Gains from Commitment: The Case for Pegging the Exchange Rate*

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Abstract

Does the exchange rate regime matter for inflation and economic activity? This paper argues that it does and that there are substantial benefits to a fixed exchange rate regime. At the heart of these benefits lies an increase in commitment for the central bank that reduces the inflationary bias of monetary policy. Using an open economy model we provide an estimate for the credibility of hundred different central banks between 1950 and 2016. Our empirical analysis demonstrates that after pegging the currency to a more credible anchor, the average economy benefits from persistently lower inflation of 3.5% per year, higher temporary economic growth and lower inflation volatility. Moreover, the less credible countries are the ones benefiting the most from committing to a fixed exchange rate regime.

JEL classification: E31, E42, E52, F41, F42

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1 Introduction

Should countries peg their currency or aim for a flexible exchange rate regime? This classical question in international economics is still an open debate. One argument in favor of fixing the exchange rate is that such a regime keeps inflation low and stable. On the other hand, a strand of literature argues for flexible exchange rates to counteract shocks. Recently, new research has emerged that emphasizes the disconnect of the exchange rate regime to macroeconomic fundamentals (Itskhoki and Muhkin, 2019) and questions the ability of the exchange rate regime to insulate from economic shocks (Corsetti et al., 2021). This paper stresses that fixing the exchange rate can indeed have positive effects on the economy, as it helps to reduce inflation and its volatility permanently. We spell out conditions under which fixing the exchange rate does have effects and when it does not. We also provide evidence for the quantitative magnitude of lower inflation when pegging and which countries in particular can benefit from such a regime shift.

In essence, we highlight and quantify the "credibility channel" in which a central bank gains commitment when pegging the exchange rate. Countries with non-credible central banks suffer an inflationary bias that has its origins in discretionary monetary policy. Higher credibility means a higher probability of being able to commit to low inflation policies.

We derive several testable implications in an estimated quantitative model when a country pegs to a more credible anchor: First, inflation and its volatility should go down permanently. Furthermore, GDP growth goes up in the short-run as the costs of high inflation go down. Last, we emphasize that those effects are stronger the less credible the pegging country is. Using this model, we provide an estimate of credibility for a large set of countries between 1950 and 2016.

In our empirical analysis we provide evidence for the implications of the model: When a country pegs its currency, inflation goes down on average by 3.5 % per year, the standard deviation of inflation is reduced by around 1.2% and real GDP goes up in the first three years by 3%. The less credible a country is, the larger are these effects. A country with a central bank that is one percentage point more likely to act under discretion (less credible) lowers annual inflation by 0.12% more when pegging. These numbers imply that countries like Spain and Italy, who are less credible according to our measure can reduce their inflation rates substantially when pegging to a credible anchor like Germany. This also means that fixing the exchange rate to an anchor that is not much more credible has only little effect on the economy.

Contribution: We develop an open economy model, based on Chari et al. (2020) that features different monetary regimes and the possibility of an inflationary bias. An inflationary bias arises when a central bank acts under discretion and uses time-inconsistent inflationary policies to stimulate economic activity. We extend the model by adding a time-varying credibility parameter for central banks, as in Schaumburg and Tambalotti (2007). This credibility parameter determines the probability of a central bank to act under discretion and determines the average magnitude of the inflationary bias over time. In such a setup, pegging the exchange rate to a credible and stable anchor can help to reduce inflation and its volatility. The client country gives up monetary autonomy and completely adopts the monetary stance of its anchor country, thereby inheriting its credibility. The magnitude of the reduction in inflation crucially depends on the initial credibility of the country and the credibility of its anchor. If inflation is costly to the economy, a long-term reduction also leads to a short-term increase in economic growth. Taking the client's and the anchor's credibility into account, we derive several testable implications about the level of inflation, its volatility and economic growth, if a country changes its monetary regime. Inflation and volatility should go permanently down when a country pegs to a more credible anchor, while GDP growth should go up in the short-run. We then estimate the time-varying credibility parameter in a model calibrated for Italy (pegging country) and Germany (anchor country) and demonstrate that the evolution of inflation and its volatility in the data can be well matched. As a last step, we extend our measure to a larger set of countries to complement our data set.

In our empirical exercises, we use the most comprehensive dataset available at the country-level, with information on 169 economies over the last 70 years, corresponding to 7,500 country-year observations including 259 pegging episodes and 266 floating episodes identified following Ilzetzki et al. (2019). We start by providing 3 stylized facts on the differences between countries in a float and fixed exchange rate regimes that are in line with the seminal contributions by Bordo and Schwartz (1999); Ghosh et al. (2002); Calvo and Reinhart (2002): 1) inflation is higher and more volatile in floats than in pegs; 2) real GDP growth is higher in pegs; 3) interest rates are higher and more volatile in floats than in pegs. In addition, in the spirit of Eichengreen and Rose (2012), we also perform an event study analysis around changes in exchange rate regimes and confirm that following a pegging episode countries display lower inflation and interest rates and higher economic growth.

Then, to causally test the implications of our model, and after acknowledging that not all changes in the exchange rate regime are unexpected or unrelated to the business cycle of each economy, we use an inverse probability weighting methodology to estimate the impact of a change in the exchange rate regime. In the first step, we use our estimated credibility parameter, lagged inflation and growth rates to predict changes in the exchange rate regime. We find that higher inflation and lower real GDP growth in the previous period together with a low level of credibility predict changes in the exchange rate regime. In the second step, we estimate local projections using as regression weights the inverse of the estimated probability for each episode in the first step.

On average, we estimate a 3.5% persistent reduction in annual inflation and a 3% increase in real GDP cumulative growth over 5 years following a pegging episode. We also provide evidence that the effect depends on how credible a country is. If a country is one percentage point more credible (that is the probability of acting under commitment is one percentage point higher), the effect of pegging the exchange rate to a stable anchor is 0.12% less in annual inflation. This finding, translates into the main policy implication of this paper: the less credible countries are the ones benefiting the most from committing to a fixed exchange rate regime.

Literature Review: By revisiting the classical question on whether and how the exchange rate regime matters for countries' economic performance, this paper aims at contributing to two strands of literature. On the empirical side, we contribute to the literature that studies the differences between exchange rate regimes and the effect of pegging and floating episodes. In his seminal work, Mussa (1986) showed that the decision to let the exchange rate regime float freely after the Bretton Woods breakdown did not only have an impact on the nominal exchange rate, but also on the *real* exchange rate.

In recent work, Itskhoki and Mukhin (2019) reconfirm this finding but emphasize that changes in the exchange rate regime fail to show up in other real macroeconomic variables such as GDP or consumption. Using a sample of the G7 countries excluding Canada plus Spain, they also argue that there is no systematic change of cyclical properties in inflation after a shift of the exchange rate regime.[1] This paper redirects the focus from the cyclical (short-run) properties and the Bretton Woods breakdown episode towards long-run level shifts of macroeconomic variables after different pegging and floating episodes over the last 70 years for 169 countries. We show that inflation and economic growth are persistently affected for non-credible countries after an exchange rate regime change. In line with findings from Levy-Yeyati and Sturzenegger (2003); De Grauwe and Schnabl (2008); Ghosh et al. (2014); Harms and Knaze (2021), we find a negative long-run response of inflation and a positive short-run response of economic growth following a pegging episode.

On the theoretical side, the paper relates to the open economy literature that examines the relationship of exchange rate regimes and the economy. We use an estimated version of the Chari et al. (2020) model. They set up an open economy model and link it to discretionary

[1]They document a significant increase in volatility of inflation after the floating events of Bretton Woods for those countries (Italy, UK) that we classify as non-credible. This is in line with our results, as other credible countries (Germany, Japan) in their dataset do not experience this increase.

monetary policy in the Barro and Gordon (1983) tradition. Models in that tradition point to the signaling content of the regime choice. Governments and monetary authorities that suffer from a credibility deficit can signal their commitment to tough policies by appropriately choosing the exchange rate regime (Giavazzi and Pagano, 1988). Indeed, Obstfeld et al. (2010) show that countries inherit the monetary stance of their corresponding anchor. Such a shift in credibility that we model as in Schaumburg and Tambalotti (2007) is able to mitigate the inflation bias arising from a discretionary monetary authority. Our paper therefore emphasizes gains from commitment by moving towards a pegged exchange rate regime. Other papers that discuss the stability of those exchange rate arrangements focus on trade gains or invoicing complementarities, see Arvai (2021) and Muhkin (2021). The literature that highlights the disconnect from exchange rate regimes and macro fundamentals (originally Meese and Rogoff (1983) and Itskhoki and Mukhin (2019), Corsetti et al. (2021) more recently) focus on short-term real macro fundamentals. Our finding stresses the permanent effect on the level of inflation and the corresponding impact on real variables stemming from such a permanent shift in inflation. This is in line with Froot and Ramadorai (2005) who find that short-term movement of the exchange rate are often disconnected with macro fundamentals while long-term movements indeed show a relationship to fundamentals.

The remainder of this paper is structured as follows. Section 2 introduces the model and derives 3 implications about economic behavior of countries that move towards a fixed exchange rate regime. Sections 3 and 3.3 present our calibration strategy and the quantitative exercise. Section 4 describes the empirical strategy and presents its results. Section 5 concludes.

2 Model

In this section, we first describe the model that follows closely Chari et al. (2020). We then expand their setup by adding a credibility parameter as in Schaumburg and Tambalotti (2007). The credibility parameter is time-varying and depends on the exchange rate regime. The goal is to use such a model setup to derive testable implications about the behavior of inflation, interest rates and economic growth under different regimes. We consider a flexible exchange rate regime, a unilateral peg and a currency union under commitment and discretion.

2.1 Setup

The model closely follows Chari et al. (2020). The economy consists out of a continuum of countries. Each country produces traded and non-traded goods. The traded good sector is assumed to be perfectly competitive while the non-traded good sector has imperfect competition and sticky prices. This assumption reflects the notion that flexible exchange rates are desirable as they ensure that the relative prices of traded goods to non-traded goods move as if all prices were flexible. There are two different sources of shocks that hit the non-traded sector only: A markup shock and a productivity shock. Each of these shocks can happen on an aggregate level that hits the whole world equally and on a country-specific level. All of the shocks are i.i.d. over time and across country [2]. The timing is as in Chari et al. (2020). First the markup shock is realized, then non-traded good firms set their prices, then productivity is realized, then monetary policy reacts and last the rest of the economy takes places where traded good firms set their prices and households make their decision. The important feature in this setup is that a discretionary monetary authority has an incentive to use surprise-inflation to inflate away the socially inefficient markups of firms. Firms anticipate the attempt of the central bank to inflate and raise their prices for non-traded goods before. In equilibrium, the economy ends up with higher prices. A lack of commitment by the central bank results in an inflationary bias for the economy. In contrast, a central bank that commits to policies realizes that it cannot inflate away the markups. Hence it promises ex ante to focus on productivity shocks only when using monetary policy and successfully avoids the inflationary bias. Countries are symmetric with respect to their parameters, technology and preferences. We first consider how the economy works for one single "home" country and then consider country blocks and unions in Section 2.3.

2.1.1 Production

Firms are owned by households. Production of traded goods in state s_t is given by

$$Y_T(s^t) = L_T(s^t).$$

Production is linear in the labor input $L_T(s^t)$. Traded good firms maximize their profits $P_T\left(s^t\right) L_T\left(s^t\right) - W\left(s^t\right) L_T\left(s^t\right)$. Optimally firms set the price of traded goods $P_T\left(s^t\right)$ equal to the wage $W\left(s^t\right)$. $W(s^t)$ can therefore be replaced by $P_T\left(s^t\right)$.

Production of non-traded goods is subject to two frictions, namely monopolistic markets and rigid prices. This gives rise to markups that increase prices of non-traded goods. A microfoundation for markups can be given by following the setup of Smets and Wouters (2007) which is also described in the Appendix of Chari et al. (2020). The non-traded good is produced by a competitive final producer who uses differentiated inputs $y_N(j, s^t)$ from input firms of

[2] This keeps the model tractable, as it becomes static. There is no persistence such that a large shock today affects future states. The calibration discusses the shock process in more detail.

mass $j \in [0,1]$ to produce the final good $Y_N(s^t)$:

$$Y_N\left(s^t\right) = \left[\int y_N\left(j, s^t\right)^{\theta(s_t)} dj\right]^{1/\theta(s_t)}, \quad \theta\left(s_t\right) \in (0,1).$$

where $\theta\left(s_t\right)$ is the time-varying substitution parameter between the inputs [3]. $\theta\left(s_t\right) \in (0,1)$ implies that demand for inputs is elastic. If $\theta\left(s_t\right)$ is very close to 1 goods are almost perfect substitutes and firms are not able to use any monopolistic power. The closer $\theta\left(s_t\right)$ is to 0, the more monopolistic power a firm has. The final good firm maximizes profits which gives demand for intermediate goods. Intermediate goods are produced by monopolistic firms who use a linear production function: $y_N(j, s^t) = A(s_t)L_N(j, s^t)$. Intermediate good firms choose their prices one period in advance $P = P(j, s^{t-1}, s_{1t})$ to maximize their expected profits. s_{1t} indicates the state when the markup shock has realized for period t, but productivity is still not known. Optimally, intermediate good producer j sets the price on non-traded goods as a time-varying markup over a weighted average of marginal costs. The price equation is not a function of j such that the price is the same for all intermediate firms. Plugging in $W(s^t) = P_T(s^t)$ gives the pricing equation of non-traded goods as a function of prices for traded goods:

$$P_N\left(s^{t-1}, s_{1t}\right) = \frac{1}{\theta\left(s_{1t}\right)} \sum_{s_t} \left(\frac{Q\left(s^t\right) Y_N\left(s^t\right)}{\sum_{\tilde{s}_{2t}} Q\left(\tilde{s}^t\right) Y_N\left(\tilde{s}^t\right)}\right) \frac{P_T\left(s^t\right)}{A\left(s_t\right)}. \tag{1}$$

where $Q(s^t)$ is the discount factor, the price of a state-contingent claim to local currency units at s^t in units of local currency in s^{t-1} and $\frac{1}{\theta(s_{1t})}$ is the markup. This implies that all intermediate firms hire the same amount of labor and their production function is then given by

$$Y_N(s^t) = A(s_t)L_N(s^t).$$

2.1.2 Households

Households derive utility from consumption of traded goods $C_T(s^t)$ and from consumption of non-traded goods $C_N(s^t)$. In addition, they experience disutility from labor $L(s^t)$:

$\sum_{t=0}^{\infty} \sum_{s^t} \beta^t h_t\left(s^t\right) U\left(C_T\left(s^t\right), C_N\left(s^t\right), L\left(s^t\right)\right)$. As in Chari et al. (2020), we specialize preferences as

$$U\left(C_T, C_N, L\right) = \alpha \log C_T + (1-\alpha) \log C_N - \psi L.$$

[3] The elasticity of substitution between the inputs is $\frac{1}{1-\theta(s^t)}$

This specification entails several simplifying assumptions, first it assumes that the elasticity of substitution between traded and non-traded goods is 1. Second, log-utility in consumption means that the inter-temporal elasticity of substitution is 1 as well. Those assumptions imply that households do not have an incentive to borrow or save across countries, as the willingness to substitute goods across time is exactly offset by the willingness to substitute traded goods to non-traded goods. α reflects the weight of traded goods in the overall consumption basket, large values imply that the countries in the economy have a very high degree of trade openness. Finally, the preferences are quasi-linear in labor, which simplifies aggregation results[4]. The budget constraint of households is given by

$$\begin{aligned} & P_T\left(s^t\right) C_T\left(s^t\right)+P_N\left(s^{t-1}, s_{1t}\right) C_N\left(s^t\right)+M_H\left(s^t\right)+B\left(s^t\right) \\ = & P_T\left(s^t\right) L\left(s^t\right)+M_H\left(s^{t-1}\right)+R\left(s^t\right) B\left(s^{t-1}\right)+T\left(s^t\right)+\Pi\left(s^t\right) \end{aligned} \tag{2}$$

where $T(s^t)$ are nominal transfers. $\Pi\left(s^t\right) = P_N(s^{t-1}, s_{1t})Y_N(s^t) - P_T(s^t)L_N(s^t)$ are profits from the traded-goods sectors. As households own the firms in their corresponding country, these profits go to the households. Firms themselves are not traded on international markets. $R(s^t)$ is the interest rate paid on the non-contingent one-period nominal bond in the domestic currency and $B(s^t)$ are the nominal government bonds[5]

There is also a cash-in-advance constraint for consumers, that requires domestic money brought from period $t-1$ to be used to purchase traded goods:

$$P_T\left(s^t\right) C_T\left(s^t\right) \leq M_H\left(s^{t-1}\right)$$

Under flexible exchange rates, consumers use their local currency $M_H\left(s^{t-1}\right)$ to pay for these goods. The superscript H denotes the individual holding of money. Domestic money is only hold by domestic households. Even though money is dominated by bonds as they pay interest on the existing stock, households need money to buy traded-goods. The assumption of cash-in-advance makes surprise inflation costly, as they can only use cash from the last period. In addition, the assumption that only traded goods are affected by this is for simplicity. This assumption can also be interpreted as a trade friction that requires to commit a certain amount of cash beforehand when internationally traded goods are bought from a foreign country. Note that current money injection that increase the nominal price of traded goods cannot be used

[4]Quasi-linear utility eliminates any wealth effects in the demand for money, which makes all agents choose the same amount of money. See Ricardo and Wright (2005)

[5]Compared to Chari et al. (2020), we replaced the price that is paid to buy new bonds with interest rates that are paid on existing bonds. We show in the Appendix B.3 that the price of bonds in Chari et al. (2020) is simply the inverse of interest rates used here. The model abstracts from international capital markets, as households do not have an incentive to borrow or lend across countries, given the considered preferences.

for the cash in advance constraint. In a currency union they use the common currency to pay for the traded goods.

The Euler equation can be obtained by combining the home bonds first order condition with the consumption first order condition. It governs the household's intertemporal decision:

$$\frac{1}{C_N(s^t)} = \beta \mathbb{E}_t \left[\frac{1}{C_N(s^{t+1})} \frac{P_N(s^t)}{P_N(s^{t+1})} R(s^{t+1}) \right] \tag{3}$$

The nominal stochastic discount factor is defined as

$$Q\left(s^{t+1}\right) = \beta h\left(s^{t+1} \mid s^t\right) U_N\left(s^{t+1}\right) P_N\left(s^{t-1}, s_{1t}\right) / \left(P_N\left(s^t, s_{1t+1}\right) U_N\left(s^t\right)\right).$$

This discount factor is also used by firms to discount their profits.

2.1.3 Government

The government budget constraint for each country under flexible exchange rates is given by

$$B\left(s^t\right) = R\left(s^t\right) B\left(s^{t-1}\right) + T\left(s^t\right) - \left(M(s^t) - M(s^{t-1})\right),$$

where $M(s^t)$ denotes the money supply in the economy. The last term is seignorage income from the growth in money supply. In a currency union, union-wide seignorage is equally split across countries according to their size. The initial money supply for each consumer in each country is set to M_{-1} and the initial bond holding B_{-1} are zero. The central bank specifies nominal interest rates, the quantity of debt and taxes for each country, satisfying the budget constraint. Note that there are no externalities for the central banks. This ensures that monetary policy does not have any incentive to set monetary policy in a non-cooperative way and to use its monopoly on its currency to manipulate the terms of trade.

2.2 Market Clearing and Equilibrium

Labor markets clear, which means that the demand for non-traded goods labor and traded goods labor equals overall labor supply

$$L_N\left(s^t\right) + L_T\left(s^t\right) = L\left(s^t\right).$$

Good markets clear for traded and non-traded goods.

$$C_T\left(s^t\right) = Y_T\left(s^t\right), \quad C_N\left(s^t\right) = A\left(s^t\right) Y_N\left(s^t\right).$$

GDP in this model is defined as the sum of consumption of traded and non-traded goods. Money demand from households $M_H(s^t)$ is met by money supply of the central bank

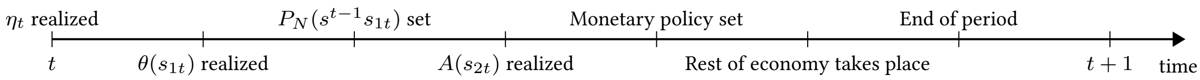
$$M_H\left(s^t\right) = M\left(s^t\right).$$

An equilibrium under flexible exchange rates is defined as an allocation in which 1) consumers behave optimally, 2) firms behave optimally, 3) the government's budget constraint holds and 4) markets clear.

As the law of one price holds in this model, the bilateral exchange rate can be defined as the price of traded goods in the considered country relative to the price of traded goods in the other country. In a monetary union money supply is chosen by the union-wide central bank. The nominal exchange rate is fixed for all states: $e\left(s^t\right) = 1 \quad \forall s^t$ and consequently, the price of traded goods is the same everywhere. This means that only aggregate shocks can change the price of traded goods.

2.3 Monetary Regimes

This subsection discusses the equilibrium of real and nominal variables under different monetary regimes. We consider three regimes: A floating regime with flexible exchange rates, a unilateral peg with a fixed exchange rate and a currency union. A country can conduct monetary policy under commitment and under discretion. We then extend the model and include a credibility parameter as in Schaumburg and Tambalotti (2007) that governs the probability of being in a discretionary regime. The interpretation is that a new governor gets selected with probability ξ_t in every period. If a new governor is selected, she acts under discretion in the first period and commits to policy thereafter as long as she is in office. It is not possible to restrain the successor. Formally, there is a sequence of Bernoulli signals η_t: With probability ξ_t, η_t is one and a new governor is chosen, otherwise η_t is zero and the old governor stays in place. We assume that this signal is known *before* productivity has realized. This implies that firms know if monetary policy acts under commitment or under discretion in a certain period. The timing of the model then looks like this:



The central bank ends up with a policy rule that is either discretionary or commitment based. Firms set their prices accordingly to each regime. As the signal is i.i.d. and there are no other state variables so far, the solution to the model under each regime separately is not affected. The average value of variables over a long time horizon is changed however. Average inflation for example is then the weighted average of inflation under discretion and under commitment. The weights correspond to the parameter ξ_t that determines the probability of acting under discretion. This probability is time-varying. We will estimate this time-varying probability in Section 3. If a country in this setup decides to peg its currency to a stable anchor, the probability of being in a discretionary regime decreases to the level of the anchor country. In a currency union, the central bank is as credible as the most credible member state. Next, we describe how policy in each regime under discretion and commitment looks like. These results reproduce those in Chari et al. (2020).

2.3.1 Flexible Exchange Rates: Monetary Policy under Commitment

The central bank conducts monetary policy under commitment. This means that the central bank maximizes ex ante lifetime utility of its representative household. It chooses an appropriate state-contingent path of prices subject to the consumer and firm first order conditions, the resource constraint, as well as the production function.[6] The central bank sets its policy after productivity has realized. Importantly, the central bank realizes that firms will set their relative prices equal to expected productivity times the markup. In a world under discretion, in which the central bank would take $P_N(s^{t-1}, s_{1t})$ as given, it would try to inflate away the markup, to set $P_T(s^t)/P_N(s^{t-1}, s_{1t}) = A(s_{2t})$. Under commitment the central bank realizes that this attempt of surprise inflation will not work. Therefore, optimal policy does not respond to markup shocks. It only responds to domestic productivity shocks. Intuitively, the monetary authority has to live with the distortions from markup shocks and attempts to accommodate productivity shocks. Therefore, the optimal policy of the central bank implies

$$\frac{P_T(s^t)}{P_N(s^{t-1}, s_{1t})} = \theta(s_{1t})A(s_{2t}). \tag{4}$$

The interpretation of that policy rule is straightforward: After productivity has realized the central bank makes sure that relative prices move in such a way that they replicate the out-

[6] For details, see the Appendix B.6 or Chari et al. (2020).

come as if non-traded good prices were flexible. This way the central bank can eliminate any distortions coming from rigid prices. The central bank engineers a movement of the exchange rate in such a way that relative prices align. For example, if productivity of the non-traded goods sector is high today, P_N should decrease as it is easier to produce that good. As prices of that good do not adjust, the central bank instead uses the exchange rate to let the currency depreciate so such P_T rises, which means that the relative price for P_N falls. The movement of the exchange rate aims to replicate the outcome of relative prices as if all prices were flexible. In this setup monetary policy is completely inward looking.[7]

Note also, that optimal monetary policy would never cause consumers to lose consumption because they do not have enough cash. Therefore, the cash in advance constraint is never binding in a way that would lower the household's consumption.

2.3.2 Flexible Exchange Rates: Monetary Policy under Discretion

Now consider how a non-credible central bank sets monetary policy. The important difference when a central bank acts under discretion is that it takes the price of non-traded goods as given, as firms have set their prices before the central bank acts. As a consequence, the central bank will try to use monetary policy to inflate away the inefficient monopolistic markups and implement an allocation, that equalizes household's marginal rate of substitution with the marginal rate of transformation of the economy. That is $P_T(s^t)/P_N(s^{t-1}, s_{1t}) = A(s_{2t})$. In order to do that the central bank will go so far to make the cash in advance constraint binding. As long as this constraint is slack, the central bank can use more inflation to reduce the markups. Therefore, the central bank makes the cash in advance constraint binding and ultimately trades off the costs of markups with the costs of surprise inflation that lower the household's purchasing power. For further details of the optimization problem, see Appendix B.6. The best response of the monetary authority is to set the price of traded goods as:

$$p_T\left(s_t\right) = p_N\left(s_{1t}\right) A\left(s_{2t}\right) \underbrace{\frac{1}{2(1-\alpha)}\left[(1-2\alpha)+\sqrt{(1-2\alpha)^2+4(1-\alpha)\frac{1}{A\left(s_{2t}\right)}\frac{\psi}{p_N\left(s_{1t}\right)}}\right]}_{F\left(\frac{1}{A(s_{2t})p_N(s_{1t})}\right)} \tag{5}$$

where the first part on the right-hand side $p_N\left(s_{1t}\right) A\left(s_{2t}\right)$ captures the willingness of the central bank to put the marginal rate of transformation equal to the marginal rate of substitution and $F(\cdot)$ captures the costs from surprise inflation. If p_N increases by one, p_T increases less than one-to-one. In the following we assume as in Chari et al. (2020) that $\frac{1}{\theta(s)} < \frac{1-\alpha}{1-2\alpha}$ so that there is a point where marginal costs of surprise inflation equal their marginal benefits.

[7] Chari et al. (2020) use the implicit notion of producer currency pricing.

This simply bounds markups from above, meaning that it is not possible that reducing markup distortions always exceed the costs of reducing trade goods consumption.

Another aspect that needs to be mentioned is, when productivity is stochastic and is sufficiently low compared to its average value, it can happen that the cash in advance constraint is not binding despite the central bank's policy. That is if $Ap_N < C_T$ then $p_T = p_N A$. Taken this into account as well, it implies that the price of traded goods is described by $p_T(s_t) = \max\{p_N(s_{1t}) A(s_{2t}), p_N(s_{1t}) A(s_{2t}) F(\cdot)\}$.

For policy under discretion, it is also important to consider the firms. They take into account that the central bank will try to inflate away their markups. Optimally firms still set prices of traded goods as in equation (1). Remember that firms observe the markup shock and then set their price taking their expectation for future productivity into account. Overall, the price of traded goods in the equilibrium solves the fixed-point problem of equaling the optimal price firms would set and what the central bank wants to implement. So, in equilibrium, any attempt of the central bank to inflate away the markup is frustrated, as firms anticipate the central bank's move and set their prices accordingly. The only thing the central bank achieves is an inflationary bias with higher volatility of prices and consumption.

2.3.3 Unilateral Peg to an Anchor

Consider now the case in which one country (the client country) pegs its currency to another country (the anchor). The anchor is assumed to conduct monetary policy under commitment or discretion, as in Section 2.3.1 and 2.3.2. The client country then ensures that the exchange rate to the anchor country stays constant at all points in time. This implies that monetary policy of the client loses its independence and follows the anchor. The main difference to this regime and a currency union is that the client country has no influence how the anchor conducts monetary policy. In a currency union the union-wide central bank considers all its member states. The peg implies that the price of traded goods is the same for both countries. Firms of the client country realize that monetary policy will be as in the anchor country. After markup shocks have realized in the anchor country, they form expectations about productivity and how the central bank of the anchor chooses the price of traded goods. In general, distortions coming from productivity fluctuations will be completely offset in the anchor country, while they will be present in the client country. These distortions are reflected in a volatile movement of employment. There can be an inflationary bias in both countries if the anchor acts under discretion a certain period.

2.3.4 Currency Union: Monetary Policy under Commitment

In a monetary union, the exchange rate is fixed and set to $e(s^t) = 1$ for all states. This implies that P_T cannot vary across countries and is only a function of aggregate union-wide shocks. The union consists out of many blocks, each block i having a mass of countries n^i. The relative weight of block i is $\lambda^i = \frac{n^i}{\sum_i n^i}$. Countries are all the same across blocks, except for the shock process of their markup. The central bank acts under commitment and chooses the union-wide price of traded goods and the prices of non-traded goods to maximize an equally weighted average of all countries of the world. Optimally, the cash in advance constraint does not bind to avoid losses in consumption as in the case under commitment before. The central bank sets prices such that it stabilizes the average of the whole union. This gives rise to a rule analogous to equation (4), with the central bank stabilizing a weighted average of productivity in the union. For further details see Appendix B.6. As the exchange rate is fixed, prices of traded goods are the same for all countries and the only thing the union-wide central bank can do is to set relative prices equal to the markup times the *average* productivity of the union. If productivity is asymmetric across countries monetary policy cannot eliminate all frictions coming from price rigidity. The price of non-traded goods fluctuates together with markups and the central bank under commitment does not react to that.

