Monetary Policy and the Maturity Structure of Public Debt

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Abstract

This paper studies the mediating impact of the maturity of public debt in the transmission of monetary policy shocks to economic activity. A longer debt maturity attenuates greatly the effect of monetary policy: going from the average historical duration of US debt to very short term debt doubles the impact of a rise of the policy rate on output. A similar result holds in UK data. Using data on corporate debt, spreads, investment, and fiscal variables, I show that these effects can be traced back to a quantitatively important *financing channel*. A model featuring an interaction between an empirically estimated primary market friction and a standard financial accelerator is able to account for these facts.

JEL classification: E52, E63, G20, H32, H63.
Key words: monetary policy transmission, public debt management, maturity structure, primary market friction.

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1 Introduction

One of the major legacies of Covid 19 is an increase in public debt. Monetary policy plays a crucial role in cushioning large shocks and in helping economies on the recovery path, balancing inflationary risks and economic activity in an environment of large balance sheets. This paper studies the effect of public indebtedness and especially its *maturity composition* on the transmission of monetary policy. Economists and policy makers intuitively feel that the maturity composition of public debt is important for macroeconomic stabilization policies. Yet it has not been analysed much. It turns out to be a lot more complex to build macroeconomic models featuring an array of debt duration than to analyse models with one-period debt contract or, at the opposite end of the spectrum, consols. Empirical work on this topic is also almost non-existent. As a result, if one asks macroeconomists how the transmission of monetary policy differs in countries in which public debt duration is high on average versus in countries in which it is low, one gets all possible answers. Some, thinking through the lenses of the fiscal theory of the price level, will argue that monetary policy is transmitted more powerfully in high duration cases. Others, seeing through the prism of heterogeneous agents models with a fraction of hands-to-mouth consumers will conjecture the opposite. Some think different effects will cancel one another. In a standard New Keynesian model the maturity structure would be irrelevant due to the Ricardian equivalence. But in a post Covid world with large balance sheets and where very different debt durations are observed - low for the US for example, high for the UK - can we afford not to know the answer to that question?

This paper is the first one to provide an answer: i) It shows empirically that monetary policy transmission to GDP is substantially *dampened* when debt is of long duration while debt maturity matters less for inflation; ii) it identifies the *financing channel* and a market friction as the main cause behind those results; iii) it uses hand collected Debt Management Office high frequency issuance data to estimate the magnitude of this market friction; iv) finally, it builds a financial accelerator model enriched with a financing channel to account for the data.

The maturity structure of debt matters for the transmission of monetary policy because of valuation effects and because debt duration affects the interest rate risk exposure of government. This is important as monetary policy is a large source of interest rate risk. As a simple example, take a country with a 100% debt to GDP ratio which has no further borrowing needs and each year covers only the interest payments. Consider two cases: in the first the whole debt is issued in 10 years nominal zero coupons bonds and in the second in bonds with overnight maturity. In the first case, the government budget is insulated from interest rate changes; in the second, a hike will push up the cost of borrowing proportionally. We can rephrase the argument in terms of market value of debt: after a hike in the first case the market value of debt will decrease as we are now discounting with a higher rate, whereas in the second the market value will remain unchanged, *ceteris paribus*. This paper argues that duration-to-GDP, which measures the changes in market value of public debt to GDP due to interest rate movements, is an important metric for fiscal authorities. As public debts are sizable for many countries, the impact of the maturity structure on fiscal balances and financial stability is high and frictions that break Ricardian equivalence matter.

In the empirical part of the paper, I construct the entire time series of the duration-to-GDP of public debt using bond by bond data in the US and in the UK since the 1970s at monthly frequency. Using local projection methods à la Jordà (2005), I show that the transmission of monetary policy is substantially dampened when debt duration is high. Going from very short term debt to the average historical duration of US debt halves the impact of a rise of the policy rate on output while having very limited effects on inflation. This result is subjected to a large array of robustness checks including regarding the possible endogeneity of the maturity structure with a novel narrative identification. I exploit the gradual repeal of a law instituted in 1918 that limited the maturity choices and subjected them to changes in the political landscape that were exogenous to the monetary policy cycle. By looking at the impulse responses of a broad range of variables, from corporate debt issuance, various budgetary items, corporate sector balance sheet items to investment and consumption responses, I can identify the main channel through which duration dampens the effect of monetary policy on output. When the government is insured against interest rate risk thanks to long maturity debt and the interest rate goes up, it does not need to refinance at the new higher rate. When this *insurance payout* materializes, the government borrows relatively less and this is associated to a relatively higher borrowing by the non-financial corporates, at a cheaper relative price. The non-financial sector uses these financial resources to invest more, and therefore, to increase output relatively. I therefore call this channel the*financing channel* of monetary policy[1].

The paper then provides a theoretical model of the *financing channel*. I enrich Bernanke, Gertler and Gilchrist (1999) financial accelerator model by adding a long maturity fixed rate public debt and a primary market friction for which I provide independent empirical evidence. I use institutional features of the budget process in the UK and hand collected data from the Debt Management Office to construct a series of unexpected news shocks to the supply of public debt. Importantly those shocks are orthogonal to the fiscal policy stance. This debt issuance friction reflects the the competition for funds between public and private sectors. Strikingly, even this very small friction in the issuance market, is enough to account quantitatively for all the empirical results. I can empirically and quantitatively trace the macroeconomic effects of this friction on the debt issuance market in the model and in the data. To sum up, this paper therefore establishes the existence of another transmission channel of monetary policy, the *financing channel of monetary policy* which is linked to the rollover needs of governments

[1] In the paper, I discuss thoroughly and rule out other channels.

which themselves depend on the duration of their debt and on the path of interest rates. This channel is quantitatively important in the current macroeconomic configuration where governments have large balance sheets and heterogeneous debt duration.

Related literature. This paper contributes to the literature on monetary policy transmission. The literature so far has analyzed how debt characteristics interact with monetary policy transmission in the context of corporate or household debt with very different channels from mine (see Ippolito, Ozdagli and Perez-Orive, 2018, Darmouni, Giesecke and Rodnyansky, 2020, Jungherr et al., 2020, Fabiani, Falasconi and Heineken, 2021, Gürkaynak, Lee and Karasoy Can, 2019, Huang, Lu and Zhou, 2021, Calza, Monacelli and Stracca, 2013, Garriga, Kydland and Šustek, 2017, Beraja et al., 2019, Wong, 2021, Auclert, 2019, Deng and Fang, 2022). An exception is Sterk and Tenreyro (2018) which studies the role of public debt but focuses on the overall stock rather than the maturity composition, as in my paper.

A related literature studies the effect of public debt supply and its structure on asset prices (see Vayanos and Vila, 2021, Greenwood, Hanson and Stein, 2010, Greenwood and Vayanos, 2010, 2014, Greenwood, Hanson and Stein, 2015, Krishnamurthy and Vissing-Jorgensen, 2012, Bianchi and Bigio, 2021, Papoutsi, Piazzesi and Schneider, 2021, Elenev et al., 2021). While I build on the premise of imperfect asset substitutability like these papers[2], I also analyze the causal effect of monetary policy, produce a clean high frequency identification of debt supply shocks using Debt Management Office announcements, and present a DGSE model of the economy.

The interaction between fiscal and monetary policies has been studied in the context of the fiscal theory of the price level by, among others, Leeper (1991), Cochrane (2001, 2020), also in the context of long-debt. My paper provides evidence of a new channel, *the financing channel*, through which monetary and fiscal policies interact, via segmented issuance markets.

The possibility of inflating away public debt with surprise inflation by the central bank is discussed by Hall and Sargent (2011), Giannitsarou and Scott (2008), Hilscher, Raviv and Reis (2021), Krause and Moyen (2016). I do not focus on the incentives to inflate away public debt, but I present evidence that public debt maturity matters more generally in conducting monetary policy and in shaping its transmission mechanism.

The optimal debt policy literature has studied how nominal and long maturity debt can provide insurance against exogenous shocks (see Bohn, 1988, Angeletos, 2002, Faraglia et al., 2013, 2018, Bigio, Nuño and Passadore, 2019, Bhandari et al., 2017, 2021). As an example, Bhandari et al. (2021) argue that optimal debt policy seeks to minimize interest rate risk with long maturity public debt. In this paper I focus on monetary policy as one source of interest

[2]More generally, I build on the idea that asset quantities matter per se in determining asset prices (see Koijen and Yogo, 2019, Gabaix and Koijen, 2020).

rate risk and quantify the effects.

Finally, I contribute to the literature on the financial accelerator and find an important role for investment in the transmission of. monetary policy. I build a theoretical model incorporating financial constraints that amplify the effects of monetary policy through investment in the tradition of Kiyotaki and Moore (1997), Bernanke, Gertler and Gilchrist (1999), Christiano, Motto and Rostagno (2014), Gomes, Jermann and Schmid (2016), Dmitriev and Hoddenbagh (2017).

Structure of the paper. The remainder of the paper is organized as follows. Section 2 discusses the data on public debt duration-to-GDP and its construction. In Section 3, I present the econometric methodology and the identification strategy. Section 4 presents the main results on monetary transmission in function of debt duration for the US. Section 5 examines the economic channels which may account for the results. Section 6 presents the theoretical model featuring a financial accelerator and a small debt issuance friction and Section 7 shows that it can account for the empirical evidence. Section 8 concludes[3].

2 The Maturity Structure of Public Debt

Fixed-rate debt allows the issuers to be insured against interest rate risk for the duration of the contract, with longer dated debt providing insurance for a longer time period. Fiscal authorities are concerned by increases in debt servicing costs due to interest rate changes. In this paper, I propose to use *duration-to-GDP* as a metric to measure the amount of interest rate risk exposure over GDP. Duration-to-GDP measures savings and losses due to interest rate changes not in terms of units of debt but in terms of debt servicing costs over GDP, which is what matters for fiscal accounts. As an example, if we take a government with public debt equal to 1 percent of GDP, it will be immaterial for debt servicing costs if debt is overnight or in consols (perpetual) bonds. On the other hand, for a government with public debt of 100 percent of GDP, the debt maturity will have first order effects on debt servicing costs. Following a one percent permanent increase in interest rates across the yield curve, with all debt overnight, debt servicing costs on existing debt would increase by one percent of GDP in perpetuity. On the other hand, they would not move at all on existing debt under a consol strategy. Equivalently, in the first case, the market value of public debt would remain constant at 100 percent of GDP.

