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The monetary financing of a large fiscal shock[☆]

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ABSTRACT

Motivated by the surge in debt levels through the pandemic crisis, we revisit the issue of the optimal financing of public debt. In contrast to existing results, we find that the optimal response of inflation to a large increase in public spending is a gradual, significant and long-lasting rise in inflation. Our conclusion is due to a different assumption on the source of nominal rigidities. While the literature has focused on sticky prices, of either the Calvo (1983) or Rotemberg (1982) type, we consider sticky plans as in the sticky information set up of Mankiw and Reis (2002). A crucial feature of our results is that a significant inflation response is desirable if the maturity of public debt is (realistically) long.

1. Introduction

The COVID-19 pandemic caused a surge in debt levels in all advanced economies. The health emergency, along with the ensuing economic lockdowns, led to a sharp increase in transfers and public consumption, as well as to a fall in tax revenues. In the euro area, starting from an average level of 86% of GDP at the end of 2019, public debt was expected to exceed 102% of GDP by the end of 2021.[1] The increase in public debt turned out to be smaller than expected, but it was still very large. Actual euro area public debt reached 97% by the end of 2021.

Motivated by these developments, we revisit the issue of the optimal financing of a public expenditure, or transfer, shock.[2] The main policy question is whether it should be financed with higher taxes or, instead, the real value of nominal government debt should be depleted through surprise inflation. We provide an answer based on the standard Ramsey optimal fiscal and monetary policy exercise with noncontingent nominal debt, in the tradition of Chari et al. (1991) under flexible prices, and Benigno and Woodford

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[1] See (European Commission, 2020). The effect of the pandemic crisis on debt levels would have been substantially higher than these forecasts if the public guarantees on private loans had also been included.

[2] Galí (2020) studies a related question. He compares the effects of financing a fiscal stimulus through the issuance of money with those resulting from an increase in public debt. He finds that a money-financed fiscal stimulus has a larger multiplier. See also Bianchi et al. (2020) and Jacobson et al. (2019) for related approaches to the question.

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(2003), Schmitt-Grohé and Uribe (2004) and Siu (2004) under sticky prices. While the sticky-price literature has established that inflation should never be used for this purpose, our analysis suggests that the optimal response of inflation to a large fiscal shock may be substantial.

As shown in Chari et al. (1991), absent costs of price adjustment, inflation can be used to replicate state-contingent real debt, so that taxes do not need to be adjusted in response to public spending shocks. If such shocks are large and frequent, optimal inflation will be very volatile. The literature on optimal fiscal and monetary policy with sticky prices has reversed this result and concluded that using price level surprises to adjust the real value of nominal public debt is too costly, since it inevitably generates very large price dispersion. This is intuitively clear when debt has short maturity, as in Benigno and Woodford (2003), Schmitt-Grohé and Uribe (2004) and Siu (2004), because sudden and very large inflation surprises are necessary to affect the real value of debt. However the result also holds when debt is long-term and the required inflationary changes are smaller, smoother and more persistent — see Lustig et al. (2008), and Faraglia et al. (2013, 2019).

These results are striking, since one would expect that firms would be able to incorporate a fully announced, persistent change in inflation in their pricing decisions in ways that would not induce large price dispersion. However, in the standard (Calvo, 1983) framework, that is not possible. Independently of the policy environment, Calvo firms set a constant price for their goods at random, time-dependent intervals. If inflation is high, they find themselves having to catch up with a drifting price level, which causes prohibitive costs in terms of price dispersion. This is not an intuitively appealing feature of the baseline sticky price model. More importantly, it is not a feature of the data. The high inflation experience of the 1970s showed that many nominal contracts, from rents to wages, can be indexed. Furthermore, using BLS micro-data on U.S. consumer prices dating back to 1977, Nakamura et al. (2018) argue that the Calvo set-up overstates the costs of inflation.[3] No large increase in price dispersion can be detected from the micro-data during the high-inflation episode at the end of the 1970s.

We adopt the sticky information model, introduced by Mankiw and Reis (2002), as an alternative framework. The model still imposes exogenous constraints on the access to information, but it does not impose constraints directly on the setting of prices. As a result, the firms have more flexibility in taking into account changes in inflation trends when setting their prices. In the U.S., the sticky information model has been shown to perform well empirically, possibly better than the Calvo model over the period between 1965 and 2002, which includes the Great Inflation episode (Kiley, 2007). This relative advantage disappears in the more recent period, between 1983 and 2002, when inflation is low. Dupor et al. (2010) also estimate both models over a longer timeframe, from 1960 to 2007, and find them comparable in terms of data fit. Klenow and Willis (2007) show that a sticky information model, in which price setters update information on macro shocks less frequently than information on micro shocks, is able to reconcile two apparently inconsistent facts: prices change at least once a year but nominal macro shocks seem to have real effects lasting well beyond a year. The sticky information model effectively captures the delayed response of individual firms' prices to macroeconomic shocks, which is particularly relevant for the impact of the monetary policy changes that we are focusing on (see Boivin et al. (2009)).

In sharp contrast with the results in the previous literature, we find that the optimal response to a large increase in public spending, such as the one observed through the COVID-19 pandemic, includes a gradual, sizable, and long-lasting rise in inflation.[4] Both sticky information and long-term maturity of debt are crucial assumptions to deliver this result. Sticky information is important because it makes inflationary episodes less costly, the further in advance they are anticipated. The reason is that many firms will be able to incorporate inflation in their pricing decisions, if inflation is pre-announced. However, the credible promise of inflation far in the future is irrelevant to determine the real value of the outstanding public debt, if debt has short-term maturity. The maturity of debt must be (realistically) long for its real value to be affected by surprise changes in future inflation.

We also show that the interaction of price adjustment costs and financing benefits is non monotonic in the maturity of debt. Using inflation to finance fiscal shocks is especially desirable when the maturity of public debt is as observed in the data. If average maturity were lower, the increase in the path of inflation necessary to deplete the real value of debt would have to be less gradual and, consequently, costlier. The optimal response of inflation would be smaller. If average maturity were higher, a smaller inflation increase would suffice to reduce the real value of debt.

Sticky information is not the only model of nominal rigidity competing with the Calvo model. Another possibility is to combine the two models, i.e. to incorporate elements of sticky information into the Calvo model. Dupor et al. (2010) follow this approach and estimate the resulting, "dual stickiness" model. The fit of such model, that is more heavily parameterized, is superior to that of its two building blocks. Kurozumi et al. (2022) estimate a variant of the dual stickiness model over a longer sample. We use their estimates of the probabilities to change prices and update information to explore the implications of the dual stickiness model for the optimal use of inflation to finance a government spending shock. The result is that optimal inflation should be very low, because the dual stickiness model boils down to a Calvo model with additional inertia. The sizable and persistent inflationary response that we find to be optimal in the environment with sticky information would produce too large costs of price dispersion. As we have argued above, those costs are implausible.

An increasing number of studies has recently argued that models with state-dependent pricing are more useful models of price rigidities than the time-dependent models of Calvo (1983) or Rotemberg (1982), especially when inflation is high.— see for example Alvarez et al. (2019). One of the insights of this literature is that, while for small shocks, state-dependent models behave like time-dependent models, if shocks are large, the economy behaves more like the flexible-price benchmark. The reason is that firms will

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[3] See also Alvarez et al. (2019).

[4] It is remarkable that large spending shocks seem to be followed by inflationary episodes. The empirical work on the financing of wars or a pandemic can be found in Ohanian (1997) or Hall and Sargent (2022). Hall and Sargent discuss the financing of the war on Covid in addition to the two World Wars.

want to pay their menu costs to adjust the prices of their goods together with a fast-growing price level. More specifically, standard state-dependent pricing models can deliver the sudden inflation increase recently observed in the euro area after the rise in energy costs (Cavallo et al., 2023). Whether these models would also deliver a large response of inflation to a large fiscal shock is left for future research.

In order to focus on our main point, that the costs of monetary financing of a large fiscal shock may be lower than previously thought, we abstract from a few relevant issues that should be taken into account in a more complete assessment.