2.3.5 Currency Union: Monetary Policy under Discretion

The central bank acts under discretion and chooses the union-wide price of traded goods to maximize an equally weighted average of all countries of the world. The union-wide central bank chooses a traded good price for the union taking the non-traded good prices as given. The policy of the central bank implies to set the price of traded goods analogous to monetary policy under discretion in equation (5). Compared to the policy rule under discretion with an independent national central bank single country-specific shocks are replaced by the average shock realization of the union, for more details consider the Appendix B.6.

As before, firms anticipate the policy of the central bank and take this into account when setting their prices. In a currency union however, they realize that the central bank will only react to the average temptation shock, not the country-specific one. The result is still more inflation. The next section discusses how the policy under discretion in a currency union can still yield some benefits compared to discretion of a single country.

2.4 Overview

This section summarizes key real and nominal variables given the policy rules under different monetary regimes. We derive four implications about the behavior of inflation and economic activity if countries switch their exchange rate regime.

The following table summarizes the regimes and how we match those regimes to the empirical classification in Section 4.1.

Table 1: Monetary regimes Model and Data.

Model Regime Classification	Probability	Empirical Regime Classification
Float & Commitment	$1-\xi_t$	Float
Float & Discretion	ξ_t	
Peg & Commitment	$1-\xi_t^{Anch}$	Peg
Peg & Discretion	ξ_t^{Anch}	
Union & Commitment	$1-\min\{\xi_t^i\}$	Union
Union & Discretion	$\min\{\xi_t^i\}$	

For simplicity, we focus on a model solution with productivity such that the cash in advance constraint is exactly binding in discretion. First, turn to the nominal variables of the model. Table 2 shows average inflation of non-traded goods:[8]

Table 2: Average inflation rate under different regimes for state s

Regime	π_N
Float	$(1-\xi_t)\frac{\theta(s)}{\theta(s')}\beta+\xi_t\frac{\theta(s)}{\theta(s')}\beta\frac{\alpha}{\alpha-(1-\alpha)(1-\theta(s))}\Theta(s')$
Peg	$(1-\xi_t^{Anch})\frac{\theta(s)}{\theta(s')}\beta+\xi_t^{Anch}\frac{\theta(s)}{\theta(s')}\beta\frac{\alpha}{\alpha-(1-\alpha)(1-\theta^{Anch}(s))}\Theta^{Anch}(s')$
Union	$(1-\min\{\xi_t^i\})\frac{\theta(s)}{\theta(s')}\beta+\min\{\xi_t^i\}\frac{\theta(s)}{\theta(s')}\frac{\beta\alpha}{\alpha-(1-\alpha)(1-\sum_i\lambda^i\theta^i(s))}\Theta^U(s')$

Notes: Average inflation of non-traded goods (π_N) under all regimes. Average inflation is the weighted average under discretion with probability ξ_t and under commitment with probability $(1-\xi_t)$. In a currency union there are blocks of countries each with a mass λ^i.

where $\Theta(s')=\frac{\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\theta(s))}{\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\theta(s'))}$ and $\Theta^U(s')=\frac{\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\sum_i\lambda^i\mathbb{E}_v\theta^i(s))}{\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\sum_i\lambda^i\mathbb{E}_v\theta^i(s'))}$. Under commitment, monetary policy is deflationary. The central bank follows the Friedman (1969) rule implying a negative money growth rate and zero interest rates. The intuition why zero interest rates are optimal under commitment is the following. For households, nominal bonds dominate money holding as long as they pay an interest on its stock, Money does not pay any returns for its holder. Nevertheless, households need to hold money to buy traded goods. Therefore, the

[8] For a derivation see the Appendix B.6 and Table B.3, nominal interest rates are reported there too.

central bank optimally implements zero interest rates to make the necessary money holding as good as the bond holding. In addition, deflation ensures that the cash in advance constraint is never binding for households.

In contrast, inflation, interest rates and money growth rates are larger in discretionary regimes. As discussed before, the central bank has an incentive to use surprise inflation to inflate away markups. Ultimately, the central bank trades off costs of inflation in from of a binding cash in advance constraint with reduced markups. Firms anticipate this attempt and simply raise their prices. In equilibrium, the economy ends up with higher inflation. The size of the inflationary bias depends on $\frac{\alpha}{\alpha-(1-\alpha)(1-\theta(s))}$. Values of that term close to one imply no inflationary bias. This means that larger markups (small θ) correspond to a larger inflationary bias. The larger trade-openness (large α) the lower is the inflationary bias. As internationally traded goods are more important to households, the central bank is careful not to induce too much inflation that lowers consumption of internationally traded goods. The central bank achieves higher inflation by inducing a positive growth rate for money supply. The Euler equation then dictates that nominal interest rates have to be higher as well. As before, the average level of inflation and interest rates is a weighted sum of the values under different regimes with the credibility parameter ξ_t determining the likelihood. The first theorem summarizes the implication for the level of inflation and interest rates when a country pegs to another country.

Theorem 1 *If a country pegs its currency to a more credible anchor country, its inflation and interest rates fall permanently. If a group of countries form a currency union, the level of inflation and interest rates converge to the rates of the most credible member states.*

Proof: See Appendix B.7.

Next, we consider how output compares across the three regimes:[9]

Table 3: Average Output under different regimes for state s

Regime	Y_T	Y_N
Float	$(1-\xi_t)\frac{\alpha}{\psi} + \xi_t\left(\frac{\alpha}{\psi} - \frac{1-\alpha}{\psi}(1-\theta(s))\right)$	$\frac{1-\alpha}{\psi}\theta(s)A(s)$
Peg	$(1-\xi_t^{Anch})\frac{\alpha}{\psi} + \xi_t^{Anch}\left(\frac{\alpha}{\psi} - \frac{1-\alpha}{\psi}(1-\theta(s))\right)$	$\frac{1-\alpha}{\psi}\theta(s)\mathbb{E}_v(1/A(s))^{-1}$
Union	$(1-\min\{\xi_t^i\})\frac{\alpha}{\psi} + \min\{\xi_t^i\}\left(\frac{\alpha}{\psi} - \frac{1-\alpha}{\psi}\left(1-\sum_i\lambda^i\mathbb{E}_v\left(\theta^i(s)\right)\right)\right)$	$\frac{1-\alpha}{\psi}\theta(s)\left(\sum_i\lambda^i\mathbb{E}_v\left(1/A^i(s)\right)\right)^{-1}$

Notes: Average output of traded goods (Y_T) and non-traded goods (Y_N) under all regimes. Average output of traded goods is the weighted average under discretion with probability ξ_t and under commitment with probability $(1-\xi_t)$. In a currency union there are blocks of countries each with a mass λ^i.

[9] Discretionary and commitment-based regimes are separately reported in the Appendix, Table B.2.

In general, output of traded goods is larger the larger the trade openness α. Large values of disutility from work $\psi > 0$ lower output. The average output of traded goods is a weighted average of output under a discretionary regime and commitment. Under discretion C_T is lower than with commitment, as the central bank follows an inflationary policy. With high inflation, the household's cash in advance constraint is binding such that traded good consumption is lower, implying lower output. Larger markups increase the inflationary bias and hence decrease the amount of traded goods output under discretion. That is, if $\theta \in (0, 1)$ is relatively small. If a country follows a unilateral peg, the probability of being in a regime with high inflation is ξ_t^{Anch}. If the anchor country is more credible, average output will be higher. If a currency union is formed the union-wide central bank becomes as credible as the most credible member state. The following proposition summarizes a testable implication for output under different regimes:

Theorem 2 *If a country pegs its currency to a more credible country, output rises. If a group of countries form a currency union, output of all countries where inflation goes down rises.*

Next, we discuss the behavior of inflation volatility. Consider for this the role of $\Theta(s)$ that impacts inflation under discretion: This term adds more volatility in the inflation process. If the markup rises in the future, this also increases inflation of this good by a larger amount. If markups are lower than usual, then inflation decreases more than without this term. It is an amplifier. Together with the higher money growth rate, inflation rates *are higher on average and more volatile* in a discretionary float. A currency union can ensure that Θ is more stable over time when countries with the same markup shock process form a union. Country-specific markup shocks vary more than the average of all markup shocks. Therefore, a currency union is able to reduce the volatility of inflation not only because the frequency of discretionary regimes is reduced, but also because in times of discretion monetary policy for the whole union is less erratic. For the anchor country another effect is important too: As the growth rate of its markup is less correlated with Θ^U than with Θ^{Anch}, inflation volatility goes down for it even more. This leads to the third theorem that we can test with the data:

Theorem 3 *Inflation volatility under pure commitment is lower than under pure discretion. If a country pegs its currency to a more credible anchor country, the volatility of inflation goes only down if the anchor country is sufficiently credible.*

The proof can be found in the Appendix B.7.

Last we emphasize the relevance of credibility differences between anchor and client in a theorem. This will help us to distinguish the reaction of non-credible countries pegging their exchange rate versus credible countries who peg their exchange rates.

Theorem 4 *The less credible a client country is, the larger the reaction in inflation and output if it pegs to a credible anchor.*

This theorem directly follows from Theorem 1 and 2. The next chapter calibrates the shock process in more detail.

3 Calibration and Results

This section calibrates the model. We use the simulated method of moments to calibrate the time-varying credibility parameter and the markup process, matching inflation moments of Italy and Germany. How well the estimated model matches the data of these two countries is discussed afterwards. As a last step, we extend our credibility measure to a larger set of countries.

3.1 Calibration Strategy

The model seeks to highlight the effects of fixing the exchange rate via a unilateral peg or forming a currency union. Towards that aim, we focus on Germany and Italy between 1950 to today. During this time horizon, both countries went through various different exchange rate regimes.[10] That sample includes the time after the breakdown of Bretton Woods in which the exchange rate of Italy moved by a great margin. In 1985 Italy decided to peg its currency to the German Mark. In the end of the 90s, both countries formed the European currency union together with other European countries. The reason why we focus on Germany and Italy is that they are the largest countries of their respective block: Germany being part of the core (or the northern) block in the currency union, with relatively low and stable inflation rates before; while Italy is the largest country of the periphery (or the southern block) that experienced large increases in inflation during the mid 70s and 80s. One period in the model corresponds to one year. The calibration proceeds in two steps. First, we calibrate parameters based on long-run moments in the data and the outside literature. Thereafter, taking these as given, we calibrate the process for markup shocks and the credibility parameter to match key stylized facts on the properties of inflation for Germany and Italy.

The model is kept simple, therefore only a handful of parameters need to be calibrated.

[10] Appendix A.1 presents a detailed case study for the evolution of the bilateral exchange rate, exchange rate regimes and inflation in Italy and Germany since 1950.

The time discount factor is chosen to replicate a real interest rate of around 2% per year, in line with estimates for European countries by Brand et al. (2018). Next, we choose α – a measure of trade openness– to be 35 % in line with imports over GDP for Germany in 2015. We also consider the impact of smaller values of trade-openness in Figure B.3. The trade elasticity and intertemporal elasticity is already chosen to be 1 in the specification of preferences.

Next, we turn to the heart of the calibration, that aims to match cyclical inflation movements in Europe with the evolution of markups and the credibility parameter in the model. We will consider a model under a floating exchange regime and compute its moment. This way, we can assess whether the estimated evolution of credibility is consistent with credibility in the model under different regimes, e.g. whether Italy's credibility indeed approached the German level, when it decided to peg its currency.

Calibrating the parameter ξ_t is crucial, as it determines how often a country is in a discretionary regime. This impacts average inflation and its volatility over a considered time horizon. This credibility parameter is country-specific and time-varying. Next to this, the markups process $1/\theta(s)$ is important too. It determines how large and volatile the inflationary bias is for those countries. The range of estimates of markups varies widely, see for example De Loecker and Warzynski (2012), Christopoulou and Vermeulen (2012), Kuester (2010) or Midrigan (2011). In most applications, as for instant in Gomes et al. (2012), markups vary between 15% and 50%. The higher the markup, the higher inflation under discretion. For more open economies -larger α- inflation is lower. In our model, relatively low markups already lead to very high inflation values under discretion, see Figure B.3. Therefore, to avoid unreasonably high inflation rates, we aim for a macro-markup of 7% for both countries which is substantially lower what the literature usually chooses. The goal is to match the behavior of inflation using the simulated method of moments: The model generates certain moments of inflation given a process for $\theta(s)$ and $\eta(s)$, like the mean and volatility of inflation in a float. The model predicts that countries in a float have potentially different inflation rates, depending on their shock process and credibility. We then assume that the country-specific component of θ is beta distributed between 0 and 1 with parameters $\underline{\beta}$ and $\bar{\beta}$. We estimate these two parameters at each point in time such that the shape of the distribution for markup shocks fits the data well. The global component is muted for this exercise, the process is still assumed to be i.i.d. The same applies for η_t, we estimate the probability ξ_t of acting under discretion in a given period. I.i.d is an important assumption as there is no persistent component in the process that we estimate. Large shocks today do not have an impact on future shocks, if a country is discretionary today is has the same chance to be discretionary tomorrow. Even though this assumption limits the behavior of markups and regimes, it keeps the model simple and tractable. For now, we also impose zero correlation of these shocks between countries. Our method will then choose the two parameters of the beta distribution and the credibility parameter for each country separately for each year. A country with very volatile inflation will require a flatter distribution of θ and to have lower credibility. Low average inflation values would correspond to relatively low markups, that is a distribution of theta that centers around a value close to 1, together with a high degree of credibility. We also impose that the model assumption $\theta > 1 - \alpha/(1-2\alpha)$ still holds. For further details how SMM works, see Appendix B.10.1

3.2 Calibration for Germany and Italy

Table 4 summarizes the mean estimation, the moments of the data and the moments of the model under a discretionary float for both countries.

The average of the estimated credibility parameter indicates that Italy is under discretion more often than Germany, Figure B.2 shows how calibrated credibility evolves over time for both countries and how it reacts under different regimes. Mean markups for both countries are between 5% and 6 % on average and vary around this value. These lower markups coincide with a slightly too low inflation rate for both countries, that is mainly driven by the low inflation rates that the model predicts in a currency union[11]. On the other hand inflation volatility is too large in the model. This might reflect the lack of persistence in the shock process and in prices. This implies that switches between commitment- and discretionary policies cause a lot of variation in inflation.

Table 4: SMM Calibration

[11] We assume that the size of the two countries in the currency union λ^i is the same, such that the central bank puts an equal weight on both countries.

	Italy	Germany	Description
Parameters			
ξ	73.19%	50.15%	mean credibility: Prob. of discretion
$\bar{\beta}$	38.6	38.4	Parameter 1 beta distribution
$\underline{\beta}$	777.3	795.8	Parameter 2 beta distribution
Moments			
$\mu(\pi)$ data	5.7%	2.5%	Av. inflation 1950-end
$\mu(\pi)$ model	4.92%	1.22%	Av. inflation in the model
$std(\pi)$ data	0.05	0.02	Standard dev. inflation 1950-end
$std(\pi)$ model	0.05	0.03	Standard dev. inflation in the model
$\mu(\theta^{-1})$ data	7%	7%	Target markup
$\mu(\theta^{-1})$ model	5.5%	5.4%	Average markup in the model

3.3 Quantitative results for Germany and Italy

This section uses the calibration of the model to compute the model-based moments under all different regimes. In addition to that, mean inflation over time is computed, given the estimated parameters over time. Table 5 reports the moments of inflation in the model under the three regimes for Italy and Germany. The empirical analog to this table for all countries can be found in the summary statistics Table 6.

Table 5: Inflation under all regimes, model and data

		Float (1972-1985)		Peg (1986-1999)		Union (2000-end)	
		mean	std. dev.	mean	std. dev.	mean	std. dev.
Italy	π data	14.5%	0.04	4.5%	0.02	1.8%	0.01
	π model	13.8%	0.04	4.6%	0.02	0%	0.01
	ξ (SMM)	96.99%		90.81%		40.78%	
Germany	π data	4.6%	0.02	2.1%	0.02	1.4%	0.01
	π model	4.9%	0.03	1.1%	0.02	-1.7%	0.01
	ξ (SMM)	91.88%		48.23%		5.95%	

Notes: Data for float: 1972-1985. For peg:1986-1999. For union: 2000-end.

For Italy, inflation after the collapse of Bretton Woods was very high, both in the model and in the data. This coincided with a very large probability of acting under discretion. The central bank was not credible and there is a big inflationary bias as a consequence. After Italy pegs its currency to Germany, its central bank becomes more credible, in fact as credible as the German central bank was after the collapse of Bretton Woods. Its inflation rates are also similar on average to the rates of Germany during the time of the float.[12] For Germany in contrast, the time after Italy pegged its currency is characterized by even lower inflation rates, which the model achieves by assigning Germany a substantially more credible central bank for that time period. The creation of the currency union then leads to a substantial reduction in inflation and volatility again. Interestingly, even though both countries are subject to the same monetary policy in the data, the model assigns lower credibility to Italy, as its inflation rate is on average larger and still more volatile than Germany's which is particularly true during the financial crisis 2009. The estimated model suggests that Italy managed to increase its credibility substantially over time. This coincided with moving towards a more fixed exchange rate regime with Germany. The same is however true for Germany, the original anchor. Its monetary authority got more credible as well over time.

Next, Figure 1 displays how the model replicates the evolution of inflation between 1950 and 2016, given the time varying parameters of credibility for Germany and Italy. We also plot the evolution of traded goods consumption.

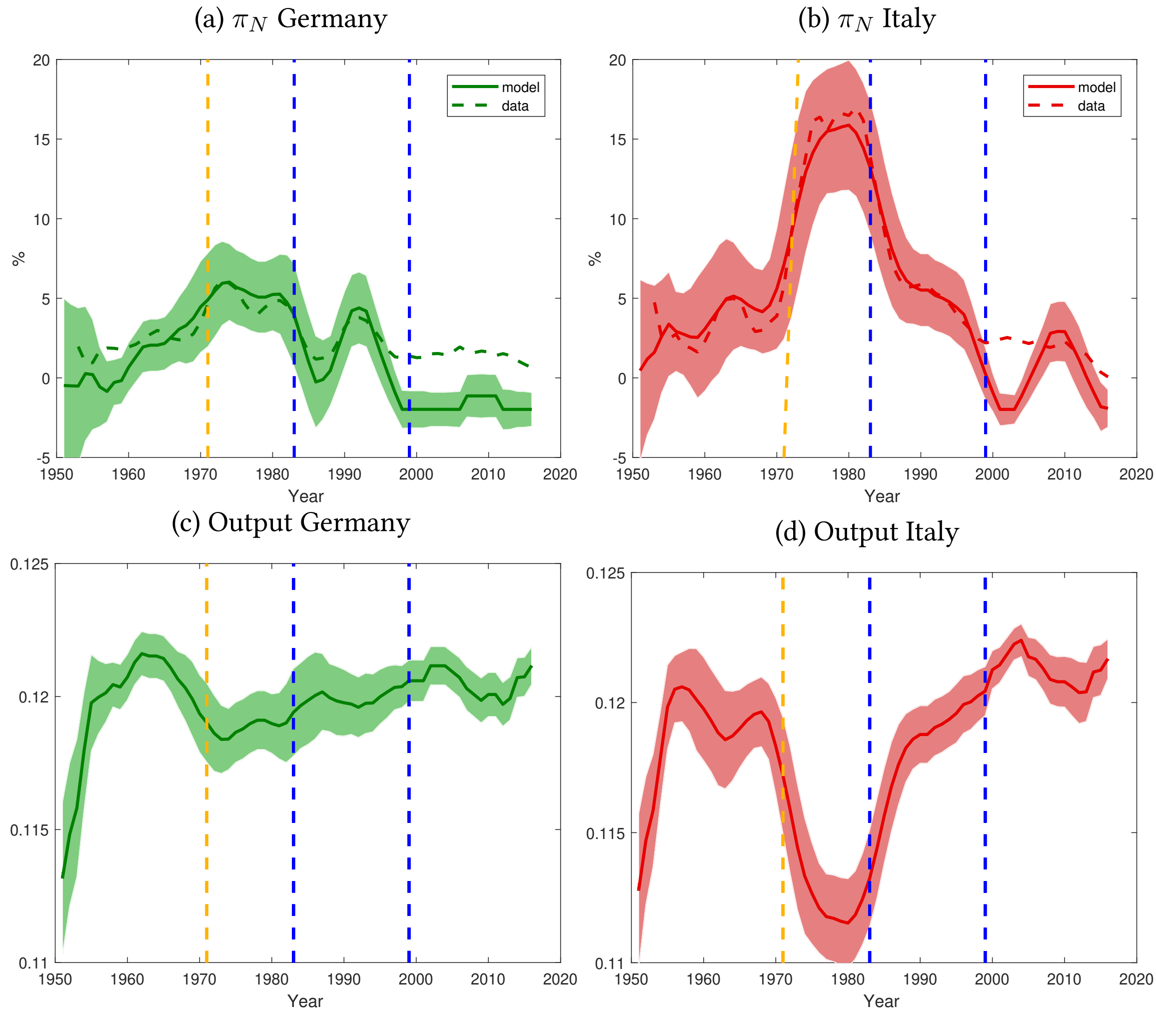
Inflation is well tracked, until both countries prepare to enter the European currency union in the late 90s. Empirically, the period from the currency union onward is characterized by low levels of inflation, together with very low values of inflation volatility. The model matches these moments best, if it assigns nearly full credibility to the central bank. Full credibility in the model implies the Friedman rule for both countries. This means zero interest rates and negative inflation in the steady state. There are no costs of deflation in the model, which is why this is the outcome under commitment. The model then undershoots the empirical level target for inflation, matches however its volatility.

Output is negatively correlated with inflation. The reason for that is, that inflation is costly and reduces traded goods consumption, an important component of GDP. Whenever a country is in a discretionary regime with high inflation rates, C_T is lower. This is why we observe temporarily lower values of output after the collapse of Bretton Woods in the early 70s, which subsequently rises again when lower inflation rates coincide together with more fixed exchange rate regimes.

Changes in the exchange rate regime have an impact on credibility in the model. When

[12] In Appendix A.1, we illustrate how inflation and changes in the exchange rate regime interact for these countries.

Figure 1: π_N and GDP in the model



Notes: Evolution of inflation of output ($Y_T + Y_N$) in the data (dashed lines) and in the model (solid line) in panel (a) and (b). The shaded areas indicate the one standard deviation confidence intervals in the simulation for inflation and of output in panel (c) and (d). The dotted vertical lines indicate floating events (orange) and pegging events (blue), the empirical analog to this figure is in Appendix A.1

Italy pegs its currency to Germany, its monetary policy should become more credible and in fact as credible as the one of Germany. The estimated path of ξ_t suggests that this is true, see Figure B.2 and Table 5. This implies that, whenever we see in the data non-credible countries pegging their currency to a stable anchor, their inflation rates should drop (in line with the work from Levy-Yeyati and Sturzenegger (2010)) and their output should rise. The estimated values for credibility also suggest that even Germany gets more credible when Italy pegs its currency. The model is not able to explain this phenomenon in a unilateral peg where Germany still does monetary policy only for itself.[13] It can however explain a rise in measured credibility when a currency union is formed. A union-wide central bank that is as credible as the German central bank will conduct monetary policy for the whole union, which makes the policy less erratic as the central bank only reacts to average shock and not country specific shocks. In

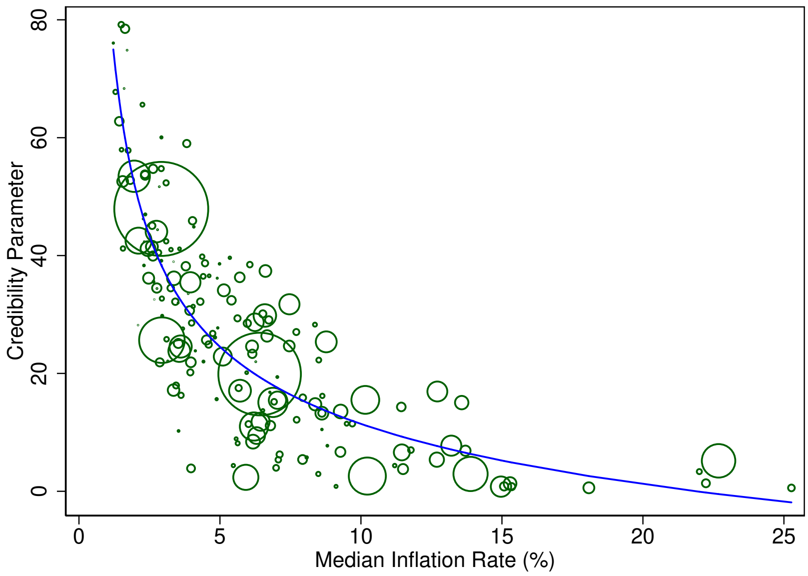
[13]There are only shocks to the non-traded goods sector. The German central bank does not care about non-traded goods in Italy, as it does not enter the consumption basket.

the data, this would mean that inflation is overall less volatile and also a bit lower on average, which is reflected in higher measured credibility.

3.4 Credibility measure for other countries

We extend our credibility measure to our dataset that contains more than 169 economies between 1950 and 2016. As our approach aims to match the level and the standard deviation of inflation well by choosing the appropriate time-varying value for credibility, the measure is strongly correlated with average inflation rates. In the following we plot $c_i = (1 - \bar{\xi}_i) \cdot 100$, so that higher values for the credibility parameter indicate more credibility.

Figure 2: Relation between credibility measure and median inflation in our sample



Notes: This figure plots the average credibility parameter $c_i = (1 - \bar{\xi}_i) \cdot 100$ against the median inflation rate in our historical sample for country i. The size of the circles represent population size which is not a predictor of credibility. Our measure of credibility displays a non-linear negative relationship with median inflation in our cross section. Table A.2 displays the data coverage for each individual country.

In general, the model assigns countries with low and stable inflation rates a relative low probability of acting under discretion, while the opposite is true for high- inflation countries. Large countries such as the United States are relatively credible on average, though not as credible as Germany or Japan. The model also succeeds in identifying small and credible countries, that do not act as anchor currencies such as Singapore. This will help us to distinguish in our empirical analysis the degree of credibility of countries who peg their currency to a stable anchor.

4 Empirical analysis

In this section, we start by describing the details of the global dataset that we compiled for our analysis. Besides presenting the data sources, we provide a set of descriptive statistics together with an event study focusing on the dynamics of inflation, GDP and interest rates before and after a change in the exchange rate regime. To test the implications of our model, we complement our dataset with our credibility measure and provide reduced form evidence on the impact of changing the exchange rate regime. Then, we present our econometric analysis where we use an inverse probability weighted estimator to address the identification challenge present in our analysis - not all changes in the exchange rate regime are unexpected or exogenous to the business cycle. We test the four theorems that are outlined in the model section and base our empirical analysis on the same global dataset. In Section 4.2.1, we ask what is the impact of a change in the exchange rate regime on inflation (Theorem 1) and on real GDP growth (Theorem 2). Then, in Section 4.2.2 we assess what is the impact of a regime change on inflation volatility (Theorem 3) and how a country's credibility affect the response of the variables to a regime shift (Theorem 4).

4.1 Data

We base our analysis on an unbalanced panel with annual data for 169 economies, including both Advanced Economies (AEs) and Emerging Economies (EMEs) over the last 70 years. The data used in this paper mainly relies on two sources: the IMF International Financial Statistics (IFS) database and the Penn World Table version 10.0 (Feenstra et al., 2015). We then complement these two datasets with information from the Macrohistory Database (Jordà et al., 2017) and the Macro-financial dataset from Monnet and Puy (2021). We assemble data on the consumer price index, short- (Bills) and long-term (Bonds) interest rates, real gross domestic product growth rates, government spending, imports and exports.[14]

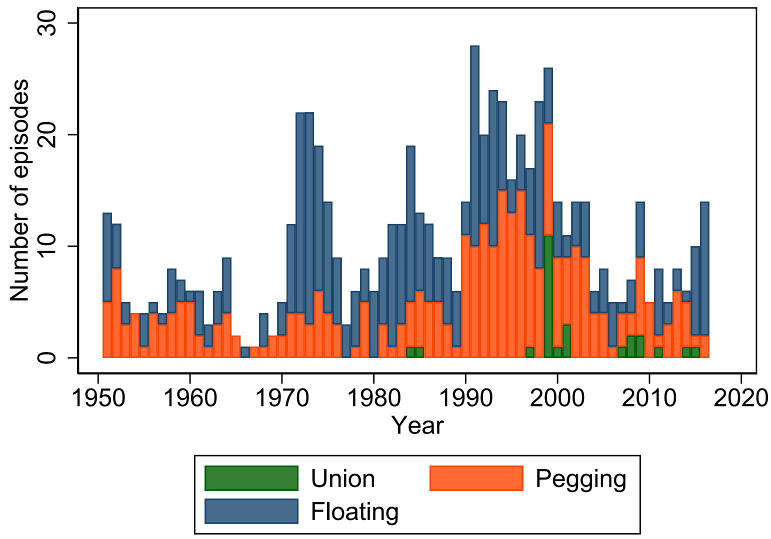
We further complement the resulting dataset with the exchange rate regime classification from Ilzetzki et al. (2019). They identify the exchange rate regime in place for all countries in our sample based on both *de jure* and *de facto* classifications. Throughout the study, we rely on their coarse episode classification which arguably identifies significant changes in the regime while further differentiating between a union and a peg regime. To identify a change in the exchange rate regime we depart from the *de facto exchange rate arrangement classification* by Ilzetzki et al. (2019). We code a floating episode every time there was a change in the coarse classification towards a more flexible exchange rate regime; a pegging episode when

[14] More information on the definition and source of these and other variables can be found in Appendix, Table A.1.

the change was towards a more fixed exchange rate regime; and finally a union episode when the regime changed to a currency union or when there was no separate legal tender. Figure A.1 summarizes the 15 different regimes identified by (Ilzetzki et al., 2019) and how we identify the episodes.