[3]Appendix A presents the narrative account of the maturity choices. Appendix B provides the microfoundations of the primary market friction. The first set of online appendices expand on the data and on the empirical results. Appendix C presents the full data construction. Appendix D discusses the sensitivity analysis on the main specification. Appendix E shows additional empirical results for the US and Appendix F shows the empirical results for the UK. The second set of online appendices discuss the theoretical framework. Appendix G presents the full derivation of the model, Appendix H shows further theoretical results.

In the second case, the market value of public debt would decline substantially, exactly by the duration amount. Following a one percent increase permanent in interest rates across the yield curve, debt duration measures both the decline in market value of this debt and the net present value of debt servicing cost savings compared with overnight debt. I show this equivalence formally in the context of the model in Proposition 1.

In order to measure duration-to-GDP precisely, I construct a monthly dataset of public nominal fixed-rate marketable debt promises held by the general public at market prices for each future month; the current value of the government promises for j months ahead, following Hall and Sargent (2011) methodology. The market value of public debt for nominal fixed-rate marketable promises is

$$\sum_{j=1}^{n} q_{t,j} d_{t,j}$$

where, $q_{t,j}$ is the amount of nominal currency in period t that one needs to purchase one unit of nominal currency in period $t+j$, $d_{t,j}$ is the amount of the promises that the government has in period t to pay in period $t+j$, n is the maximum maturity of public debt[4]. *Macaulay duration* measures the percent decrease in the market value of this debt following an infinitesimal change in interest rates uniformly across the yield curve $dr = dr_{t,j}$, for $j > 0$.

$$MacDur_t = -\frac{\frac{\partial\left(\sum_{j=1}^{n} q_{t,j} d_{t,j}\right)}{\partial r}}{\sum_{j=1}^{n} q_{t,j} d_{t,j}} = -\frac{\frac{\partial\left(\sum_{j=1}^{n} e^{-\frac{j}{12} r_{t,j}} d_{t,j}\right)}{\partial r}}{\sum_{j=1}^{n} q_{t,j} d_{t,j}} = \frac{\sum_{j=1}^{n} \frac{j}{12} q_{t,j} d_{t,j}}{\sum_{j=1}^{n} q_{t,j} d_{t,j}}$$

Duration-to-GDP measures the same change but in percentage points of GDP, thereby capturing the overall insurance amount relevant for debt management[5]:

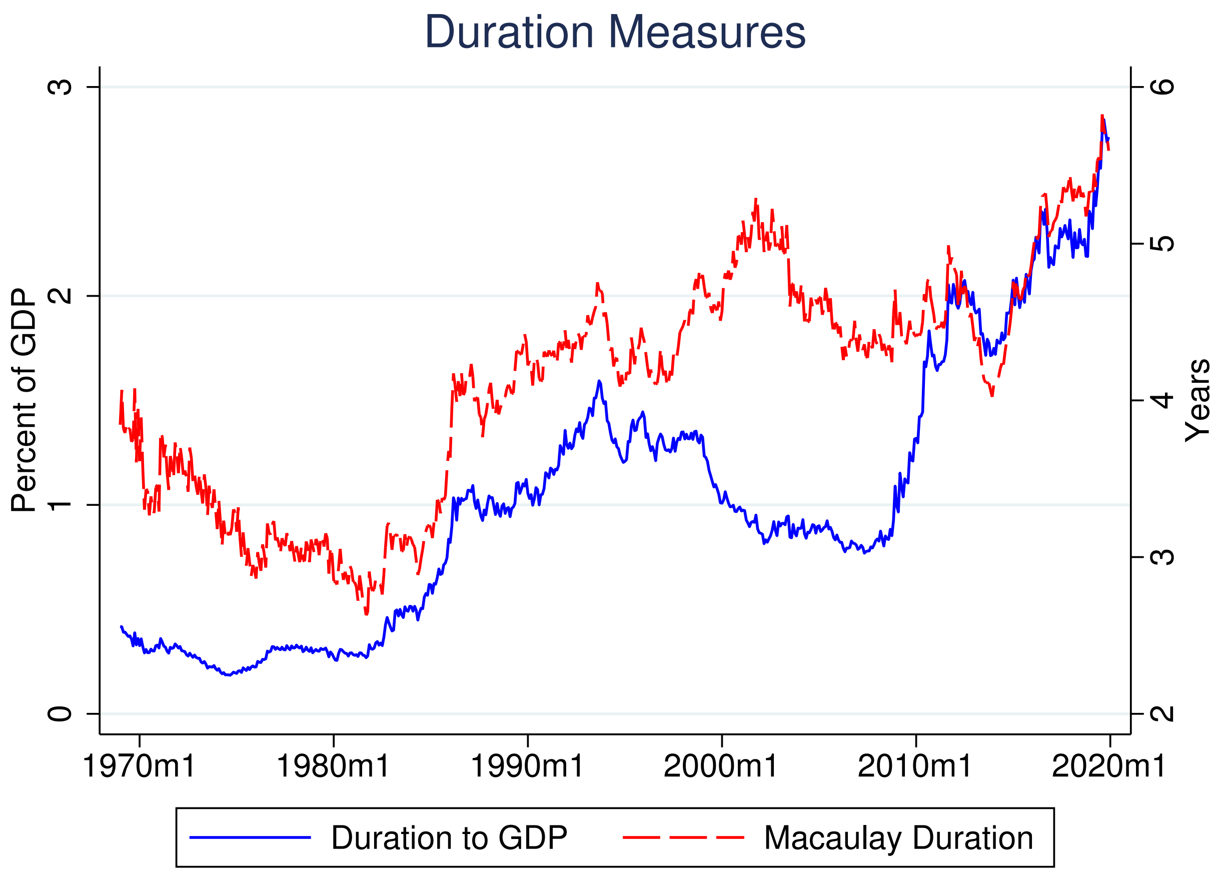
$$DurGDP_t = \frac{\sum_{j=1}^{\infty} \frac{j}{12} q_{t,j} d_{t,j}}{GDP_t} \tag{1}$$

Figure 1 presents the Macaulay duration and the duration to GDP for marketable nominal public debt held by the public for the US. It does not include the holdings of the Federal Reserve and of other public entities. A few features stand out. First, the overall level of

[4]As governments issue bonds which are not zero coupon, I strip the coupons and create the equivalent series for the marketable part of $d_{t,j}$ in each month for future promises also dated monthly. With respect to the prices, I use the continuously compounded zero coupon yield curve data and compute the zero coupon prices with $q_{t,j} = e^{-\frac{j}{12} r_{t,j}}$ where j is divided by 12 to convert it to annual frequency and $r_{t,j}$ is the appropriate interest rate on the yield curve.

[5]The full description of the details to construct the data is in Appendix C.1. That appendix also examines how these measure behave with different assumptions: in case we use face value debt, in case we include also debt held by the FED or by other public entities, or if we include the inflation-linked debt as well. The UK data is also shown in Appendix C.1.

Figure 1: Time series of public debt Macaulay duration and duration to GDP for the US



Notes: The figure shows the time series for public debt Macaulay duration (in red dashed line) and duration to GDP (in blue solid line) for the US. The public debt used to construct the measure is nominally fixed rate, marketable bonds held by the public. Each bond is stripped in principal and coupon promises and each promise is discounted at market value with yield curve data. To construct duration to GDP each public debt discounted promise is multiplied by its maturity in years and these; then these objects are summed for each period and then divided by nominal GDP. To construct Macaulay duration each public debt discounted promise is multiplied by its maturity in years and these; then these objects are summed for each period and then divided by the sum of market value of the same bonds. GDP is converted from quarterly to monthly values by using the latest value available (e.g. March, April, and May use Q1 values). The sample goes from 1969m1 to 2019m12 with US data.

Macaulay duration in the US has been quite low, at around 4 years on average, lower than most advanced economies. Second, Macaulay duration and duration-to-GDP often go in tandem but not always: from the late nineties to the mid aughts duration was on a increasing path, while duration-to-GDP was declining due to lower public debt. Third, duration-to-GDP displays decade-long waves in the US, with low levels up to the early eighties and from the late nineties and early aughts, and higher levels in the remaining periods. This contrasts with the UK with shorter cycles of around 5 years, with the two measures being negatively correlated across the two countries[6]. Finally, the path of the maturity choices was constrained by political constraints that affected the maturity choices. In 1918, a law instituted a 4.25% interest rate ceiling on long bonds (above 7/10 years) that was repealed slowly and in steps from the early 70s up to 1988. This first pushed down the average maturity and then constrained the Treasury which wanted to raise it. From 1993 the trade-off calculations between cost vs insurance properties of debt shifted toward costs pushing towards shorter maturities, and then again, in 2005 it shifted back toward rollover risk and toward longer maturities. In short, maturity choices were *exogenous* with respect to the monetary policy cycle. A more detailed narrative account of the history of the maturity structure of public debt is in Appendix A.

At the end of 2019 duration to GDP was at 2.8 % of GDP. This means that if interest rates were to increase by one percentage point across the yield curve, the market value of public debt would decline by 2.8 percent of GDP. Equivalently this number would be the net present value of interest rate savings with this level of public debt and this maturity profile, relative to a scenario with the same level of debt but with overnight debt[7]. This is not a small number and it is a lower bound as I focus only on nominal marketable bonds. If we add inflation-linked TIPS and assume a one to one correlation between nominal yield curve rates and real yield curve rates (as Nakamura and Steinsson (2018) show to be the case following monetary policy shocks), the estimate increases modestly to 3.2 %. The reason is that, although of longer maturity, TIPS are not a large share of public debt.

