronger aggregate demand and declining market contestability could lead to inflationary pressures in the medium term.

#### B.5.2 Technology

In addition to factors relating to globalization, a view embraced by several authors in recent years is the possibility of disinflationary effects arising from technical innovations in many areas of the global economy by permitting a more intense and efficient utilization of resources. The basic argument is that innovation spawned new computer, telecommunication, and networking technologies, which in turn suppressed unit labor costs. Research on the impact of technology on inflation is divided into three aspects (Lv et al. (2019)). First, technological innovation directly impacts changes in the prices of information and communication technologies, leading to declining prices of information and communications technology (ICT) products. Second, new technology affects competition and market structure. This reduces entry barriers and increases price transparency and comparability. Third, technological progress lowers the rate of wage growth relative to productivity. Lv et al. (2019) used an extended hybrid New Keynesian Phillips Curve model to quantify the contribution of technology and globalization variables to inflation in the U.S. from 1999-2016. Their analysis suggests that both globalization and technology explain low inflation dynamics. While the impact of globalization weakened, the effect of technology increased.

Related and growing literature studies discuss how the internet is affecting inflation. Gorodnichenko and Talavera (2017) and Gorodnichenko et al. (2018) found that prices in online marketplaces such as Google Shopping are far more flexible and exhibit more exchange-rate pass-through than prices found in CPI data. Cavallo (2018) built on their findings to show how online competition is affecting traditional multi-channel retailers and their pricing across locations and over time.

## B.6 Demography

One noticeable fact observable since the 1980s in most advanced countries has been an increase in the proportion of middle-aged people and retirees. In the effort to understand the sources of the decline in inflation observed over the recent past, the adverse demographic trend has been invoked as a further possible driver. There have been extensive studies on various aspects of demographic changes and their effect on the economy, for instance, economic growth. However, until recently, little attention was paid to whether there is a connection between the observed disinflationary trend and aging societies.

The resulting empirical evidence is inconclusive. One reason may be that it is not easy to choose appropriate variables for capturing demographic changes. Another, more critical reason is that the theoretical transmission channels from aging populations to economic variables are manifold, working their ways through simultaneously and with offsetting effects. For example, aging has multifarious demand-side effects due to changing consumption preferences, possibly reducing aggregate demand and lower inflation. On the other hand, it would reduce the effective supply of labor, adding inflation pressures.

The most prominent hypotheses on the link between population aging and inflation relate to the theories on life-cycle consumption and savings, secular stagnation, impact on financial wealth, and political economy, whose underlying channels reach contradictory conclusions on the impact of demographic developments on inflation (Bobeica et al. (2017)).

**Life-cycle theory** According to the life-cycle theory, individuals smooth their consumption over a lifetime. As the savings rate tends to be lower when the share of young and old-age dependents in total population increase, a discrepancy between aggregate demand and supply arises, and props up inflation to equate at a steady state. The shrinking labor supply puts upward pressure on wages, further pushing up inflation. The bottom line is that aging is inflationary.

**Secular stagnation** Secular stagnation describes an economic condition of negligible economic growth and low potential growth, as savings are higher due to demographic changes than long-term investments needed to promote future growth. A lower rate of return on capital depresses investment and economic growth and dampens price dynamics. Shirakawa (2013) argued that aging could exert deflationary pressures by lowering expectations of future economic growth. While people may ignore the implications of population aging for a while, they revise their expectations when they recognize the extent of the economic impact. The resulting loss of demand and investment might not be easily offset by monetary policy, especially if inflation is already low and policy rates are close to the effective lower bound.

**Financial wealth** Pensioners sell accumulated wealth held abroad and repatriate funds leading to an appreciation of the domestic currency, which lowers costs of imports and exerts deflationary pressure.

**Political economy** Bullard et al. (2012) suggested an explanation based on the political economy of central banking. Based on the life-cycle hypothesis, as young and working-age people have fewer assets and receive wages, they prefer higher inflation, whereas older people who depend more on asset returns as a source of income influence redistributive policy to grant low inflation. The swelling share of pensioners causes their political power to increase and express their preferences for low inflation that would otherwise erode the real rate of return from their savings. To the degree their policies reflect voter preferences, central banks may place a greater emphasis on price stability.

Given the theoretical ambiguity, some empirical investigations have stepped in to shed light, but, not surprisingly, their conclusions are contradictory. Most of the studies have focused on Japan, as its transition from aging society to an aged society is the fastest in the world, but other advanced economies have also started to be in the limelight. Recent work, using survey data, suggests that inflation expectations rise with age, implying higher concern and, hence, risk aversion to inflation in a graying society (Blanchflower and MacCoille (2009)).

Some empirical studies including Anderson et al. (2014), Yoon et al. (2014), Gajewski (2015), and Bobeica et al. (2017) found empirical evidence for aging to be associated with deflationary pressures. In contrast, Juselius and Takáts (2015) documented that aging leads to more inflation. Similarly, Aksoy et al. (2015) estimated long-run effects of the changing age profile and found that dependent cohorts enhance the inflationary pressures in the long run.