Figure 3 illustrates how many times countries moved towards a more pegged or flexible regime over time. In our sample, we observe 259 pegging episodes, 266 floating episodes, and only 23 union episodes.

Figure 3: Frequency of flexible and fixed regime changes



Notes: Number of the changes of the exchange rate regime classification from Ilzetzki et al. (2019). Green bars: Move into a currency union or a no separate legal tender ($N = 23$). Orange bars: Move towards a peg regime ($N = 259$). Blue bars: Move towards a float' regime ($N = 266$). Figure A.2 in the Appendix further decomposes this graph between advanced and developing economies.

There are two big waves of regime adjustment episodes: One following the Bretton Woods collapse in 1971 when pegged countries were forced to float their currency or peg it to another anchor currency and the other after 1990 when there was a surge on pegging episodes (orange bars) preceding both the Euro creation and the dollarization of emerging economies. Such variation is important to motivate our analysis.

In order to perform a consistent analysis, throughout the rest of the empirical analysis, we only use observations for which we have data on the exchange rate regime, CPI inflation and real GDP growth, rendering roughly 7,500 country-year observations between 1950 and 2016.[15]

[15] In Appendix, Table A.4 gives more details about our sample coverage including the number of episodes by country.

4.1.1 Descriptive Statistics

Table 6 reports summary statistics of the key macroeconomics variables.[16] We can highlight three stylized facts from the literature that are summarized in this Table: 1) inflation is higher and more volatile in floats than in pegs; 2) real GDP growth has similar behaviour; 3) interest rates are higher and more volatile in floats than in pegs.

Table 6: Summary Statistics (unweighted)

	Float		Peg		Union	
	mean	std. dev.	mean	std. dev.	mean	std. dev.
Inflation	11.78	12.31	5.59	6.02	4.19	6.62
Obs	3997		2258		1211	
Real GDP growth	4.18	4.78	4.57	4.81	3.74	6.09
Obs	3997		2258		1211	
Bills	9.97	7.53	5.40	2.78	3.88	1.29
Obs	1836		861		325	
Bonds	8.32	3.26	6.48	2.08	4.16	1.84
Obs	1201		593		271	

Notes: This table reports the mean, within standard deviation and number of observations of each variable in our sample divided by exchange rate regime. Inflation, real GDP growth, short- and long-run interest rates are all in percent units. According to Ilzetzki et al. (2019) classification, the **Union** columns comprise countries with no separate legal tender or in currency union. The **Peg** columns comprise countries in either a pre-announced peg or currency board arrangement, a pre-announced horizontal band that is narrower than or equal to +/-2%, or a *de facto* peg. Finally, the **Float** column comprises countries in all remaining exchange rate regimes. Figure A.1 summarizes the classification. We only consider country-year observations for which inflation rates and real GDP growth were below 100%.

4.1.2 Event Study

In the spirit of Eichengreen and Rose (2012), we now revisit our data and perform an event study exercise in order to analyze how key economic variables varied before and after a change in the exchange rate regime. Table 7 summarizes the mean and the standard deviation of inflation, real GDP growth, short- and long-term interest rates before and after an episode where countries change their exchange rate regime, for the cross-section of countries in our sample that went through at least one such episode.[17]

Table 7: Event Study

[16] Table A.2 in the Appendix provides further summary statistics when weighting the importance of a country by its population size.

[17] For completeness, we present the event study figures for this exercise in Appendix, Figures A.3, A.4, and A.5.

	Float				Peg				Union			
	mean		std. dev.		mean		std. dev.		mean		std. dev.	
	pre	post	pre	post	pre	post	pre	post	pre	post	pre	post
inflation	11.82	17.35	9.42	14.69	17.84	11.02	15.02	9.58	8.11	3.04	7.25	3.60
gdp	4.19	4.25	4.85	4.13	3.42	4.82	4.82	3.36	3.20	2.78	3.02	3.07
Bills	9.99	12.80	4.95	7.57	13.87	10.62	7.88	5.34	5.01	3.80	1.56	1.14
Bond	8.49	9.34	2.52	2.66	9.23	8.41	2.81	3.02	6.44	4.59	1.59	0.64

Notes: This table presents both the mean and the within standard deviation of the four macroeconomics series (inflation, real GDP growth, short-term and long-term interest rates) before and after joining one of the three identified exchange rate regimes, according to Ilzetzki et al. (2019) classification. We only consider country-year observations for which inflation rates and real GDP growth were below 100%.

Table 7 establishes three main observations. First, on average, inflation and interest rates decrease (increase) after a pegging (floating) episode. Second, the variability of inflation and interest rates goes down (up) under a peg (float), as the within country standard deviation gets smaller (larger). Third, we also find that real GDP slightly increases when the currency gets pegged.

4.2 The Effects of an Exchange Rate Regime Change

To estimate the impact of changing the exchange rate regime (ERR), we need to compare two counterfactual scenarios: One where the representative country in our sample effectively changed the ERR and the other where it did not. If the ERR change decision was random, it would be sufficient to compare the average performance of changers to non-changers. However, we know that most countries do not randomly decide to change their ERR.

For the time horizon in our dataset, there are two well studied episodes that offer quasi-random variation. First, the United States' unilateral decision of terminating the convertibility of the US dollar to gold on 15 August 1971. This event effectively led to the collapse of the Bretton Woods agreement, and thus forced countries to change their ERR (Bordo and Eichengreen, 2019). While some were forced to immediately float their currency, others decided to peg to another anchor currency, with the German Mark being one of the preferred currencies (Ilzetzki et al., 2019).

The second episode was the Euro creation. Eurozone accession was driven mainly by political rather than economic factors (Feldstein, 1997). In fact, by not satisfying the requirements of an Optimum Currency Area, many economists believed that countries adopting the Euro would face economic losses (Jonung et al., 2009), belief that was later corroborated in recent works by Puzzello and Gomis-Porqueras (2018) and Gabriel and Pessoa (2020). Notwithstanding, it is not true that all such events in our sample are as good as random.

We thus accept that some changes in the ERR decisions in our dataset are more endogenous than others, but we seek to explicitly model this endogenous decision process and account for it in our estimation. By modelling the ERR change decision, we can effectively reverse-engineer it and re-balance the sample "as if" it was taken at random. To do this, we use the inverse probability weighting methodology exposed in Caliendo and Kopeinig (2008).

4.2.1 The Impact of an Exchange Rate Regime Change on Inflation and Economic Growth

It is possible that policymakers choose a specific ERRe due to current economic circumstances or because they wanted to achieve a certain economic outcome such as lower inflation. Those changes in the ERR cannot be seen as exogenous and are hence uninformative in inferring causal effects of a fixed or a flexible regime. Our model suggests that policy makers who want to maximize their citizen's welfare would opt for a fixed regime if the credibility of their central bank is low.

To estimate the causal response, we thus employ an inverse probability weighted regression-adjusted (IPWRA) estimator which gives more weight to those events that are difficult to predict based on observable macroeconomic variables and less weight to those instances that are endogenous due to the other factors. This estimator will thus re-balance the sample to mimic a setting where the ERR change decision was random. Applications of such method study not only the effect of changes in the ERR on the foreign direct investment (Cushman and De Vita, 2017), but also other macroeconomic topics such as the economic response to austerity (Jordà and Taylor, 2016), sovereign defaults (Kuvshinov and Zimmermann, 2019), and macroprudential policy changes (Richter et al., 2019). We will follow the notation established in the latter work throughout the rest of the empirical section.

Let $d_{i,t}$ be a dummy variable that takes value 1 if there was a change in the exchange rate regime towards a peg (P), float (F) or union (U) and zero otherwise. The estimation proceeds in two stages. In the first stage, we model the ERR change decision for each type of change separately by estimating a propensity score for each observation in our sample. Such score is obtained by a logit model which estimates the probability that the ERR is going to change as follows:

$$log\left(\frac{P[d_{i,t}^{P,F,U}=1|Z_{i,t-1}]}{P[d_{i,t}^{P,F,U}=0|Z_{i,t-1}]}\right)=c_i+\beta Z_{i,t-1}+\varepsilon_{i,t} \tag{6}$$

where $Z_{i,t-k}$ is a vector of macroeconomic controls at time $t-1$ and $t-2$ with the purpose of controlling for business cycle fluctuations, where we include the lagged growth rates of real GDP, trade openness, government consumption, and CPI inflation.[18] We do not include a set

[18]The choice of control variables follows the work of Poirson (2001). In order to keep the number of studied episodes and, consequently, observations at the maximum possible level, we do not include other important control variables like the short- and long-term interest rates, and the standard deviation of the 12 months exchange rate against the US dollar. Results are available on request.

of country fixed effects because we include the credibility measure $c_i = (1-\bar{\xi}_i)100$ estimated in section 3.4. Growth rates are computed as log differences to avoid results being driven by extreme values. Moreover, we exclude observations where lagged absolute values of inflation was above 100%. We refer to the probability of fixing the currency as the propensity score and its estimate from Equation (6) is denoted by $p_{i,t}$. We report results using logit but using probit made very little difference to the results of a number of cases where we tried it, consistent with the discussion in Caliendo and Kopeinig (2008).

Table 8: First-stage results: Prediction of a change in the Exchange Rate Regime

	Float	Peg	Union
credibility	-0.03***	-0.02***	0.00
	(0.01)	(0.01)	(0.01)
l1.CPI	1.18**	5.24***	7.61***
	(0.60)	(0.53)	(2.63)
l2.CPI	-1.21**	-5.18***	-5.67**
	(0.59)	(0.52)	(2.32)
l1.rGDP	-1.06	-3.15**	0.27
	(1.38)	(1.37)	(3.98)
l2.rGDP	-0.58	0.54	-3.95
	(1.27)	(1.32)	(3.70)
Pseudo R^2	0.04	0.08	0.10
AUC	0.67	0.71	0.80
	(0.02)	(0.02)	(0.02)
Observations	6018	6018	6018

Notes: This table shows logit classification models where the dependent variable is the $d_{i,t}^{P,F,U}$ dummies for a pegging, floating, and union episodes. All controls are lagged growth rates together with the credibility parameter. Clustered (by country) standard errors in parentheses. $^{*}(p < 0.10)$, $^{**}(p < 0.05)$, $^{***}(p < 0.01)$.

Table 8 presents the results of our first stage. We run logit classification models for the $d_{i,t}^{P,F,U}$ dummies for a pegging, floating, and union episodes as we want to account for changes in economic variables relevant for policy making which presumably could be targeted by such regime changes. Table 8 shows that higher inflation and lower real GDP growth in the previous period predict changes in the ERR. Moreover, we also find that less credible countries are more likely to float or to peg their currency - as our measure of credibility is inversely related to the probability of discretion, it is reassuring for our approach to find this relation. Trade openness and government consumption which we use as a controls are not good predictors of shifts in the ERR.

We report the AUC statistics which stands for area under the receiver operating curve. The statistic measures the ability of a model to correctly sort observations into the "episode" and "no episode" bins as combinations of true positive and false positive rates. It yields a summary measure of predictive ability that is independent of individual cut-off values chosen. The AUC takes on the value of 1 for perfect classification ability and 0.5 for an uninformed classifier or the results of a "coin toss". Our measures for the AUC are across the models are between 0.67 and 0.80 which is a significant improvement over the coin toss. Figure A.6 in the appendix plot the estimated probabilities of treatment based on the first stage, differentiating between treated units (red) and control units (blue).

In the second stage, we estimate local projections using regression weights given by the inverse of $p_{i,t}$. To be precise, the weights are defined by $w_{i,t} = \frac{d_{i,t}}{p_{i,t}} + \frac{1-d_{i,t}}{1-p_{i,t}}$, where we truncate $w_{i,t}$ at 10. Weighting by the inverse of the propensity score puts more weight on those observations that were difficult to predict and thereby re-randomizes the treatment. In our application, this implies putting more weight on exchange rate regime changes that were taken as a surprise based on observable macroeconomic variables, and putting less weight on those changes that could be predicted. For example, for the evaluation of the impact of pegging a currency we are giving more weight to the de facto peg to the Deutsche Mark by Spain in 1994, and less weight to the de facto peg to the US dollar by Ukraine in 2000. This reflects the economic crisis that Ukraine experienced during that time, which motivated its peg towards the US Dollar, while Spain's decision to peg towards the Deutsche Mark was rather driven by political considerations to join the Euro, and not economic ones. We therefore give a lower weight to ERR changes that were driven by economics goals and a bigger weight those events that were not driven by economic reasoning.

Once the sample is re-balanced, the impact of an ERR change is measured as its "average treatment effect", that is, the average difference in potential outcomes of changers and non-changers across the sample. Potential outcomes are computed using a conditional local projection forecast over a horizon of 5 years (Jordà, 2005). To implement the second stage, we thus run the following specification using weighted least squares:

$$\Delta_h y_{i,t+h} = c_i^h + \gamma_t^h + \Gamma^h d_{i,t}^{P,F,U} + \phi_h Z_{i,t-k} + \epsilon_{i,t+h}, \quad \forall h \in \{0, ..., 5\} \tag{7}$$

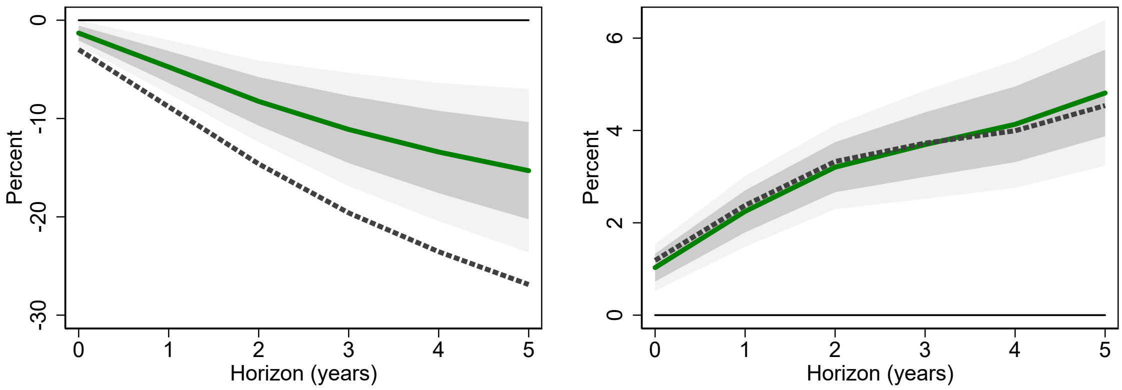
where $\Delta_h y_{i,t+h} = log(y_{i,t+h}) - log(y_{i,t-1})$ is the conditional forecast of the cumulative growth in percent in one of the outcome variables (real GDP or the price level), in country i between base year $t-1$ and year $t+h$ over varying prediction horizons $h = 0, 1, ..., 5$ years. $d_{i,t}^{P,F,U}$ is the treatment dummy variable as before, taking a value of 1 whenever there is a Pegging (P), Floating (F), or Union (U) episode and thus Γ^h is our coefficient of interest.

We include a rich set of covariates in each specification including the country-specific credibility parameter c_i^h as well as time-fixed effects γ_t^h. Moreover, we include $Z_{i,t-k}$ which is a vector consisting of 2 lags real GDP growth, inflation, trade openness, and government consumption; the same set of controls in equation 6. Finally, $\epsilon_{i,t+h}$ is the error term, and the standard errors are clustered by country. This procedure assigns a higher weight to the treated observations that were less likely to be treated based on this analysis, i.e. those observations with very low probabilities. Further details on the methodology can be found in Jordà and Taylor (2016). In order to test Theorems 1 and 2, we estimate equation (7) for the percent change in the price level and real GDP approximated by taking log differences.

Figures 4 and 5 present the main results and provide evidence in favor of the first two theorems. To put our findings in perspective, we estimate Equation (7) using both WLS and OLS. This way we can evaluate the correction of the expected bias.

Figure 4: IPWRA Results of a pegging event

(a) Cumulative price level change (b) Cumulative real GDP change



Notes: The figure shows the impulse response functions for the price level and real GDP growth rates in percent over time, after a pegging episode. The IRFs compares the cumulative response of the price level and GDP relative to a counterfactual country that did not peg its currency. I.e the price level after 5 years is around 17.5% lower than for a country that did not peg its currency. Equation (7) has been estimated with weighted least squares. The weights correspond to the inverse estimated probability of an exchange rate regime change from (6). The (dark) gray shaded areas indicate a confidence interval of (68%) 90%. The black dashed line shows the OLS estimates. Figure A.8 presents the non-cumulative responses.

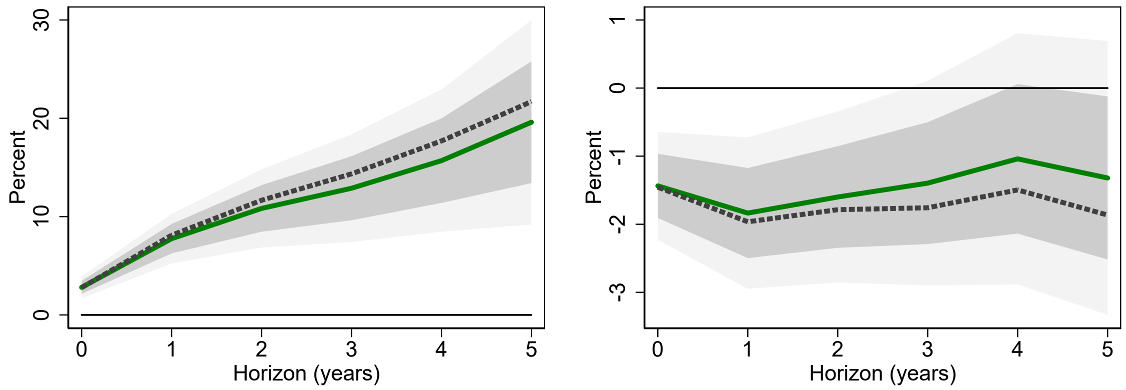
The estimates in Figure 4 suggest that pegging episodes seem to have significant and persistent effects on both the price level and real GDP. We see that adopting a fixed exchange rate regime leads to an average 17.5% decline in the price level - about 3.5% per year lower inflation - and to a 5% increase in real GDP whereas most of the GDP growth takes place in the first three years. Keep in mind that the measurements are cumulative over the horizon of 5 years and both effects are relative to the no-change policy counterfactual. Thus, the fact that the price level is decreasing does not mean that a country experienced deflation after a pegging event, but rather means that the inflation rates experienced are smaller than the no-change policy counterfactual. For non-cumulative responses check Figure A.8.

For the price level response, the OLS estimate (dashed black line) displays a stronger reaction than the IPWRA estimate. This suggests that, not surprisingly, countries with large inflationary bias are more likely to change their exchange rate regime. Our IPWRA approach corrects for such bias by giving more weight to episodes in countries that are more stable but still change their exchange rate regime.

Figure 5: IPWRA Results of a floating episode

(a) Cumulative price level change

(b) Cumulative real GDP change

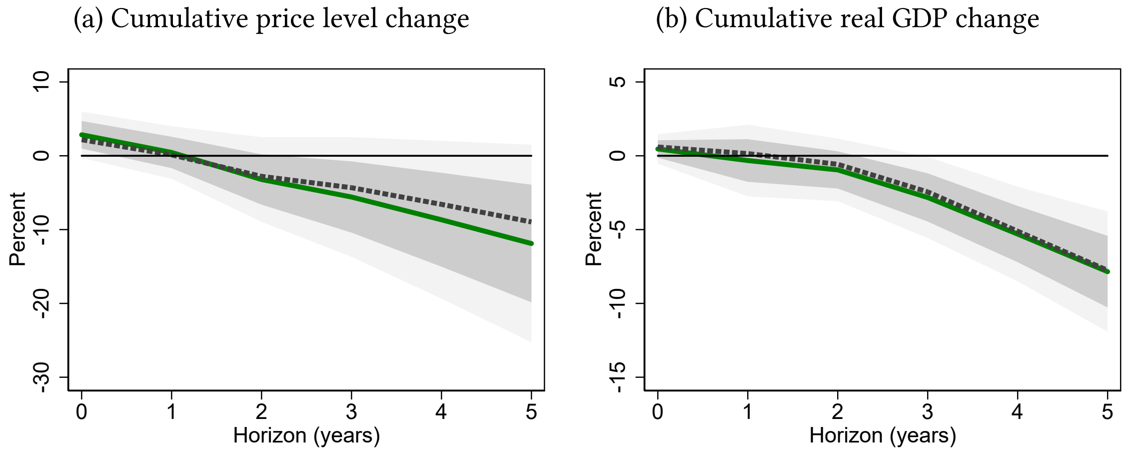


Notes: The figure shows the impulse response functions for the price level and real GDP growth rates in percent over time, after a floating episode. Equation (7) has been estimated with weighted least squares. The weights correspond to the inverse estimated probability of an exchange rate regime change from (6). The (dark) gray shaded areas indicate a confidence interval of (68%) 90%. The black dashed line shows the OLS estimates. Figure A.8 presents the non-cumulative responses.

In contrast and almost symmetrically, a shift towards a more floating regime leads to a strong positive response of the price level and a negative response of real GDP. Figure 5 shows that adopting a floating exchange rate regime leads to a 20% increase in the price level - about 4% per annum higher inflation than the counterfactual - and to a 1% decrease in real GDP, albeit not statistically significant in the long-run.

For completeness, Figure 6 presents the effect on the price level and the real GDP growth rates after an episode where a country joined a currency union or adopted a no separate legal tender. Albeit displaying more noise given the small number of events ($N = 23$), the responses go in line with the ones for a pegging episode in Figure 4 for the price level that qualitatively declines. According to our Theorem 2, the output of countries forming a currency union is expected to rise only if inflation goes down. Hence, it is not surprising that the cumulative real GDP response is actually negative. Notwithstanding, we must acknowledge that our empirical setting is not the ideal to specifically test for the effects of entering a currency union. Out of the few, 23, such episodes, the majority lies within the Eurozone creation. According to other papers studying the Eurozone accession impact on real GDP, this negative cumulative response against a counterfactual scenario of not entering the Eurozone should not come as a surprise (Puzzello and Gomis-Porqueras, 2018; Gabriel and Pessoa, 2020).

Figure 6: IPWRA Results of a union event



Notes: The figure shows the impulse response functions for the price level and real GDP growth rates in percent over time, after an episode where a country joined a currency union or adopted a no separate legal tender. Equation (7) has been estimated with weighted least squares. The weights correspond to the inverse estimated probability of an exchange rate regime change from (6). The (dark) gray shaded areas indicate a confidence interval of (68%) 90%. The black dashed line shows the OLS estimates. Figure A.8 presents the non-cumulative responses.

In Appendix, Figure A.7 displays the response of the short-run interest rate to each one of the studied episodes. The unambiguous responses show an increase (decrease) in the short run interest rates following a floating (pegging) episode of 200 basis points. The interest rate response therefore moves in parallel to the inflation rate when the exchange rate regime is altered towards a fixed or a float exchange rate regime, as we can see from the non-cumulative responses of the price level in Figure A.8. This is in line with findings of Schmitt-Grohe and Uribe (2021) who find that interest rate and inflation move in parallel when a permanent monetary policy shock arises.

All in all, we are able to find supporting evidence for Theorems 1 and 2. We provide empirical evidence in favor of a decrease in inflation and an increase in output after a pegging episode, even when accounting for the fact that changes in the exchange regime are not random by employing an inverse probability weighted regression-adjusted estimator.

4.2.2 Exchange Rate Regime Changes, Inflation Volatility, and Credibility

To test Theorem 3, we estimate the same model as in the previous section with a different dependent variable. We will use the difference in the volatility (standard deviation) of inflation in the 5 years preceding the adoption of the new exchange rate regime compared to the 5 years after and use it as our key dependent variable.

In order to test Theorem 4 - "response of inflation, output, and inflation volatility varies with the degree of credibility" - we add an interaction term between the main variable of interest and the credibility measure derived from our model according to section 3.3. To make it consistent across dependent variables we look at the five-year window and adapt equation

(7). To be precise, we estimate:

$$\Delta y_{i,t+5} = \Gamma d_{i,t}^{P,F,U} + \Omega d_{i,t}^{P,F,U} \times c_i + \omega c_i + \phi Z_{i,t-k} + \gamma_t + \epsilon_{i,t} \tag{8}$$

where $\Delta y_{i,t+5} = log(y_{i,t+5}) - log(y_{i,t-1})$ is the conditional forecast of the cumulative growth in percent in one of the outcome variables (real GDP or the price level), in country i; or $\Delta y_{i,t+5} = \frac{std(\pi_{i,t+1:t+5}) - std(\pi_{i,t-4:t})}{std(\pi_{i,t-4:t})}$ for the inflation volatility variable. c_i is the average credibility parameter as presented in section 3.4. The coefficient of interest here is Ω that will test Theorem 4 and tell us whether countries with different credibility profiles react differently to a change in the exchange rate regime.

Let us recall the main hypothesis coming from our model: Less credible countries benefit more from pegging to a credible anchor country. By definition, in our sample, all anchor countries are credible countries, or at least more credible than the pegging country. Thus, our hypothesis implies that the Ω coefficient should display the symmetric sign of the Γ coefficient. Table 9 presents the key results of this exercise.

Table 9: The Credibility Channel Effects

	Real GDP		Price Level		Inflation Volatility	
Peg (Γ)	4.92^{***}	4.41^{**}	-17.13^{***}	-29.66^{***}	-1.12^{**}	-2.00^{**}
	(0.95)	(1.93)	(5.52)	(9.34)	(0.51)	(0.90)
Interaction (Ω)		0.02		0.59^{**}		0.04^{*}
		(0.08)		(0.24)		(0.02)
Observations	6018	6018	5973	5973	4592	4592

Notes: This table presents the impact of a pegging episode on Real GDP, the price level, and inflation volatility. For each dependent variable, the first column presents the coefficients and standard errors in parentheses for model (7) while the second column for model (8). $^{*}(p < 0.10)$, $^{**}(p < 0.05)$, $^{***}(p < 0.01)$.

From Table 9, we can provide some evidence in favor of Theorem 4. While columns 1 and 3 reproduce our findings in the previous section for the 5-year horizon, column 4 qualitatively supports our model Theorem 4. We find that after a pegging episode for each extra point in the credibility index, annual inflation decreases 0.6% less after 5 years compared to a counterfactual scenario of no policy intervention - numbers are in line with the model in Section 2. This means that the more credible a country is, the smaller the price level response. **This finding, translates into the main policy implication of this paper: the less credible countries are the ones benefiting the most from committing to a fixed exchange rate regime.**

According to our calibrated model, a central bank that is one index point more credible experiences 0.14% less inflation per year, compared to 0.12% per year in the data as the slope in Figure B.4 displays. With our estimates from column 4 at hand, we can compute an individual response of inflation for each country. For example, a non-credible country such as Italy reduce its inflation rate by 3 % per year by pegging their exchange rate. On the other hand, credible countries such as Germany experience only a small reduction in their inflation rate of 0.8% when fixing their currency. This result reconciles our findings with the ones in Itskhoki and Mukhin (2019) who find no macroeconomic effects of changing the regime. They focus on the United States (a country with medium credibility according to our dataset) and on a composite of countries consisting out of Germany and Japan (both credible) as well as Italy and Spain (both non-credible). The composite is as credible as the US and therefore features no substantial effects when changing the regime towards the United States.

In the last two columns, we provide empirical evidence in favor of Theorem 3. The standard deviation of inflation decreased by 1.12% after a pegging episode. Moreover, it is worth noticing that the interaction term in the last column is positive and statistically significant. The latter implies that the more credible a country is, the smaller is the inflation volatility reduction.

5 Conclusion

We assess the gains from commitment of adopting a fixed exchange rate regime. This paper argues that countries suffering from high inflation due to non-credible monetary policy can reduce the level and the volatility of inflation by pegging their currency to a stable anchor. The reduction in the level of inflation can be substantial, depending on the initial credibility of the country that pegs its currency. In particular, low credibility countries such as Italy or Spain have managed to bring inflation down by several percentage points by entering a fixed exchange rate regime. We also provide evidence that this permanent reduction of inflation goes hand in hand with a short-run increase in real GDP as the costs of inflation go down as well. Our focus on the credibility of the country that wants to peg aligns our results with the exchange rate disconnect literature. This strand of literature provides evidence for no effects of the exchange rates on the economy, as they consider a mix of very credible and non-credible countries who change the regime. According to our estimates, very credible countries see little to no effect, while this is not true for non-credible countries.