Two papers propose related measures to capture the value over GDP of long public debt. Greenwood and Vayanos (2014) propose to use a face value version of the duration-to-GDP measure. Specifically, they do not discount cash promises $d_{t,j}$ by $q_{t,j}$ but multiply them by 1, irrespective of maturity j: $DurGDP_t^{FaceValue} = \frac{\sum_{j=0}^{\infty} \frac{j}{12} d_{t,j}}{GDP_t}$. They do that to decrease concerns with endogeneity in prices, which is crucial for their empirical setting, where they already have debt prices in the left hand side of their regressions. However, that measure is not what the fiscal authority cares about when measuring the insurance implications for public finances of the maturity of public debt, since the level of interest rate matters.[8] Krishnamurthy and

[6]The corresponding figure for the UK is Appendix Figure C.5. Appendix Table D.4 shows the negative correlation across US and UK duration metrics.

[7]I prove this equivalence formally in Proposition 1.

[8]At a theoretical level, one cannot see the impact on the market value of public debt of a change in interest

Vissing-Jorgensen (2012) propose a measure at face value where they sum all debt promises above a 10 years threshold and ignore the ones below, this effectively sets $q_{t,j}$ to 1 and forces the weight on $d_{t,j}$ to be zero or one depending on whether the debt promises are due before or after the threshold: $LongDebtGDP_t^{FaceValue} = \frac{\sum_{j=10*12}^{\infty} d_{t,j}}{GDP_t}$. From the perspective of the fiscal authority, this measure captures the amount (at face value) of debt which is insured against a monetary policy rate increase, but does not give a full picture of a quantitative measure of insurance provided by public debt as duration to GDP at market value does. In Appendix D, I show how my main empirical results are robust to these alternative measures as well.

3 Empirical Methodology

The aim of this paper is to identify empirically how the impact of a monetary policy shock on economic activity depends on the current public debt structure. I interact a measure of monetary policy shocks and duration-to-GDP to see the conditional impact on economic output and prices. To identify an exogenous measure of monetary policy, in the baseline main results, I employ a narrative based monetary policy measure: the update of Romer and Romer (2004) series by Yang and Wieland (2015) for the US and the series by Cloyne and Hürtgen (2016) for the UK. The key idea it to purge the policy rate from the central bank forecasts on future economic activity. The narrative identification has the main advantage that it is available for a long sample, which is crucial in this exercise in order to have enough variation in the maturity profile of public debt, has a high power, and is available in the periods when there was the strongest separation between the Treasury and the Fed[9].

Single equation local projections à la Jordà (2005) is an appropriate estimation technique to estimate differential effects. It is flexible in the dynamic response of the variable of interest and, more importantly, it allows for non-linearities (interaction between the shock and the level of duration-to-GDP). Another benefit of a non-linear local projection is that it enables to study the effect of a shock conditionally on a current state, without imposing any restriction on the evolution of the state, as argued also by Ramey and Zubairy (2018) and Tenreyro and Thwaites (2016)[10]. The main disadvantage is that it is less efficient than a VAR, which, however, would not be able to handle the non linearity as flexibly. The baseline specification I run is a reduced

rates without using the yield curve. At a practical level, the face value measure tends to overstate the duration (both Macaulay and over GDP) when interest rates are high as can be seen in Figure C.2.

[9]To strengthen identification I also employ alternative identification schemes, such as a Cholesky recursive identification, presented in Appendix D.12, or a high frequency identification based on Gertler and Karadi (2015), presented in Appendix D.14.

[10]Gonçalves et al. (2021) show theoretically that local projections in a non-linear model are consistent estimators for conditional impulse responses (the object of interest in this paper, the effect of a monetary policy shock when debt is long vs short) but that one should add a correction term to build for unconditional IRFs from non-linear models.

form regression, with the narrative monetary policy shock entering directly in the regression:

$$y_{t+h} = \beta_{0,h} + \beta_{1,h} Shock_t + \beta_{2,h} Shock_t DurGDP_{t-1} + \beta_{3,h}(L)' controls_t + \varepsilon_{t+h} \tag{2}$$

For $h \geq 0$ and where y_{t+h} is the variable of interest, such as the log of industrial production, $Shock_t$ is the measure of monetary policy shock, $DurGDP_{t-1}$ is the duration-to-GDP in the month prior to the shock, divided by its own standard deviation, $controls_t$ is a vector of controls, with the associated vector of coefficients in term of the lag operator $\beta_{3,h}(L)$. As an additional estimation technique, I present the results from local projections instrumental variables, LP-IV as in Stock and Watson (2017), which controls for measurement error in the shock estimate[11]:

$$y_{t+h} = \beta_{0,h} + \beta_{1,h} \Delta i_{t,t-1} + \beta_{2,h} \Delta i_{t,t-1} DurGDP_{t-1} + \beta_{3,h}(L)' controls_t + \varepsilon_{t+h} \tag{3}$$

$$\Delta i_{t,t-1} = \gamma_{10} + \gamma_{11} Shock_t + \gamma_{12} Shock_t DurGDP_{t-1} + \gamma_{13}(L)' controls_t + \eta_{1,t}$$

$$\Delta i_{t,t-1} DurGDP_{t-1} = \gamma_{20} + \gamma_{21} Shock_t + \gamma_{22} Shock_t DurGDP_{t-1} + \gamma_{23}(L)' controls_t + \eta_{2,t}$$

for $h \geq 0$. $\Delta i_{t,t-1}$ is the first difference of the monetary policy rate. Lag controls are present to improve the fit of the IV estimate and to strengthen the identification assumption of lag exogeneity as discussed in Stock and Watson (2017). To properly identify the coefficient of interest $\beta_{2,h}$, we need four assumptions to be satisfied[12]. The first assumption is *relevance* as in standard IV and it can be tested: $Shock_t^{\perp}$ and $(Shock_t DurGDP_{t-1})^{\perp}$ must be relevant to predict $\Delta i_{t,t-1}^{\perp}$ and $(\Delta i_{t,t-1} DurGDP_{t-1})^{\perp}$. The relevant statistic is the first stage Kleibergen-Paap Wald F statistic, which allows for non iid errors. The second assumption, also present in standard IV, is *contemporaneous exogeneity*: $Shock_t^{\perp}$ and $(Shock_t DurGDP_{t-1})^{\perp}$ should be uncorrelated with ε_t. As long as $Shock_t^{\perp}$ is exogenous, than it should also be uncorrelated with $DurGDP_{t-1}^{\perp}$ and the interaction term should not be an additional hurdle for identification. Furthermore, $DurGDP_t$ is a stock variable dated at the last day of month t; this implies that $DurGDP_{t-1}^{\perp}$ is not yet affected by $Shock_t^{\perp}$ and it is a relevant state variable for macroeconomic decisions in period t. The third identification assumption is *lead/lag exogeneity*, that is $Shock_t^{\perp}$ and $(Shock_t DurGDP_{t-1})^{\perp}$ are uncorrelated with future and past values of $\varepsilon_{t+j}^{\perp}$, $\eta_{1,t+j}^{\perp}$, and $\eta_{2,t+j}^{\perp}$ (for $j \neq 0$). This assumption is not problematic for $j > 0$ as structural (unforecastable) shocks which have not yet realized are not likely to affect today's variables, however the past one might. As long as our instruments are correlated only with past values of $\eta_{1,t+j}^{\perp}$ and $\eta_{2,t+j}^{\perp}$ (for $j < 0$), then we can solve the potential problem by including lags of the instruments.

[11] The drawback is that this does not allow for a differential effect of the shock on the Fed fund rate on impact as it normalizes the effect of the monetary policy shock to increase this rate by 1%.

[12] I follow Stock and Watson (2017) exposition and, as they do, I define $v_t^{\perp} = v_t - Proj(v_t | W_t)$ for any variable v_t and any set of controls W_t.

Otherwise we need a suitable set of controls to make this assumption hold.

The final assumptions I need, is that the maturity structure of public debt is not correlated with other determinants of the effectiveness of monetary policy on output and prices. While it cannot be tested directly, the very different time series properties of debt maturity structures in the US and in the UK assuage this concern as most potential confounding factors co-move across the two countries. Public debt management choices are also very slow moving, anticipated by long cycles of policy debates, and often constrained by law so that they are exogenous with respect to business cycles movements and monetary policy decisions. For this reason, possible endogeneity is less of a concern than for private debt maturity choices for corporations[13].

The estimation with local projections produces serially correlated errors even if the original data generating process does not exhibit serial correlation, for this reason all standard errors are computed with Newey and West (1987) method[14]. In all regressions, I control for the lags of the left hand side variable and the lags of economic activity, exemplified by the industrial production, the price level, commodity prices, the policy rate, and unemployment rate. An important discussion in the literature has been on whether monetary policy shocks can affect output and prices on the same month as when they happen. The assumption that they do not is called the recursiveness assumption by Christiano, Eichenbaum and Evans (1999). It is not necessary for the identification strategy with narrative measure of monetary policy shocks, but I still present my main finding with this assumption for comparability with Ramey (2016)[15]. Operationally, the implementation of the recursiveness assumption follows by including the contemporaneous value of all controls except the policy rate.

4 Empirical Results

As a first step, I replicate the results of Ramey (2016) for the impact of a monetary policy tightening on key macroeconomic variables as shown in Figure D.2 in Appendix D for the US. The regressions assume recursiveness and have 2 lags of the log of industrial production, the log of the price level, the unemployment rate, the effective federal funds rate, and the log of the commodity price index. Industrial production and the unemployment rate exhibit a mild expansion puzzle the first months as was previously documented in the literature. Industrial

[13]In Appendix A I provide a detailed historical narrative account of the US Treasury public debt maturity choices to highlight their independence of to the monetary policy cycle. As additional evidence, in Appendix D.15, I discuss how the most likely confounding factors could affect both the effectiveness of monetary policy and the maturity structure and show that they do not apply in my setting. I also employ an instrumental variable approach for duration-to-GDP to check robustness. The results hold as well.