First, in our analysis, public debt is available in a single, exogenous maturity, assumed to be equal to the average maturity in the euro area. Angeletos (2002) and Buera and Nicolini (2004) have shown that, with multiple maturities, the government can choose large positive and negative positions in the different-maturity bonds to achieve state-contingent debt. Short-selling constraints would prevent this outcome — Lustig et al. (2008).

Second, we compute the optimal response of both fiscal and monetary policy for the euro area as a whole, but different countries within the area have different debt levels and different maturities. For example, Austria, has an average debt maturity of 10.5 years while the maturity in the euro area is 7.4 years. This means that the policies studied here would have distributional implications across countries. Furthermore, unanticipated inflation also affects the real value of net external debt, that differs widely across countries in the euro area. Our analysis abstracts from these features.

Third, in line with the previous literature, we abstract from the broader distributional effects of these financing policies across households, firms and financial institutions. Private agents with different nominal assets/liabilities and different financial constraints would be affected differently by the state contingency of inflation under the optimal strategy to finance the public debt. Heterogeneous households with financing constraints also alter the incentives for optimal debt management. In an insightful paper, LeGrand and Ragot (2023) show that, depending on the persistence of the spending shock, it may be optimal to give up some tax smoothing benefits and use debt levels to increase the provision of public liquidity. For example, when there is a large positive spending shock, the government would want to increase debt so that liquidity constrained agents can save in government bonds rather than capital, whose level goes down.

Fourth, other options are available to deplete the value of debt without producing costs in terms of price dispersion. An obvious one is default. But default has additional reputational costs. Another possibility is to adjust taxes, other than the labor income tax that we analyze. One could consider using the consumption tax, but it would create intratemporal wedges that would require adjusting labor income taxes as well. In a model with capital, a capital income tax could in theory be used, but its effectiveness would be limited if the tax rate must be capped at 100% of capital income.

Finally, we study the optimal financing of a fiscal shock for given level and duration of the outstanding public debt, and therefore abstract from the optimal maturity choice. Calvo pricing, as in Lustig et al. (2008), would produce a bias towards long maturities because inflation volatility is less costly with long term bonds. In our set up, the optimal maturity would be infinite. With perpetual bonds, the change in inflation necessary to deplete the real value of debt would be very small. Its costs would be minimal. We demonstrate this point through a comparison of the optimal response of inflation to fiscal shocks for different maturities. For very long maturity, the solution is very close to state-contingent debt. This shows that, with sticky information, the bias in Lustig et al. towards long-maturity bonds becomes extreme, and multiple maturities are no longer necessary to achieve state-contingency.

The paper is organized as follows. Section 2 sketches the key model ingredients. Since our framework draws on Benigno and Woodford (2003), we mostly focus on our particular implementation of the sticky information model. We develop an intuition for our main result in Section 3, which shows the optimal policy responses to a temporary government spending shock under different assumptions on firms' pricing and on the duration of government debt. We also show that our results are robust to changes in key model parameters. Section 4 presents our main results regarding the optimal fiscal and monetary policy response to a pandemic-size shock.

2. The model

The model we consider is similar to the one in Benigno and Woodford (2003), with two main differences: the maturity of debt is long rather one period; and the price setting assumptions are the ones in the sticky information framework of Mankiw and Reis (2002) rather than Calvo (1983).[5]

Households. A representative household derives utility from the consumption of a final good, C_t, and disutility from hours worked on each of a continuum of intermediate good firms indexed by k, $H_{k,t}$, with $k \in [0,1]$. The utility function is

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t U_t \left(C_t, H_{k,t} \right). \tag{1}$$

The temporary utility is

$$U_t = \frac{1}{1+\sigma} C_t^{1+\sigma} - \frac{\gamma}{1+\upsilon} \int_0^1 H_{k,t}^{1+\upsilon} \mathrm{d}k. \tag{2}$$

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[5] With sticky information, because firms can adjust price plans, optimal policy does not pin down a single deterministic path for the price level. For this reason, we consider that there is a small number of Calvo-type firms. This allows us to pin down a single deterministic price path in the set of optimal ones.

The period $t \geq 0$ budget constraint of the household is

$$Q_t^B B_t = \left(1 + \rho Q_t^B\right) B_{t-1} + \left(1 - \tau_t^W\right) \int_0^1 W_{k,t} H_{k,t} \mathrm{d}k + \left(1 - \tau_t^{\Pi}\right) \int_0^1 \Pi_{k,t} \mathrm{d}k + T_t - P_t C_t, \tag{3}$$

where B_t are noncontingent, nominal consol bonds issued by the government, Q_t^B is their price, T_t are exogenous lump-sum transfers, P_t is the price of the final good, $W_{k,t}$ is the wage rate of firm k, $\Pi_{k,t}$ are profits from firm k, and τ_t^W and τ_t^{Π} are possibly different income tax rates levied on salaries and profits.

A consol bond issued at t has a geometrically declining coupon ρ^{s-t}, for $s \geq t \geq 0$. In steady state, the Macaulay duration of the bond, i.e. the weighted average duration of its cash flows, can be expressed as MacD $= 1/(1-\beta\rho)$.[6]

Consol bonds with a geometrically declining coupon are often used to approximate the average distribution of a portfolio of long-term bonds in a parsimonious way (see e.g. Woodford (2001)). As we illustrate below, the average duration of government bonds is of the order of many years, hence the frequent assumption of short-term (i.e. 1-quarter) bonds is clearly unrealistic. Nevertheless, the literature on optimal fiscal and monetary policy with sticky prices has shown that long-term bonds do not significantly alter the conclusions of analyses based on short-term bonds. Even if the optimal inflation response tends to be smaller, smoother and more persistent with long-term bonds, inflation remains extremely costly and it is therefore as undesirable for a Ramsey planner as in the case of short-term bonds (see Faraglia et al. (2013)). We will show that this conclusion is starkly different when firms have sticky information.

Firms. There is a continuum of firms indexed by $k \in [0,1]$ producing intermediate goods under monopolistic competition. The intermediate goods are bundled into a final good by a competitive industry.

Final good firms produce a final consumption good Y_t which is the aggregate of intermediate goods $Y_{k,t}$ according to the aggregator

$$Y_t = \left\{ \int_0^1 Y_{k,t}^{\frac{\theta-1}{\theta}} \mathrm{d}k \right\}^{\frac{\theta}{\theta-1}}.$$

We assume that a mass $0 < \delta < 1$ of firms is subject to sticky prices as in Calvo (1983) and the remaining mass $1-\delta$, to sticky information. Accordingly, we can split the production of the composite good into two sub-bundles,

$$Y_t = \left\{ \delta^{\frac{1}{\theta}} Y_{C,t}^{\frac{\theta-1}{\theta}} + (1-\delta)^{\frac{1}{\theta}} Y_{S,t}^{\frac{\theta-1}{\theta}} \right\}^{\frac{\theta}{\theta-1}},$$

where

$$Y_{C,t} = \left\{ \int_0^{\delta} \frac{Y_{k,t}^{\frac{\theta-1}{\theta}}}{\delta^{\frac{1}{\theta}}} \mathrm{d}k \right\}^{\frac{\theta}{\theta-1}} \quad \text{and} \quad Y_{S,t} = \left\{ \int_{\delta}^{1} \frac{Y_{k,t}^{\frac{\theta-1}{\theta}}}{(1-\delta)^{\frac{1}{\theta}}} \mathrm{d}k \right\}^{\frac{\theta}{\theta-1}}.$$

We can then define intermediate price indices $P_{C,t}$ and $P_{S,t}$ as the minimum cost of a unit of the composite sub-aggregates $Y_{C,t}$ and $Y_{S,t}$, respectively. The two price indices are

$$P_{C,t} = \left\{ \frac{\int_0^{\delta} P_{k,t}^{1-\theta} \mathrm{d}k}{\delta} \right\}^{\frac{1}{1-\theta}} \quad \text{and} \quad P_{S,t} = \left\{ \frac{\int_{\delta}^{1} P_{k,t}^{1-\theta} \mathrm{d}k}{1-\delta} \right\}^{\frac{1}{1-\theta}};$$

and the overall price index can be written as

$$P_t = \left\{ \delta P_{C,t}^{1-\theta} + (1-\delta) P_{S,t}^{1-\theta} \right\}^{\frac{1}{1-\theta}}.$$

Intermediate goods are produced according to

$$Y_{k,t} = A_t \left(H_{k,t}\right)^{\frac{1}{\phi}}.$$

The assumed Dixit–Stiglitz preferences imply that the demand for the intermediate good is $Y_{k,t} = \left(\frac{p_{k,t}}{P_t}\right)^{-\theta} Y_t$.