Motivated by the experience of Japan, Anderson et al. (2014) found that substantial deflationary pressures arise from population aging, mainly through declining growth and falling land prices, based on simulations of a calibrated model (rather than being empirically motivated and validated). Yoon et al. (2014) used panel data covering 30 OECD economies from 1960 to 2013 for regressions of inflation on population growth, the share of 65 and over, the share of 15-64, life expectancy, terms-of-trade changes, GDP growth, M2 growth, and budget balance changes. The results suggest that aging, measured by the share of 65 and over, is deflationary.[49]

Gajewski (2015) examined the relationship between inflation and aging in a panel data model estimated for all 34 OECD member countries over the period ranging from 1970 to 2013 employing four-year averages for the variables (and controlling for the log of per capital GDP). The results suggest that there are deflationary rather than inflationary consequences of aging.

Bobeica et al. (2017) investigated the case of the euro area and in comparison to the U.S. and Germany. This allowed them to treat each economy individually, as opposed to papers investigating relationships in a panel framework, pooling together countries with very different demographic situations. Demographics is a slow-moving process, unlikely to influence inflation at business cycle frequency. For this reason, they focused on long-term relationships between the two variables by employing

[49] All other exogenous variables are highly significant with the expected signs.

a cointegration framework. Bobeica et al. (2017) found supporting evidence for a positive relationship between inflation and the growth of working-age population in total population. A diminishing growth rate of the working age population, which can occur due to a higher share of the elderly, comes hand in hand with fading inflationary pressures if the monetary policy does not react.

Juselius and Takáts (2015) attributed different effects of dependents and working-age cohorts to a possible demand channel. They argued that countries with more people consuming goods and services than producing them are liable to having excess demand and thus inflationary tendencies. Those with more producers than consumers, by contrast, have excess supply and a deflationary bias. In line with this explanation they found in a panel of 22 advanced countries over the period 1955 to 2010 that an increase in the number of dependents, young and old, is generally inflationary, whereas having more people of working age is linked to lower inflation. They also show that the deflationary effects of aging found in previous studies are driven primarily by the very old (80+ year old) cohort. These results are robust to different country samples, periods, control variables, and estimation techniques. Overall, according to their results, aging would eventually lead to higher inflation, contrary to most arguments and previous evidence. In a more recent paper, Juselius and Takáts (2018) obtained similar results derived from long panel data stretching 1870 to 2016 from 22 advanced economies. A robust relationship emerges that accords with the lifecycle hypothesis: inflationary pressure rises when the share of dependents increases and, conversely, subsides when the share of working-age population increases.

Aksoy et al. (2015) estimated effects of changes in demographic structure on medium-run trends of key macroeconomic variables using a Panel VAR of 21 OECD economies over a sample period 1970-2007 based on annual observations. Young and old dependents were found to have a negative impact while workers contributed positively.

## B.7 Natural Resources

The oil price is a well-known source of inflationary pressures in the world economy. However, the precise transmission mechanism between commodity price changes and inflation is only inadequately understood.[50] Ball and Mankiw (1995) proposed a theoretical model to describe supply-side shocks, wherein an increase in the relative price of oil could affect the aggregate price level.

The change in the oil price has been used as a control variable in several empirical studies.[51] Cuñado and Pérez de Gracia (2003) found evidence of cointegration in the oil price-inflation relation in 11 of 15 European countries between 1960 and 1999.

Either oil prices are denominated in dollar terms or in domestic currency. For instance, Loungani and Swagel (2003) used oil prices in dollar terms, and each country has the same values for the price of oil in a particular year. By contrast, Lin and Chu (2013) employed oil prices in the local currency, so that each country faces different energy prices. These empirical studies show that the impact of oil prices on long-term domestic inflation is stronger among advanced countries than among developing countries. For instance, LeBlanc and Chinn (2004) showed that a 10 percentage points oil price increase boosts inflation by 0.1-0.8 percentage points in the U.S. and the E.U. In Catão and Terrones (2005) a 1 percentage point increase in oil price inflation is estimated to raise advanced country inflation by near 0.2 percentage points. Ha et al. (2019) documented in an exceptionally large sample of countries of 141 EMDEs and 34 advanced economies over 1970-2018 that rapid changes in global inflation have occurred near turning points of the global business cycle or in the wake of sharp movements in global oil prices.

As is well documented in the literature, survey data of household inflation expectations may differ from professional inflation forecasts. One of the explanations put forward is that households expectations respond excessively to fluctuations in the oil price. For example, in the study cited above, Coibion and Gorodnichenko (2015) suggested that one-year mean household inflation forecasts, as measured by the Michigan Survey of Consumers, have tracked the price of oil closely with a contemporaneous correlation of 74% between January 2000 and March 2013. Accordingly, almost all of the short-run volatility of inflation expectations is explained by changes in the level of the price of oil. Kilian and Zhou (2020) reexamined the evidence and showed that the stylized fact reported in Coibion and Gorodnichenko (2015) is highly sensitive to the estimation period. As demonstrated by Kilian and Zhou (2020), the type of single-equation regression that has been used to establish the link between increases in the price of oil and increases in household inflation expectations is problematic. A more promising approach seems to be a structural vector autoregressive model that sheds light on the interaction of actual inflation rates, household inflation expectations, and gasoline's real price. Using such a structural vector regression model, Kilian and Zhou (2020) showed that gasoline price shocks may indeed drive one-year household inflation expectations. In particular, the rise in household inflation expectations between 2009 and 2013 is almost entirely explained by a large increase in gasoline prices. However, on average, gasoline price shocks account for only 39% of the variation in household inflation expectations since 1981.