[14]Montiel Olea and Plagborg-Møller (2020) argue that with lag-augmentation local projection errors are not serially correlated, my main results go through with lag-augmentation of the dependent variables and controls and heteroskedasticity robust standard errors and are available upon request.

[15]I show in a robustness check in Appendix D.11, that my results do not hinge on this assumption

production decreases by around one percent at peak and inflation starts decreasing only after 2.5 years and reaches a decline of almost 2 percent after 4 years. The unemployment rate increases by 0.2 percentage points at the peak effect.

Those results show the average response of macroeconomic variables after a monetary policy tightening. We now turn to the main results of the paper: the transmission of monetary policy conditional on the maturity structure of government debt. Figure 2 shows the results for the US. The regressions are the same with the addition of the interaction term and controlling for a lag of duration-to-GDP. Each row shows a different left hand side variable: in the first row industrial production, in the second the price level, in the third the unemployment rate, and in the fourth the federal funds rate. The columns show different coefficients from (2). In the first column the coefficient presented is $\beta_{2,h}$, which is associated with the interaction of duration-to-GDP and the monetary policy shock; the second column is $\beta_{1,h}$, which is the coefficient associated with the shock on its own. Thus, the second column shows what is the impact of a monetary policy shock when duration-to-GDP is zero (that is, when all debt has an overnight maturity), while the first column shows how much more (or less) effective is a monetary policy shock when duration-to-GDP is one standard deviation higher.

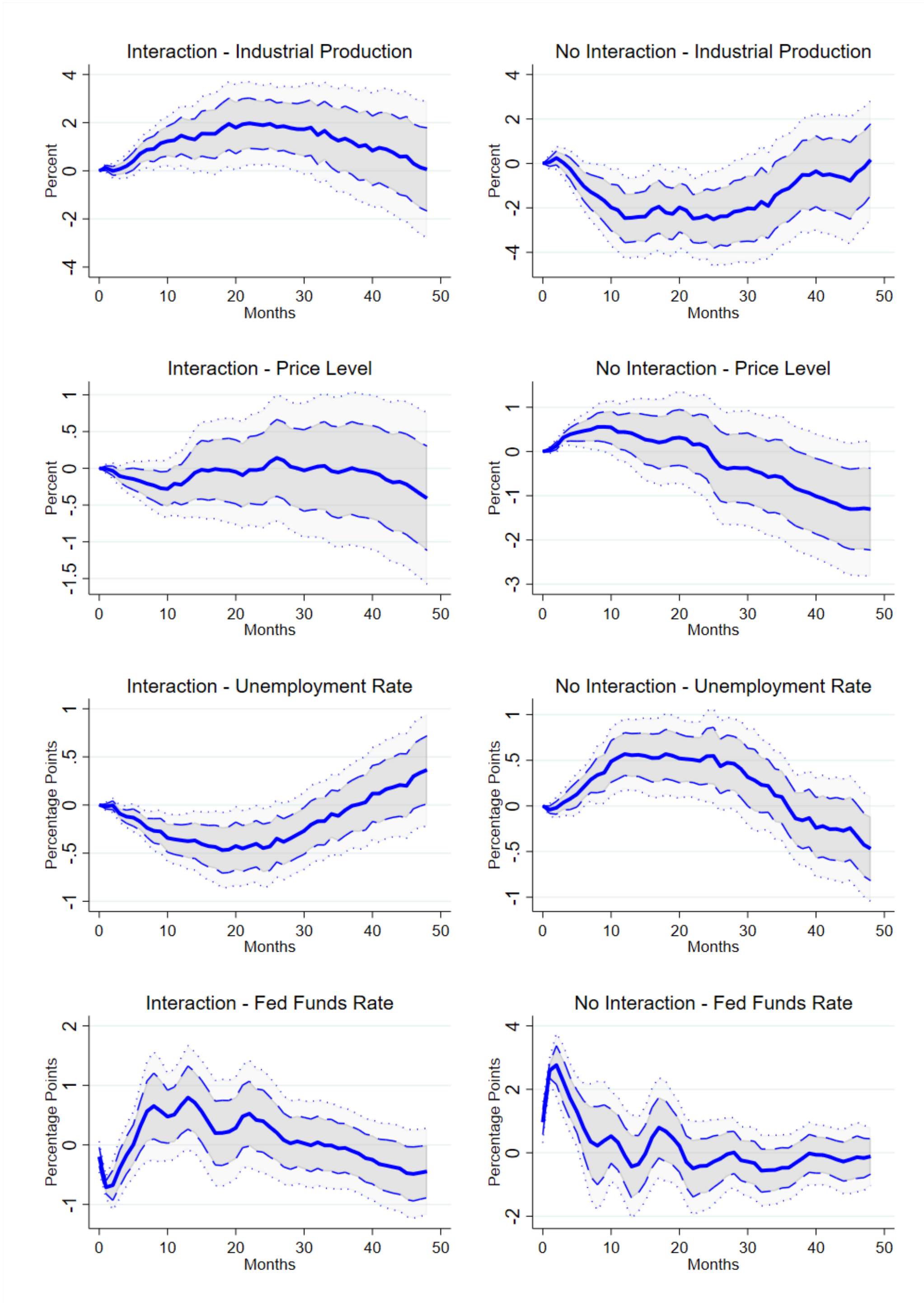
There is a positive, large and statistically significant effect of the interaction term with industrial production as a dependent variable. *This is one of the key results of the paper: when public debt to GDP has a relatively higher duration, the effect of monetary policy shocks on industrial production are muted.* At peak the differential effect reaches a value of 2 % in magnitude. This is large. A mirror way of looking at this result can be found in the second column: when all debt is overnight, the effect of a monetary policy shock reduces industrial production by as much as 2% at peak, compared with an unconditional effect of 1% reduction at peak[16].

In contrast, inspecting the second row of Figure 2, shows that the effect of a contractionary monetary policy shock on inflation does not depend on the maturity structure of public debt. This is the second key result of this paper: *there is no differential effect of inflation.* The interaction between duration-to-GDP and the shock is not statistically different from zero at any horizon. By the same token, the effect of the shock without the interaction term is very similar to the unconditional effect: there is a small price puzzle at the beginning and but the inflation effect turns negative to around -1% after 4 years. This shows that the presence of high duration debt has no inflationary effect.

The conditional effect of the contractionary monetary policy shock on unemployment is consistent with the effect on industrial production. The interaction coefficient is negative and

[16]Note that the positive coefficient does not imply that when public debt duration-to-GDP is high the effect of a contractionary monetary policy on output is positive. Instead, it becomes statistically indistinguishable from zero, as shown in Appendix D.4.

Figure 2: Local projection baseline interaction regressions for the US



Notes: 68 and 90 confidence intervals. Newey-West standard errors. The sample goes from 1969m1 to 2007m12 with US data. Identification of the monetary policy shock is achieved with the updated narrative method. Regressions performed with the recursiveness assumption on industrial production, the price level, the commodity price index, and the unemployment rate. In addition, each regression contains the first two lags of industrial production, the price level, the commodity price index, the unemployment rate, and the Fed funds rate and one lag of duration-to-GDP. The first column shows the interaction term of the shock with the Duration-to-GDP, the second column shows the shock term not interacted. Each row shows a different LHS variable.

statistically significant. At peak, a monetary tightening increases unemployment by 0.5 percentage points less if duration-to-GDP is one standard deviation higher. Similarly, if duration-to-GDP is at zero, the effect on unemployment is magnified: unemployment increases by 0.5 percentage points rather than 0.3 unconditionally.

Finally, the last row of Figure 2 shows the effect on the Effective Federal Funds Rate. On impact, the federal funds rate increases relatively less under a high duration case, but the effect is short lived, with the interaction response turning insignificant from 5 months onward. There is relatively less overshooting following the initial shock under the longer duration case[17].

The key takeaway is that the contractionary monetary policy shocks is attenuated on industrial production when debt has longer duration-to-GDP, and there is no differential effect on inflation.

4.1 Sensitivity Analysis

Appendix D shows a vast set of robustness checks. In this section, I briefly summarize the key empirical challenges and how the sensitivity analysis addresses them.

4.1.1 Measurement Errors

The reduced form local projections are a very transparent method to estimate the dynamic effects of an identified shock, and they allow for a differential effect of the shock on the Fed funds on impact, depending on the state of the economy. However, using the shock measure directly in the local projection can lead to biased estimates if the shock metric estimates the true structural monetary policy shock with a measurement error. LP-IV methods allow to overcome the measurement error at the cost of imposing a normalization, whereby the monetary policy shock cannot affect interest rate on impact differentially depending on the state of the economy. Appendix D.3 shows that the results go through almost one-to-one with the LP-IV framework.

4.1.2 Measurement of the Maturity Structure of Public Debt

Duration-to-GDP measured with nominally fixed rate public debt held by the general public is the metric that the fiscal authority should focus on when assessing the impact of monetary policy on the government budget constraint and on financing. However, one might worry that the results hinge on the specific way duration-to-GDP was built. It does not, and we can go over a number of possible alternatives.

[17] In Appendix Figure D.4, I show that the same results go through when running the same regression at quarterly frequency, with also GDP as an outcome variable.

Macaulay duration. Duration-to-GDP is a volume measure that reflects the overall economy-wide amount of insurance long debt provides, rather than the insurance per unit of debt. In Appendix D.5, I provide the same results with the Macaulay duration of public debt to show robustness to the measure per unit of debt. The results all go through but are less precisely estimated, in line with the idea that the volume measure is the correct theoretical metric. One might wonder if we can separately identify the role of debt to GDP and Macaulay duration, but this is challenging due to the multicollinearity of the shock, the interaction of the shock with debt to GDP, and the interaction of the shock with Macaulay duration. Appendix D.6 shows the result of this exercise. Whereas most IRFs present large swings hinting to multicollinearity, overall the results point to a mediating level of duration for each level of debt to GDP.