When they have the chance, which happens with probability $1-\alpha_C$, sticky-price firms set a constant price p_t^* so as to maximize expected discounted future profits. When they update their information, with probability $1-\alpha_S$, sticky-information firms pick a sequence of (possibly different) prices, for the current period and all future periods, again with the objective of maximizing expected discounted future profits.

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[6] With the Macaulay duration, for $\rho = 0$, the bond is a zero-coupon bond that pays the principal in the first period and nothing afterwards. For $\rho = 1$, it is a perpetuity of 1.

Government. In every period $t \geq 0$, the real government surplus, s_t, is equal to the revenues from labor and profit taxes minus government expenditure, G_t, and real transfers $t_t = T_t/P_t$:

$$s_t = \tau_t^W \int_0^1 \frac{W_{k,t}}{P_t} H_{k,t} \mathrm{d}k + \tau_t^{\Pi} \int_0^1 \frac{\Pi_{k,t}}{P_t} \mathrm{d}k - G_t - t_t$$

In the paper we focus on the case where $t_t = 0$. This expression can be rewritten as

$$s_t = \gamma C_t^{\sigma} \frac{\tau_t^W - \tau_t^{\Pi}}{1 - \tau_t^W} \left(\frac{Y_t}{A_t} \right)^{1+\omega} d_t + \tau_t^{\Pi} Y_t - G_t,$$

where d_t is a measure of price dispersion, which is given by $d_t = \delta d_{C,t} + (1-\delta) d_{S,t}$, that combines the price dispersion for sticky-price firms ($d_{C,t}$) and sticky-information ($d_{S,t}$) firms, both defined in the online appendix.

Government expenditure and transfers are exogenously given by

$$G_t = \left(1 - \rho_g\right) G + \rho_g G_{t-1} + \sigma_g \varepsilon_t^g$$

where ε_t^g is an i.i.d. shock with zero mean and unit variance.

Given that bonds are long-term, the period-by-period government budget constraint is

$$Q_t^B B_t = \left(1 + \rho Q_t^B\right) B_{t-1} - P_t s_t.$$

The intertemporal budget constraint of the government, for each period $t \geq 0$, can be written as

$$C_t^{-\sigma} \left(1 + \rho Q_t^B\right) \frac{b_{t-1}}{\Pi_t} = \mathrm{E}_t \sum_{T=t}^{\infty} \beta^{T-t} C_T^{-\sigma} s_T,$$

where $b_t \equiv B_t/P_t$ and $\Pi_t = \frac{P_t}{P_{t-1}}$. When $\rho > 0$, corresponding to a duration of debt greater than one quarter, the real value of outstanding debt is decreasing in both current inflation, Π_t, and future inflation, which causes a fall in the price of debt, Q_t^B.

In our numerical simulations we concentrate on the problem of financing a new government expenditure path. We assume that profits are fully taxed, $\tau_t^{\Pi} = 1$, which is the efficient solution for this tax (see Schmitt-Grohé and Uribe (2004).)

Resource constraint. Market clearing in this economy implies that

$$Y_t = C_t + G_t.$$

A (monopolistic) competitive equilibrium is a sequence of quantities, prices and policies that (i) solve the problem of the household, maximizing utility subject to the budget constraint given prices, (ii) solve the problem of the monopolistic competitive firms, (iii) satisfy the budget constraint of the government, and (iv) satisfy the market clearing conditions.

Ramsey policy. The Ramsey solution is the competitive equilibrium that maximizes utility for the representative household, (1), from the perspective of period $t = 0$. The Ramsey plan requires commitment because it is time dependent. Given the choice to reoptimize at a future date $t > 0$, the planner would not select the continuation of the plan chosen at $t = 0$. To obtain policies that are time consistent, we follow Woodford's timeless perspective (see Woodford (2003)). We select the optimal policy that the Ramsey planner would be willing to follow asymptotically, provided the time dependence of the Ramsey solution vanishes (which is the case in the economy we analyze).

As in Benigno and Woodford (2003) and Schmitt-Grohé and Uribe (2004), we analyze the response to shocks around a non-stochastic steady state in which the outstanding level of government debt is given and inflation is equal to zero.[7] By construction, therefore, we ignore any stochastic, nonlinear effects which may be produced in equilibrium in our model economy. Siu (2004) demonstrates that such effects can be sizeable if the variance of government spending shocks is large, i.e. as large as in war-time periods. However, we think that this was not the situation at the onset of the pandemic. We assume that pandemic-like shocks are a black swan. The conditional variance of government spending will therefore return to relatively low, post-WWII levels. Our question is how to respond to exceptionally large shocks in an environment where such shocks are very unlikely to occur going forward.

3. Sticky prices vs. sticky information

3.1. Solution and calibration

In our numerical exercises, we abstract from the underlying reasons for the increase in the government deficit. We simply assume an exogenous increase in government spending and focus on its financing.[8]

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[7] As in the rest of this literature, we take the average maturity of the public debt as given. A related literature has studied optimal debt management — see e.g. Angeletos (2002), Buera and Nicolini (2004), Lustig et al. (2008), Faraglia et al. (2019).

[8] The results would be similar, but not identical, if we assumed instead an increase in government transfers. The responses of taxes to the two shocks are different under flexible prices, and therefore they would also be different with nominal rigidities. For the separable and isoelastic preferences that we consider, which are also the ones in Benigno and Woodford (2003), uniform taxation is optimal in response to a government consumption shock, while it is not optimal in response to a shock in government transfers. The reason is that the Ramsey planner, in the case of transfers, is able to affect directly the value of the time varying transfers, relaxing the financing problem.

It is well-known that the sticky information Phillips curve has an infinite state-space representation, because it includes an infinite sum of lagged expectations. This feature is challenging for numerical solution methods. Meyer-Gohde (2010) proposes an efficient solution algorithm suitable for the linearized model. Since we jointly solve for optimal fiscal and monetary policy, we focus on model deviations around a distorted steady-state and must work with the non-linear version of the model.

Our solution strategy is similar to that pursued in Trabandt (2007). For each lagged expectation term, we define a dummy variable. The infinite sum of lagged expectations is then approximated up to a truncation point. This is the number of lagged expectations such that impulse responses do not change significantly when additional lags are taken into account. Trabandt (2007) finds that including up to 20 lags of expectations delivers an accurate solution for a version of the model solved under a Taylor rule for monetary policy. In our case, we find that the truncation point must be higher. Our results below are based on 45 lagged expectations.

The optimal Ramsey plan from a timeless perspective can be implemented through a time-invariant rule (Benigno and Woodford, 2003). The first order conditions can therefore be derived in a time-invariant form. We compute them using an algorithm that relies on analytical derivatives. Impulse responses to fiscal shocks under optimal policy are based on a first-order approximation of the solution.

For most parameters, we rely on the calibration in Benigno and Woodford (2003). The parameters are standard and they facilitate the comparison to the previous analyses in the literature with sticky prices. The main exception is the rate of time preference β. Standard calibrations in the literature are consistent with a steady state real interest rate of 4%. This value was reasonable in the 80s and 90s, but real interest rates on public debt have been much lower in recent decades. Estimates of the natural rate of interest find that it is equal to or even lower than 1%.[9] We therefore set $\beta = 0.9975$, corresponding to a steady state real interest rate of 1%.