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Appendix A Data and Empirics

Table A.1: Data Description

Variable Name	Definition	Sources
Bills	Treasury Yields, Percent per annum	IMF, JST
Bond	Long-Term Government Bond Yields, Percent per annum	IMF, JST, MP
CPI	Counsumer Price Index of All Commodities	IMF
ERA	Exchange Rate Agreement	Ilzetzki et al. (2019)
Exchange Rate	National Currency to German Mark	Bundesbank
GDP	Real Gross Domestic Product Real	Penn World Table
Gov	Government Consumption	Penn World Table
Trade	Total value of imports and exports	Penn World Table
Population	Number of Inhabitants	IMF, Penn World Table

Notes: This table reports the data sources for our sample. IMF stands for the International Monetary Fund, International Financial Statistics (IFS) database and the Penn World Table corresponds to the version 10.0 (Feenstra et al., 2015). JST stands for the Macrohistory Database (Jordà et al., 2017) while MP for the Macro-financial dataset from Monnet and Puy (2021).

Table A.2: Summary Statistics (weighted by population size)

	Float		Peg		Union	
	mean	std. dev.	mean	std. dev.	mean	std. dev.
inflation	9.58	11.81	5.73	7.02	3.13	7.31
Obs	3997		2258		1211	
gdp	4.83	3.83	5.38	3.92	2.80	4.67
Obs	3997		2258		1211	
Bills	8.56	8.29	4.91	3.34	2.01	1.56
Obs	1836		861		325	
Bond	7.66	3.34	5.93	2.74	3.88	1.87
Obs	1201		593		271	

Notes: This table reports the mean, within standard deviation and number of observations of each variable for our sample divided by exchange rate regime and weighted by the population size.. According to Ilzetzki et al. (2019) classification, the **Union** columns comprise countries with no separate legal tender or in currency union. The **Peg** columns comprise countries in either a pre-announced peg or currency board arrangement, a pre-announced horizontal band that is narrower than or equal to +/-2%, or a *de facto* peg. Finally, the **Float** columns comprise countries in all remaining exchange rate regimes.

Table A.3: Average Duration of Exchange Rate Regimes

	Float	**Peg**	**Union**
Average Duration (years)	22.8	15.1	23.8

Notes: This table reports the average duration of each exchange rate regime in years in our sample, according to the Ilzetzki et al. (2019) classification.

Table A.4: Episodes and Data Coverage

Country	Peg	Float	Begin	End	Country	Peg	Float	Begin	End	Country	Peg	Float	Begin	End	Country	Peg	Float	Begin	End
Albania	2	1	1992	2016	D.R. of the Congo	3	4	1964	2016	Kyrgyzstan	1	1	1996	2016	Russian Federation	1	3	1993	2016
Algeria	1	1	1970	2016	Denmark	2	2	1950	2016	Lao People's DR	3	1	1989	2016	Rwanda	1	1	1967	2016
Angola	1	2	1991	2016	Djibouti	0	0	1980	2016	Latvia	3	2	1992	2016	Saint Kitts and Nevis	0	0	1980	2016
Antigua and Barbuda	0	0	1999	2016	Dominica	0	0	1970	2016	Lebanon	0	0	2009	2016	Saint Lucia	0	0	1970	2016
Argentina	7	6	1950	2016	Dominican Republic	5	5	1950	2016	Lesotho	0	0	1974	2016	Sao Tome and Principe	2	0	1997	2016
Armenia	1	0	1994	2016	Ecuador	6	5	1952	2016	Liberia	1	0	2002	2016	Saudi Arabia	0	0	1970	2016
Australia	0	3	1950	2016	Egypt	1	1	1950	2016	Lithuania	1	0	1992	2016	Senegal	0	0	1968	2016
Austria	3	2	1950	2016	El Salvador	1	2	1950	2016	Luxembourg	0	0	1950	2016	Serbia	0	2	1995	2016
Azerbaijan	1	2	1992	2016	Equatorial Guinea	0	0	1986	2016	Madagascar	3	5	1965	2016	Seychelles	0	2	1971	2016
Bahamas	0	0	1970	2016	Estonia	0	0	1993	2016	Malawi	4	5	1981	2016	Sierra Leone	0	0	2007	2016
Bahrain	0	0	1970	2016	Eswatini	0	0	1970	2016	Malaysia	1	3	1955	2016	Singapore	0	1	1961	2016
Bangladesh	1	0	1987	2016	Ethiopia	2	2	1966	2016	Maldives	1	0	1986	2016	Slovakia	1	2	1992	2016
Barbados	0	0	1967	2016	Fiji	0	1	1970	2016	Mali	0	0	1989	2016	Slovenia	2	1	1990	2016
Belarus	2	2	1993	2016	Finland	2	2	1950	2016	Malta	1	1	1954	2016	South Africa	1	3	1950	2016
Belgium	1	0	1950	2016	France	5	3	1950	2016	Mauritania	1	0	1986	2016	Spain	3	1	1950	2016
Benin	0	0	1993	2016	Gabon	0	0	1963	2016	Mauritius	2	2	1964	2016	Sri Lanka	3	3	1950	2016
Bhutan	0	0	1981	2016	Gambia	2	2	1962	2016	Mexico	3	4	1950	2016	St. Vincent Grenadines	0	0	1975	2016
Bolivia	6	4	1950	2016	Georgia	2	1	1995	2016	Mongolia	1	1	1993	2016	Sudan	2	2	1970	2016
Bosnia and Herzegovina	0	0	2006	2016	Germany	2	2	1950	2016	Montserrat	0	0	2002	2016	Suriname	3	5	1970	2016
Botswana	0	2	1975	2016	Ghana	3	7	1965	2016	Morocco	2	1	1950	2016	Sweden	3	3	1950	2016
Brazil	4	4	1950	2016	Greece	3	2	1950	2016	Mozambique	1	1	2005	2016	Switzerland	1	2	1950	2016
Brunei Darussalam	0	0	1981	2016	Grenada	0	0	1977	2016	Myanmar	4	6	1962	2016	Syrian Arab Republic	1	1	1960	2012
Bulgaria	1	0	1986	2016	Guatemala	3	2	1950	2016	Namibia	0	0	2003	2016	Tajikistan	1	0	2001	2016
Burkina Faso	0	0	1959	2016	Guinea	1	1	2005	2016	Nepal	3	4	1965	2016	Thailand	2	1	1950	2016
Burundi	2	4	1966	2016	Guinea-Bissau	0	1	1988	2016	Netherlands	3	1	1950	2016	Togo	0	0	1967	2016
Cabo Verde	0	0	1984	2016	Guyana	1	0	1995	2016	New Zealand	0	1	1950	2016	Trinidad and Tobago	0	0	1953	2016
Cambodia	2	0	1995	2016	Haiti	2	5	1960	2016	Nicaragua	0	0	2000	2016	Tunisia	0	0	1984	2016
Cameroon	0	0	1969	2016	Honduras	3	3	1950	2016	Niger	0	0	1964	2016	Turkey	4	4	1950	2016
Canada	0	2	1950	2016	Hungary	2	1	1973	2016	Nigeria	4	5	1954	2016	U.R. of Tanzania: Mainland	5	5	1966	2016
Central African Republic	0	0	1981	2016	Iceland	3	4	1950	2016	North Macedonia	2	0	1994	2016	Uganda	0	0	1994	2016
Chad	0	0	1984	2016	India	2	3	1950	2016	Norway	1	1	1950	2016	Ukraine	3	2	1993	2016
Chile	6	5	1950	2016	Indonesia	5	4	1960	2016	Oman	0	0	2001	2016	United Arab Emirates	0	0	2008	2016
China	2	1	1987	2016	Iran	4	4	1955	2016	Pakistan	3	4	1950	2016	United Kingdom	1	2	1950	2016
China, Hong Kong SAR	1	0	1982	2016	Iraq	2	1	1970	2016	Panama	0	0	1950	2016	United States	0	2	1950	2016
China, Macao SAR	0	0	1989	2016	Ireland	1	1	1950	2016	Paraguay	3	5	1950	2016	Uruguay	5	6	1950	2016
Colombia	2	3	1950	2016	Israel	3	5	1952	2016	Peru	3	3	1950	2016	Venezuela	0	1	2009	2016
Comoros	0	0	2001	2013	Italy	3	2	1950	2016	Philippines	4	5	1950	2016	Viet Nam	0	0	1996	2016
Congo	0	0	1986	2016	Jamaica	4	3	1954	2016	Poland	1	1	1971	2016	Yemen	1	1	1991	2014
Costa Rica	4	3	1950	2016	Japan	2	2	1950	2016	Portugal	2	1	1950	2016	Zambia	1	1	1986	2016
Croatia	2	0	1990	2016	Jordan	2	1	1970	2016	Qatar	0	0	1980	2016	Zimbabwe	0	0	2010	2016
Cyprus	1	1	1950	2016	Kazakhstan	1	1	1994	2016	Republic of Korea	4	4	1953	2016					
Czech Republic	1	2	1992	2016	Kenya	2	2	1960	2016	Republic of Moldova	3	2	1992	2016					
Côte d'Ivoire	0	0	1961	2016	Kuwait	1	1	1973	2016	Romania	3	1	1991	2016					

Notes: Number of the changes of the exchange rate regime classification towards a more Peg or Float regime from Ilzetzki et al. (2019). Given its small number of occurrences, in this Table, a Union episode is counted as a Peg episode. Data coverage for each country, begin and end of sample, for which we have information on the exchange rate regime classification, inflation, and real GDP growth rate, our baseline sample.

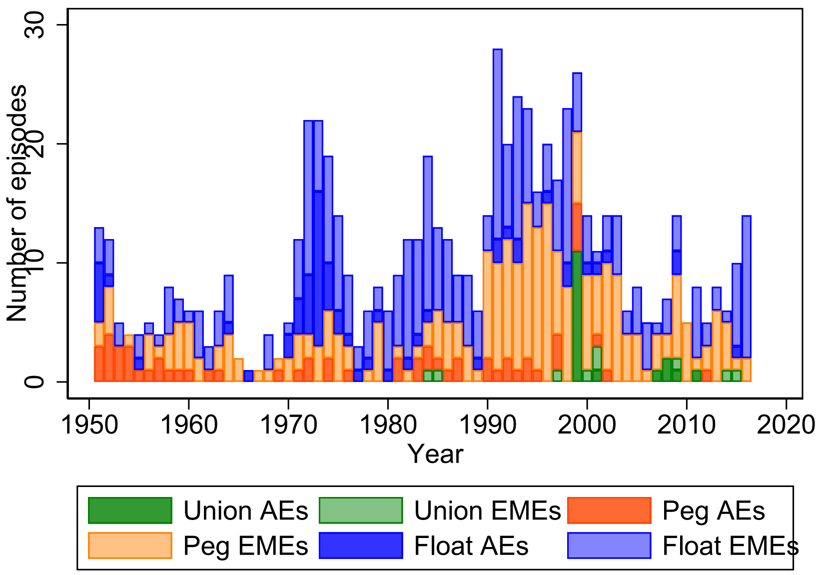
Figure A.1: De Facto Exchange Rate Arrangement Classification (Ilzetzki et al., 2019)

Coarse	Fine	
1	1	• No separate legal tender or currency union
1	2	• Pre announced peg or currency board arrangement
1	3	• Pre announced horizontal band that is narrower than or equal to +/-2%
1	4	• De facto peg
2	5	• Pre announced crawling peg; de facto moving band narrower than +/- 1%
2	6	• Pre announced crawling band that is narrower than or equal to +/-2%
2	7	• De facto crawling peg
2	8	• De facto crawling band that is narrower than or equal to +/-2%
3	9	• Pre announced crawling band that is wider than or equal to +/-2%
3	10	• De facto crawling band that is narrower than or equal to +/-5%
3	11	• Moving band that is narrower than or equal to +/-2%
3	12	• De facto moving band +/-5%/ Managed floating
4	13	• Freely floating
5	14	• Freely falling
6	15	• Dual market in which parallel market data is missing.

Union Episode	
Fine	
[2:15] -> [1]	
Pegging Episodes	
Fine	Coarse
[5:15] -> [2:4]	[2:6] -> [1]
[9:15] -> [5:8]	[3:6] -> [2]
[13:15] -> [9:12]	[4:6] -> [3]
Floating Episodes	
Fine	Coarse
[1:4] -> [5:15]	[1] -> [2:6]
[5:8] -> [9:15]	[2] -> [3:6]
[9:12] -> [13:15]	[3] -> [4:6]

Notes: We code a floating episode every time there was a change in the coarse classification towards a more flexible exchange rate regime; a pegging episode when the change was towards a more fixed exchange rate regime; and finally a union episode when the regime changed to a currency union or when there was no separate legal tender.

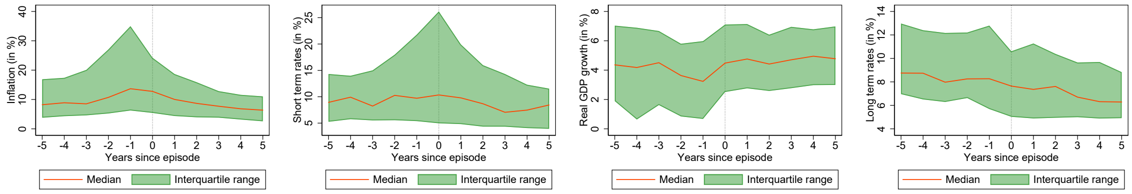
Figure A.2: Frequency of flexible and fixed regime changes



Notes: Number of the changes of the exchange rate regime classification from Ilzetzki et al. (2019). Orange bars: Move towards a peg regime ($N = 259$). Blue bars: Move towards a float' regime ($N = 266$).

Figure A.3: Event study for a pegging episode

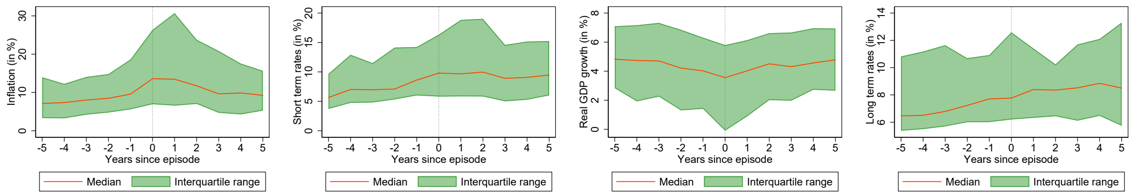
(a) Inflation (b) Short interest rate (c) Real GDP growth (d) Long interest rate



Notes: The figure shows the event-study for median inflation and median interest rates in percentage points, and median real GDP growth in percent before and after a pegging episode, when the exchange rate regime becomes more pegged.

Figure A.4: Event study for a floating episode

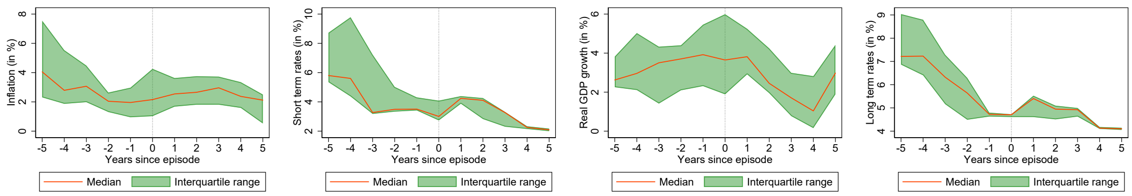
(a) Inflation (b) Short interest rate (c) Real GDP growth (d) Long interest rate



Notes: The figure shows the event-study for median inflation and median interest rates in percentage points, and median real GDP growth in percent before and after a floating episode, when the exchange rate regime becomes more float.

Figure A.5: Event study for a union episode

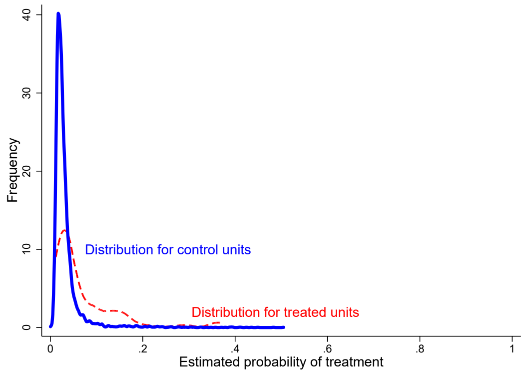
(a) Inflation (b) Short interest rate (c) Real GDP growth (d) Long interest rate



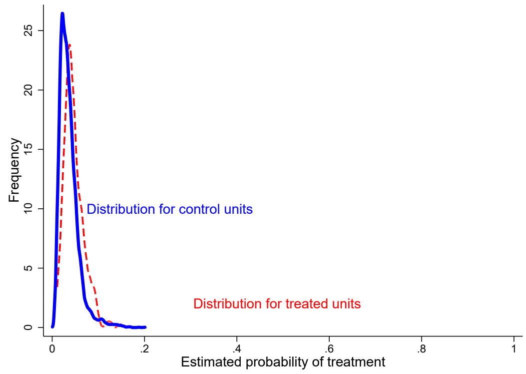
Notes: The figure shows the event-study for median inflation and median interest rates in percentage points, and median real GDP growth in percent before and after a union episode, when countries enter in a currency union.

Figure A.6: Treatment propensity score: First-stage results

(a) Peg



(b) Float



(c) Union

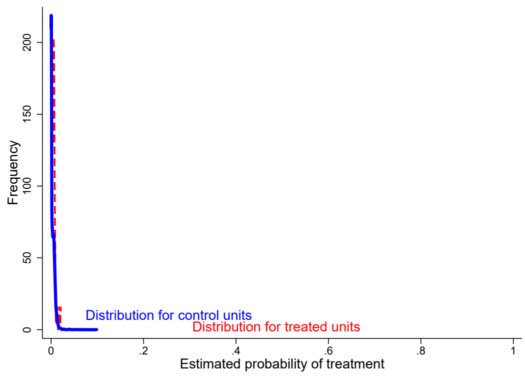
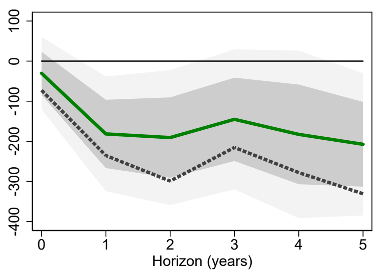
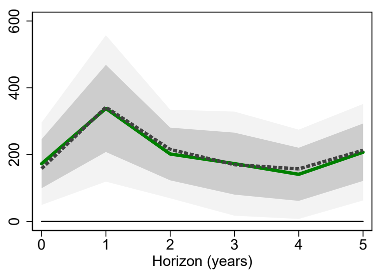


Figure A.7: IPWRA Results for the Short-run Interest Rate

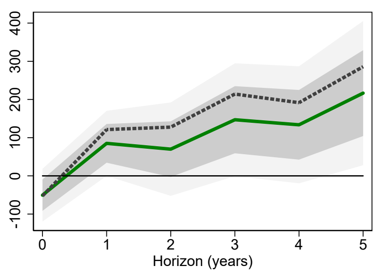
(a) Peg



(b) Float

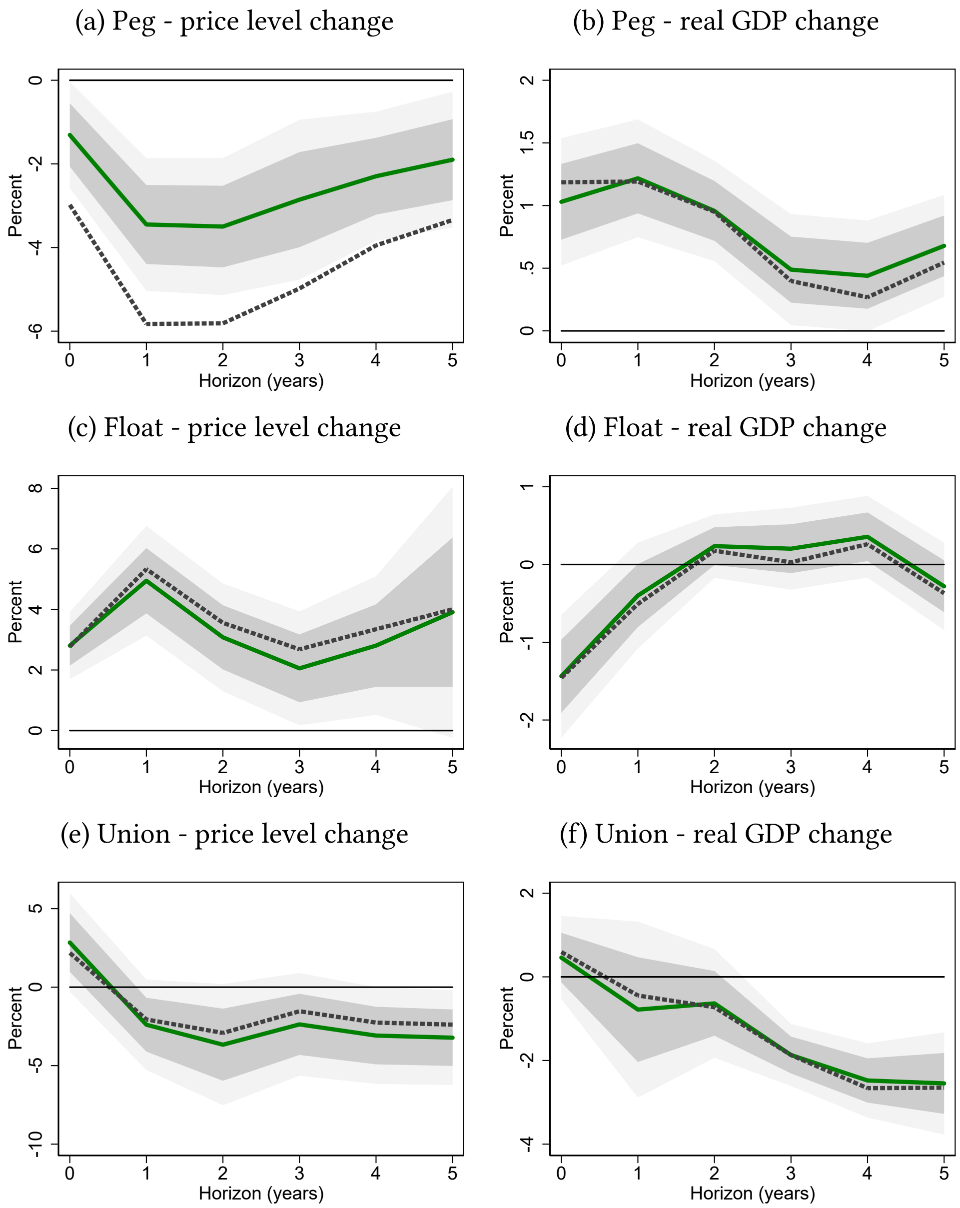


(c) Union



Notes: The figure shows the IRFs for the short run interest rate in **basis points** after each of the studied episodes. Equation (7) has been estimated with weighted least squares. The weights correspond to the inverse estimated probability of an exchange rate regime change from (6). The (dark) gray shaded areas indicate a confidence interval of (68%) 90%. The black dashed line shows the OLS estimates.

Figure A.8: IPWRA Results for Non-Cumulative Variables



Notes: The figure shows the IRFs for non-cumulative dependent variables after each of the studied episodes. We compute our dependent variables by taking the first differences at each horizon h in equation (7) that has been estimated with weighted least squares. The weights correspond to the inverse estimated probability of an exchange rate regime change from (6). The (dark) gray shaded areas indicate a confidence interval of (68%) 90%. The black dashed line shows the OLS estimates.

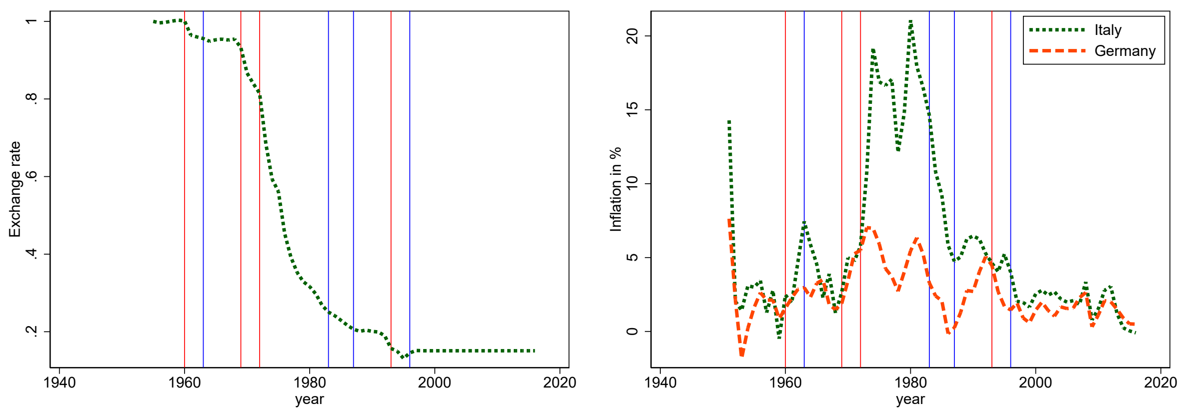
A.1 Case Study: Italy and Germany

We provide descriptive evidence about the relationship between the exchange rate regime and inflation in Italy (as the pegging country) and Germany (as the anchor country). We take Germany as the benchmark because it is the largest economy in Europe and plays a pronounced role for the continent's economy. With this assessment, we follow Ilzetzki et al. (2019) who identify Germany as the anchor country for most continental (western) European countries following the breakdown of the Bretton Woods agreement.

Figure A.9a shows the bilateral exchange rate of the Italian Lira to the German Mark between 1954 and 2016. The exchange rate is indexed to 1 in 1955, the data are taken from the Bundesbank. Figure A.9b shows the inflation rate of Italy and Germany. The exchange rate regime changes are identified by a vertical blue (peg) and red (float) lines:

Figure A.9: Exchange rate and inflation in Italy

(a) Exchange Rate (1955=1) (b) Inflation (in %)



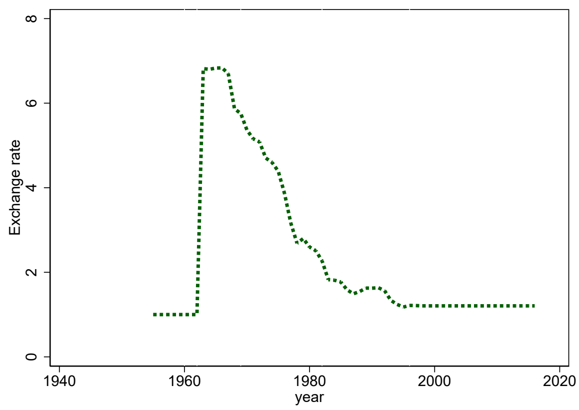
Notes: Graph (a) shows the evolution of the bilateral exchange rate of the Italian Lira to the German Mark normalized to 1 in 1955. Graph (b) shows how inflation in Germany (dashed red line) and Italy (dotted green line) co-moved over time. According to the fine classification of Ilzetzki et al. (2019), the vertical red lines indicate a fall of the exchange rate or a shift towards a floating exchange rate regime, the blue vertical lines a shift towards an exchange rate regime that is more pegged and that was followed by a stabilization of the exchange rate. Sources: Bundesbank, IFS, and Ilzetzki et al. (2019).

At the beginning of our sample Italy and Germany were both in a fixed exchange rate regime. There is almost no movement in the exchange rate and inflation moves below 5% for both countries. After the end of Bretton Woods, Italy's currency experiences a large depreciation. This coincides with a large increase of Italy's inflation. Inflation peaks at over 20 percent after 1980. After 1985, as the exchange rate gets pegged to the German Mark, the behavior of Italy's inflation changes: Fixing the exchange rate to Germany coincides with a convergence of inflation to the relatively low and stable German level.

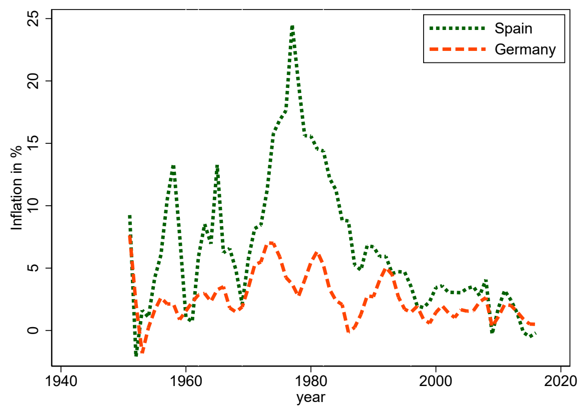
Moreover, there seems to be a change in the behavior of the variability of inflation: During the time of a flexible exchange rate regime - between 1972 and 1985 - inflation displayed higher volatility. In contrast, volatility decreased from the 90's onward, marking the arrival of the Euro. This decline in volatility was very pronounced for Italy, but also clearly visible for Germany. Furthermore, when comparing Germany's inflation during the episodes of flexible exchange rates with those episodes with fixed exchange rates, it seems that average inflation is also slightly lower with fixed rates.

Other southern European countries, like Spain or Portugal, experienced similar patterns: A stable exchange rate to the German Mark coincided with similar inflation rates, but when monetary policy was conducted independently without any exchange rate goal, the exchange rate depreciated, inflation substantially increased compared to Germany and the variability went up. Contrarily, countries like Austria and the Netherlands had their inflation closely tracking Germany's inflation (Figure A.11).