TIPS. The main measure excludes inflation-linked debt as its value might behave differently from nominal debt following a change in nominal rates. However, Nakamura and Steinsson (2018) point out that real and nominal yield curve rates all move similarly following a monetary policy shock. Therefore, in Appendix D.7, I show that results are very similar if we include TIPS in duration-to-GDP.

Fed holdings. The duration-to-GDP variable also excludes debt held by the Fed and other public entities as the valuation gains and losses on the government bonds holdings of the Fed are matched with the opposite sign for the Treasury. One might worry that due to institutional frictions across government departments, the consolidation of public debt liabilities across the government might not be fully warranted. Therefore, in Appendix D.7 I show how the results go through if we do not net out public sector holdings of debt.

Face value. In order to compute the derivative with respect to interest rate changes of the market value of public debt[18], we need to compute duration-to-GDP at market value, with yield curve data. However, a possible worry is that interest rate levels are endogenous, so that we are actually picking up the effect of low versus high interest rates rather than the mediating effect of the public debt maturity structure. For this reason, I show in Appendix D.7 that the results go through if we construct the same measure at face value, without discounting by the yield curve (similarly to Greenwood and Vayanos (2014)).

Long debt over GDP. Duration to GDP uses all the cash flow promises public debt entails to compute the insurance amount that long maturity provides. An alternative metric could be to compute the amount of long maturity debt to GDP. This alternative metric gives equal

[18] Or, equivalently, the insurance amount that long debt provides on the net present value of interest rate payments over GDP.

weight to all debt above a threshold, in line with the idea that to study a monetary policy shock that affects the economy at a business cycle frequency, a 7 year debt promise provides a similar amount of insurance as a 15 year debt promise. The drawback of this measure is that we lose the direct mapping that duration-to-GDP has to changes in the market value of public debt. Appendix D.8 shows that the results are nevertheless very close if we use this metric with debt promises above a threshold (5 or 10 years) to GDP. This is the metric proposed by Krishnamurthy and Vissing-Jorgensen (2012).

Comparison with one quarter maturity debt. The baseline specification in (2) brings as a reference comparison in $\beta_{1,h}$ what would be the impact of a monetary policy shock under an overnight debt with zero duration. However, in the theoretical model presented in Section 6 the reference is one period debt, that is quarterly debt. For this reason, in Appendix D.9, I construct the difference in duration-to-GDP from an hypothetical quarterly debt to give a direct mapping to the theoretical model. The results are virtually indistinguishable and can be used to assess the performance of the theoretical exercise.

Smooth transition. I employ duration-to-GDP directly in the main empirical specification. This allows to give a cardinal value to the various levels of this variable. However, this does not allow to interpret the results as effect of monetary policy under different regimes: the effect under a low duration-to-GDP regime, or the effects under a long duration-to-GDP regime. Moreover, the interpretation of $\beta_{1,h}$ in the baseline specification implies a degree of extrapolation, as we never observe all debt being overnight. For this reason, in Appendix D.10, I present the results with a Smooth Transition Local Projection Method, used among other by Tenreyro and Thwaites (2016), Auerbach and Gorodnichenko (2017). I employ a logistic function transformation on the standardized duration-to-GDP, and then use this metric instead of $DurGDP$ in the regression. All the results go through: monetary policy has stronger contractionary effects under a low duration-to-GDP regime on output but not on the price level. Moving from a low to a long duration-to-GDP regime attenuates the effects on output and has no effect on inflation.

4.1.3 Identification of Monetary Policy Shocks

The updated Romer and Romer shock allows to have an identified monetary policy shock, for a long time sample. The long sample is particularly useful to identify the coefficient associated with the interaction term with duration-to-GDP, in order to have enough variation in this measure. However, one might worry that shock measure is picking up forward guidance shocks, that the recursiveness assumption is too restrictive, or in general that the shock measure is not well identified. For this reason, I show that using alternative identification schemes yield similar results. Appendix D.11, presents the results when not including the recursiveness assumption. Appendix D.12 presents the results without external instruments, when using a recursive identification only which is equivalent to a Cholesky identification (as presented by Christiano, Eichenbaum and Evans (1999)); I present results for the same sample as in the baseline and for an extended sample. In Appendix D.13, I show the IRFs using the original Romer and Romer (2004) narrative measure on their original sample. Finally, in Appendix D.14, I show the results by using a high frequency identification, from Gertler and Karadi (2015)[19]. The results from these alternative identification schemes all support the result that high duration of debt to GDP attenuates the contractionary effects of monetary policy on industrial production and unemployment but not on inflation.

4.1.4 Identification of Duration-to-GDP

The baseline specification employs directly duration-to-GDP in the local projection. The reason is that it is transparent and reverse causality is unlikely. In Appendix A, I provide a detailed narrative account of the debt maturity decisions and show how the Treasury chose the debt composition *exogenously* with respect to the actions and to the effectiveness of monetary policy on the business cycle[20].

In order to provide even stronger identification, I discuss potential confounding factors. Monetary policy could be more effective on output when duration-to-GDP is low for reasons that do not hinge on the maturity structure of public debt. In Appendix D.15, I discuss how the most likely confounding factors (whether the economy is in a recession or the slope of the yield curve) are actually likely to go in the *opposite* direction. They would imply stronger effects of monetary policy on output when debt has long duration.

Additionally, I present an instrumental variable approach for duration-to-GDP proposed by Krishnamurthy and Vissing-Jorgensen (2012) and Greenwood and Vayanos (2014). They suggest that the overall stock of government debt at book value is a good instrument for its maturity structure as it depends on past deficits and it is independent of current market conditions. This approach yields strong instruments and IRFs very close to the baseline.

[19]Results are very similar with high frequency identification schemes that control for the central bank information effect as Jarociński and Karadi (2020), Miranda-Agrippino and Ricco (2021).

[20]A law introduced in 1918 that capped interest rates on long bonds 4.25% constrained the Treasury up to 1988 in its desire to lengthen the maturity. From 1993 the trade-off calculation shifted toward costs pushing towards shorter maturities, and then again, in 2005 it shifted back toward rollover risk and toward longer maturities.

4.2 External Validity

I presented the main results for the US. However, a possible worry is that the US is special so that the results would not go through in other countries. Moreover, testing the relationship in another country can help to disentangle the mechanism at play. The US government debt has a central and unique role in the global monetary system, it plays the main role as a safe asset as surveyed in Gourinchas, Rey and Sauzet (2019). A direct implication is that US treasuries earn a convenience yield relative to similar government bonds as shows by Krishnamurthy and Lustig (2019). One might wonder if the unique situation of the US is crucial for the results or if they go through more generally.

The UK presents an excellent laboratory to test this hypothesis. The UK government debt has relatively low default risk, but in the post war period has not been the key safe asset in the global monetary system. Very importantly for this study, the level and the time series properties of the UK duration of government debt to GDP have been markedly different from the US one. The lowest values were in the 70s and 90s, with shorter times in each regime than in the US. The correlation between duration-to-GDP across the two countries is *negative*[21]. Moreover, the UK is the country which historically had the longest maturity structure among large countries. As the US had one of of the lowest, they provide a useful contrast.

Appendix F shows the same analysis for the UK. Despite the differences in level and time series for duration-to-GDP in the two countries, the interaction coefficients, presented in Figure F.2, are remarkably similar. An increase in one standard deviation of duration-to-GDP reduces the contractionary effect of a monetary policy shock on industrial production by 2% at peak, as in the US. Moreover, the reduction of inflation is not affected by duration-to-GDP, as in the US.

That appendix also shows a number of sensitivity checks for the UK, similar to the US ones. They also highlight that the result is robust. Specifically, it shows robustness for using, Macaulay duration (Figure F.3), inflation linked debt as well (Figure F.4), and the smooth transition local projection method (Figure F.5)[22].

The main takeaway from this set of results is that the effect of a monetary policy tightening on output is greatly reduced when public debt has a longer duration-to-GDP. In contrast there is no differential effect on inflation. This is very robust across specifications, identification schemes, countries, and measurement choices. In the next section, we examine the economic channels that can explain this result.

[21] See Table D.4.

[22] Available upon request are also the results on LP-IV, debt at face value, and no recursiveness assumption. They are robust.

5 Inspecting the Mechanism

In the previous section we established that the maturity structure of public debt matters in the transmission of monetary policy, now we turn on why this may be the case. If public debt to GDP has a higher duration the government is insured at least partially against an interest rate rise. The government has locked-in the pre-shock lower interest rate and does not need to refinance as much at the new higher prevailing rate. The government budget constraint implies that either the government borrows relatively less or the budget surplus decreases relatively. Although the central bank controls only short interest rates[23], monetary policy shocks can affect the whole yield curve and are important for the valuation of public debt. In Appendix E.1, I show that all yields move following a monetary policy shock with short yields moving more than long yields, but bond prices proportionally move more at longer horizons due to valuation effects.

In this section, I will present a number of possible hypotheses which could explain the aggregate finding uncovered in Section 4, obtain testable implications and distinguish between them. The main three possible economic mechanisms are: (i) financing frictions "*financing channel*", (ii) heterogeneous agents models; (iii) distortionary taxation on corporates. Additionally, the fiscal theory of the price level and models that feature substitution of maturities across public and private borrowers speak directly to the phenomenon under study. I review each hypothesis in turn and present evidence on fiscal policy, non financial corporations behavior and financial variables to discriminate among them (see Figures 3, 4, and 5).

In each of these figures, I present a different dependent variable in each row. The first column shows the average response of the variable of interest to a contractionary monetary policy shock. The second column presents the interaction term between duration-to-GDP and the shock. The third column presents the coefficient without the interaction term, that is the response of a monetary policy shock with overnight debt. The econometric specification is the same as in the baseline results of Figures 2 and D.4, depending on the frequency of the dependent variable. In addition, the first two lags of the dependent variable are included. The full description of each variable is presented in Appendixes C.3 and C.4.