The level and maturity of the initial nominal liabilities of the government are estimated using euro area data. A relatively small part of such liabilities are inflation-linked bonds that have to be excluded from the total debt level. We also take into account the impact of QE-type programmes on the average maturity.[10]

More specifically, regarding the debt stock, we start again from (European Commission, 2020), where it is reported that the debt-to-GDP ratio in the euro area at the end of 2019 was 85.7%. Since inflation-linked securities amounted to approximately 5% of GDP (see Bańkowski et al. (2023)), we calibrate the initial stock of government debt at 80% of GDP.

The average maturity of debt across euro area countries is obtained from the ECB's Centralized Securities Database (CSDB), which holds information on all individual securities relevant for the statistical purposes of the European System of Central Banks.[11] The data we use are taken from ECB (2020).[12] We start from country-level data on the average residual maturity of the outstanding debt and obtain the euro area average residual maturity as a weighted average across countries, with weights given by the value of each country's debt as a fraction of total euro area debt. This yields an average residual maturity of 7.4 years. We then consolidate the liabilities of the public sector (governments and central bank), i.e. take into account the impact of ECB bond purchases, and find that their average maturity ranges between approximately 4 and 9 years across euro area countries.[13] Finally, we obtain euro area data as a weighted average of the national maturities, with weights given by national public debts as a fraction of euro area public debt. The result is an average maturity of total public liabilities in the euro area of 5.8 years.

Finally, we need to calibrate the degree of price stickiness, α_C, and information stickiness, α_S. For price stickiness we use as benchmark the degree of price stickiness in Benigno and Woodford (2003), $\alpha_C = 0.635$. For the degree of information stickiness, many estimates for the U.S. are consistent with relatively high values of α_S, around 0.75.[14] In an estimated model, Reis (2009) finds values of 0.48 for the U.S. and 0.42 for the euro area. These values are consistent with the estimates for different euro area countries in Döpke et al. (2008). They report values for Germany and France, between 0.7 and 0.85, and values for Italy close to the low estimates of Reis (2009). In the paper, we use $\alpha_S = 0.75$ as the benchmark, but also report results for $\alpha_S = 0.42$.

We also consider the estimates in the dual model of Dupor et al. (2010) and Kurozumi et al. (2022), with both price and information stickiness. Dupor et al. (2010) estimate the price stickiness parameter to be 0.86 and the information stickiness parameter to be 0.58. Kurozumi et al. (2022) obtain lower estimates. They distinguish between the period of the Great Inflation and the subsequent period. For the first period, the probability of no price change is 0.57 and the probability of no information update is 0.52. The estimates translate into time varying probabilities in a Calvo model. On impact, in response to a shock, the probability

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[9] See for example Holston et al. (2017).

[10] Hilscher et al. (2022) perform a related exercise for the U.S. in which they assess the likelihood of future inflation eroding the real value of current debt. They also exclude TIPS.

[11] The data is for the maturity of debt, not for duration, since there is limited data on duration for the euro area. Because the measure of duration is for a coupon bond and the measure of maturity is for a zero coupon bond, the difference between the two can be sizable, as shown by Hilscher et al. (2022) for the U.S. We checked the difference in the data for maturity and duration for the four largest economies in the euro area and the difference is small.

[12] The information from this source may be different from the government finance statistics, partly because it is not consolidated within the general government sector, partly due to discrepancies in valuation, scope (e.g. bonds without an ISIN are not included in ECB (2020)), sectoral classification and time of recording.

[13] Central bank purchases result in a shortening of the maturity of the total public liabilities held by the private sector, since they are a swap of overnight reserves against long-term debt. We therefore use information on quantities and average maturity of ECB government bond holdings from the ECB web-page – see https://www.ecb.europa.eu/mopo/implement/app/html/index.en.html – and proceed as follows. First, we estimate in each country i the average maturity of the remaining government debt in private hands m_i^P (in years) as $m_i^P = \frac{B_i m_i^B - B_i^C m_i^C}{B_i - B_i^C}$, where B is the total stock of government debt, m_i^B is its average maturity, B_i^C is the government debt purchased by the ECB, and m_i^C is its average maturity. We then impute to central bank reserves a maturity of zero, because reserves are overnight. Since the amount of ECB reserves held by the private sector is equal to B_i^C, the average maturity of the total public liabilities in private hands, m_i^T, can be estimated as $m_i^T = \frac{B_i^C}{B_i} \cdot 0 + \frac{B_i - B_i^C}{B_i} \cdot m_i^P$.

[14] Khan and Zhu (2006) obtain an average estimate of 0.76. Similar values are found in Mankiw and Reis (2002) and Carroll (2003), 0.75 and 0.73 respectively.

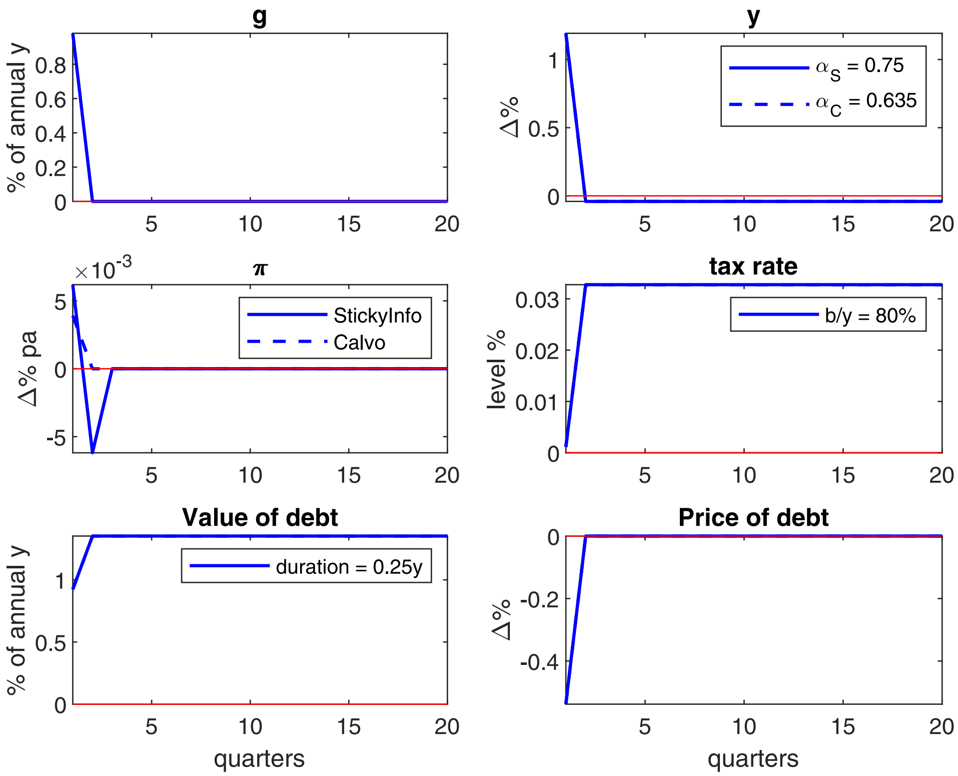

Fig. 1. Optimal responses with short-term bonds: sticky information vs sticky prices.
Legend: "b/y" denotes the initial amount of government debt, as a ratio of annual GDP; "duration" is the average duration of government bonds, in years. The price of debt is Q_t^B and the value of debt is $Q_t^B B_t$.

of price change with information updating is low, but it increases over time eventually converging to the Calvo probability. This means that, for the Great Inflation period, on impact, the corresponding Calvo probability of no price change would be 0.79, and that it converges to 0.57. We compute the optimal policy for the two extreme values of 0.79 and 0.57.

3.2. Short-term vs. long-term bonds

It is well known that, under flexible prices, inflation can be used, in response to shocks, to adjust the real value of government debt, replicating state-contingent real debt and avoiding changes in taxes — see Chari et al. (1991). If bonds have short maturity, the required price changes in reaction to public finance shocks tend to be large. When prices are sticky, large changes in prices are costly. Schmitt-Grohé and Uribe (2004) and Benigno and Woodford (2003) show that the optimal combination of fiscal and monetary policy is to keep prices almost unchanged in reaction to shocks.

Fig. 1 confirms these results for the sticky-price case. A one quarter increase in government spending equal to 1% of annual GDP is reflected in a permanent increase in public debt of a comparable size (in percent of GDP). Inflation increases for one quarter, but the increase is tiny. The tax rate must therefore increase to finance the larger debt.