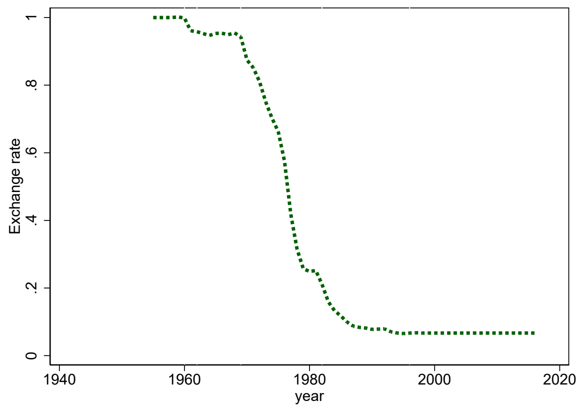
Figure A.10: Exchange rate and inflation in Spain and Portugal



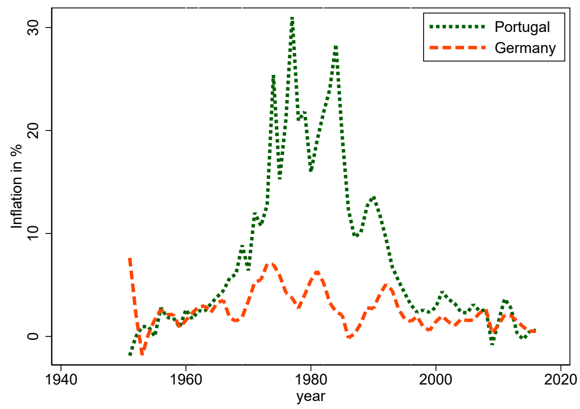
(a) Exchange Rate ESP-DEU (1955=1)



(b) Inflation (in %)



(c) Exchange Rate PRT-DEU (1955=1)



(d) Inflation (in %)

Notes: Graph (a) shows the evolution of the bilateral exchange rate of the Spanish currency to the German Mark normalized to 1 in 1955. Graph (b) shows how inflation in Germany (dashed red line) and the Spain (dotted green line) co-moved over time. Inflation and Exchange rate Portugal Graph (c) shows the evolution of the bilateral exchange rate of the Portuguese currency to the German Mark normalized to 1 in 1955. Graph (d) shows how inflation in Germany (dashed red line) and the Portugal (dotted green line) co-moved over time.

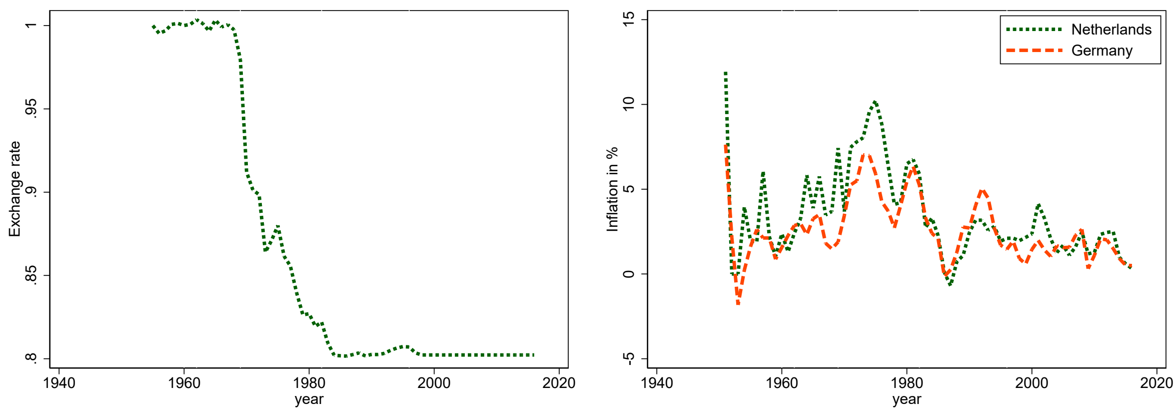
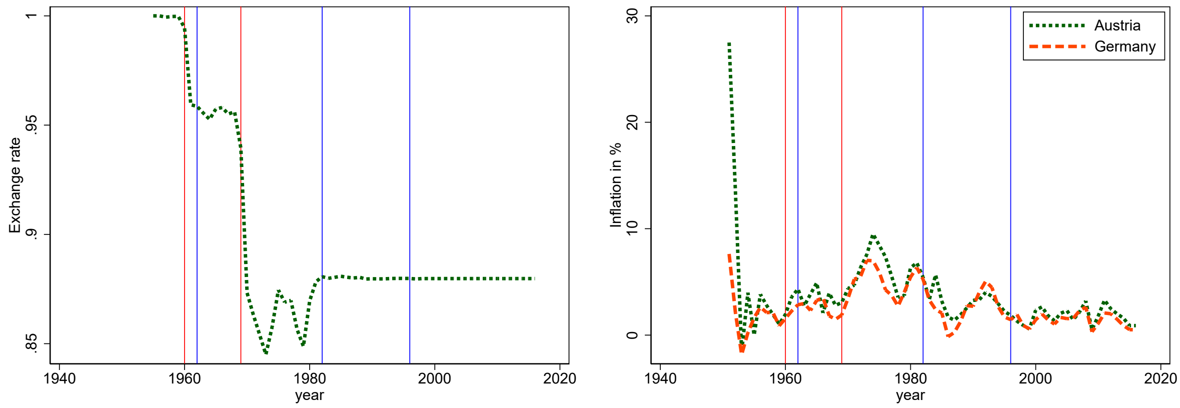


Figure A.11: Exchange rate and inflation in Austria and the Netherlands



(a) Exchange Rate AUT-DEU (1955=1)

(b) Inflation (in %)

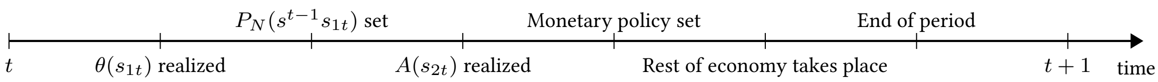
Notes: Graph (a) shows the evolution of the bilateral exchange rate of the Austrian Schilling to the German Mark normalized to 1 in 1955. Graph (b) shows how inflation in Germany (dashed red line) and Austria (dotted green line) co-moved over time. The vertical red lines indicate a fall of the exchange rate or a shift towards a floating exchange rate regime, the blue vertical lines a shift towards an exchange rate regime that is more pegged and that was followed by a stabilization of the exchange rate.

Appendix B Model

B.1 Setup

The model closely follows Chari et al. (2020). The economy consists out of a continuum of countries. Each country produces traded and non-traded goods. The traded good sector is assumed to be perfectly competitive while the non-traded good sector has imperfect competition and sticky prices. This assumption reflects the notion that flexible exchange rates are desirable as they ensure that the relative prices of traded goods to non-traded goods move as if all prices were flexible.

There are two different sources of shocks that hit the non-traded sector only: A markup shock and a productivity shock. Each of these shocks can happen on an aggregate level that hits the whole world equally and on a country-specific level. We adopt the same notation as in Chari et al. (2020) and denote $z_t = (z_{1t}, z_{2t}) \in Z$ as an aggregate shock in time t where the subindex 1 refers to the markup shock and the subindex 2 to the productivity shock. The country-specific shock $v_t = (v_{1t}, v_{2t}) \in V$ is drawn each period. All of the shocks are i.i.d. over time and across country [19]. The probability of aggregate shocks is $f(z_{1t}, z_{2t}) = f^1(z_{1t})f^2(z_{2t})$, while the probability for country-specific shocks is given by $g(v_{1t}, v_{2t}) = g^1(v_{1t})g^2(v_{2t})$. Let $s_t = (s_{1t}, s_{2t})$ summarize the current state of the world with $s_{it} = (z_{it}, v_{it})$ and let $h(s_t) = h^1(s_{1t})h^2(s_{2t})$ denote the probability of that specific state with $h^i(s_{it}) = f^i(z_{it})g^i(v_{it})$. In particular let $A(s_{2t})$ denote the productivity shock and $\theta(s_{1t})$ denote the markup shocks to the non-traded sector. The conditional mean of the shocks is given by $E_v(\theta \mid z) = \sum_{v_1} g^1(v_1)\,\theta(z_1, v_1)$ and $E_v(A \mid z) = \sum_{v_2} g^2(v_2)\,A(z_2, v_2)$. The timing is as in Chari et al. (2020). First the markup shock is realized, then non-traded good firms set their prices, then productivity is realized, then monetary policy reacts and last the rest of the economy takes places where traded good firms set their prices and households make their decision.



The important feature in this setup is that a discretionary monetary authority has an incentive to use surprise-inflation to inflate away the socially inefficient markups of firms. Firms anticipate the attempt of the central bank to inflate and raise their prices for non-traded goods before. In equilibrium, the economy ends up with higher prices. A lack of commitment by the central bank results in an inflationary bias for the economy. In contrast, a central bank that commits to policies realizes that it cannot inflate away the markups. Hence it promises ex ante to focus on productivity shocks only when using monetary policy and successfully avoids the inflationary bias.

Countries can be identified by the history of country-specific shocks $v^t = (v_0, v_1, ..., v_t)$ and are therefore symmetric with respect to their parameters, technology and preferences.

[19] This keeps the model tractable, as it becomes static. There is no persistence such that a large shock today affects future states. The calibration discusses the shock process in more detail.

We first consider how the economy works for one single "home" country and then consider country blocks and unions in Section 2.3.

B.1.1 Production

Firms are owned by households. Production of traded goods is given by

$$Y_T(s^t) = L_T(s^t).$$

Production is linear in the labor input $L_T(s^t)$. Traded good firms maximize their profits $P_T(s^t) L_T(s^t) - W(s^t) L_T(s^t)$. Optimally firms set the price of traded goods $P_T(s^t)$ equal to the wage $W(s^t)$. $W(s^t)$ can therefore be replaced by $P_T(s^t)$.

Production of non-traded goods is subject to two frictions, namely monopolistic markets and rigid prices. This gives rise to markups that increase prices of non-traded goods. A microfoundation for markups can be given by closely following the setup of Smets and Wouters (2007) which is also described in the Appendix of Chari et al. (2020). The non-traded good is produced by a competitive final producer who uses differentiated inputs $y_N(j, s^t)$ from input firms of mass $j \in [0, 1]$ to produce the final good $Y_N(s^t)$:

$$Y_N\left(s^t\right) = \left[\int y_N\left(j, s^t\right)^{\theta(s_{1t})} dj\right]^{1/\theta(s_{1t})}, \quad \theta\left(s_{1t}\right) \in (0, 1).$$

where $\theta(s_{1t})$ is the time-varying substitution parameter between the inputs [20]. $\theta(s_{1t}) \in (0, 1)$ implies that demand for inputs is elastic. If $\theta(s_{1t})$ is very close to 1 goods are almost perfect substitutes and firms are not able to use any monopolistic power. The closer $\theta(s_{1t})$ is to 0, the more monopolistic power a firm has. The final good firm maximizes

$$P_N\left(s^{t-1}, s_{1t}\right) Y_N\left(s^t\right) - \int P_N\left(j, s^{t-1}, s_{1t}\right) y_N\left(j, s^t\right) dj.$$

Demand for intermediate goods is therefore

$$y_N\left(j, s^t\right) = \left(\frac{P_N\left(s^{t-1}, s_{1t}\right)}{P_N\left(j, s^{t-1}, s_{1t}\right)}\right)^{\frac{1}{1-\theta(s_{1t})}} Y_N\left(s^t\right).$$

Intermediate goods are produced by monopolistic firms who use a linear production function: $y_N(j, s^t) = A(s_{2t}) L_N(j, s^t)$. Intermediate good firms choose their prices $P = P(j, s^{t-1}, s_{1t})$ to maximize their expected profits:

$$\max_P \sum_{s_{2t}} Q\left(s^t\right)\left[P - \frac{W\left(s^t\right)}{A\left(s_{2t}\right)}\right]\left(\frac{P_N\left(s^{t-1}, s_{1t}\right)}{P}\right)^{\frac{1}{1-\theta(s_{1t})}} Y_N\left(s^t\right)$$

where $Q(s^t)$ is the discount factor, the price of a state-contingent claim to local currency units

[20] The elasticity of substitution between the inputs is $\frac{1}{1-\theta(s^t)}$

at s^t in units of local currency in s^{t-1}. Optimally, intermediate good producer j sets the price on non-traded goods as a time-varying markup over a weighted average of marginal costs:

$$P_N\left(j, s^{t-1}, s_{1t}\right) = \frac{1}{\theta\left(s_{1t}\right)} \frac{\sum_{s_{2t}} Q\left(s^t\right) Y_N\left(s^t\right) \frac{W\left(s^t\right)}{A(s_t)}}{\sum_{s_{2t}} Q\left(s^t\right) Y_N\left(s^t\right)}$$

where $\frac{1}{\theta(s_{1t})}$ is the markup that increases prices. Note that the price equation is not a function of j such that the price is the same for all intermediate firms. Plugging in $W(s^t) = P_T(s^t)$ gives the pricing equation

$$P_N\left(s^{t-1}, s_{1t}\right) = \frac{1}{\theta\left(s_{1t}\right)} \sum_{s_{2t}} \left(\frac{Q\left(s^t\right) Y_N\left(s^t\right)}{\sum_{\tilde{s}_{2t}} Q\left(\tilde{s}^t\right) Y_N\left(\tilde{s}^t\right)} \right) \frac{P_T\left(s^t\right)}{A\left(s_t\right)}. \tag{B.1}$$

This implies that all intermediate firms hire the same amount of labor and their production function is then simply given by

$$Y_N(s^t) = A(s_{2t}) L_N(s^t).$$

B.1.2 Households

Households derive utility from consumption of traded goods $C_T(s^t)$ and from consumption of non-traded goods $C_N(s^t)$. In addition, they experience disutility from labor $L(s^t)$:
$\sum_{t=0}^{\infty} \sum_{s^t} \beta^t h_t\left(s^t\right) U\left(C_T\left(s^t\right), C_N\left(s^t\right), L\left(s^t\right)\right)$. As in Chari et al. (2020), we specialize preferences as

$$U\left(C_T, C_N, L\right) = \alpha \log C_T + (1-\alpha) \log C_N - \psi L.$$

This specification entails several simplifying assumptions, first it assumes that the elasticity of substitution between traded and non-traded goods is 1. Second, log-utility in consumption means that the inter-temporal elasticity of substitution is 1 as well. Those assumptions imply that households do not have an incentive to borrow or save across countries, as the willingness to substitute goods across time is exactly offset by the willingness to substitute traded goods to non-traded goods. α reflects the weight of traded goods in the overall consumption basket, large values imply that the countries in the economy have a very high degree of trade openness. Finally, the preferences are quasi-linear in labor, which simplifies aggregation results[21]. The budget constraint of households is given by

$$\begin{aligned} P_T\left(s^t\right) C_T\left(s^t\right) + P_N\left(s^{t-1}, s_{1t}\right) C_N\left(s^t\right) + M_H\left(s^t\right) + B\left(s^t\right) \\ \leq P_T\left(s^t\right) L\left(s^t\right) + M_H\left(s^{t-1}\right) + R\left(s^t\right) B\left(s^{t-1}\right) + T\left(s^t\right) + \Pi\left(s^t\right) \end{aligned} \tag{B.2}$$

where $T(s^t)$ are nominal transfers. $\Pi\left(s^t\right) = P_N(s^{t-1}, s_{1t}) Y_N(s^t) - P_T(s^t) L_N(s^t)$ are profits from the traded-goods sectors. As households own the firms in their corresponding country,

[21] Quasi-linear utility eliminates any wealth effects in the demand for money, which makes all agents choose the same amount of money. See Ricardo and Wright (2005)

these profits go to the households. Firms themselves are not traded on international markets. $R(s^t)$ is the interest rate paid on the non-contingent one-period nominal bond in the domestic currency and $B(s^t)$ are the nominal government bonds. Compared to Chari et al. (2020), we replaced the price that is paid to buy new bonds with interest rates that are paid on existing bonds. We show in the Appendix B.3 that the price of bonds in Chari et al. (2020) is simply the inverse of interest rates used here. The model abstracts from international capital markets, as households do not have an incentive to borrow or lend across countries, given the considered preferences.

There is also a cash-in-advance constraint for consumers, that requires domestic money brought from period $t-1$ to be used to purchase traded goods:

$$P_T\left(s^t\right) C_T\left(s^t\right) \leq M_H\left(s^{t-1}\right)$$

Under flexible exchange rates, consumers use their local currency $M_H\left(s^{t-1}\right)$ to pay for these goods. The superscript H denotes the individual holding of money. Domestic money is only hold by domestic households. Even though money is dominated by bonds as they pay interest on the existing stock, households need money to buy traded-goods. The assumption of cash-in-advance makes surprise inflation costly, as they can only use cash from the last period. In addition, the assumption that only traded goods are affected by this is for simplicity. This assumption can also be interpreted as a trade friction that requires to commit a certain amount of cash beforehand when internationally traded goods are bought from a foreign country. Note that current money injection that increase the nominal price of traded goods cannot be used for the cash in advance constraint. In a currency union they use the common currency to pay for the traded goods.

The first order conditions for the households imply

$$\begin{aligned}
\frac{U_N\left(s^t\right)}{P_N(s^{t-1}, s_{1t})} &= -\frac{U_L\left(s^t\right)}{W\left(s^t\right)}, \\
\frac{U_T\left(s^t\right)}{P_T\left(s^t\right)} &= -\frac{U_L\left(s^t\right)}{W\left(s^t\right)} + \phi\left(s^t\right), \\
-\frac{U_L\left(s^t\right)}{W\left(s^t\right)} &= \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{U_T\left(s^{t+1}\right)}{P_T\left(s^{t+1}\right)}, \\
1 &= \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) R(s^{t+1}) \frac{U_N\left(s^{t+1}\right)}{P_N\left(s^t, s_{1t+1}\right)} \frac{P_N\left(s^{t-1}, s_{1t}\right)}{U_N\left(s^t\right)},
\end{aligned}$$

where $\phi(s^t)$ is the normalized multiplier of the cash-in-advance constraint. The Euler equation can be obtained by combining the home bonds first order condition with the consumption first order condition. It governs the household's intertemporal decision:

$$\frac{1}{C_N(s^t)} = \beta \mathbb{E}_t \left[\frac{1}{C_N(s^{t+1})} \frac{P_N(s^t)}{P_N(s^{t+1})} R(s^{t+1})\right] \tag{B.3}$$

The nominal stochastic discount factor is defined as

$$Q\left(s^{t+1}\right)=\beta h\left(s^{t+1} \mid s^{t}\right) U_{N}\left(s^{t+1}\right) P_{N}\left(s^{t-1}, s_{1t}\right) / \left(P_{N}\left(s^{t}, s_{1t+1}\right) U_{N}\left(s^{t}\right)\right).$$

This discount factor is also used by firms to discount their profits.

B.1.3 Government

The government budget constraint for each country under flexible exchange rates is given by

$$B\left(s^{t}\right)=R\left(s^{t}\right) B\left(s^{t-1}\right)+T\left(s^{t}\right)-\left(M(s^{t})-M(s^{t-1})\right),$$

where $M(s^t)$ denotes the money supply in the economy. The last term is seignorage income from the growth in money supply. In a currency union, union-wide seignorage is equally split across countries according to their size. The initial money supply for each consumer in each country is set to M_{-1} and the initial bond holding B_{-1} are zero. The central bank specifies nominal interest rates, the quantity of debt and taxes for each country, satisfying the budget constraint. Note that there are no externalities for the central banks. This ensures that monetary policy does not have any incentive to set monetary policy in a non-cooperative way and to use its monopoly on its currency to manipulate the terms of trade.

B.2 Market Clearing and Equilibrium

Labor markets clear, which means that the demand for non-traded goods labor and traded goods labor equals overall labor supply

$$L_{N}\left(s^{t}\right)+L_{T}\left(s^{t}\right)=L\left(s^{t}\right).$$

Good markets clear for traded and non-traded goods.

$$C_{T}\left(s^{t}\right)=Y_{T}\left(s^{t}\right), \quad C_{N}\left(s^{t}\right)=A\left(s^{t}\right) Y_{N}\left(s^{t}\right).$$

GDP in this model is defined as the sum of consumption of traded and non-traded goods. Money demand from households $M_H(s^t)$ is met by money supply of the central bank

$$M_{H}\left(s^{t}\right)=M\left(s^{t}\right).$$

An equilibrium under flexible exchange rates is defined as an allocation in which 1) consumers behave optimally, 2) firms behave optimally, 3) the government's budget constraint holds and 4) markets clear.

As the law of one price holds in this model, the multilateral exchange rate can be defined as the price of traded goods in the considered country relative to the average price of traded goods in the rest of the world:

$$e\left(s^{t}\right)=\frac{P_{T}\left(s^{t}\right)}{\sum_{v^{t}} P_{T}\left(z^{t}, v^{t}\right) g^{t}\left(v^{t}\right)},$$

where $g^t(v^t) = g(v_0)...g(v_t)$ is simply the average over all countries. With a sufficiently large rest of the world, only country-specific shocks of the considered country can change the exchange rate, as the common shocks are the same and the average of the price of traded goods in the rest of the world is independent of shocks to small countries in the rest of the world.

In a monetary union money supply is chosen by the union-wide central bank. The nominal exchange rate is fixed for all states: $e\left(s^{t}\right)=1 \quad \forall s^{t}$ and consequently, the price of traded goods is the same everywhere. This means that only aggregate shocks can change the price of traded goods. Formally, if the state of the world in one country is $s^t = z^t, v^t$ and $\tilde{s}^t = z^t, \tilde{v}^t$ in the other country, then prices of traded goods are still the same

$$P_T(s^t) = P_T(\tilde{s}^t).$$

An equilibrium in a monetary union is defined in the same way as with flexible exchange rates, the only difference being that the exchange rate is set to 1 for all states and that total money holding in a union adds up to the overall money supply

$$\sum_{v^{t}} M_{H}\left(z^{t}, v^{t}\right) g_{t}\left(v^{t}\right)=\bar{M}\left(z^{t}\right).$$

In this model, shocks to markups lead to distortions in the economy that vary over time. This can be seen when combining the first order conditions of households with the first order condition of firms. Suppose productivity is constant, then the marginal rate of substitution (MRS) between labor and non-traded goods equals the marginal rate of transformation (MRT) of labor times the inverse markup

$$-\frac{U_{L}}{U_{N}}=A \theta\left(s_{t}\right)<A.$$

This means that the markup drives a wedge $1-\theta(s^t)$ between the MRS and the MRT. The larger the markup $1/\theta(s^t)$, the greater the distortions resulting from imperfect competition. The next section explains how monetary policy deals with that issue and how a lack of commitment can lead to an inflationary bias in that environment.

B.3 Consumer Optimization

The Lagrangean is

$$\max_{C_T,C_N,L,B,B^*,M_H} \mathcal{L} = \sum_{t=0}^{\infty}\sum_{s^t}\beta^t h_t\left(s^t\right)\Big[\alpha\log C_T\left(s^t\right)+(1-\alpha)\log C_N\left(s^t\right)-\psi L\left(s^t\right)-$$

$$\lambda(s^t)\Big(P_T\left(s^t\right)C_T\left(s^t\right)+P_N\left(s^{t-1},s_{1t}\right)C_N\left(s^t\right)+M_H\left(s^t\right)+B\left(s^t\right)+e\left(s^t\right)B^*\left(s^t\right)-$$

$$\left(P_T\left(s^t\right)L\left(s^t\right)+M_H\left(s^{t-1}\right)+R\left(s^t\right)B\left(s^{t-1}\right)+e\left(s^t\right)R^*\left(s^t\right)B^*\left(s^{t-1}\right)+T\left(s^t\right)+\Pi\left(s^t\right)\right)\Big)$$

$$-\mu(s^t)\left(P_T(s^t)C_T(s^t)-M_H(s^{t-1})\right)\Big]$$

The first order conditions are

$$\frac{\alpha}{C_T(s^t)} = \lambda(s^t)P_T(s^t)+\mu(s^t)P_T(s^t) \tag{B.4}$$

$$\frac{1-\alpha}{C_N(s^t)} = \lambda(s^t)P_N(s^t) \tag{B.5}$$

$$\psi = \lambda(s^t)P_T(s^t) \tag{B.6}$$

$$\lambda(s^t) = \beta\mathbb{E}_t\left[\lambda(s^{t+1})R(s^{t+1})\right] \tag{B.7}$$

$$\lambda(s^t)e(s^t) = \beta\mathbb{E}_t\left[\lambda(s^{t+1})e(s^{t+1})R^*(s^{t+1})\right] \tag{B.8}$$

$$\lambda(s^t) = \beta\mathbb{E}_t\left[\lambda(s^{t+1})\right]+\beta\mathbb{E}_t\left[\phi(s^{t+1})\right] \tag{B.9}$$

Combining (B.5) and (B.7) gives the Euler equation:

$$\frac{1}{C_N(s^t)} = \beta\mathbb{E}_t\left[\frac{1}{C_N(s^{t+1})}\frac{P_N(s^t)}{P_N(s^{t+1})}R(s^{t+1})\right]$$

Combining (B.7) and(B.8) gives the uncovered interest parity condition:

$$\beta\mathbb{E}_t\left[\lambda(s^{t+1})R(s^{t+1})\right] = \beta\mathbb{E}_t\left[\lambda(s^{t+1})\frac{e(s^{t+1})}{e(s^t)}R^*(s^{t+1})\right]$$

The standardized multiplier on the cash in advance constraint is $\phi(s^t)=\mu(s^t)P_T(s^t)$.

If we use Chari et al. (2020) framework of prices on bonds instead of interest rates, the budget constraint changes to

$$P_T\left(s^t\right)C_T\left(s^t\right)+P_N\left(s^{t-1},s_{1t}\right)C_N\left(s^t\right)+M_H\left(s^t\right)+\bar{Q}(s^t)B\left(s^t\right)+\bar{Q}^*(s^t)e\left(s^t\right)B^*\left(s^t\right)$$
$$\leq P_T\left(s^t\right)L\left(s^t\right)+M_H\left(s^{t-1}\right)+B\left(s^{t-1}\right)+e\left(s^t\right)B^*\left(s^{t-1}\right)+T\left(s^t\right)+\Pi\left(s^t\right)$$

The first order condition is then

$$\lambda(s^t) = \beta \mathbb{E}_t \Bigg[\lambda(s^{t+1}) \underbrace{\frac{1}{\bar{Q}(s^t)}}_{R(s^{t+1})} \Bigg]$$

So, using a framework with bond prices instead of interest rates on one period government bonds means that the price of a new bond is the inverse nominal interest rate on bonds that are being hold. $R(s^{t+1})$ is known in t.

B.4 International Capital Markets

The budget constraint is extended to allow households to buy non-domestic bonds as well. These bonds B^* are risk free and denoted in foreign currency:

$$\begin{aligned} P_T\left(s^t\right) C_T\left(s^t\right) + P_N\left(s^{t-1}, s_{1t}\right) C_N\left(s^t\right) + M_H\left(s^t\right) + \bar{Q}\left(s^t\right) B\left(s^t\right) + e(s^t)\bar{Q}^*\left(s^t\right) B^*\left(s^t\right) \\ \leq P_T\left(s^t\right) L\left(s^t\right) + M_H\left(s^{t-1}\right) + B\left(s^{t-1}\right) + e(s^t) B^*\left(s^{t-1}\right) + T\left(s^t\right) + \Pi\left(s^t\right) \end{aligned} \tag{B.10}$$

The exchange rate $e(s^t)$ has to be taken into account. As households can now choose non-domestic bonds, there is a a new first order condition:

$$\bar{Q}^*(s^t)\lambda(s^t)e(s^t) = \beta \mathbb{E}_t\left[\lambda(s^{t+1})e(s^{t+1})\right]$$

Combining it with the old conditions

$$\begin{aligned} \bar{Q}(s^t)\lambda(s^t) &= \beta \mathbb{E}_t\left[\lambda(s^{t+1})\right] \\ \lambda(s^t) &= \frac{\alpha}{P_T(s^t)C(s^t)} \end{aligned}$$

gives the so-called uncovered interest rate parity that relates domestic with foreign interest rates:

$$\frac{\bar{Q}^*(s^t)e(s^t)}{\bar{Q}(s^t)} = \frac{\mathbb{E}_t\left[\lambda(s^{t+1})e(s^{t+1})\right]}{\mathbb{E}_t\left[\lambda(s^{t+1})\right]}$$

with iid shocks we have

$$\mathbb{E}_t\left[Q\left(s^{t+1}\right) R(s^{t+1})\right] = \mathbb{E}_t\left[Q\left(s^{t+1}\right) \frac{e(s^{t+1})}{e(s^t)} R^*(s^{t+1})\right]$$

The nominal interest rate spread is offset by a continuous devaluation of the home currency vis-a-vis to the rest of the world. The rest of the model is not altered by the introduction of international capital markets, as households do not have an incentive to borrow or lend across countries given their current preference structure (log utility and Cobb Douglas consumption aggregator).