Financing Channel. The hypothesis which is in line with the empirical facts is the *financing channel*. The key idea is that when the government borrows relatively less, the non-financial corporate sector has relatively more resources at its disposal and it can borrow relatively more at a cheaper price. There is less "crowding-out". The non-financial sector will be able to use these financial resources to invest more, and therefore, to increase relatively output. In addition, the non-financial corporate sector is hit less by the rate increase, so that leverage and

[23] In the sample period under study, monetary policy was mainly conducted with conventional methods.

credit risk will be relatively lower.

Figures 3 and 4 test this hypothesis and find supporting evidence. The first row of Figure 3 presents the effects on net lending by the government (the negative of borrowing). On average, the government borrows more following an interest rate increase, with a higher borrowing by 0.5 percent of GDP after 4 years. The difference across maturity regimes is striking. When the government has a one standard deviation higher duration-to-GDP it borrows relatively less by an amount of 1 percent of GDP at peak. Similarly, when all debt is short term the government borrows more by 1 percent to GDP. This difference is large economically and very precisely estimated.

On the corporate debt quantity side, we can see that non-financial corporates issue relatively more debt (row 2, column 2 of Figure 3)[24]. As an additional check, we can see that overall bank loans increase relatively (row 1, column 2 of Figure 4).

Rows 2 to 4 of Figure 4 present various relative price measures, the spread between AAA corporate bonds and 10 years treasuries, the spread between BAA and 10 year treasuries, and the excess bond premium by Gilchrist and Zakrajšek (2012). All these measures mildly increase on average following a monetary policy shock. Importantly, all these measures decline relatively when duration-to-GDP is higher and are more strongly positive when all debt is overnight. The magnitude of the decline at peak is of a similar order of magnitude across the various measures, by about 20 basis points for the AAA-treasury spread and for the excess bond premium and by 40 basis points for the BAA-treasury spread. This is important information and even for measures with low (AAA-treasury) or no-credit risk (the excess bond premium purges the default risk from corporate bond spreads) we see a relative decline. Furthermore, the relatively higher decline in the BAA-treasury spread suggests that the credit risk also declines.

So far, we established the *financing channel* result on the debt side: when the government borrows less, the non-financial corporates borrow more at a cheaper price. We now turn to the real side of the *financing channel* hypothesis. The third row of Figure 3 shows that on average investment by non-financial corporates declines following a contractionary monetary policy shock, with the effect not being strongly statistically significant. However, the conditional interaction effect is positive and statistically significant, with a positive coefficient of more than 4% at peak. Similarly, if all debt is short term the contractionary monetary policy shock reduces investment by 5%. These are large numbers, but in line with the high volatility of investment.

The fourth row of Figure 3 shows the response of non-financial corporates' debt leverage. On average leverage increases by 3% after 3 years following the contractionary shock. When we turn to conditional effects, we see that leverage decreases relatively by almost 5% for a one

[24]This debt issuance metric consolidates all debt instruments, following Greenwood, Hanson and Stein (2010) with Flow of Funds data, the detailed description is in Appendix C.4

standard deviation higher duration-to-GDP.

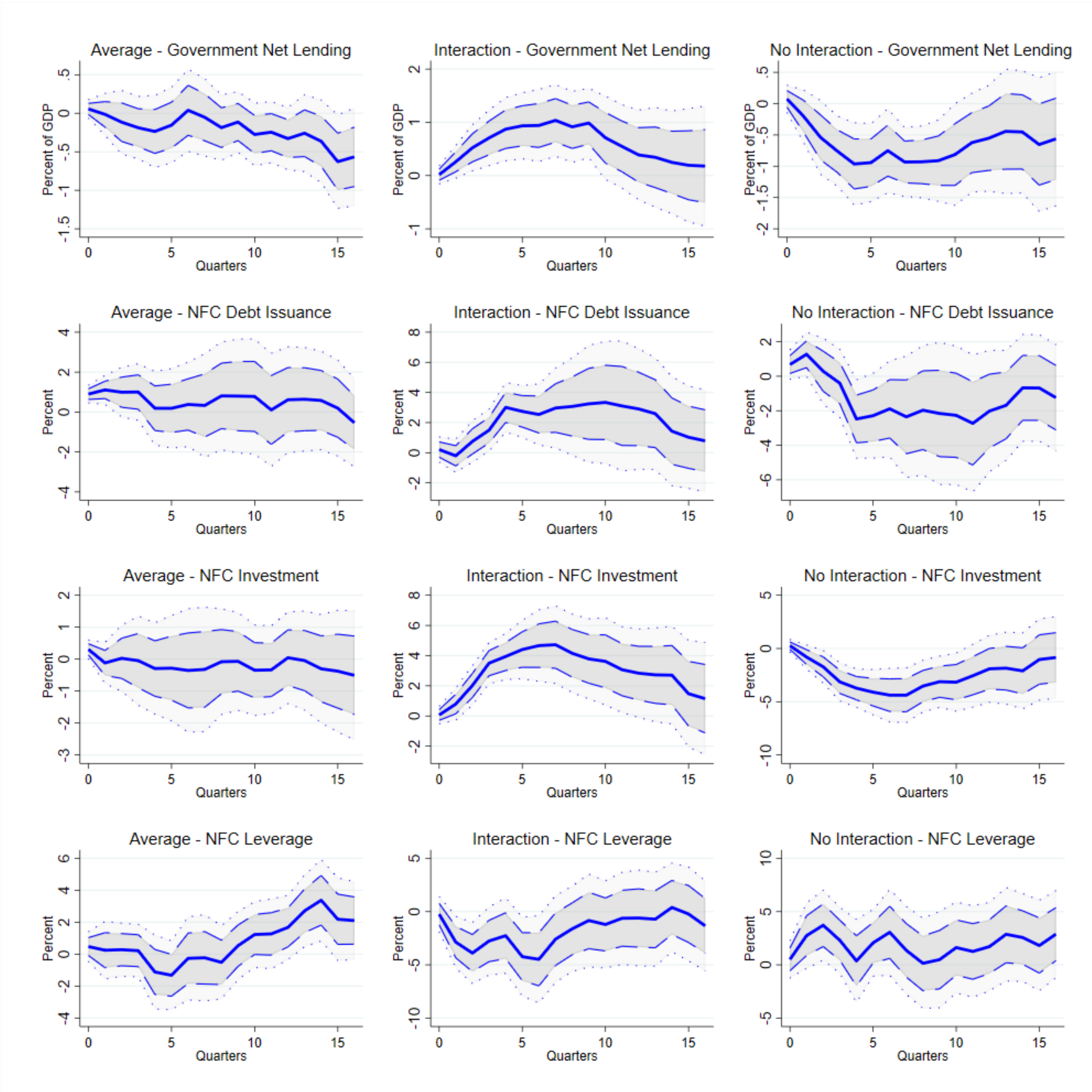
Direct Evidence for the *financing channel*. The *financing channel* hypothesis relies on a financial market friction that hinders the smooth function of primary markets: when the government goes less to the market, it becomes cheaper to borrow not only for the government, but also for non-financial corporates[25]. In a companion paper (Andreolli, 2021), I provide direct evidence for the salience of this friction. I estimate news shocks to the supply of marketable public debt which are orthogonal to the fiscal policy stance and other confounding factors and show how increases in the supply in public debt increase interest rates on government bonds and on corporate bonds. I estimate the shock with a high frequency approach exploiting a specific institutional feature of the UK: the Debt Management Office publishes updates on supply of marketable public securities (Gilts) just after the budget speeches of the Chancellor of the Exchequer, where he discusses the fiscal policy stance but not the supply of marketable public debt. Changes in the price of futures on long Gilts around news published by the DMO can therefore be used as instruments for marketable debt supply shocks. I provide a theoretical model of the *financing channel* in Section 6 and show that a plausible calibration is able to reproduce the empirical evidence.

Heterogeneous Agents Models. The presence of hand-to-mouth agents could deliver a relatively higher output response when the government is insured without necessarily a strong effect on inflation. Following a contractionary monetary policy shock when public debt has a longer maturity, the government gains relatively due to valuation effects on public debt. The bondholders lose by the same token. If Ricardian equivalence held this would not matter. However, with heterogeneous agents it might. We should see bondholders cutting their consumption relatively, pushing the aggregate relative output response to a contractionary monetary policy shock to be negative (so that monetary policy should lower output more when duration-to-GDP is high). Therefore, in order to obtain a relatively positive effect on output as shown in the previous section, the response of the hand-to-mouths is crucial. In this framework, hand-to-mouth agents would respond positively if the government uses the relative windfall on expansionary contemporaneous fiscal policy. We should see either relatively higher government expenditures, lower taxes, higher transfers, or in general lower fiscal surplus *today*. So a testable implication of this hypothesis is that we should see a contemporaneous expansionary fiscal policy response.