Fig. 1 compares these results to the sticky information case and shows that they are almost identical. The only qualitative difference is that the price level returns to the original value under sticky information.[15] Inflation must be negative in the second quarter after the shock, before returning to zero. This ensures that all firms which did not have an opportunity to change their prices one or two quarters after the shock will automatically choose the optimal price. As in the sticky price case, however, the tax rate must increase to finance the higher public debt.

Fig. 2 shows the same comparison in the case of long-term bonds. Under sticky prices, the results on inflation are essentially unchanged. Once again the tax rate must rise to finance the larger stock of private debt, but the rise can be smaller, because the fall in the bond price reduces the value of the outstanding government debt.

Results are quite different with sticky information. Inflation is still kept constant on impact, but it slowly and progressively increases to reach a peak of 20 basis points after approximately 8 years. The inflation increase is not too costly in terms of price

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[15] In the case of sticky prices, the price level goes up on impact and stays up. Firms that have raised prices initially lower them when they get the chance and firms that were not able to change the price initially, raise it when they get the chance. The combined effect is to have zero inflation after the first period.

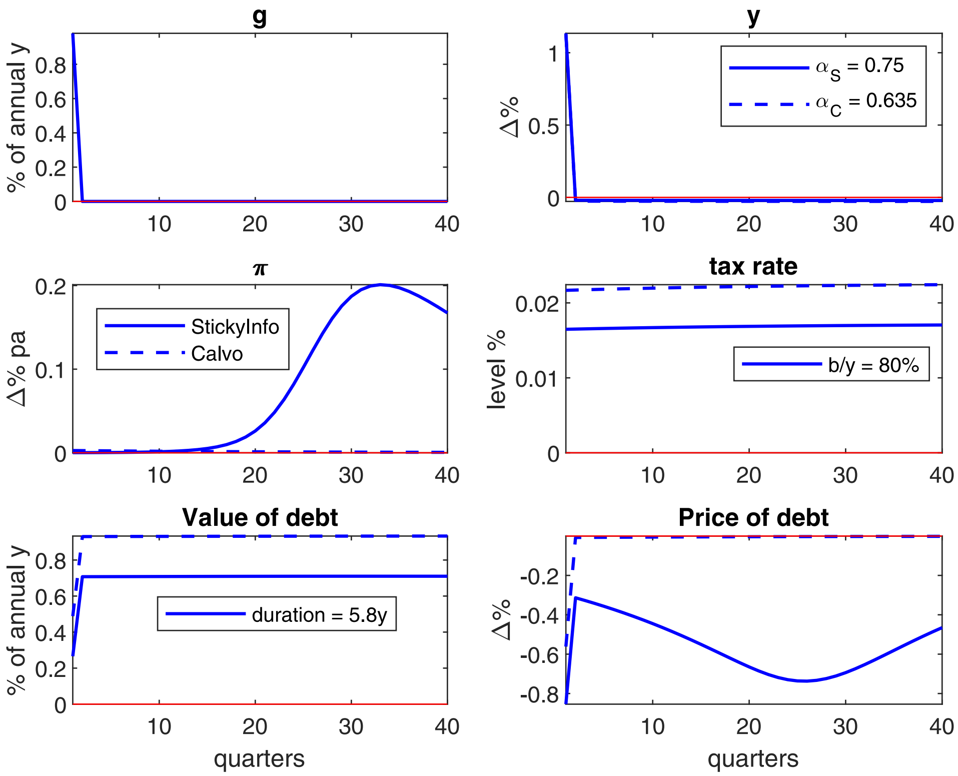

Fig. 2. Optimal responses with long-term bonds: sticky information vs sticky prices. Legend: see Fig. 1.

dispersion. Due to its preannounced nature, all firms that do not have the opportunity to adjust their information in the first three years after the shock will nevertheless have a near-optimal price, given that the price level remains unchanged. Thereafter most firms will have the chance to revise their information, hence price dispersion will remain contained.

Of course these considerations are also valid when bonds are short term, but an increase in future inflation would not change the real value of short-term debt. In contrast, future inflation is effective in replicating state contingent real debt when bonds have long maturities. The benefits of this policy coupled with its limited cost in terms of price dispersion explain why it is optimal to let inflation increase. The key benefit is that inflation reduces the price of public debt. As a result, the real value of public debt, whose quantity must increase to finance the larger government spending, increases by less than in the Calvo case. Consequently, the tax rate increases by a smaller amount than in the case with sticky prices.

Fig. 3 provides some intuition as to why sticky information generates different results from sticky prices. It displays the overall price level together with the individual prices set by firms that have the opportunity to revise them zero, twenty and twenty four quarters after the shock.

Under sticky information, firms that have an early opportunity to reoptimize their prices after the shock will not only set current prices differently from other firms, but they will also fully take into account the expected dynamics of the price level in their future pricing plans. As more and more firms update their information over time, all individual prices will become consistent with the evolution of the price level. Consequently, price dispersion will quickly be reabsorbed and the inflationary episode will not generate large productive inefficiencies.

In the Calvo case, price dispersion will also emerge as soon as some firms have the opportunity to reset their prices. Even if they know that the price level will continue increasing in the future, these firms must set a constant price for the whole time period over which they expect to be unable to re-optimize. As a result, they will choose reset prices that temporarily overshoot the price level. Price dispersion will be much more persistent and the inflationary episode will be very costly.

3.3. The role of information stickiness and bond maturity

Fig. 2 is derived under a benchmark calibration of the probability to adjust prices or to make new price plans. Under sticky prices, this probability is of little importance in determining optimal policy. As highlighted by Schmitt-Grohé and Uribe (2004), even a small probability that firms will be unable to change prices is sufficient to make price stability desirable at all times.

With sticky information, inflation must increase earlier, the higher the frequency at which firms update their information. Fig. 4 shows results for two values of the probability of not adjusting information, α_S: the benchmark value of 0.75 and the value estimated

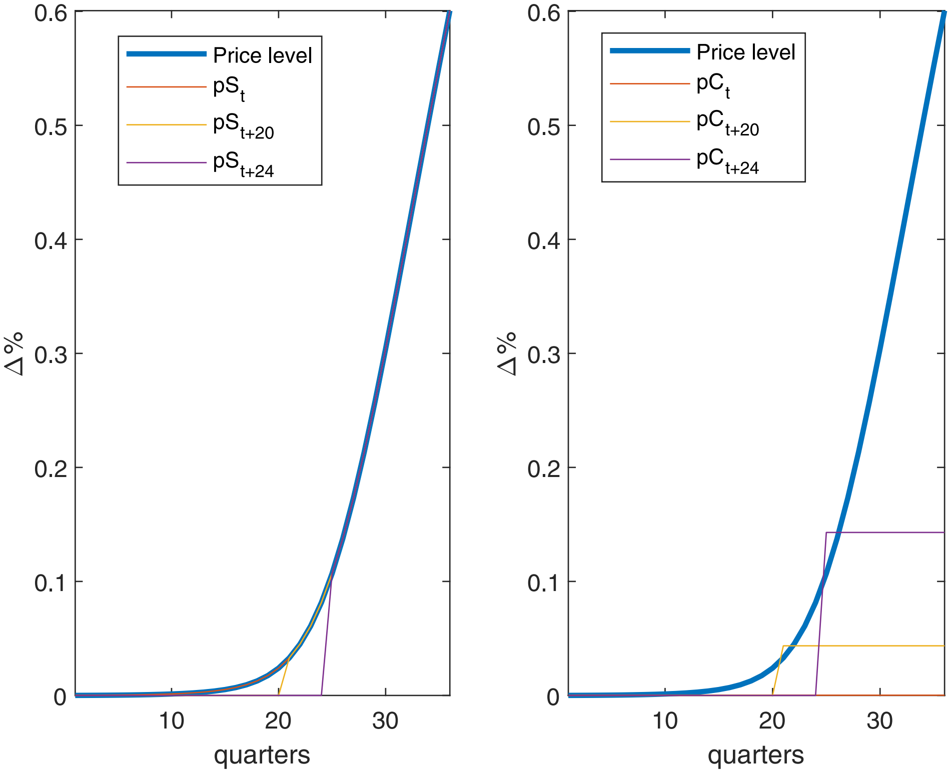

Fig. 3. Optimal price paths for sticky-price and sticky-information firms.
Legend: "Price level" is the optimal path of the price level after the same government spending shock as in Figs. 1 and 2 in an economy with sticky information firms; "pS$_t$", "pS$_{t+20}$" and "pS$_{t+24}$ " denote the reset prices selected by the firms that have a chance to update their information 0, 20 and 24 quarters after the shock; "pC$_t$", "pC$_{t+20}$" and "pC$_{t+24}$" are the reset prices that would be selected in the same economy by sticky price firms having the chance to reset their prices 0, 20 and 24 quarters after the shock.