Feldkircher and Siklos (2019) investigated dynamics of inflation and short-run inflation expectations of professional forecasters in a global vector autoregressive (GVAR) model. The results indicate that inflation expectations increase in the short run if inflationary pressure stems from either domestic supply or demand shocks. However, the effects of the demand and supply shocks are short-lived for most countries. This result changes when global oil price inflation accelerates. In this case, a more pronounced and long-lasting long-run effect on inflation expectations is found for a range of countries. The

[50] See, among others, Bernanke et al. (2008), De Gregorio (2012), and Gospodinov and Ng (2013).

[51] See Barsky and Kilian (2002), Loungani and Swagel (2003), LeBlanc and Chinn (2004), Hamilton and Herrera (2004), Catão and Terrones (2005), Lin and Chu (2013). See Kilian (2008) and Hamilton (2008) for a review of the literature on the effect of energy price shocks on the U.S. economy.

impact on inflation is even larger than on inflation expectations. Hence, oil price shocks drive a wedge between inflation and inflation expectations even among professional forecasters. The authors further provide evidence that after the GFC the transmission between inflation and inflation expectations was largely unaffected in response to domestic demand and supply shocks, whereas the effects of an oil price shock on inflation expectations were smaller.

## B.8 Past Inflation

In empirical studies, past inflation is often controlled for.[52] Countries that experienced high inflation might be more aware of its negative consequences and oppose it more forcefully. Germany's hyperinflation experience is frequently offered as the reason for its inflation aversion (Cukierman (1992)). A survey conducted by Ehrmann and Tzamourani (2009) in 23 countries from 1981–2000 reveals that memories of hyperinflation are there to last. However, memories of moderately high inflation tend to fade after around 10 to 15 years.

Hayo (1998), asking the same survey question as Ehrmann and Tzamourani (2009), argued that there is no "inflation gene that determines their preference". Rather, the preferences for price stability are seen as a result of a country's economic culture. Survey respondents in low-inflation countries tend to be more sensitive to increasing inflation than in higher-inflation countries.

A related effect that can be assessed by past inflation rates is inflation inertia, according to which inflationary shocks may translate into higher inflation expectations through wage and price contracts, which in turn materialize in terms of higher actual inflation.[53] Also, as Alpanda and Honig (2014) pointed out, lagged inflation may account for mean reversion as inflation targeting countries tend to start with higher inflation rates and thus are more likely to experience larger drops in their inflation rates. Omitting this variable would bias the estimate of the IT coefficient.

In the New Keynesian literature, there are four approaches establishing a link between past and current inflation. The first is the model by Gali and Gertler (1999) in which price reoptimization is done following a rule of thumb, the second is the indexation model proposed by Christiano et al. (2005), and the third is the sticky information model of Mankiw and Reis (2002) which distinguishes between reoptimizing agents with adaptive expectations and those relying on past inflation as a proxy for expected inflation.

Bikai et al. (2016) used a Panel Vector Autoregressive approach on CEMAC countries (Economic and Monetary Community of Central Africa) and data from 1990 to 2014 to show that money supply and imported inflation are the two main sources of inflation in CEMAC countries. Nevertheless, money supply and imported inflation account for only 30% of the dynamics of inflation. 64% of it is determined by inflation itself.

Binder (2021) provided empirical support for the general premise of heterogeneous agent models with two types of private agents, distinguished by their expectations formation. In several papers, the two types are "credibility believers" and "adaptive expectations users". The former trusts the central bank, expects future inflation to be near the central bank's inflation target, and uses a Phillips curve. The latter uses only past inflation to forecast future inflation (Hommes and Lustenhouwer, 2019). Binder (2021) showed that forecasters who report using the natural rate of unemployment to make forecasts resemble the "credibility believers" whereas the forecasters reporting not to rely on it are akin to the "adaptive expectations users" in the models of Goy et al. (2018) and others. The presence of these two types of agents can have implications for macroeconomic dynamics and policymaking. Goy et al. (2018) studied forward guidance at the ELB in a New Keynesian model with these two types, assuming that only the "credibility believers" respond to forward guidance. The smaller the share of "credibility believers", the less effective forward guidance is. Thus, the presence of "adaptive expectations users" helps resolve the forward-guidance puzzle in standard New Keynesian models with rational expectations (Del Negro et al., 2012).

[52]See Campillo and Miron (1997), Kwon et al. (2009), Calderón and Schmidt-Hebbel (2010), Lin and Chu (2013), Alpanda and Honig (2014), Dincer and Eichengreen (2014).

[53]See Lim and Papi (1997), Loungani and Swagel (2003), and Kamin and Klau (2003).

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