Figure 5 tests the hand-to-mouth hypothesis. The first row shows that on average the government does not respond contemporaneously with higher government expenditures following an interest rate increase. There is a mild increase after 4 years. More importantly, the second

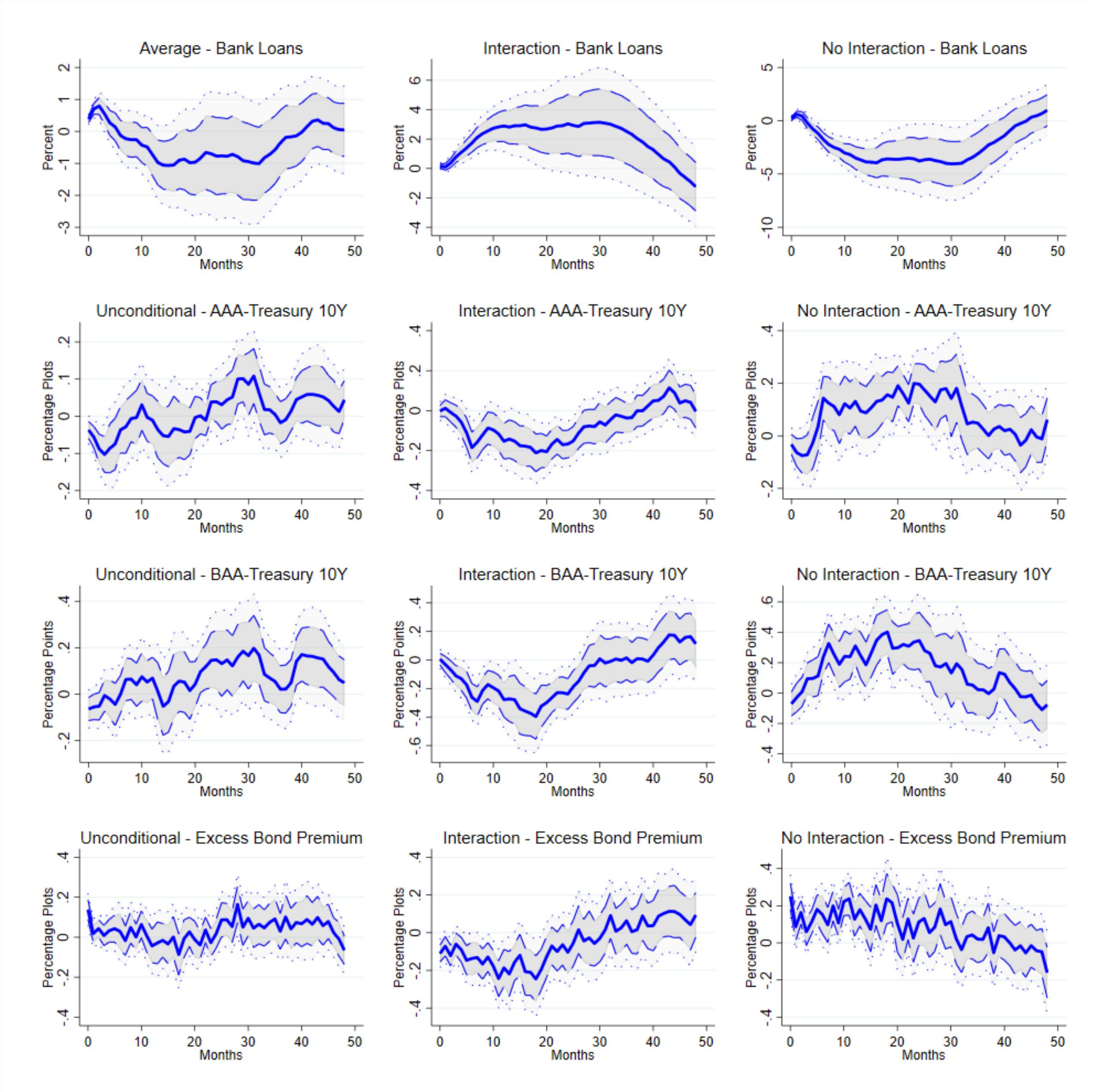
[25] This pass-through is in line with the evidence provided by Krishnamurthy and Vissing-Jorgensen (2012) and Papoutsi, Piazzesi and Schneider (2021).

Figure 3: Economic channel - competition for financing with quarterly data



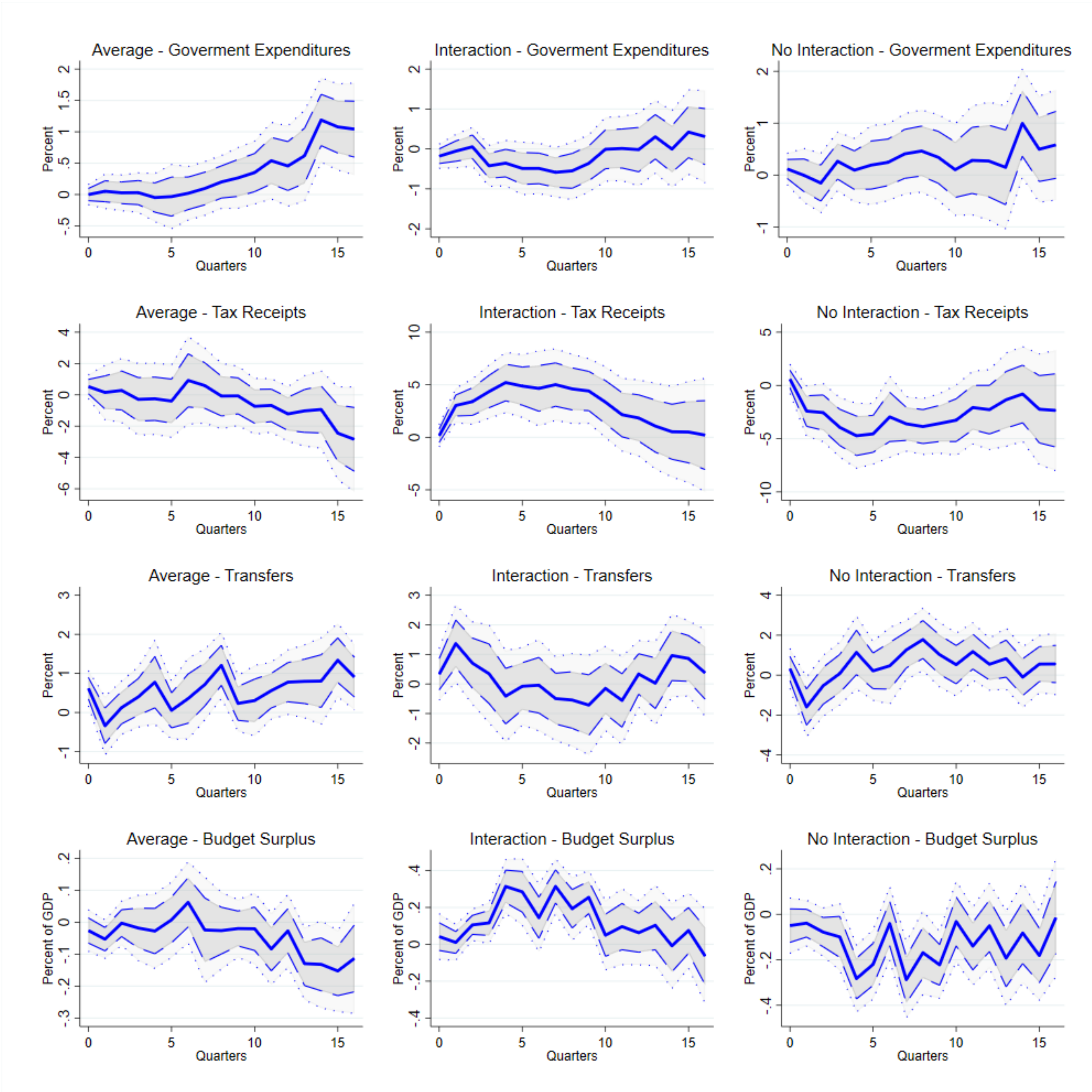
Notes: 68 and 90 confidence intervals. Newey-West standard errors. The sample goes from 1969Q1 to 2007Q4 with US data. Identification of the monetary policy shock is achieved with the updated narrative method. Regressions performed with the recursiveness assumption on industrial production, GDP, the price level, the commodity price index, and the unemployment rate. In addition, each regression contains the first two lags of the left hand side variable, industrial production, GDP, the price level, the commodity price index, the unemployment rate, and the Fed funds rate and one lag of duration-to-GDP. The first column shows the average response to a monetary policy shock. The second column shows the interaction term of the shock with the duration-to-GDP, the third column shows the shock term not interacted. Each row shows a different LHS variable.

Figure 4: Economic channel - competition for financing with monthly data



Notes: 68 and 90 confidence intervals. Newey-West standard errors. The sample goes from 1969m1 to 2007m12 for all variables except for the excess bond premium, which goes from 1979m9 to 2007m12. The sample uses US data. Identification of the monetary policy shock is achieved with the updated narrative method. Regressions performed with the recursiveness assumption on industrial production, GDP, the price level, the commodity price index, and the unemployment rate. In addition, each regression contains the first two lags of the left hand side variable, industrial production, GDP, the price level, the commodity price index, the unemployment rate, and the Fed funds rate and one lag of duration-to-GDP. The first column shows the average response to a monetary policy shock. The second column shows the interaction term of the shock with the duration-to-GDP, the third column shows the shock term not interacted. Each row shows a different LHS variable.

Figure 5: Economic channel - contemporaneous fiscal policy



Notes: 68 and 90 confidence intervals. Newey-West standard errors. The sample goes from 1969Q1 to 2007Q12 with US data. Identification of the monetary policy shock is achieved with the updated narrative method. Regressions performed with the recursiveness assumption on industrial production, GDP, the price level, the commodity price index, and the unemployment rate. In addition, each regression contains the first two lags of the left hand side variable, industrial production, GDP, the price level, the commodity price index, the unemployment rate, and the Fed funds rate and one lag of duration-to-GDP. The first column shows the average response to a monetary policy shock. The second column shows the interaction term of the shock with the duration-to-GDP, the third column shows the shock term not interacted. Each row shows a different LHS variable.

column shows that the interaction coefficient is not statistically different from zero. This implies that the government does not spend relatively more under a high duration-to-GDP case, as would be necessary for the hand-to-mouth hypothesis to be corroborated. The second row shows tax receipts. On average they do not respond much, with a mild decline at the end of the horizon. However, the interaction coefficient is positive, large, and statistically significant. This seems to follow the output response, but crucially, it would need to be negative, for the hand-to-mouth hypothesis to work. The third row shows transfers, where we do not see any significant response on average or conditionally to duration-to-GDP. Again, we should have seen a positive coefficient on the interaction term to corroborate the hand-to-mouth hypothesis. Finally, we can bring the sub-components together and look at the government budget surplus in the fourth row. On average, the budget surplus mildly declines following a contractionary monetary policy shock after 4 years. More importantly, the budget surplus relatively increases following the contractionary monetary with a longer duration-to-GDP (second column). This means that the overall relative fiscal stance goes in the *wrong direction for hand-to-mouth consumers to explain the aggregate results.*

Hence, the government does *not* give a contemporaneous fiscal impulse when it is insured against the interest rate hike. What we find instead, is a *strong differential effect on net borrowing* as shown in the first row of Figure 3.