by Reis (2009) for the euro area (0.42). In the latter case, the increase in government spending can be financed with a much smaller increase in the tax rate. The reason is that an earlier and larger increase in inflation is less costly, because many firms will update their information accordingly and price dispersion will remain low. Compared to this case, the benchmark calibration ($\alpha_S = 0.75$) makes it desirable to delay the inflationary episode, so as to give more firms the chance to update their information. However, a large and sufficiently delayed inflation increase would be less effective for financing purposes, because a large fraction of the outstanding debt would have been retired. The inflation peak is therefore more delayed, but lower.

This result is affected by the maturity of the outstanding public debt. The announced inflation increase can only affect the real value of debt if its maturity is sufficiently long. The stickier information, the longer the required maturity of public debt to make a delayed inflationary episode desirable.

The link between optimal policy and the maturity of outstanding debt is explored in Fig. 5. We report results in four cases: the benchmark corresponding to the average duration of euro area government bonds held by the private sector (5.8 years); a higher average duration, which would be observed in the absence of central bank purchases of sovereign bonds (7.4 years); an arbitrarily lower value (4 years); and a very high one (35 years). The figure shows that the optimal fiscal and monetary policy responses to the shock are not monotonic in the maturity of debt.

Compared to the benchmark, a lower debt duration (4 years) leads to a reduced use of inflation for debt financing. The reason is that the inflation surprise necessary to finance the fiscal shock would have to be very high and very abrupt. These two features would make inflation more costly in terms of price dispersion. There is the need for a higher tax increase.

A moderately higher debt duration (7.4 years) than the benchmark increases the optimal use of inflation for debt financing. The increase in inflation can be pushed further away into the future. This makes it less costly, because more firms have the chance to reset their price plans before the price level increase. A smaller tax hike is sufficient to finance a given fiscal shock.

Results change for a much higher debt duration (35 years). Inflation can be pushed further away in the future, so that its peak occurs later. In this case, inflation is so effective, that even if it is not very costly, it is not used much. A much smaller inflation increase is sufficient to finance the fiscal shock, at an almost unchanged tax rate.

In summary, in a framework with information stickiness, inflation should be used for debt financing purposes especially when the average maturity of public debt is around the levels observed in reality. For a shorter maturity, inflation would be used less because it would be more costly, while for a longer maturity, inflation would be used less because it would be very effective. In

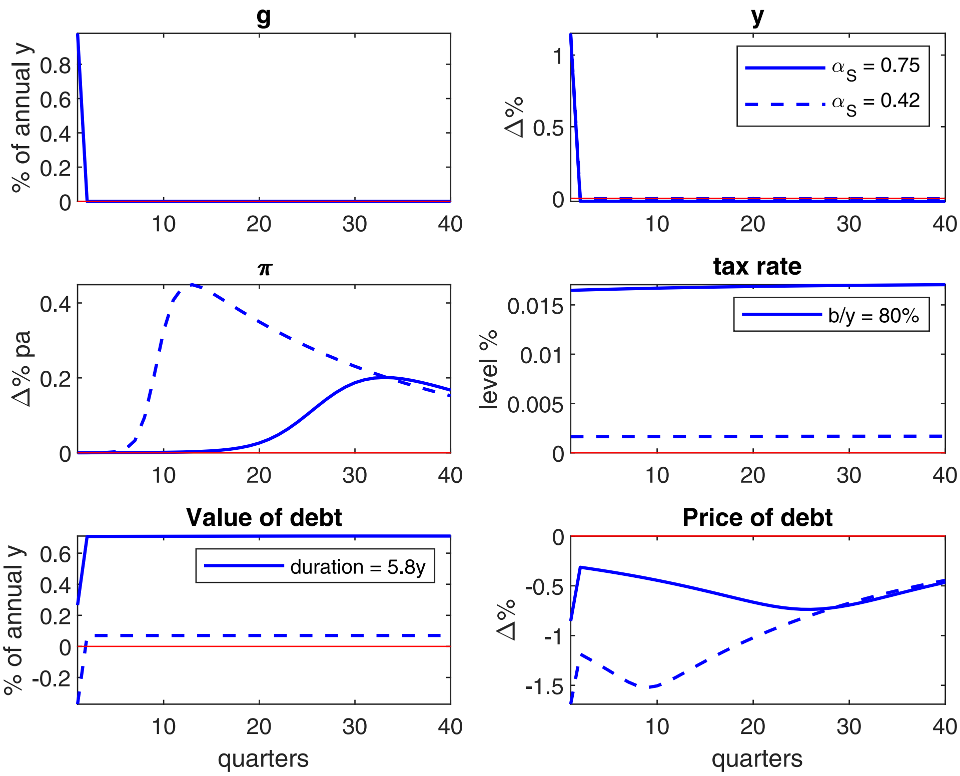

Fig. 4. Optimal responses with long-term bonds: varying the stickiness of information. Legend: see Fig. 1.

the realistic case, inflation is neither very effective (in terms of achieving the required debt devaluation) nor very costly (in terms of generating price dispersion).

Endogenous maturity. Our interest in this paper is to study the optimal financing of a fiscal shock, given observed level and duration of the outstanding public debt. The reason is that the outstanding public debt was a state variable when the COVID shock occurred. Governments did not have the option to change it ex post. In other words, the optimal choice of maturity is an ex-ante decision, which we want to take as given. Changing the maturity ex-post, after the shock occurred, would not help its financing.

The most useful reference for the optimal maturity structure in a similar set up to ours is Lustig et al. (2008). They consider multiple maturities with short selling constraints and impose Calvo pricing. As shown in Angeletos (2002) or Buera and Nicolini (2004), in this case the government can hold large positive and negative positions in the different maturity bonds to achieve state-contingent debt. Lustig et al. (2008) impose short-selling constraints so that the capacity to replicate state-contingent debt without using inflation volatility is limited. With Calvo pricing, the optimal maturity structure is biased towards long maturities, since the volatility of inflation is less costly with long term bonds.

In our set up with a single maturity, the optimal duration would be infinite. With an infinite duration, the change in inflation necessary to adjust the real value of debt is very small and can be fully smoothed out. The costs in terms of price dispersion are minimal. The features of this limiting case are already apparent in Fig. 5 when looking at impulse responses for debt duration equal to 35 years. The solution is quite close to state contingent debt. The fiscal shock can be financed with a small inflation increase and almost no tax changes. The case of state-contingent debt would be reached in the limit of infinite debt duration. This result implies that once we deviate from Calvo pricing, and use the alternative sticky information structure, there is a full bias towards an infinite maturity, and the multiple maturities in Lustig et al. (2008) are unnecessary to help replicate state-contingent debt.

This result, of an optimal infinite duration, should be interpreted with caution. There are reasons, not taken into account in our model, to shorten the maturity. One of those reasons is the provision of liquidity.

3.4. Sticky prices plus sticky information

Sticky information has been added to models of sticky prices of the Calvo (1983) type to induce inertia. Here, we compute bounds on the optimal policy implied by the estimated dual stickiness models of and Dupor et al. (2010) and Kurozumi et al. (2022).[16] These

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[16] We thank the referee for suggesting this exercise.