B.5 Firm Optimization

A microfoundation for markups can be given by following the setup of Smets and Wouters (2007). The non-traded good is produced by a competitive final producer who uses differentiated inputs $y_N(j,s^t)$ from input firms of mass $j \in [0,1]$ to produce the final good $Y_N(s^t)$:

$$Y_N\left(s^t\right) = \left[\int y_N\left(j,s^t\right)^{\theta(s_{1t})} dj\right]^{1/\theta(s_{1t})}$$

This firm maximizes

$$P_N\left(s^{t-1},s_{1t}\right) Y_N\left(s^t\right) - \int P_N\left(j,s^{t-1},s_{1t}\right) y_N\left(j,s^t\right) dj$$

Demand for intermediate goods is therefore

$$y_N\left(j,s^t\right) = \left(\frac{P_N\left(s^{t-1},s_{1t}\right)}{P_N\left(j,s^{t-1},s_{1t}\right)}\right)^{\frac{1}{1-\theta(s_{1t})}} Y_N\left(s^t\right)$$

Intermediate goods are produced by monopolistic firms who use a linear production function: $y_N(j,s^t) = A(s_{2t})L_N(j,s^t)$. Intermediate good firms choose their prices $P = P(j,s^{t-1},s_{1t})$ to maximize their profits:

$$\max_P \sum_{s_{2t}} Q\left(s^t\right)\left[P - \frac{W\left(s^t\right)}{A\left(s_{2t}\right)}\right]\left(\frac{P_N\left(s^{t-1},s_{1t}\right)}{P}\right)^{\frac{1}{1-\theta(s_1t)}} Y_N\left(s^t\right)$$

where $Q(s^t)$ is the discount factor as before. We assume that $\theta(s_{1t} \in (0,1)$ implying elastic demand and finite prices. Optimally, intermediate good producer j sets the price in the following way:

$$P_N\left(j,s^{t-1},s_{1t}\right) = \frac{1}{\theta\left(s_{1t}\right)} \frac{\sum_{s_{2t}} Q\left(s^t\right) Y_N\left(s^t\right) \frac{W\left(s^t\right)}{A(s_t)}}{\sum_{s_{2t}} Q\left(s^t\right) Y_N\left(s^t\right)}$$

Where $\frac{1}{\theta(s_{1t}}$ is the markup that increases prices. Note that the price equation is not a function of j such that the price is the same for all intermediate firms. Plugging in $W(s^t) = P_T(s^t)$ gives the same formula as in equation (1). This implies that all intermediate firms hire the same amount of labor and their production function is then simply $Y_N(s^t) = A(s_{2t}L_N(s^t)$.

B.6 Monetary Policy Optimization

Commitment and Float The central bank makes a state-contingent plan for prices of traded and non traded goods to maximize the representative households ex ante utility

$$
\begin{aligned}
\max_{\{P_T(s^t),P_N(s^t)\}_{t=0}^{\infty}} \quad & \mathbb{E}_0\left[\sum_{\tau=t}\beta^t\left(\alpha\log(C_T(s^\tau)+(1-\alpha)\log(C_N(s^\tau))-\psi L(s^\tau)\right)\right] \\
\text{s.t.} \quad & L(s^t)=\frac{C_N(s^t)}{A(s_{2t})}+C_T(s^t) \\
& C_T(s^t)=\frac{\alpha}{\psi} \\
& C_N(s^t)=\frac{1-\alpha}{\psi}\frac{P_T(s^t)}{P_N(s^{t-1},s_{1t})} \\
& \sum_{s_{2t}} h\left(s^t \mid s^{t-1},s_{1t}\right)C_N\left(s^t\right)\left[U_N\left(s^t\right)+\frac{1}{\theta\left(s_{1t}\right)}\frac{U_L\left(s^t\right)}{A\left(s_{2t}\right)}\right]=0
\end{aligned}
$$

Looking at the plugged in firm's first order condition:

$$
\sum_{s_{2t}} h\left(s^t \mid s^{t-1},s_{1t}\right)C_N\left(s^t\right)\left[\frac{1-\alpha}{C_N\left(s^t\right)}-\frac{1}{\theta\left(s_{1t}\right)}\frac{\psi}{A\left(s_{2t}\right)}\right]=0
$$

Plugging in C_N

$$
\sum_{s_{2t}} h\left(s^t \mid s^{t-1},s_{1t}\right)C_N\left(s^t\right)\left[\frac{1-\alpha}{\frac{1-\alpha}{\psi}\frac{P_T(s^t)}{P_N(s^{t-1},s_{1t})}}-\frac{1}{\theta\left(s_{1t}\right)}\frac{\psi}{A\left(s_{2t}\right)}\right]=0
$$

This can only be zero if

$$
\frac{P_T(s^t)}{P_N(s^{t-1},s_{1t})}=A\left(s_{2t}\right)\theta\left(s_{1t}\right)
$$

The best the central bank can do is to ensure that this condition holds. The central bank realizes that it is not possible to reduce markups by manipulating relative prices with inflation. Therefore it focuses to stabilize productivity shocks.

Nominal variables can be computed as well, using the following trick: First normalize all variables with their money supply of the last period, $p_T=\frac{P_T(s^t)}{M(s^{t-1})}$ and $p_N(s^{t-1},s_{1t})=\frac{P_N(s^{t-1},s_{1t})}{M(s^{t-1})}$. Then construct prices in such a way, that the cash in advance constraint is *exactly* binding in the highest possible productivity state[22]. Then use that $p_T(s^t)/p_N(s^{t-1},s_{1t})=A(s_{2t})\theta(s_{1t})$ and $p_T(s^t)=\gamma C_T(s^t)^{-1}$ if the cash in advance constraint binds in the highest

[22] This way, no consumption is lost.

state to get:

$$p_N(s^{t-1}, s_{1t}) = \frac{1}{\theta(s_{1t})}\frac{\psi}{\alpha}\frac{1}{\max\{A(s_{2t})\}}$$
$$p_T(s^t) = A(s_{2t})\theta(s_{1t})p_N(s^{t-1}, s_{1t})$$
$$\frac{M\left(s^t\right)}{M\left(s^{t-1}\right)} = \beta\sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right)\frac{A\left(s_{2t}\right)}{A\left(s_{2t+1}\right)}$$

Together with an initial level for $M(s^0)$, the nominal equilibrium is pinned down. The per period money growth rate equals productivity today times the discounted expected inverse productivity in the future. If productivity today is relatively large, money growth will also be relatively large, reflecting expansionary monetary policy and a depreciating exchange rate from the example before. If productivity is not stochastic, money gross growth rate is $\beta < 1$.

The derivation from the money growth rate comes from the consumer's first order condition, that combines the labor and traded goods first order condition with the money first order condition. As $p_T(s^t) = P_T(s^t)/M(s^{t-1})$, we can draw out the money growth rate as follows

$$-\frac{M(s^t)}{M(s^{t-1})}\frac{U_L}{p_T} = \beta\sum_{s'} h\left(s'\right)\frac{U_T\left(b', 1, x'_T, S'_T\right)}{p_T\left(x'_T, S'_T\right)}$$

If you rearrange and plug in, you arrive at

$$\frac{M(s^t)}{M(s^{t-1})} = \beta\sum_{s'} h\left(s'\right)\frac{p_T(s)}{p_T(s')}\frac{\alpha/\psi}{C_T(s')}$$

Plugging in $p_T = A\theta p_N$ with $p_N = \frac{1}{\theta}\frac{\psi}{\alpha}\frac{1}{max(A)}$ at a binding cash in advance constraint with $C_T(s') = \frac{1}{p_T(s')}$ gives the money growth rate as above, only a function of productivity.

Nominal interest rates can then be computed via the Euler equation, see Appendix B.8 for a derivation

$$R\left(s^t\right) = \frac{\max\{A(s_{2t})\}}{\max\{A(s_{2t+1})\}}$$

Interest rates are simply the ratio of the maximum value of productivity today and tomorrow. If productivity stays always the same, then $R(s^t) = 1$ and $M(s^t)/M(s^{t-1}) = \beta < 1$. This means that nominal interest rates are zero and the central bank follows the Friedman rule implying a negative money growth rate. The intuition why zero interest rates are optimal is the following. Nominal bonds dominate money holding as they pay an interest on its stock, while money does not. Nevertheless, households need to hold money to buy traded goods. Therefore, the central bank optimally implements zero interest rates to make the necessary money holding as good as the bond holding. Inflation rates of both goods are given by

$$\pi_N(s^t, s_{1t+1}) = \frac{P_N(s^t, s_{1t+1})}{P_N(s^{t-1}, s_{1t})} = \frac{\theta(s_{1t}) \max\{A(s_{2t}\}}{\theta(s_{1t+1}) \max\{A(s_{2t+1})\}} \frac{M(s^t)}{M(s^{t-1})}$$

$$\pi_T(s^{t+1}) = \frac{P_T(s^{t+1})}{P_T(s^t)} = \frac{A(s^{t+1})\theta(s_{1t+1}) P_N(s^t, s_{1t+1})}{A(s^t)\theta(s_{1t}) P_N(s^{t-1}, s_{1t})} = \frac{A(s_{2t+1}) \max\{A(s_{2t})\}}{A(s_{2t}) \max\{A(s_{2t+1}\}} \frac{M(s^t)}{M(s^{t-1})}$$

Markups influence prices of non-traded goods only. The bigger the markup ($1/\theta$ is high) compared to last period, the higher is inflation. Higher productivity of the non-traded good increases prices of traded goods, the relative price adjusts. Higher money growth rates increase both inflation rates. In a world with no stochastic components, inflation is determined by the money growth rate which is then simply $\beta < 1$. This implies deflation. The Friedman rule is a solution for the nominal equilibrium, a continued contraction of the money supply implies deflation which ensures that the cash in advance constraint is never binding.

Discretion and Float Chari et al. (2020) show, that there is no intertemporal dimension of the problem for the central bank. The reason is that in equilibrium there is no bond holding and that lump-sum transfers are always available to the government. In addition, households do not derive utility out of money, such that the growth rate of money supply is not intertwined with the static problem. The optimal problem of the central bank can then be thought of as choosing the price of the traded good subject to the first order conditions of households. As the cash in advance constraint optimally binds for the traded good, the primal problem of the central bank is to maximize

$$\begin{aligned} \max_{P_T(s^t)} \quad & \alpha \ln C_T(s^t) + (1-\alpha) \ln C_N(s^t) - \psi(C_T(s^t) + C_N(s^t)/A(s^t)) \\ \text{s.t.} \quad & C_T(s^t) = \frac{M(s^{t-1})}{P_T(s^t)} \\ & C_N(s^t) = \frac{1-\alpha}{\psi} \frac{P_T(s^t)}{P_N(s^t)} \end{aligned}$$

The first order condition is (already divided by $M(s^{t-1})$

$$-\frac{\alpha}{p_T(s^t)} + \frac{1-\alpha}{p_T(s^t)} - \psi\left(-\frac{1}{p_T(s^t)^2} + \frac{1-\alpha}{\psi}\frac{1}{A(s^t)}\frac{1}{p_N(s^t)}\right) = 0$$

Solving for $p_T(s^t)$ gives the optimal reaction function of the central bank under discretion:

$$p_T(s_t) = p_N(s_{1t}) A(s_{2t}) \underbrace{\frac{1}{2(1-\alpha)}\left[(1-2\alpha) + \sqrt{(1-2\alpha)^2 + 4(1-\alpha)\frac{1}{A(s_{2t})}\frac{\psi}{p_N(s_{1t})}}\right]}_{F\left(\frac{\gamma}{A(s_{2t})p_N(s_{1t})}\right)}$$

If you consider the firm's price setting equation 1, then you can compute prices:

$$p_N\left(s^{t-1}, s_{1t}\right) = \frac{1}{\theta\left(s_{1t}\right)} \sum_{s_{2t}} \left(\frac{Q\left(s^t\right) Y_N\left(s^t\right)}{\sum_{\tilde{s}_{2t}} Q\left(\tilde{s}^t\right) Y_N\left(\tilde{s}^t\right)} \right)$$
$$\frac{p_N\left(s_{1t}\right) A\left(s_{2t}\right) \frac{1}{2(1-\alpha)} \left[(1-2\alpha) + \sqrt{(1-2\alpha)^2 + 4(1-\alpha)\frac{1}{A(s_{2t})}\frac{\psi}{p_N(s_{1t})}}\right]}{A\left(s_t\right)}$$

If p_N rises, p_T will then in general rise by less than 1 to 1, reflecting the costs of higher inflation.

If A is not stochastic the cash in advance constraint never binds (implicit assumption here). We can then write

$$1 = \frac{1}{\theta\left(s_{1t}\right)} \frac{A\left(s_{2t}\right) \frac{1}{2(1-\alpha)} \left[(1-2\alpha) + \sqrt{(1-2\alpha)^2 + 4(1-\alpha)\frac{1}{A(s_{2t})}\frac{\psi}{p_N(s_{1t})}}\right]}{A\left(s_t\right)}$$

Solving for $p_N(s_{1t})$ gives

$$(2(1-\alpha)\theta - (1-2\alpha))^2 = (1-2\alpha)^2 + 4(1-\alpha)\frac{\psi}{A(s_{2t})p_N(s_{1t})}$$

With this we get p_N as in the main text:

$$p_N(s^t) = \frac{1}{\theta(s_{1t})} \frac{1}{A(s_{2t})} \frac{\psi}{\alpha - (1-\alpha)(1-\theta(s_{1t}))}$$
$$p_T(s^t) = \frac{\psi}{\alpha - (1-\alpha)(1-\theta(s_{1t}))}$$

Consumption is then

$$C_T(s^t) = \frac{1}{p_T(s^t)} \quad C_N(s^t) = \frac{1-\alpha}{\psi}\frac{p_T(s^t)}{p_N(s^t)}$$

The money growth rate and inflation rates can be computed as before

$$\frac{M(s^t)}{M(s^{t-1})} = \beta \sum_{s'} h\left(s'\right) \frac{p_T(s)}{p_T(s')} \frac{\alpha/\psi}{C_T(s')}$$
$$\frac{M(s^t)}{M(s^{t-1})} = \beta \sum_{s'} h\left(s'\right) \frac{p_T(s)}{p_T(s')} \frac{\alpha/\psi}{\frac{1}{p_T(s')}}$$
$$\frac{M(s^t)}{M(s^{t-1})} = \beta \sum_{s'} h\left(s'\right) p_T(s) \frac{\alpha}{\psi}$$
$$\frac{M(s^t)}{M(s^{t-1})} = \beta \frac{\alpha}{\psi} \frac{\psi}{\alpha - (1-\alpha)(1-\theta(s^t))}$$

Inflation rates are then

$$\pi_T(s^t) = \frac{P_T(s^{t+1})}{P_T(s^t)} = \frac{M(s^t)}{M(s^{t-1})} \frac{\alpha - (1-\alpha)(1-\theta(s_{1t}))}{\alpha - (1-\alpha)(1-\theta(s_{1t+1}))}$$
$$\pi_N(s^t) = \frac{P_N(s^{t+1})}{P_N(s^t)} = \frac{M(s^t)}{M(s^{t-1})} \frac{A(s^t)\theta(s^t)}{A(s^{t+1})\theta(s^{t+1})} \frac{\alpha - (1-\alpha)(1-\theta(s_{1t}))}{\alpha - (1-\alpha)(1-\theta(s_{1t+1}))}$$

Unilateral Peg to a Credible Anchor The central bank of the anchor country sets monetary policy as before

$$\frac{P_T^{Anch}(s^t)}{P_N^{Anch}(s^{t-1}, s_{1t})} = A^{Anch}\left(s_{2t}\right)\theta^{Anch}\left(s_{1t}\right)$$

The client country's central bank then ensures that the exchange rate is always constant such that the price of traded goods is exactly the same in both countries.

Firms of the client country, after their markup shock has realized then set prices the following way:

$$p_N(s) = \frac{1}{\theta(s)}\mathbb{E}\left[\frac{p_T^{Anch}(s)}{A^{Anch}(s)}\right]$$

For the client country the allocation of consumption is then given by

$$C_T(s) = \min\{\frac{1}{p_T^{Anch}(s)}, \frac{\alpha}{\psi}\}$$
$$C_N(s) = \frac{1-\alpha}{\psi}\frac{p_T^{Anch}(s)}{p_N(s)} = \frac{1-\alpha}{\psi}\theta(s)\frac{p_T^{Anch}(s)}{\mathbb{E}\left[\frac{p_T^{Anch}(s)}{A(s)}\right]}$$

Employment is then given by

$$L(s) = C_T(s) + C_N(s)/A(s) = \frac{\alpha}{\psi} + \frac{1-\alpha}{\psi}\theta(s)\frac{p_T^{Anch}(s)}{A(s)}\left(\mathbb{E}\left[\frac{p_T^{Anch}(s)}{A(s)}\right]\right)^{-1}$$

It fluctuates with productivity and the actual realization of the traded good price. For the anchor country it only fluctuates together with the markups.

Inflation rates are a function money growth rate, that is determined by the anchor as in a float under discretion

$$\pi_N(s^t, s_{1t+1}) = \frac{P_N(s^t, s_{1t+1})}{P_N(s^{t-1}, s_{1t})} = \frac{\theta(s_{1t})\max\{A(s_{2t}\}}{\theta(s_{1t+1})\max\{A(s_{2t+1})\}}\frac{M^{Anch}(s^t)}{M^{Anch}(s^{t-1})}$$
$$\pi_T(s^{t+1}) = \frac{P_T(s^{t+1})}{P_T(s^t)} = \frac{A^{Anch}(s^{t+1})\theta(s^{t+1})P_N(s^{t+1})}{A^{Anch}(s^t)\theta(s^t)P_N(s^t)} = \frac{A^{Anch}(s^{t+1})\max\{A^{Anch}(s^t)\}}{A^{Anch}(s^t)\max\{A^{Anch}(s^{t+1}\}}\frac{M^{Anch}(s^t)}{M^{Anch}(s^{t-1})}$$

Inflation of traded goods is only a function of anchor variables, while inflation of non-traded goods in the client country depends on anchor and client variables.

Peg to a Discretionary Anchor Under discretion with a peg prices of traded goods are as prices under discretion for the anchor, for non-traded good prices domestic markups and productivity of the anchor are decisive.

$$
\begin{aligned}
p_T &= \frac{\psi}{\alpha-(1-\alpha)(1-\theta^{Anch})} \\
p_N(s^t) &= \frac{1}{\theta(s_{1t})}\frac{1}{A^{Anch}(s_{2t})}\frac{\psi}{\alpha-(1-\alpha)(1-\theta^{Anch}(s_{1t}))}
\end{aligned}
$$

Money growth rate is the one of the anchor and given by

$$
\frac{M(s^t)}{M(s^{t-1})} = \beta\frac{\alpha}{\psi}\frac{\psi}{\alpha-(1-\alpha)(1-\theta^{Anch}(s^t))}
$$

Inflation in the client country is then given by

$$
\begin{aligned}
\pi_T(s^t) &= \frac{P_T(s^{t+1})}{P_T(s^t)} = \frac{M^{Anch}(s^t)}{M^{Anch}(s^{t-1})}\frac{\alpha-(1-\alpha)(1-\theta^{Anch}(s_{1t}))}{\alpha-(1-\alpha)(1-\theta^{Anch}(s_{1t+1}))} \\
\pi_N(s^t) = \frac{P_N(s^{t+1})}{P_N(s^t)} &= \frac{M^{Anch}(s^t)}{M^{Anch}(s^{t-1})}\frac{A^{Anch}(s^t)\theta(s^t)}{A^{Anch}(s^{t+1})\theta(s^{t+1})}\frac{\alpha-(1-\alpha)(1-\theta^{Anch}(s_{1t}))}{\alpha-(1-\alpha)(1-\theta^{Anch}(s_{1t+1}))}
\end{aligned}
$$

while inflation of non-traded goods in the anchor country is

$$
\pi_N^{Anch}(s^t) = \frac{P_N(s^{t+1})}{P_N(s^t)} = \frac{M^{Anch}(s^t)}{M^{Anch}(s^{t-1})}\frac{A^{Anch}(s^t)\theta^{Anch}(s^t)}{A^{Anch}(s^{t+1})\theta^{Anch}(s^{t+1})}\frac{\alpha-(1-\alpha)(1-\theta^{Anch}(s_{1t}))}{\alpha-(1-\alpha)(1-\theta^{Anch}(s_{1t+1}))}
$$

Note that inflation of non-traded good is different. For both countries their own corresponding markup shocks play a role. As the correlation of markups between countries is not perfect, but rather zero in the iid example here, this implies that volatility of non-traded goods for the client country is lower than for the anchor country. This is because if $\frac{\theta^{Anch}(s^t)}{\theta^{Anch}(s^{t+1})}$ is large $\frac{\alpha-(1-\alpha)(1-\theta^{Anch}(s_{1t}))}{\alpha-(1-\alpha)(1-\theta^{Anch}(s_{1t+1}))}$ is large as well. Overall π_N^{Anch} is more volatile than π_N if the underlying markup shock process is the same and uncorrelated to the process in the anchor country.

Discretion and Currency Union There is a mass of $\bar{n}^N$ northern countries and n^S southern countries. The relative weight of north is then $\lambda^N = \frac{\bar{n}^N}{\bar{n}^N+n^S}$. The union-wide central bank chooses a traded good price for the union taking the non-traded good prices as given. The current state is $s = (z, p_N^i(z, v))$, the primal problem is then

$$
\begin{aligned}
\max_{p_T} \quad & \sum_{\lambda^i \in (N,S)} \lambda^i \sum_{v^t} g(v^t) \left[\alpha \log C_T^i(s^t) + (1-\alpha) \log C_N^i(s^t) - \psi \left(L^i(s^t) \right) \right] \\
\text{s.t.} \quad & L^i(s^t) = \frac{C_N^i(s^t)}{A^i(s_{2t})} + C_L^i(s^t) \\
& C_T^i(s^t) = \frac{1}{p_T} \\
& C_N^i(s^t) = \frac{1-\alpha}{\psi} \frac{p_T(s^t)}{p_N^i(s^{t-1}, s_{1t})} \\
& \frac{U_T(s^t)}{U_N(s^t)} = \frac{U_T(\tilde{s}^t)}{U_N(\tilde{s}^t)}
\end{aligned}
$$

where $g(v)$ is again just the average of the union, given the aggregate state. The first order condition is given by:

$$
0 = (1-2\alpha) \frac{1}{p_T} + \psi \frac{1}{p_T^2} - (1-\alpha) \sum_{i=N,S} \lambda^i \sum_v g(v) \frac{1}{p_N^i(z, v) A^i}
$$

We can solve the quadratic equation to get the monetary authorities best response:

$$
p_T\left(z, \left\{p_N^i\left(z_1, v_1\right)\right\}\right) = \frac{(1-2\alpha) + \sqrt{(1-2\alpha)^2 + 4 \sum_{i=N,S} \lambda^i \sum_v g(v) \frac{(1-\alpha)}{A^i(z_2, v_2)} \frac{\psi}{p_N^i(z_1, v_1)}}}{\sum_{i=N,S} \lambda^i \sum_v g(v) \frac{2(1-\alpha)}{A^i(z_2, v_2)} \frac{1}{p_N^i(z_1, v_1)}},
$$

As a next step consider again the pricing equation of firms in country i: $p_N^i = \mathbb{E}_v \left(\frac{1}{A^i} \right) \frac{1}{\theta^i} p_T^i$. As with a single country under discretion, we can solve the problem by plugging in the reaction functions into each other, this gives a fixed point problem and can explicitly be solved for p_T. Let $\sum_v g(v) \frac{1}{A^i(z_2, v_2) p_N^i(z_1, v_1)} = \mathbb{E}_v[\frac{1}{A^i p_N^i} \mid z]$. Then

$$
p_N^j = \mathbb{E}_v \left(\frac{1}{A^j} \right) \frac{1}{\theta^j} \frac{\psi}{(1-\alpha) p_N^j \sum_{i=N,S} \lambda^i \mathbb{E}_v[\frac{1}{A^i p_N^i}] \theta^j A^j - (1-2\alpha)}
$$

For the p_N^i on the right hand side of the equation, plug in $p_N^i = \mathbb{E}\left(\frac{1}{A^i}\right) \frac{p_T}{\theta^i}$

$$
\begin{aligned}
p_N^j &= \mathbb{E}_v \left(\frac{1}{A^j} \right) \frac{1}{\theta^j} \frac{\psi}{(1-\alpha) \frac{p_T}{A^j \theta^j} \sum_{i=N,S} \lambda^i \mathbb{E}_v[\frac{1}{A^i \frac{p_T}{A^i \theta^i}} \mid z] \theta^j A^j - (1-2\alpha)} \\
p_N^j &= \mathbb{E}_v \left(\frac{1}{A^j} \right) \frac{1}{\theta^j} \frac{\psi}{(1-\alpha) \sum_{i=N,S} \lambda^i \mathbb{E}_v \left(\theta^i \mid z \right) - (1-2\alpha)}
\end{aligned}
$$

This gives p_T

$$
p_T = \frac{\psi}{(1-\alpha) \sum_{i=N,S} \lambda^i \mathbb{E}_v[\theta^i \mid z] - (1-2\alpha)}
$$

C_T is then given by:

$$C_T = \frac{1}{p_T} = \frac{\alpha}{\psi} - \frac{1-\alpha}{\psi}\left(1 - \sum_{i=N,S} \lambda^i \mathbb{E}_v\left(\theta^i \mid z\right)\right)$$

and C_N

$$C_N^i = \frac{1-\alpha}{\psi}\mathbb{E}_v\left(\frac{1}{A^i}\right)^{-1}\theta^i(s)$$

Money growth rate is

$$\Delta M = \beta\frac{\alpha}{\psi}p_T = \beta\frac{\alpha}{\psi}\frac{\psi}{(1-\alpha)\sum_{i=N,S}\lambda^i\mathbb{E}_v[\theta^i \mid z] - (1-2\alpha)}$$

Inflation for the (former) client are then given by

$$\pi_T(s^t) = \frac{P_T(s^{t+1})}{P_T(s^t)} = \frac{M(s^t)}{M(s^{t-1})}\frac{\alpha - (1-\alpha)(1-\sum_{i=N,S}\lambda^i\mathbb{E}_v[\theta^i \mid z])}{\alpha - (1-\alpha)(1-\sum_{i=N,S}\lambda^i\mathbb{E}_v[\theta^i \mid z])}$$

$$\pi_N(s^t) = \frac{P_N(s^{t+1})}{P_N(s^t)} = \frac{M(s^t)}{M(s^{t-1})}\frac{\mathbb{E}_v\left(\frac{1}{A^i(s^t)}\right)^{-1}\theta(s^t)}{\mathbb{E}_v\left(\frac{1}{A^i(s^{t+1})}\right)^{-1}\theta(s^{t+1})}\frac{\alpha - (1-\alpha)(1-\sum_{i=N,S}\lambda^i\mathbb{E}_v[\theta^i \mid z])}{\alpha - (1-\alpha)(1-\sum_{i=N,S}\lambda^i\mathbb{E}_v[\theta^i \mid z])}$$

For the former anchor country, inflation of non-traded goods is

$$\pi_N(s^t) = \frac{P_N(s^{t+1})}{P_N(s^t)} = \frac{M(s^t)}{M(s^{t-1})}\frac{\mathbb{E}_v\left(\frac{1}{A^i(s^t)}\right)^{-1}\theta^{Anch}(s^t)}{\mathbb{E}_v\left(\frac{1}{A^i(s^{t+1})}\right)^{-1}\theta^{Anch}(s^{t+1})}\frac{\alpha - (1-\alpha)(1-\sum_{i=N,S}\lambda^i\mathbb{E}_v[\theta^i \mid z])}{\alpha - (1-\alpha)(1-\sum_{i=N,S}\lambda^i\mathbb{E}_v[\theta^i \mid z])}$$

Compared to the peg $\frac{\alpha-(1-\alpha)(1-\sum_{i=N,S}\lambda^i\mathbb{E}_v[\theta^i|z])}{\alpha-(1-\alpha)(1-\sum_{i=N,S}\lambda^i\mathbb{E}_v[\theta^i|z])}$ consists now out of the weighted average of markups in the union, and not out of markups of the anchor only. If the union is really large, this term would be constant (1) over time. Volatility of inflation would then only originate from markup variations over time (as money growth rate becomes less erratic as well).

Commitment and Currency Union In a monetary union, the exchange rate is fixed and set to $e(s^t) = 1$ for all states. This implies that P_T cannot vary across countries and is only a function of aggregate union-wide shocks. This gives rise to the "Union constraint"

$$\frac{U_T(s^t)}{U_N(s^t)} = \frac{U_T(\tilde{s}^t)}{U_N(\tilde{s}^t)}$$

The central bank acts under commitment and chooses the union-wide price of traded goods and the prices of non-traded goods to maximize an equally weighted average of all countries of the world:

$$\max_{P_T, P_N(v)} \mathbb{E}_0 \left[\sum_{\tau=t} \sum_{v^\tau} \beta^\tau g(v^\tau) \left[\alpha \log C_T(z^\tau, v^\tau) + (1-\alpha) \log C_N(z^\tau, v^\tau) - \psi \left(L(z^\tau, v^\tau) \right) \right] \right]$$

$$\text{s.t.} \quad L(s^t) = \frac{C_N(s^t)}{A(s_{2t})} + C_L(s^t)$$

$$C_T(s^t) = \frac{\alpha}{\psi}$$

$$C_N(s^t) = \frac{1-\alpha}{\psi} \frac{P_T(s^t)}{P_N(s^{t-1}, s_{1t})}$$

$$\sum_{s_{2t}} h\left(s^t \mid s^{t-1}, s_{1t}\right) C_N\left(s^t\right) \left[U_N\left(s^t\right) + \frac{1}{\theta\left(s_{1t}\right)} \frac{U_L\left(s^t\right)}{A\left(s_t\right)} \right] = 0$$

$$\frac{U_T(s^t)}{U_N(s^t)} = \frac{U_T(\tilde{s}^t)}{U_N(\tilde{s}^t)}$$

where $\sum_{v^\tau} g(v^\tau)$ simply sums up all the countries. Remember that $s^t = (z^t, v^t)$ where z^t is the aggregate shock and v^t is the country-specific shock. Optimally, the cash in advance constraint does not bind to avoid losses in consumption. The central bank sets prices such that it stabilizes the average of the whole union:

$$\frac{P_T(s^t)}{P_N(s^{t-1}, s_{1t})} = \theta(s_{1t}) \left(\sum_{v_{2t}} g(v_{2t}) \frac{1}{A(z_{2t}, v_{2t})} \right)^{-1}$$

As the exchange rate is fixed, prices of traded goods are the same for all countries and the only thing the union-wide central bank can do is to set relative prices equal to the markup times the *average* productivity of the union.