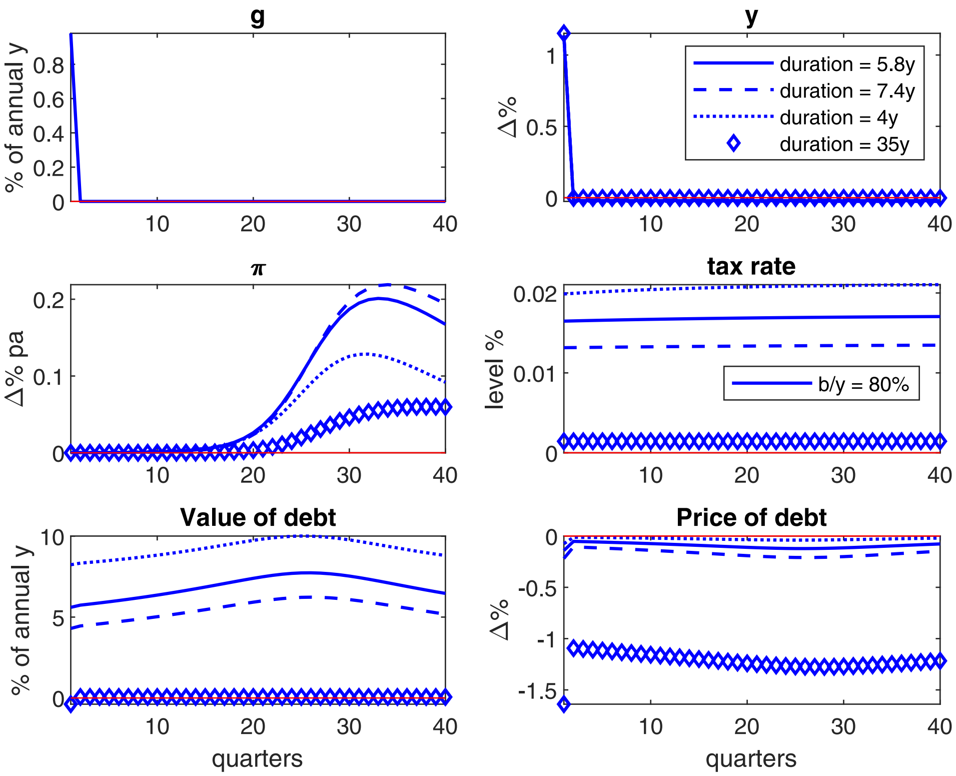

Fig. 5. Optimal responses under sticky information for different bond maturities. Legend: see Fig. 1.

papers estimate a model in which firms face both Calvo price setting restrictions and Mankiw-Reis sticky information restrictions. When firms are able to adjust the price in response to a shock, they may not have updated the information that includes the shock, in which case they will not make any adjustment. As time passes since the shock, the probability that they will have updated the information increases. The model with both restrictions amounts to a Calvo model with a lot more inertia. The probability of price adjustment is very low initially (the product of the two probabilities), but it increases fast towards the Calvo probability (once all firms have updated their information). The estimates of Kurozumi et al. (2022), for the period of the Great Inflation, are of a Calvo probability of no price change of 0.57 and a Mankiw-Reis probability of 0.52. In response to a shock, the probability of no price change is 0.79 on impact and converges fast to 0.57.

We compute the optimal policies under the lowest and the highest probability of no price change, 0.57 and 0.79 — see Fig. 6. The optimal response of inflation is very low in both cases. The reason is that price dispersion associated with persistently high inflation is very high in the Calvo model. This implies that the dual stickiness model inherits the limitations of the Calvo model. It produces a counterfactually high degree of price dispersion when inflation is high.

Dupor et al. (2010) also estimate the standard Mankiw–Reis model. Not surprisingly given its tighter parameterization, the fit of this model is inferior to that of the dual stickiness model. Nevertheless, we believe that the Mankiw–Reis model is better suited to answer the question we study in this paper. We do not claim that the model is unconditionally superior to existing alternatives. But we do believe that it is more useful to analyze the particular sort of shock that may justify a persistent deviation of inflation from target. The deviation would be intended and announced, hence akin to a temporary revision of the target. The lack of evidence of higher price dispersion during the Great Inflation period is a very compelling argument in favor of using the sticky information model rather than the standard sticky price model.

4. Optimal fiscal and monetary policy after a pandemic-size shock

This section provides illustrative results on the combination of fiscal and monetary policy which, according to our model, would be desirable in the euro area after the large increase in public spending caused by the pandemic shock. We rely on European Commission estimates of the effects of the shock. As already mentioned in the introduction, the Autumn 2020 European Economic Forecast predicted an increase in government deficits approximately equal to 16% of GDP over the 2020–2022 period. The actual increase turned out to be smaller, i.e. approximately equal to 11%. Here we provide results for an intermediate shock size, equal

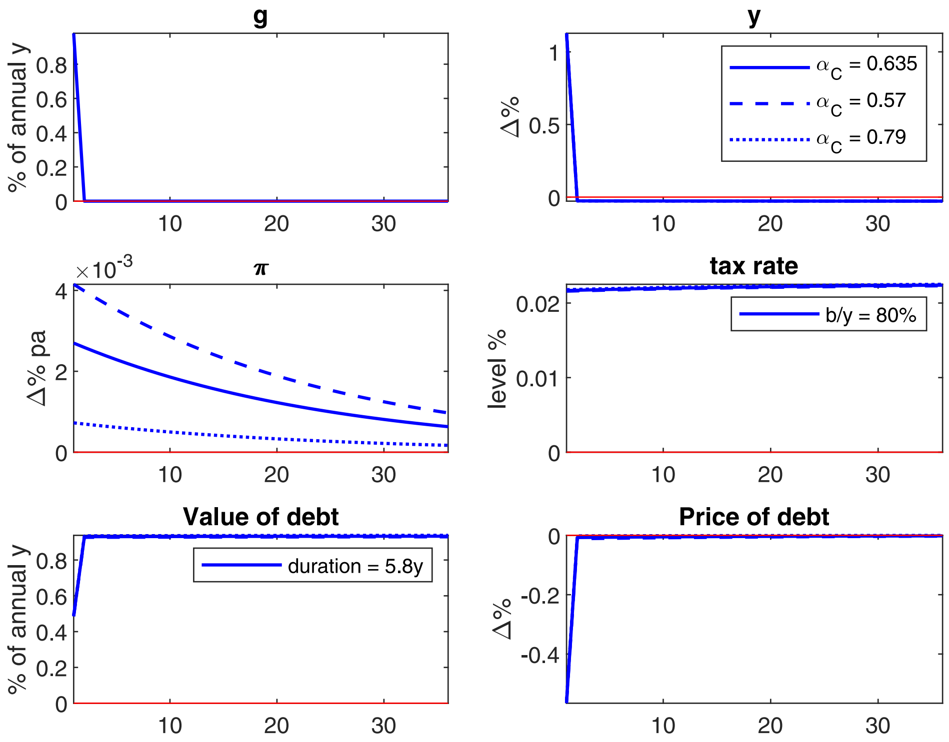

Fig. 6. The mixed sticky price & sticky information model. Legend: see Fig. 1.

to 15% of GDP.[17] All other parameters are kept at the benchmark levels discussed above.[18] The online appendix shows that, using the lower stickiness estimate of α_S for the euro area in Reis (2009), would lead to qualitatively similar conclusions.

The results are displayed in Fig. 7 together with the flexible price and the Calvo cases. The flexible price case is presented as a useful benchmark for comparison.[19] An inflation surprise occurs in reaction to the government spending shock to ensure that taxes remain constant. This is consistent with the analysis in Chari and Kehoe (1999), but the inflation surprise is smaller and much more persistent due to our assumption of long-term government debt. Inflation increases on impact by about 5% and remains at elevated levels for many years. This increase is non-negligible, but much smaller than what would be necessary if all bonds were short-term. Again, as in Chari and Kehoe (1999), unexpected inflation variations implement the same allocation of resources as with fully state-contingent public debt.