Consumption and labor are then given by

$$C_T(s^t) = \frac{\alpha}{\psi}, \quad C_N(s^t) = \frac{1-\alpha}{\psi} \frac{\theta\left(s_{1t}\right)}{E_v(1/A(v_{2t} \mid z_{2t})}, \quad L(s^t) = \frac{C_N(s^t)}{A(s_{2t})} + C_L(s^t)$$

Consumption of traded goods is as with a flexible exchange rate under commitment (Section 2.3.1) as the cash in advance constraint is not binding. The difference is that consumption of non-traded goods now depends on average productivity in the currency union, as the central bank now conditions its policy on the average of the union and not on each individual country. This will in general be costly for the economy, as the central bank is not able to eliminate all costs coming from rigid prices. For some countries, monetary policy will be too expansionary, for some it will be too contractionary.

Nominal prices, interest rates and money growth rates are computed by resolving the indeterminacy problem in the same way as before. Let $X\left(z_{2t}\right) = \sum_{v_{2t}} g\left(v_{2t}\right) \frac{1}{A(s_{2t})}$. Consider the lowest possible value of X. That corresponds to the highest possible aggregate productivity value and assume that the cash in advance constraint is exactly binding in this state. Prices are again standardized by their last period's money holding.

$$
\begin{aligned}
&p_N\left(s^{t-1}, s_{1t}\right) = \frac{1}{\theta(s_{1t})}\frac{\psi}{\alpha}\min_{z_2}\left\{X\left(z_{2t}\right)\right\}\sum_{s_2} h^2\left(s_2\right)\frac{1/A(s_{2t})}{X(z_{2t})} \\
&p_T\left(s^t\right) = A\left(s_{2t}\right)\theta\left(s_{1t}\right)p_N\left(s^{t-1}, s_{1t}\right) = \frac{\psi}{\alpha}\frac{\min_{z_2}\{X(z_{2t})\}}{X(z_{2t})} \\
&\frac{M\left(s^t\right)}{M\left(s^{t-1}\right)} = \beta\sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right)X\left(z_{2t+1}\right)/X\left(z_{2t}\right)
\end{aligned}
$$

The nominal interest rate in the currency union is given by the Euler equation as before:

$$
R\left(s^t\right) = \left(\beta\sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right)\frac{\frac{\min_{z_2}\{X(z_{2t})\}}{X(z_{2t})}}{\frac{\min_{z_2}\{X(z_{2t+1})\}}{X(z_{2t+1})}} M(s^{t-1})/M(s^t)\right)^{-1}
$$

Inflation rates are:

$$
\pi_N(s^t, s_{1t+1}) = \frac{P_N(s^t, s_{1t+1})}{P_N(s^{t-1}, s_{1t})} = \frac{\theta(s_{1t})}{\theta(s_{1t+1})}\frac{\frac{\psi}{\alpha}\min_{z_2}\left\{X\left(z_{2t+1}\right)\right\}\sum_{s_2} h^2\left(s_2\right)\frac{1/A(s_{2t+1})}{X(z_{2t+1})}}{\frac{\psi}{\alpha}\min_{z_2}\left\{X\left(z_{2t}\right)\right\}\sum_{s_2} h^2\left(s_2\right)\frac{1/A(s_{2t})}{X(z_{2t})}}\frac{M(s^t)}{M(s^{t-1})}
$$

$$
\pi_T(s^{t+1}) = \frac{P_T(s^{t+1})}{P_T(s^t)} = \frac{A(s^{t+1})\theta(s_{1t+1})P_N(s^t, s_{1t+1})}{A(s^t)\theta(s_{1t})P_N(s^{t-1}, s_{1t})} = \frac{A(s_{2t+1})}{A(s_{2t})}\frac{\min_{z_2}\{X(z_{2t+1})\}\mathbb{E}\frac{\frac{1}{A(s_{2t+1})}}{X(z_{2t+1})}}{\min_{z_2}\{X\left(z_{2t}\right)\}\mathbb{E}\frac{\frac{1}{A(s_{2t})}}{X(z_{2t})}}\frac{M(s^t)}{M(s^{t-1})}
$$

If productivity is not stochastic, then money growth is simply $\beta < 1$. For inflation this means $\pi_N = \Delta\theta\beta$, $\pi_T = \beta$. Nominal interest rates are then $R = 1$. As in the case with monetary policy under commitment with flexible exchange rates, the union-wide central bank follows the Friedman rule as well. This implies a continued contraction in money supply, zero interest rates and deflation.

Main text from before

B.6.1 Flexible Exchange Rates: Monetary Policy under Commitment

The central bank conducts monetary policy under commitment. This means that the central bank maximizes ex ante lifetime utility of its representative household. It chooses an appropriate state-contingent path of prices subject to the consumer and firm first order conditions, the resource constraint, as well as the production function [23]. The central bank sets its policy

[23] The central banks could also jointly maximize a weighted sum of all countries using their policy instrument for each country. As there are no externalities in the model of Chari et al. (2020), cooperative and non-cooperative equilibria coincide.

after productivity has realized.

$$\begin{aligned}
\max_{\{P_T(s^t), P_N(s^t)\}_{t=0}^{\infty}} \quad & \mathbb{E}_0 \left[\sum_{\tau=t} \beta^t \left(\alpha \log(C_T(s^\tau) + (1-\alpha) \log(C_N(s^\tau)) - \psi L(s^\tau) \right) \right] \\
\text{s.t.} \quad & L(s^t) = \frac{C_N(s^t)}{A(s_{2t})} + C_T(s^t), \\
& C_T(s^t) = \frac{\alpha}{\psi}, \\
& C_N(s^t) = \frac{1-\alpha}{\psi} \frac{P_T(s^t)}{P_N(s^{t-1}, s_{1t})}, \\
& \sum_{s_{2t}} h\left(s^t \mid s^{t-1}, s_{1t}\right) C_N\left(s^t\right) \left[U_N\left(s^t\right) + \frac{1}{\theta\left(s_{1t}\right)} \frac{U_L\left(s^t\right)}{A\left(s_{2t}\right)} \right] = 0,
\end{aligned}$$

where the first constraint is the resource constraint combined with the production functions, the next two are the consumers first order conditions and the last constraint is the optimality condition of firms combined with the stochastic discount factor and $W(s^t) = P_T(s^t)$. Importantly, the central bank realizes that firms will set their relative prices equal to expected productivity times the markup. In a world under discretion, in which the central bank would take $P_N(s^{t-1}, s_{1t})$ as given, it would try to inflate away the markup, to set $P_T(s^t)/P_N(s^{t-1}, s_{1t}) = A(s_{2t})$. Under commitment the central bank realizes that this attempt of surprise inflation will not work. Therefore, optimal policy does not respond to markup shocks. It only responds to productivity shocks. Intuitively, the monetary authority has to live with the distortions from markup shocks and attempts to accommodate productivity shocks. Therefore, the optimal policy of the central bank implies

$$\frac{P_T(s^t)}{P_N(s^{t-1}, s_{1t})} = \theta(s_{1t})A(s_{2t}).$$

The interpretation of that policy rule is straightforward: After productivity has realized the central bank makes sure that relative prices move in such a way that they replicate the outcome as if non-traded good prices were flexible. This way the central bank can eliminate any distortions coming from rigid prices. The central bank engineers a movement of the exchange rate in such a way that relative prices align. For example, if productivity of the non-traded goods sector is high today, P_N should decrease as it is easier to produce that good. As prices of that good do not adjust, the central bank instead uses the exchange rate to let the currency depreciate so such P_T rises, which means that the relative price for P_N falls. The movement of the exchange rate aims to replicate the outcome of relative prices as if all prices were flexible.

Note also, that optimal monetary policy would never cause consumers to lose consumption because they do not have enough cash. Therefore, the cash in advance constraint is never binding in a way that would lower the household's consumption. That is the reason why the consumer first order condition with respect to C_T has a multiplier from the cash in advance constraint equal to zero.

B.6.2 Nominal rates

Table B.1 shows average nominal interest rates under different regimes

Table B.1: Average nominal interest rates under different monetary regimes..

Regime	R
Float	$(1-\xi_t)1+\xi_t\mathbb{E}\left[\frac{\alpha-(1-\alpha)(1-\theta(s'))}{\alpha}\right]^{-1}$
Peg	$(1-\xi_t^{Anch})1+\xi_t^{Anch}\left(\mathbb{E}\left[\frac{\alpha-(1-\alpha)(1-\theta(s'))}{\alpha}\right]^{-1}\right)$
Union	$(1-\min\{\xi_t^i\})1+\min\{\xi_t^i\}\left(\mathbb{E}\left[\frac{\alpha-(1-\alpha)(1-\sum_i\lambda^i\mathbb{E}_v\theta^i(s))}{\alpha}\right]^{-1}\right)$

Notes: Average nominal interest rates (R) on one period government bonds under all regimes. Average interest rates are the weighted average under discretion with probability ξ_t and under commitment with probability $(1-\xi_t)$. In a currency union there are blocks of countries each with a mass λ^i.

B.6.3 Flexible Exchange Rates: Monetary Policy under Discretion

Now consider how a non-credible central bank sets monetary policy. The important difference when a central bank acts under discretion is that it takes the price of non-traded goods as given, as firms have set their prices before the central bank acts. As a consequence, the central bank will try to use monetary policy to inflate away the inefficient monopolistic markups and implement an allocation, that equalizes household's marginal rate of substitution with the marginal rate of transformation of the economy. That is $P_T(s^t)/P_N(s^{t-1},s_{1t})=A(s_{2t})$. In order to do that the central bank will go so far to make the cash in advance constraint binding. As long as this constraint is slack, the central bank can use more inflation to reduce the markups. Therefore, the central bank makes the cash in advance constraint binding and ultimately trades off the costs of markups with the costs of surprise inflation that lower the household's purchasing power. A central bank under discretion therefore chooses $p_T(s^t)=P_T(s^t)/M(s^{t-1})$ to maximize the following problem:

$$\max_{p_T(s^t)}\quad \mathbb{E}_t\left[\sum_{\tau=t}\beta^t\left(\alpha\log(C_T(s^\tau)+(1-\alpha)\log(C_N(s^\tau))-\psi L(s^\tau)\right)\right]$$

$$\text{s.t.}\quad C_T(s^t)=\frac{1}{p_T(s^t)},$$

$$C_N(s^t)=\frac{1-\alpha}{\psi}\frac{p_T(s^t)}{p_N(s^{t-1},s_{1t})},$$

$$L(s^t)=C_T(s^t)+\frac{C_N(s^t)}{A(s^t)}.$$

Note the following differences to the problem before: The central bank's objective function has an expectation operator that starts in t as the central bank acts under discretion and does not commit beforehand. The consumption constraint for traded goods is also altered, as the cash in advance constraint is binding. In addition, the central bank does not take the firm's first order condition into account as it acts under discretion. Chari et al. (2020) show that the dynamic dimension of this problem does not play a role, so the central bank simply acts as maximizing the per period utility of its household. The best response of the monetary authority is to set the price of traded goods as:

$$p_T\left(s_t\right) = p_N\left(s_{1t}\right) A\left(s_{2t}\right) \underbrace{\frac{1}{2(1-\alpha)}\left[(1-2\alpha)+\sqrt{(1-2\alpha)^2+4(1-\alpha)\frac{1}{A\left(s_{2t}\right)}\frac{\psi}{p_N\left(s_{1t}\right)}}\right]}_{F\left(\frac{1}{A(s_{2t})p_N(s_{1t})}\right)}$$

where the first part on the right-hand side $p_N\left(s_{1t}\right) A\left(s_{2t}\right)$ captures the willingness of the central bank to put the marginal rate of transformation equal to the marginal rate of substitution and $F(\cdot)$ captures the costs from surprise inflation. If p_N increases by one, p_T increases less than one-to-one. In the following we assume as in Chari et al. (2020) that $\frac{1}{\theta(s)} < \frac{1-\alpha}{1-2\alpha}$ so that there is a point where marginal costs of surprise inflation equal their marginal benefits. This simply bounds markups from above, meaning that it is not possible that reducing markup distortions always exceed the costs of reducing trade goods consumption.

Another aspect that needs to be mentioned is, when productivity is stochastic and is sufficiently low compared to its average value, it can happen that the cash in advance constraint is not binding despite the central bank's policy. That is if $Ap_N < C_T$ then $p_T = p_N A$. Taken this into account as well, it implies that the price of traded goods is described by $p_T\left(s_t\right) = \max\{p_N\left(s_{1t}\right) A\left(s_{2t}\right), p_N\left(s_{1t}\right) A\left(s_{2t}\right) F(\cdot)\}$.

For policy under discretion, it is also important to consider the firms. They take into account that the central bank will try to inflate away their markups. Optimally firms still set prices of traded goods as in (1). Remember that firms observe the markup shock and then set their price taking their expectation for future productivity into account. Overall, the price of traded goods in the equilibrium solves the fixed-point problem of equaling the optimal price firms would set and what the central bank wants to implement. So, in equilibrium, any attempt of the central bank to inflate away the markup is frustrated, as firms anticipate the central bank's move and set their prices accordingly. The only thing the central bank achieves is an inflationary bias with higher volatility of prices and consumption.

B.6.4 Unilateral Peg to a Stable Anchor

Consider now the case in which one country (the client country) pegs its currency to a stable country (the anchor). The anchor is assumed to conduct monetary policy under commitment, as in Section 2.3.1. The client country then ensures that the exchange rate to the anchor country stays constant at all points in time. This implies that monetary policy of the client loses its independence and follows the anchor. The main difference to this regime and a currency union is that the client country has no influence how the anchor conducts monetary policy. In a currency union the union-wide central bank considers all its member states.

The central bank of the anchor country then sets relative prices like

$$\frac{P_T(s^t)}{P_N(s^{t-1}, s_{1t})} = \theta(s_{1t})A(s_{2t}).$$

The peg implies that the price of traded goods is the same for both countries. Firms of the client country realize that monetary policy will be as in the anchor country. After markup shocks have realized in the anchor country, they form expectations about productivity and how the central bank of the anchor chooses the price of traded goods. In general, distortions coming from productivity fluctuations will be completely offset in the anchor country, while they will be present in the client country. These distortions are reflected in a volatile movement of employment. There is no inflationary bias in any of both countries

B.6.5 Currency Union: Monetary Policy under Commitment

In a monetary union, the exchange rate is fixed and set to $e(s^t) = 1$ for all states. This implies that P_T cannot vary across countries and is only a function of aggregate union-wide shocks. This gives rise to the "Union constraint"

$$\frac{U_T(s^t)}{U_N(s^t)} = \frac{U_T(\tilde{s}^t)}{U_N(\tilde{s}^t)}$$

The union consists out of many blocks, each block i having a mass of countries n^i. The relative weight of block i is $\lambda^i = \frac{n^i}{\sum_i n^i}$. Countries are all the same across blocks, except for the shock process of their markup. The central bank acts under commitment and chooses the union-wide price of traded goods and the prices of non-traded goods to maximize an equally weighted average of all countries of the world:

$$\begin{aligned}
\max_{P_T, P_N(v)} \ & \mathbb{E}_0 \left[\sum_{\lambda^i} \lambda^i \sum_{v^t} g(v^t) \left[\alpha \log C_T^i(s^t) + (1-\alpha) \log C_N^i(s^t) - \psi\left(L^i(s^t)\right) \right] \right] \\
\text{s.t.} \quad & L(s^t) = \frac{C_N(s^t)}{A(s_{2t})} + C_L(s^t) \\
& C_T(s^t) = \frac{\alpha}{\psi} \\
& C_N(s^t) = \frac{1-\alpha}{\psi} \frac{P_T(s^t)}{P_N(s^{t-1}, s_{1t})} \\
& \sum_{s_{2t}} h\left(s^t \mid s^{t-1}, s_{1t}\right) C_N\left(s^t\right) \left[U_N\left(s^t\right) + \frac{1}{\theta\left(s_{1t}\right)} \frac{U_L\left(s^t\right)}{A\left(s_t\right)} \right] = 0 \\
& \frac{U_T(s^t)}{U_N(s^t)} = \frac{U_T(\tilde{s}^t)}{U_N(\tilde{s}^t)}
\end{aligned}$$

where $\sum_{v^\tau} g(v^\tau)$ simply sums up all the countries within a block. Remember that $s^t = (z^t, v^t)$ where z^t is the aggregate shock and v^t is the country-specific shock. Optimally, the cash in advance constraint does not bind to avoid losses in consumption. The central bank sets prices such that it stabilizes the average of the whole union:

$$\frac{P_T(s^t)}{P_N(s^{t-1}, s_{1t})} = \theta(s_{1t}) \left(\sum_{v_{2t}} g(v_{2t}) \frac{1}{A(z_{2t}, v_{2t})} \right)^{-1}$$

As the exchange rate is fixed, prices of traded goods are the same for all countries and the only thing the union-wide central bank can do is to set relative prices equal to the markup times the *average* productivity of the union.

B.6.6 Currency Union: Monetary Policy under Discretion

In a monetary union, the exchange rate is fixed and set to $e(s^t) = 1$ for all states. This implies that P_T cannot vary across countries and is only a function of aggregate union-wide shocks. This gives rise to the "Union constraint"

$$\frac{U_T(s^t)}{U_N(s^t)} = \frac{U_T(\tilde{s}^t)}{U_N(\tilde{s}^t)}.$$

The union consists out of many blocks, each block i having a mass of countries n^i. The relative weight of block i is $\lambda^i = \frac{n^i}{\sum_i n^i}$. Countries are all the same across blocks, except for the shock process of their markup. The central bank acts under discretion and chooses the union-wide price of traded goods to maximize an equally weighted average of all countries of the world. The union-wide central bank chooses a traded good price for the union taking the non-traded good prices as given.

$$\begin{aligned}
\max_{p_T} & \sum_{\lambda^i} \lambda^i \sum_{v^t} g(v^t) \left[\alpha \log C_T^i(s^t) + (1-\alpha) \log C_N^i(s^t) - \psi \left(L^i(s^t) \right) \right] \\
\text{s.t.} \quad & L^i(s^t) = \frac{C_N^i(s^t)}{A^i(s_{2t})} + C_L^i(s^t), \\
& C_T^i(s^t) = \frac{1}{p_T(s^t)}, \\
& C_N^i(s^t) = \frac{1-\alpha}{\psi} \frac{p_T(s^t)}{p_N^i(s^{t-1}, s_{1t})}, \\
& \frac{U_T(s^t)}{U_N(s^t)} = \frac{U_T(\tilde{s}^t)}{U_N(\tilde{s}^t)},
\end{aligned}$$

where $g(v)$ gives the average state of all countries within a block, given the aggregate state. The policy of the central bank implies to set the price of traded goods such that:

$$p_T\left(z, \left\{p_N^i\left(z_1, v_1\right)\right\}\right) = \frac{(1-2\alpha) + \sqrt{(1-2\alpha)^2 + 4 \sum_i \lambda^i \sum_v g(v) \frac{(1-\alpha)}{A^i(z_2,v_2)} \frac{\psi}{p_N^i(z_1,v_1)}}}{\sum_{i=N,S} \lambda^i \sum_v g(v) \frac{2(1-\alpha)}{A^i(z_2,v_2)} \frac{1}{p_N^i(z_1,v_1)}}.$$

Compared to the policy rule under discretion with an independent national central bank single country-specific shocks are replaced by the average shock realization of the union.

As before, firms anticipate the policy of the central bank and take this into account when setting their prices. In a currency union however, they realize that the central bank will only react to the average temptation shock, not the country-specific one. The result is still more inflation. The next section discusses how the policy under discretion in a currency union can still yield some benefits compared to discretion of a single country.

B.6.7 Degrees of Credibility

We follow Schaumburg and Tambalotti (2007) and introduce credibility into the model, by assuming that the central bank acts under discretion in a period with a certain probability. The interpretation is that a new governor gets selected with probability ξ in every period. If a new governor is selected, she acts under discretion in the first period and commits to policy thereafter as long as she is in office. It is not possible to restrain the successor. Formally, there is a sequence of Bernoulli signals η_t, with probability ξ η_t is one and a new governor is chosen, otherwise η_t is zero and the old governor stays in place. We assume that this signal is known *before* productivity has realized. This implies that firms know if monetary policy acts under commitment or under discretion in a certain period. The optimization problem of the central bank is

$$
\begin{aligned}
\max_{\{P_T(s^t),P_N(s^t)\}_{t=0}^{\infty}} \quad & \mathbb{E}_0\left[\sum_{\tau=t}\beta^t\left(\alpha\log(C_T(s^\tau)+(1-\alpha)\log(C_N(s^\tau))-\psi L(s^\tau)\right)\right] \\
\text{s.t.} \quad & L(s^t)=\frac{C_N(s^t)}{A(s_{2t})}+C_T(s^t) \\
& (1-\eta_t)(C_T(s^t)-\frac{\alpha}{\psi})+\eta_t(\frac{1}{p_T(s^t)}-C_T(s^t))=0 \\
& C_N(s^t)=\frac{1-\alpha}{\psi}\frac{P_T(s^t)}{P_N(s^{t-1},s_{1t})} \\
& (1-\eta_t)\sum_{s_{2t}}h\left(s^t\mid s^{t-1},s_{1t}\right)C_N\left(s^t\right)\left[U_N\left(s^t\right)+\frac{1}{\theta\left(s_{1t}\right)}\frac{U_L\left(s^t\right)}{A\left(s_{2t}\right)}\right]=0
\end{aligned}
$$

The central bank ends up with a policy rule that is either discretionary or commitment based:

$$
p_T=\begin{cases} p_N\left(s_{1t}\right)A\left(s_{2t}\right)\theta(s_{1t}) & \text{if} \quad \eta_t=0 \\ p_N\left(s_{1t}\right)A\left(s_{2t}\right)\frac{1}{2(1-\alpha)}\left[(1-2\alpha)+\sqrt{(1-2\alpha)^2+4(1-\alpha)\frac{1}{A(s_{2t})}\frac{\psi}{p_N(s_{1t})}}\right] & \text{if} \quad \eta_t=1 \end{cases}
$$

Firms set their prices accordingly to each regime. Overall, average inflation over a longer time horizon for a country is then the weighted average of inflation under discretion and under commitment. The weights correspond to the credibility parameter ξ that determines the probability of having commitment and discretion. If a country in this setup decides to peg its currency to a stable anchor, the probability of being in a discretionary regime decreases to the level of the anchor country. In a currency union, the central bank is as credible as the most credible member state.

B.7 Proofs of Theorems

Theorem 1 Inflation falls if a less credible country pegs to more credible anchor. Proof: $(1-\xi)\frac{\theta(s)}{\theta(s')}\beta+\xi\frac{\theta(s)}{\theta(s')}\beta\frac{\alpha}{\alpha-(1-\alpha)(1-\theta(s))}\Theta(s') > (1-\xi^{Anch})\frac{\theta(s)}{\theta(s')}\beta+\xi^{Anch}\frac{\theta(s)}{\theta(s')}\beta\frac{\alpha}{\alpha-(1-\alpha)(1-\theta^{Anch}(s))}\Theta^{Anch}(s')$. Assuming that the underlying shock process of θ is the same for both countries, the difference between ξ and ξ^{Anch} is decisive for the average inflation rate. $-\xi+\xi\frac{\alpha}{\alpha-(1-\alpha)(1-\theta(s))}\Theta(s') > -\xi^{Anch}+\xi^{Anch}\frac{\alpha}{\alpha-(1-\alpha)(1-\theta^{Anch}(s))}\Theta^{Anch}(s') \Rightarrow \frac{\xi}{\xi^{Anch}} > \frac{\frac{\alpha}{\alpha-(1-\alpha)(1-\theta^{Anch}(s))}\Theta^{Anch}(s')-1}{\frac{\alpha}{\alpha-(1-\alpha)(1-\theta(s))}\Theta(s')-1}$ (note that $\frac{\alpha}{\alpha-(1-\alpha)(1-\theta(s))}\Theta(s')-1>1$). As the markup shock process is the same, the expected value of the right hand side is 1. Then we have $\xi > \xi^{Anch}$ which is true as the anchor is more credible and less likely to act under discretion. For the currency union the same is true as the most credible anchor determines monetary policy.

Theorem 3 Inflation volatility. Proof:

1. pure discretion vs pure commitment

$$Var(\pi_N^{discr}) > Var(\pi_N^{commit})$$
$$Var(\frac{\theta(s)}{\theta(s')}\beta\underbrace{\frac{\alpha}{\alpha-(1-\alpha)(1-\theta(s'))}}_{>1}) > Var(\frac{\theta(s)}{\theta(s')}1\cdot\beta)$$

which is under the considered restriction $\theta > 1-\alpha/(1-2\alpha)$ fulfilled.

2. Pegging to a more credible anchor only reduces volatility if anchor is very credible

$$Var(\pi_N) > Var(\pi_N^{peg})$$
$$Var(\xi\pi_N^{discr}+(1-\xi)\pi_N^{commit}) > Var(\xi^{Anch}\pi_N^{discr}+(1-\xi^{Anch})\pi_N^{commit})$$
$$\xi^2 Var(\pi_N^{discr})+(1-\xi)^2 Var(\pi_N^{commit})+2\xi(1-\xi)Cov(\pi_N^{discr},\pi_N^{commit})$$
$$> {\xi^{Anch}}^2 Var(\pi_N^{discr})+(1-\xi^{Anch})^2 Var(\pi_N^{commit})+2\xi^{Anch}(1-\xi^{Anch})Cov(\pi_N^{discr},\pi_N^{commit})$$

From Theorem 2.1. it follows, that $Var(\pi_N^{discr}) > Var(\pi_N^{commit})$. If $Cov(\pi_N^{discr},\pi_N^{commit}) = 0$ the inequality is always fulfilled. The covariance is however greater than zero in general, as inflation under commitment and discretion consist out of similar components. For given values of the variance and the covariance, the maximum volatility in a regime as a function of credibility is described by the following first order condition:

$$\xi = \frac{2var(\pi^c)-cov(\pi^C,\pi^d)}{2(var(\pi^d)+var(\pi^c)-cov(\pi^c,\pi^d))}$$

if the variance in pure discretion and commitment regimes were the same, the maximum volatility is achieved if $\xi = \frac{1}{2}$, as the maximum of $\xi(1-\xi)$ is for $\xi = \frac{1}{2}$. The volatility of pure discretionary regimes is however larger, therefore the maximum volatility in a regime is achieved for some value of $\tilde{\xi}$ greater than 0.5. For volatility to go down if a country pegs, the anchor country must be sufficiently credible and be substantially below $\tilde{\xi}$.

3. Volatiltiy in a currency union

Compare inflation for the anchor country in a pegged regime and in a currency union regime and assume that the anchor is also the most credible country. $\pi_N^{Anch,Peg} = (1-\xi^{Anch})\frac{\theta^{Anch}(s)}{\theta^{Anch}(s')}\beta + \xi^{Anch}\frac{\theta^{Anch}(s)}{\theta^{Anch}(s')}\beta\frac{\alpha}{\alpha-(1-\alpha)(1-\theta^{Anch}(s))}\Theta^{Anch}(s')$

$\pi_N^{Anch,Union} = (1-\xi^{Anch})\frac{\theta^{Anch}(s)}{\theta^{Anch}(s')}\beta + \xi^{Anch}\frac{\theta^{Anch}(s)}{\theta^{Anch}(s')}\frac{\beta\alpha}{\alpha-(1-\alpha)(1-\sum_i\lambda^i\theta^i(s))}\Theta^U(s')$

with $\Theta(s') = \frac{\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\theta(s))}{\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\theta(s'))}$ and $\Theta^U(s') = \frac{\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\sum_i\lambda^i\mathbb{E}_v\theta^i(s))}{\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\sum_i\lambda^i\mathbb{E}_v\theta^i(s'))}$

The first component under commitment is the same, while only the second under discretion is different. As the main text mentioned, Θ^U is less volatile than Θ^{Anch} as the average change of markups between countries is less volatile than the change of markups of one country. In addition to that, the correlation between $\frac{\theta^{Anch}(s)}{\theta^{Anch}(s')}$ and $\frac{\beta\alpha}{\alpha-(1-\alpha)(1-\sum_i\lambda^i\theta^i(s))}\Theta^U(s') = \frac{\beta\alpha}{\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\sum_i\lambda^i\mathbb{E}_v\theta^i(s'))}$ is lower in a union than this object in a peg: $\frac{\theta^{Anch}(s)}{\theta^{Anch}(s')}$ and $\frac{\alpha}{\alpha-(1-\alpha)(1-\theta^{Anch}(s'))}$. This leads to a reduction of volatility of inflation for the anchor country. For a client country, the opposite would be true, as its markup realization now play a role for a discretionary monetary authority. Then, only Θ^U lowers the volatility while a potentially higher correlation increases volatility for a client country entering the union.

Theorem 2 Output of N in a peg is higher than in a float if $\xi > \xi^{Anch}$, proof: $(1-\xi)\frac{\alpha}{\psi} + \xi\left(\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\theta(s))\right) < (1-\xi^{Anch})\frac{\alpha}{\psi} + \xi^{Anch}\left(\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\theta(s))\right) \Rightarrow (\xi^{Anch}-\xi)\frac{\alpha}{\psi} < (\xi^{Anch}-\xi)\left(\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\theta(s))\right)$. As $\xi^{Anch} < \xi$, we arrive at $\frac{\alpha}{\psi} > \frac{\alpha}{\psi} - (1-\alpha)(1-\theta)$ which is true for α and $\theta \in (0,1)$. The same is true for all countries entering the currency union, whose credibility is lower than the most credible country.

B.8 Computation of Interest Rates

Flexible exchange rate and commitment

$$\bar{Q}\left(s^t\right) = \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{U_N\left(s^{t+1}\right)}{P_N\left(s^t, s_{1t+1}\right)} \frac{P_N\left(s^{t-1}, s_{1t}\right)}{U_N\left(s^t\right)}$$

$$\bar{Q}\left(s^t\right) = \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{\frac{1-\alpha}{C_N(s^{t+1})}}{\frac{1-\alpha}{C_N(s^t)}} \frac{P_N\left(s^{t-1}, s_{1t}\right)}{P_N\left(s^t, s_{1t+1}\right)} \frac{M(s^{t-1})/M(s^{t-1})}{M(s^t)/M(s^t)}$$

$$\bar{Q}\left(s^t\right) = \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{C_N\left(s^t\right)}{C_N\left(s^{t+1}\right)} \frac{\frac{1}{\theta(s_{1t})} \frac{\psi}{\alpha} \frac{1}{\max\{A(s_{2t})\}} M(s^{t-1})}{\frac{1}{\theta(s_{1t+1})} \frac{\psi}{\alpha} \frac{1}{\max\{A(s_{2t+1})\}} M(s^t)}$$

$$\bar{Q}\left(s^t\right) = \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{\frac{1-\alpha}{\psi} \theta\left(s_{1t}\right) A\left(s_{2t}\right)}{\frac{1-\alpha}{\psi} \theta\left(s_{1t+1}\right) A\left(s_{2t+1}\right)} \frac{\frac{1}{\theta(s_{1t+1})} \frac{\psi}{\alpha} \frac{1}{\max\{A(s_{2t})\}} M(s^{t-1})}{\frac{1}{\theta(s_{1t+1})} \frac{\psi}{\alpha} \frac{1}{\max\{A(s_{2t+1})\}} M(s^t)}$$

$$\bar{Q}\left(s^t\right) = \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{A\left(s_{2t}\right)}{A\left(s_{2t+1}\right)} \frac{\frac{1}{\max\{A(s_{2t})\}}}{\frac{1}{\max\{A(s_{2t+1})\}}} \frac{M(s^{t-1})}{M(s^t)}$$

$$\bar{Q}\left(s^t\right) = \frac{\max\{A(s_{2t+1})\}}{\max\{A(s_{2t})\}}$$

Interest rates are zero if productivity is not stochastic.

Flexible exchange rates and discretion

$$\bar{Q}\left(s^t\right) = \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{C_N\left(s^t\right)}{C_N\left(s^{t+1}\right)} \frac{P_N\left(s^{t-1}, s_{1t}\right)}{P_N\left(s^t, s_{1t+1}\right)}$$

$$\bar{Q}\left(s^t\right) = \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{\frac{1-\alpha}{\psi} A\left(s^t\right) \theta\left(s^t\right)}{\frac{1-\alpha}{\psi} A\left(s^{t+1}\right) \theta\left(s^{t+1}\right)} \frac{p_N\left(s^{t-1}, s_{1t}\right) M(s^{t-1})}{p_N\left(s^t, s_{1t+1}\right) M(s^t)}$$

$$\bar{Q}\left(s^t\right) = \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{\frac{1-\alpha}{\psi} A\left(s^t\right) \theta\left(s^t\right)}{\frac{1-\alpha}{\psi} A\left(s^{t+1}\right) \theta\left(s^{t+1}\right)} \frac{p_N\left(s^{t-1}, s_{1t}\right)}{p_N\left(s^t, s_{1t+1}\right)} \frac{\psi}{\beta\alpha A(s_{2t}) \theta(s_{1t}) p_N(s^{t-1}, s_{1t})}$$

$$\bar{Q}\left(s^t\right) = \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{1}{A\left(s^{t+1}\right) \theta\left(s^{t+1}\right)} \frac{1}{p_N\left(s^t, s_{1t+1}\right)} \frac{\psi}{\beta\alpha}$$

$$\bar{Q}\left(s^t\right) = \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{1}{A\left(s^{t+1}\right) \theta\left(s^{t+1}\right)} \frac{1}{\frac{1}{\theta(s_{1t+1})} \frac{1}{A(s_{2t+1})} \frac{\psi}{\alpha-(1-\alpha)(1-\theta(s_{1t+1}))}} \frac{\psi}{\beta\alpha}$$

$$\bar{Q}\left(s^t\right) = \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{\alpha-(1-\alpha)(1-\theta(s_{1t+1}))}{\psi} \frac{\psi}{\beta\alpha} < \beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^t\right) \frac{\alpha}{\psi} \frac{\psi}{\beta\alpha}$$

$$R(s^{t+1})^{-1} = \mathbb{E}_t \left[\frac{\alpha - (1-\alpha)(1-\theta(s_{1t+1}))}{\alpha}\right]$$

which implies that $\bar{Q}^{disc}(s^t) < \bar{Q}^{Commit}(s^t)$ and therefore $(1+i)^{disc} > (1+i)^{commit}$.

In a currency union with commitment

$$\bar{Q}\left(s^{t}\right)=\beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^{t}\right) \frac{C_{N}\left(s^{t}\right)}{C_{N}\left(s^{t+1}\right)} \frac{P_{N}\left(s^{t-1}, s_{1 t}\right)}{P_{N}\left(s^{t}, s_{1 t+1}\right)}$$

$$\bar{Q}\left(s^{t}\right)=\beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^{t}\right) \frac{\frac{1-\alpha}{\psi} \frac{P_{T}\left(s^{t}\right)}{P_{N}\left(s^{t-1}, s_{1 t}\right)}}{\frac{1-\alpha}{\psi} \frac{P_{T}\left(s^{t+1}\right)}{P_{N}\left(s^{t}, s_{1 t+1}\right)}} \frac{P_{N}\left(s^{t-1}, s_{1 t}\right)}{P_{N}\left(s^{t}, s_{1 t+1}\right)}$$

$$\bar{Q}\left(s^{t}\right)=\beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^{t}\right) \frac{P_{T}(s^{t})}{P_{T}(s^{t+1})}$$

$$\bar{Q}\left(s^{t}\right)=\beta \sum_{s^{t+1}} h\left(s^{t+1} \mid s^{t}\right) \frac{\frac{\psi}{\alpha} \frac{\min_{z_2}\{X(z_{2t})\}}{X(z_{2t})}}{\frac{\psi}{\alpha} \frac{\min_{z_2}\{X(z_{2t+1})\}}{X(z_{2t+1})}} M(s^{t-1})/M(s^{t})$$

B.9 Overview of all six Regimes

Table B.2: Output under different monetary regimes.

Regime	Y_T	Y_N
CF	$\frac{\alpha}{\psi}$	$\frac{1-\alpha}{\psi}\theta(s)A(s)$
DF	$\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}(1-\theta(s))$	$\frac{1-\alpha}{\psi}\theta(s)A(s)$
CP	$\frac{\alpha}{\psi}$	$\frac{1-\alpha}{\psi}\theta(s)\mathbb{E}_v(1/A)^{-1}$
CU	$\frac{\alpha}{\psi}$	$\frac{1-\alpha}{\psi}\theta(s)\left(\sum_i \lambda^i \mathbb{E}_v(1/A^i)\right)^{-1}$
DU	$\frac{\alpha}{\psi}-\frac{1-\alpha}{\psi}\left(1-\sum_i \lambda^i \mathbb{E}_v\left(\theta^i(s)\right)\right)$	$\frac{1-\alpha}{\psi}\theta(s)\left(\sum_i \lambda^i \mathbb{E}_v(1/A^i)\right)^{-1}$

Notes: Output of traded goods (Y_T) and non-traded goods (Y_N) under all possible regimes: Commitment and Float (CF), Discretion and Float (DF), Commitment and Peg (CP), Commitment in a Union (CU), Discretion in a Union (DU).

Table B.3: Nominal Rates under different monetary regimes.

Regime	R	π_N	ΔM
CF	1	$\frac{\theta(s)}{\theta(s')}\beta$	β
DF	$\mathbb{E}\left[\frac{\alpha-(1-\alpha)(1-\theta(s'))}{\alpha}\right]^{-1}$	$\frac{\theta(s)}{\theta(s')}\beta\frac{\alpha}{\alpha-(1-\alpha)(1-\theta(s))}\Theta(s')$	$\beta\frac{\alpha}{\alpha-(1-\alpha)(1-\theta(s))}$
CP	1	$\frac{\theta(s)}{\theta(s')}\beta$	β
CU	1	$\frac{\theta(s)}{\theta(s')}\beta$	β
DU	$\mathbb{E}\left[\frac{\alpha-(1-\alpha)(1-\sum_i \lambda^i \mathbb{E}_v \theta^i(s))}{\alpha}\right]^{-1}$	$\frac{\theta(s)}{\theta(s')}\frac{\beta\alpha}{\alpha-(1-\alpha)(1-\sum_i \lambda^i \theta^i(s))}\Theta^U(s')$	$\beta\frac{\alpha}{\alpha-(1-\alpha)(1-\sum_i \lambda^i \mathbb{E}_v \theta^i(s))}$

Notes: Nominal Interest Rates (R), inflation of non-traded goods (π_N) and the money growth rate (ΔM) under all possible regimes: Commitment and Float (CF), Discretion and Float (DF), Commitment and Peg (CP), Commitment in a Union (CU), Discretion in a Union (DU).

B.10 Model Graphs and Estimation

B.10.1 SMM

Formally, let x be the data and $m(x)$ the moments of the data. The corresponding moments of the model are denoted by $m(\tilde{x}, \upsilon)$ where υ are the parameters of the model. We simulate the model S times, such that there are S simulations of the model data $\tilde{x} = \{\tilde{x}_1, \tilde{x}_2, ..., \tilde{x}_S\}$. The vector of moments in one simulation s of length T consists out of three expressions. The standard deviation and the mean of a country's inflation rate during a discretionary float in simulation s and the average markup

$$std(\pi_s) = \sqrt{\frac{1}{T}\sum_t^T (\pi_t - \bar{\pi}_s)^2}, \quad \mu(\pi_s) = \frac{1}{T}\sum_t^T \pi_t, \quad \mu(\theta_s) = \frac{1}{T}\sum_t^T \frac{1}{\theta_t}$$

The estimated model moments from the simulation are

$$\hat{m}(\tilde{x}, \upsilon) = \frac{1}{S}\sum_{s=1}^{S} m\left(\tilde{x}_s \mid \upsilon\right).$$

The SMM approach estimates the parameter vector $\hat{\upsilon}_{SMM}$ to choose υ in such a way that it minimizes the L^2 norm of the sum of squared errors in moments. We define the moment error function as the percent difference in the vector of simulated model moments from the data moments

$$e(\tilde{x}, x \mid x) = \frac{\hat{m}(\tilde{x} \mid \upsilon) - m(x)}{m(x)}.$$

The SMM estimator is now the following:

$$\hat{\upsilon}_{SMM} = \upsilon : \min_{\upsilon} e(\tilde{x}, x \mid x)^T W e(\tilde{x}, x \mid x)$$

where W is a weighting matrix, in a first step it is the identity matrix, implying equal weights for all moments.

Table B.4: SMM for 1960-1999

Country	$\underline{\theta}$	$\bar{\theta}$	μ_θ data	μ_θ model	σ_θ data	σ_θ model
Italy	0.9517	0.9928	7.03%	7.04%	0.057	0.057
Germany	0.976	0.991	2.96%	3.16%	0.019	0.020

B.10.2 Graphs of the model

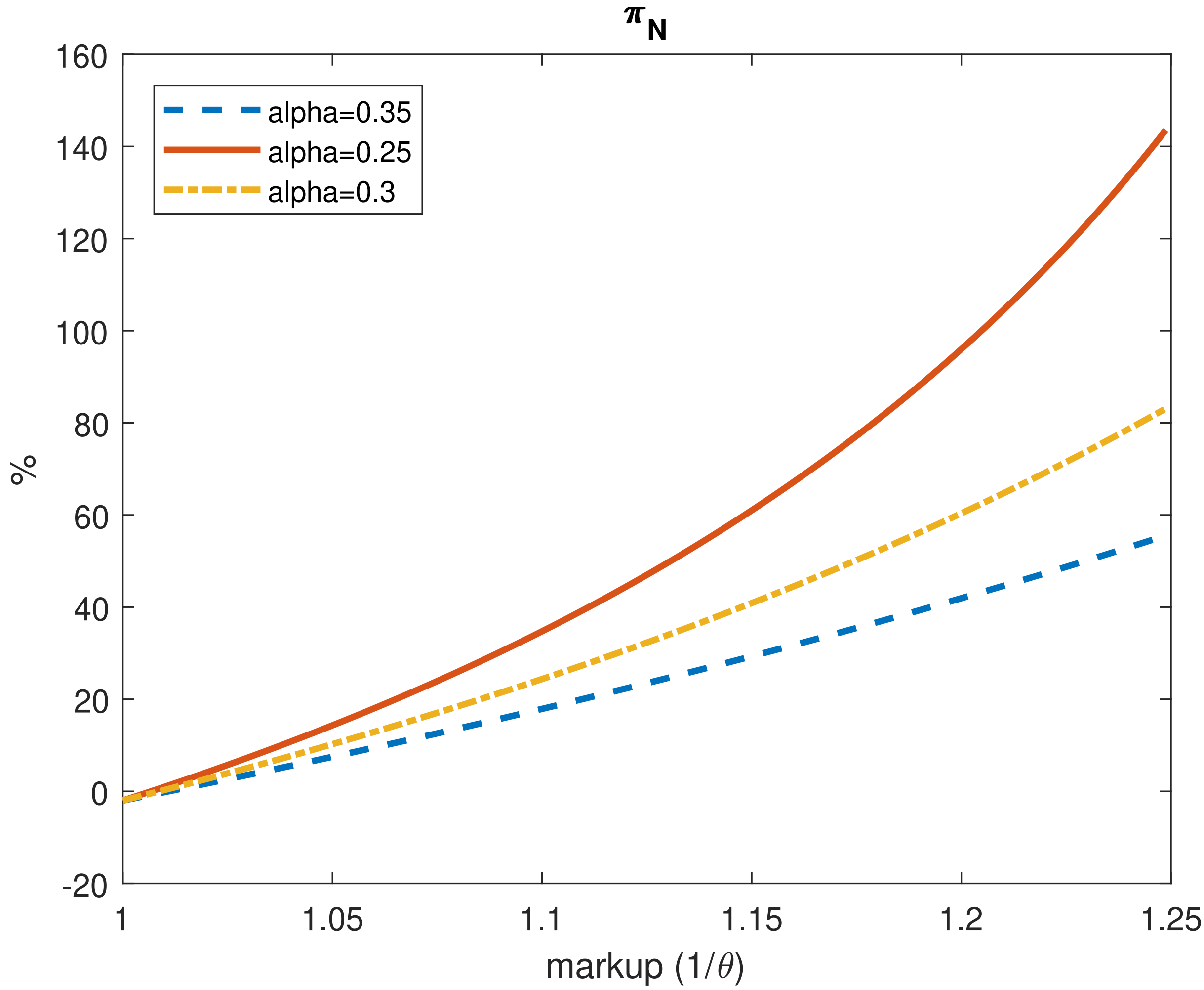


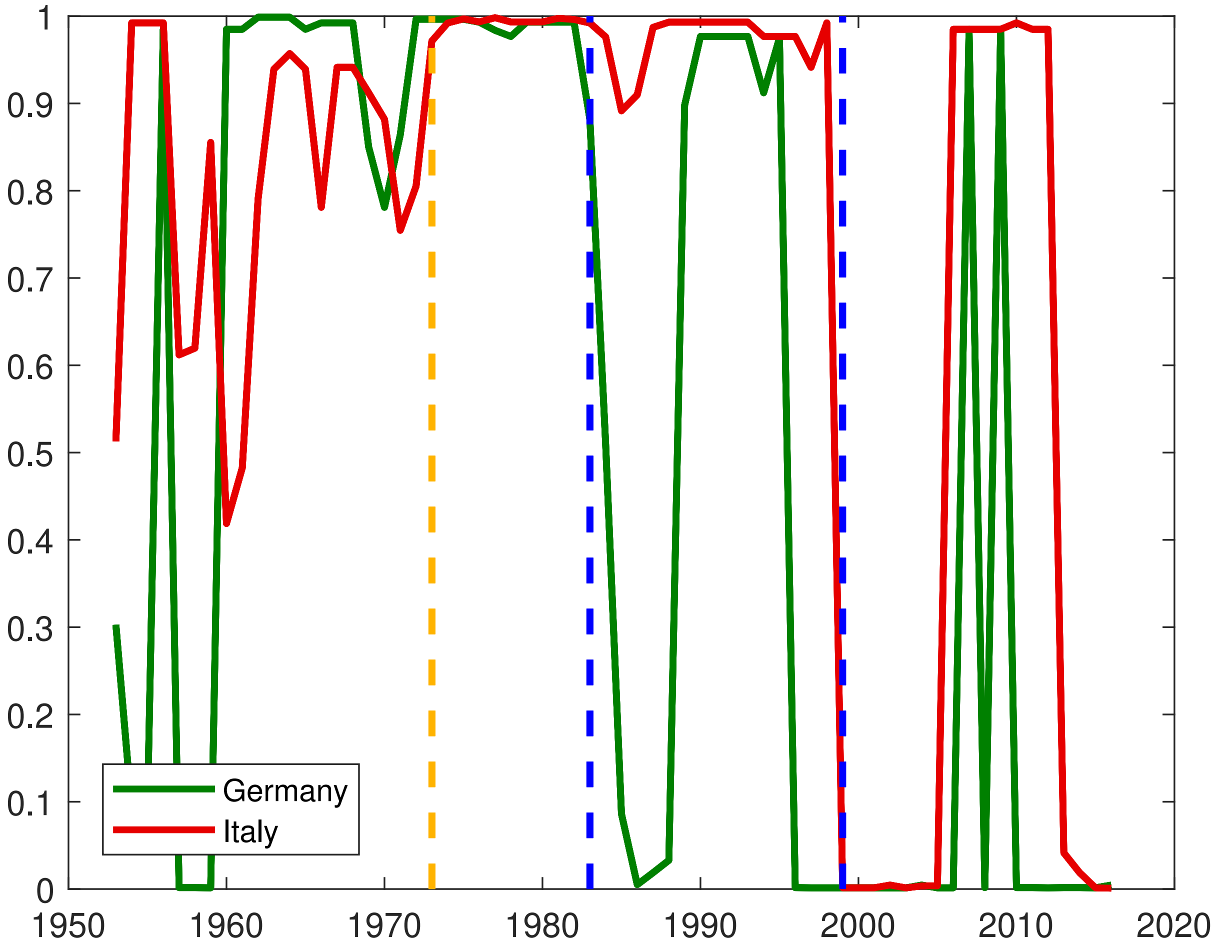
Figure B.1: π_N as a function of the markup in a monetary regime under discretion. The markup is defined as $\frac{1}{\theta}$. High markups correspond to a low elasticity of substitution between intermediate goods, allowing those firms to charge high prices. The dashed blue line corresponds to a trade openness of 35 %, the solid red line of 25% and the dashed yellow line of 30%.

Next consider the estimated probability of acting under discretion for each country between 1950 to the end. In general, the SMM approach prefers to give estimates of the probability that are close to 1 or to 0. The reason for that is, that intermediate values would imply that countries jump often between commitment and discretionary regimes, which would imply too large inflation volatility. Nevertheless a tendency can be clearly seen: Under fixed exchange rate regimes, credibility tends to be larger for both countries, it is particularly large in the currency union. The floating episode between 1971 and 1985 is characterized by higher inflation rates and for both countries, the estimate for credibility implies that both central banks acted more under discretion. Germany regained credibility quicker however, after both countries entered a more fixed exchange rate regime again.

The other figure shows markups and inflation under discretion given the markups.

Last, we show the average inflation value given the average markup for Italy as a function of the probability of acting under discretion. For each percentage point difference in credibility, average inflation changes by 0.14%. This is in line with the empirical estimate that suggests that for each percentage point difference in credibility, the inflation response is 0.12% (0.6/5)

Figure B.2: Estimated probability of acting under discretion (ξ) over time



Notes: Estimated probability of acting under discretion (ξ). The higher the value the more likely is discretionary policy in the model. The vertical dashed lines indicate exchange rate events of Italy according to Ilzetzki et al. (2019). Orange indicates a move towards a more floating regime, blue towards a more fixed regime.

per year when a country decides to peg.

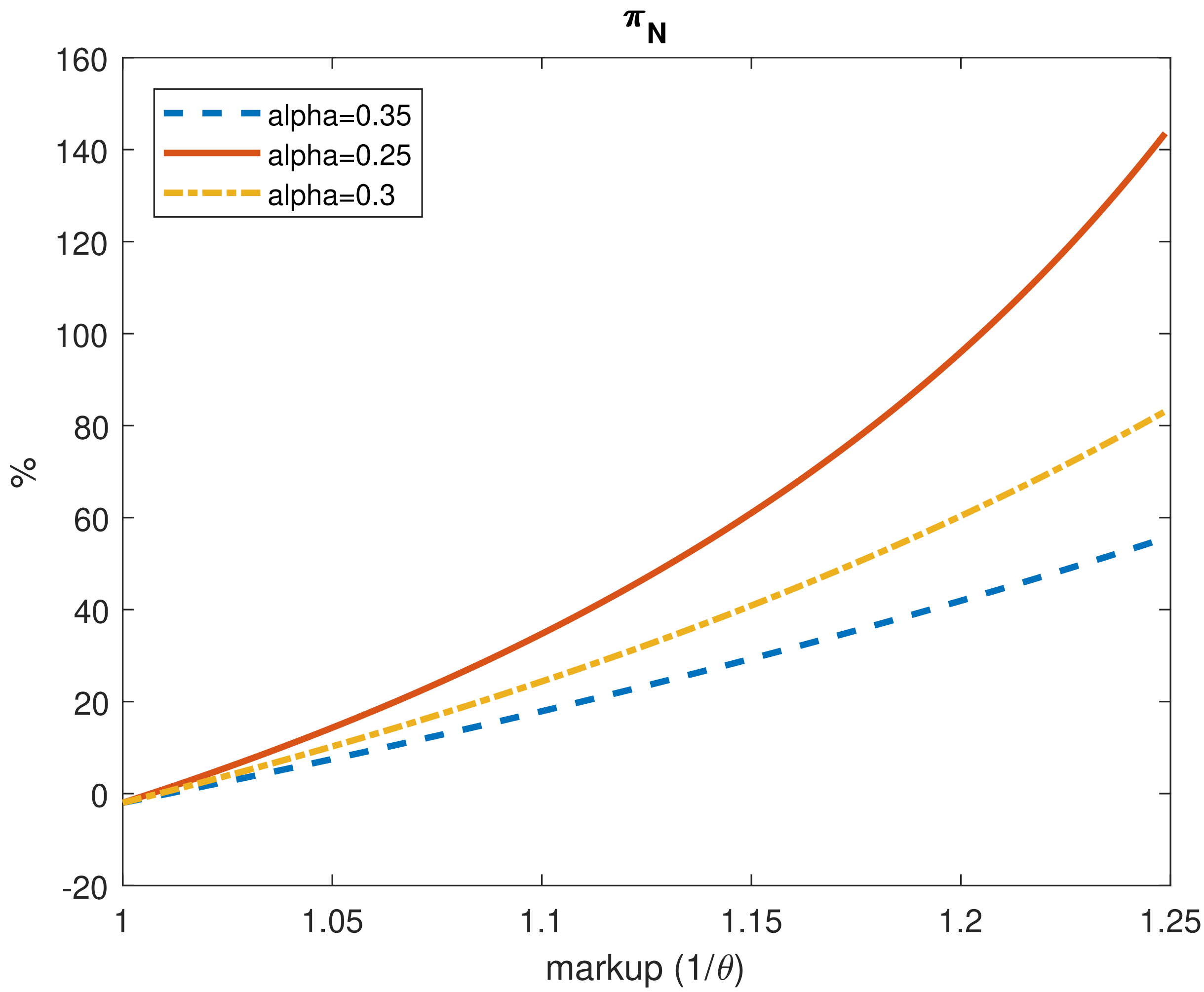


Figure B.3: π_N as a function of the markup in a monetary regime under discretion. The markup is defined as $\frac{1}{\theta}$. High markups correspond to a low elasticity of substitution between intermediate goods, allowing those firms to charge high prices. The dashed blue line corresponds to a trade openness of 35 %, the solid red line of 25% and the dashed yellow line of 30%.

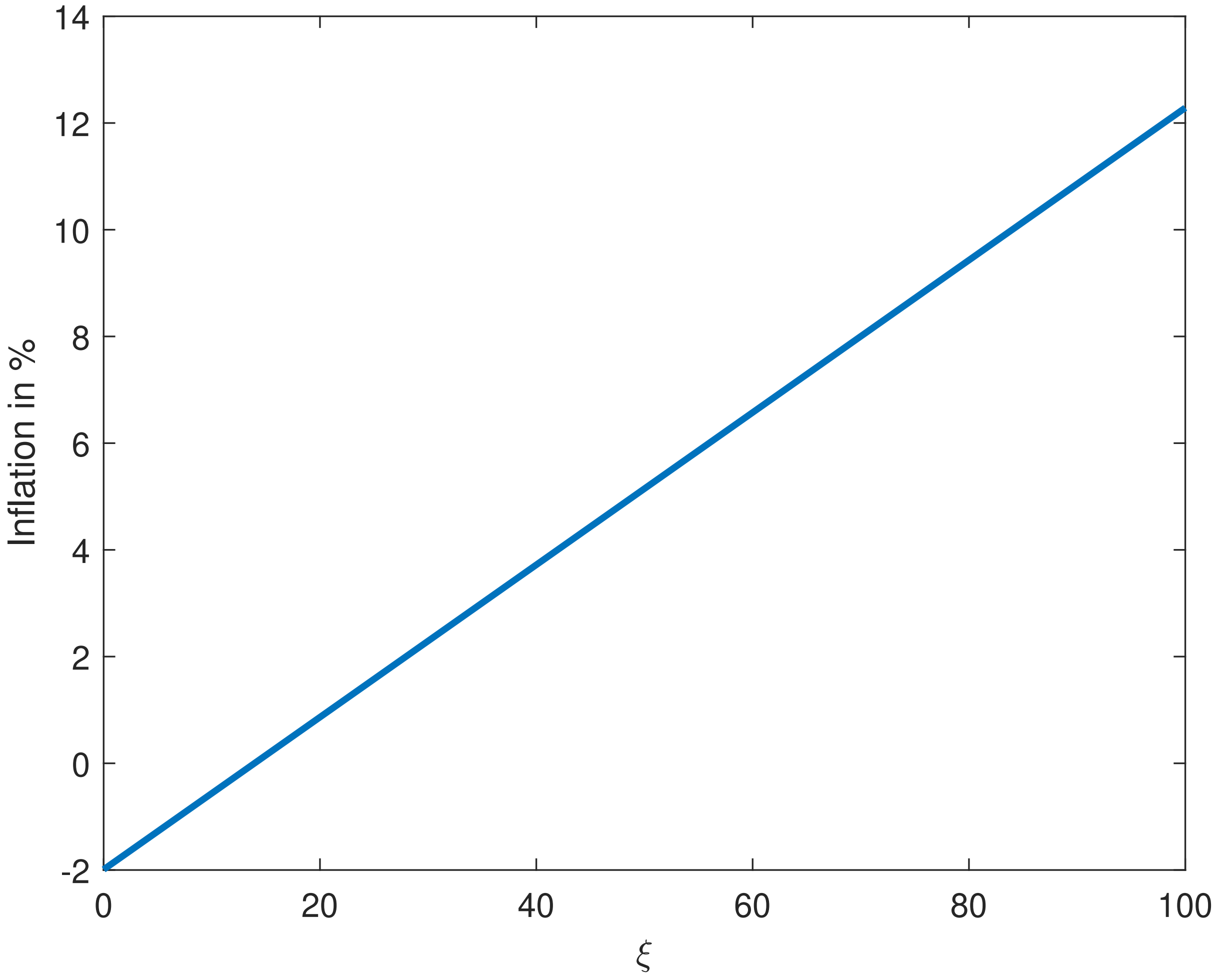


Figure B.4: Average inflation $\xi\pi_N^{fd} + (1-\xi)\pi_N^{fc}$ as a function of the probability of discretion ξ. The average markup of Italy is taken as given.