Under nominal rigidities of the Calvo type, the price level, government debt and the tax rate all have unit roots, consistent with the results of the models with short-term government debt in Benigno and Woodford (2003) and Schmitt-Grohé and Uribe (2004). Inflation is so costly that it is kept almost unchanged (and the price level moves very little, even if permanently). Consequently, the increase in government deficits is reflected in an essentially one-to-one increase in government debt, as a share of GDP. To service the cost of the debt, tax rates must increase permanently. In spite of the low level of real rates, they go up by about 0.35 percentage points. This is reflected in a permanent output loss of about 0.2% in steady state.

Sticky information produces intermediate results between the two cases above. Inflation is initially kept unchanged as in the sticky price case, but it increases quite substantially around three years after the shock up to a peak of roughly 3%. The inflation increase is temporary, but persistent, and it leads to a lower increase in the real value of debt, compared to the sticky price case. The debt to GDP ratio increases by almost 11 percentage points in steady state, compared to more than 14 percentage points in the Calvo case. Consequently, the permanent increase in the tax rate is smaller, i.e. equal to 0.25 percentage points. The permanent output loss is also somewhat smaller.

Fig. 8 focuses on the response of inflation to the shock of Fig. 7, to clarify its level and persistence. Impulse responses are displayed over a period of 25 years, rather than the 40 quarters shown in the previous figures. The most striking feature emerging from this figure is that the increase in inflation must be extremely persistent. In the sticky information case, ten years after the initial shock, inflation is still around 3%, and even twenty years after the shock it is not far below 1%. This very persistent response

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[17] More specifically, we assume that the initial shock is 3.75 times as large as in previous figures and it has a persistence of 0.76.

[18] More specifically, all other parameters are as in Fig. 2.

[19] For reasons of determinacy of the path of prices, the economy with flexible prices has a very small number of sticky information firms and a large number of Calvo firms with a probability of changing prices close to one.

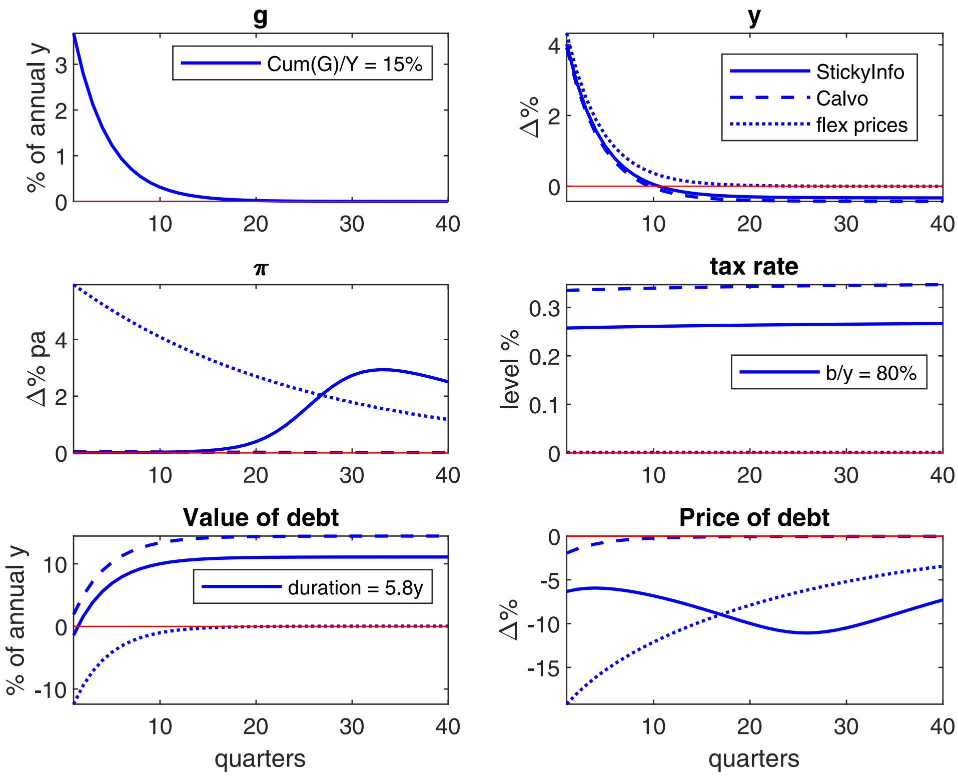

Fig. 7. Optimal responses to a pandemic-size increase in G.
Legend: see Fig. 1. "Cum(G)/Y" denotes the cumulated increase in government spending as a ratio of annual GDP.

ensures a smooth return to price stability. A pre-announced period of inflation has a low cost in the model, because, being known in advance, it can be reflected in the price plans of most firms.

5. Concluding remarks

The COVID-19 pandemic caused a surge of public debt levels that is likely to be long lasting. Given the nominal denomination of public debt, it is worth considering whether a temporary inflation increase may be preferable to permanently higher taxes. To analyze this, we have reexamined the conclusions of the literature on the optimal financing of government spending.

The research in this field has captured the costs of inflation through the assumption of sticky prices of the Calvo (1983) type. It has concluded that even mild inflation episodes are extremely costly, because they force many firms to persistently sell their goods at 'wrong' prices — that is, at prices that they would change, if they had the opportunity to do so. We have instead adopted the assumption of sticky information (Mankiw and Reis, 2002), which is arguably better suited to capture firms' responses to infrequent, aggregate shocks, as opposed to firm-specific shocks. In sharp contrast with the results of the previous literature, we find that the optimal response to a large increase in public spending includes a gradual, long-lasting and sizable rise in inflation.

Our results depend crucially on two assumptions. The first of these is that government bonds are long-term. It is only in this case that a sticky-information model justifies a highly persistent increase in inflation in the face of a pandemic-size shock to government finances. Such an increase is costly, but less costly than the alternative form of financing of the government debt available in the model, i.e. a permanent increase in taxes.

Second, we assume sticky information. We have argued that this is an appropriate assumption for the question that we ask in our paper, but we do not claim that it is the "true" model of price determination for firms. In fact, models with menu costs appear to be required to fully match the evidence from micro-price data. At minimum, our results support the view that conclusions based on the Calvo model are extreme and fragile. A different, but plausible, model of nominal rigidity alters them dramatically in response to infrequent, aggregate shocks such as the COVID-19 crisis.

Transparency declaration

The publication of the supplement is sponsored by BANQUE DE FRANCE.

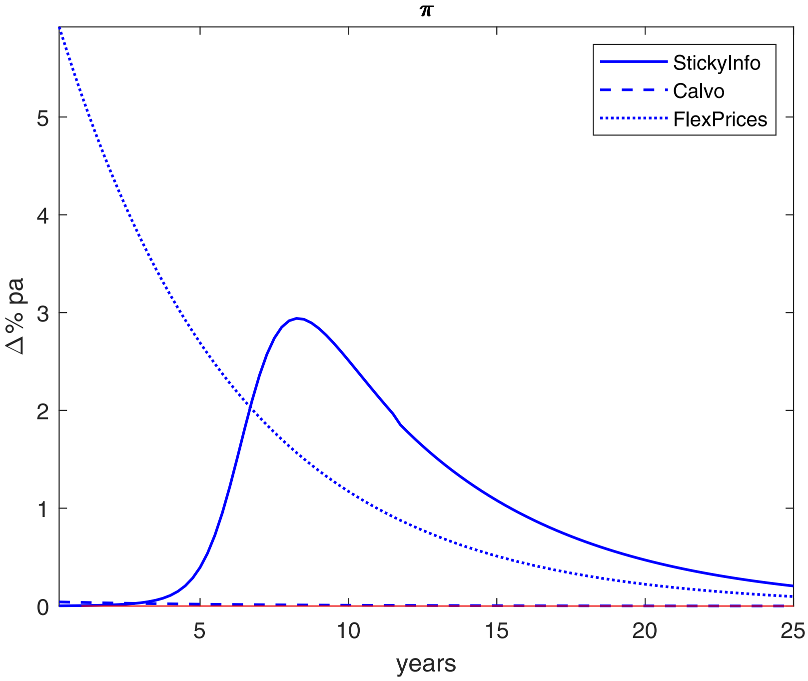

Fig. 8. Optimal response of inflation to a pandemic-size increase in G.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jmoneco.2024.103630.

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