Distortionary Corporate Taxation. Let us now turn to the distortionary corporate taxation hypothesis, which could also explain the aggregate results and the fiscal response. The main idea is that, when a government with longer dated debt borrows relatively less, following an interest rate increase, the non-financial corporates expect lower distortionary taxation in the future, they invest today and they borrow relatively more. From the perspective of debt markets, we should see an increase in demand for funds by the non-financial corporates. This implies, especially with segmented markets (see Gabaix and Koijen, 2020), that we should see an increase in the relative price of corporate debt compared to public debt. Furthermore, with relatively lower default risk and tax burden in the future, firms should be able to take on more leverage.

Figures 3 and 4 show that we find evidence for the quantity predictions of this hypothesis but not for the leverage and price predictions. The second column, fourth row of Figure 3 shows that leverage declines relatively when duration-to-GDP is higher. Rows 2 to 4 of Figure 4 show in the second column, that the various relative price measures decline when duration-to-GDP is higher. All these results on relative corporate debt prices, but especially those that purge default risks, point to the fact that *higher demand for funds by non-financial corporates due to lower future distortionary taxation cannot be the key explanation for the aggregate results.*

Fiscal Theory of the Price Level. Finally, it is important discussing theories that feature an explicit role for the maturity of public debt and its interaction with monetary policy. First of all, the fiscal theory of the price level, in its basic formulation, would predict that a contractionary monetary policy shock would lower inflation more when duration-to-GDP is higher. The reason is that, with longer duration debt, an increase in interest rates would reduce more the market value of debt. This implies that either the price level decreases relatively more, or that the primary surpluses would relatively decline, in order to keep the budget constraint satisfied. However, we do not see a differential effect on inflation and we can see in the third row second column of Figure 5 that the government budget surplus, increases relatively with more long duration debt.

Gap Filling Theory of Corporate Debt Maturity. Greenwood, Hanson and Stein (2010) show that when the government has relatively longer dated debt the non-financial corporate sector has relatively shorter debt and vice-versa. If this was the driving force of the results however, we should see the opposite response for investment and output: when the non-financial corporates have shorted maturity debt, they are more responsive to changes in interest rates, in line with the model by Gomes, Jermann and Schmid (2016). We see the opposite.

Table 1: Economic Channel Testable Hypotheses Summary

	Financing	HANK	Dist. Tax	FTPL	Gap filling	Data
Output	+	+	+		-	+
Inflation				-		0
Primary Surplus		-		-		+
Government Consumption		+				0
Transfers		+				0
Taxes		-				+
Government Borrowing	-		-			-
Corporate Debt Quantity	+		+			+
Corporate Debt Prices	-		+		+	-
Corporate Leverage	-		+		+	-
Investment	+		+		-	+

Notes: This table shows the relative IRF response to a contractionary monetary policy shock when debt is relatively longer maturity: $\beta_{2,h}$ in regression (3). All columns except the last one indicate the predictions for the various variables from each theory. For the variables for which there is no direct prediction, none is specified. The last column presents the data counterpart. *Financing* stands for the financing channel hypothesis, HANK for the heterogeneous agent New Keynesian model, Dist Tax for the distortionary taxation on corporates, FTPL for the fiscal theory of the price level, and Gap filling for the hypothesis associating a negative relationship between public and private debt maturity. In the data column, a "+" ("-") indicates that at peak $\beta_{2,h}$ is positive (negative) and statistically significant at the 90% confidence level, a "0" indicate that it is not statistically significant at the 90% confidence level.

Taking Stock. Table 1 summarizes the predictions of the various theories discussed and how they contrast with the data. Overall, we find evidence for the *financing channel* to explain the empirical results. Following an interest rate increase, when the government has relatively longer debt, it borrows relatively less. This in turns allows for more resources to be available for the corporate borrowers (less crowding out), which borrow more at a cheaper rate. This is not to say that the other hypotheses cannot be important in the data, however, they cannot explain the overall patterns we uncovered in Sections 4 and 5.

6 Model Description

In this section, I present a model which can rationalize the empirical results. The model is a standard financial accelerator New Keynesian model in the spirit of Bernanke, Gertler and Gilchrist (1999) with two modifications. First, the government can issue fixed-rate nominal long term debt, which creates a history dependence on past interest rates for public debt servicing. Second, I introduce primary dealers in this economy. They face a cost to issue new debt each period. This is akin to investment adjustment costs for debt issuance. It creates a direct mapping between the quantity of government bond issued and the financing conditions the private sector faces to issue debt. The magnitude of the primary market friction is small, but can have large macroeconomic effects when variations in public debt supply across maturity regimes interacts with the financial accelerator frictions on the firm side.

6.1 Government

The government issues a bond which has geometrically decaying amortization and which pays a fixed net nominal interest rate R_t^{new} on new bonds. The principal due decays at rate δ^d, therefore if the government issues one unit of debt today it is going to repay $\delta^d + R_t^{new}$ the next period, $(\delta^d + R_t^{new})(1-\delta^d)$ in 2 periods, $(\delta^d + R_t^{new})(1-\delta^d)^2$ in 3 periods and so on, all of these in today's dollars. In each period, the government issues L_t bonds; therefore, the end of period stock of debt D_t can be written as the sum of remaining past issuances, which allows a recursive formulation:

$$D_t = L_t + (1-\delta^d)D_{t-1}$$

Notice that all stock variables are defined as end-of-period variables, so that D_t is the stock of bonds reflecting the choices at period t. Interest rates are all defined in net terms rather than gross terms. The convenient geometric bond structure also allows for a recursive formulation for the average interest rate process on the debt stock. In each period the interest payments are:

$$R_t^{ave} = R_t^{new}\frac{L_t}{D_t} + R_{t-1}^{ave}\left(1 - \frac{L_t}{D_t}\right)$$

This debt specification allows to keep a parsimonious setting where interest rate path dependence is explicit and can have long lasting effects but the number of state variables is only two. This is close to the literature on the impact of fixed rate vs variable rate mortgages (see Kydland, Rupert and Šustek (2016)) for modeling the interest rates, and similar to Hatchondo and Martinez (2009) or Arellano and Ramanarayanan (2012) in terms of modeling long public debt as a geometric decaying process. While I model public debt with the geometric structure out of empirical relevance and theoretical parsimony, in a recent paper, Bhandari et al. (2021) show that a geometric structure for public debt is optimal in a Ramsey problem. The geometric approximation is a good fit of the data, with an average R^2 of 90%[26]. If we define F_t to be the debt payments in period t the debt dynamics system is fully determined with a third equation:

$$F_t = (R^{ave}_{t-1} + \delta^d) D_{t-1}$$

We rescale debt quantity variables in real terms with lower case letters being the real value $x_t \equiv \frac{X_t}{P_t}$ where P_t is the aggregate price level for consumption goods and inflation is defined as $\pi_t \equiv \frac{P_t}{P_{t-1}}$:

$$f_t = (R^{ave}_{t-1} + \delta^d) \frac{1}{\pi_t} d_{t-1} \tag{4}$$

$$d_t = (1 - \delta^d) \frac{1}{\pi_t} d_{t-1} + l_t \tag{5}$$

$$R^{ave}_t = \left(1 - \frac{l_t}{d_t}\right) R^{ave}_{t-1} + \frac{l_t}{d_t} R^{new}_t \tag{6}$$

We derive the following lemma linking the duration to δ^d and to R^{new}_t.

Lemma 1 *Assume public debt has a geometric principal structure, such that a fraction $(1-\delta^d)$ of the principal is repaid in each period and that interest payments on newly issued debt L_t are fixed in nominal terms for this bond vintage at R^{new}_t, then the Macaulay duration on newly issued debt is:*

$$Dur_t = \frac{1 + R^{new}_t}{\delta^d + R^{new}_t} \tag{7}$$

The proof of this lemma is in Appendix G.1.1. As an illustration, if δ^d is equal to 0.05 and R^{new}_t is 0.0123 (0.05 at annual frequency) we have a duration of 16.24 quarters, of around 4 years. On the other hand, if δ^d is equal to 1 all bonds are due next quarter and duration is 1.

[26] I compute the R^2 in each period the US estimation sample by fitting the model predicted annual principal debt promises on actual promises. The average R^2 is 0.9001 and its standard deviation is low at 0.0306.

Fiscal policy. The government spends G_t, which moves exogenously, and receives taxes T_t. The budget constraint, in real terms, is:

$$f_t = T_t - G_t + l_t \tag{8}$$

In order to match the empirical evidence (see Herbst and Schorfheide, 2015), I set up a tax reaction function where taxes react slowly to changes in financing needs (passive fiscal policy):

$$T_t = G_t + (T - G)\left(\frac{d_{t-1}}{d}\right)^{\tau_T} \tag{9}$$

With a $\tau_T \geq 0$ but low, consistent with the model presented by Eusepi and Preston (2010) and empirical evidence presented by Davig and Leeper (2007) for passive fiscal policy and Herbst and Schorfheide (2015). This means that most of the short term changes in financing needs to be absorbed by new bonds issuances. Note that this tax policy works if there is a structural primary surplus in steady state, which is the case in this model with no growth and positive steady state public debt. Government spending evolves exogenously following an AR(1) when log-linearized, with G being the steady state government consumption:

$$\frac{G_t}{G} = \left(\frac{G_{t-1}}{G}\right)^{\rho^g} \exp(\varepsilon_t^g) \tag{10}$$

The government in this model has access to a long maturity bond but behaves like an "automaton", in line with the empirical results shown in the empirical sections. This could be due to high costs of adjusting its positions, as argued by Faraglia et al. (2018) for the maturity structure choice. In this paper, I abstract from the optimal choice of the government for the maturity structure of debt.

6.2 Primary Market Participants

The primary market participants buy new debt issuances of the government and of the private sector on the primary market and sell them within the period to final investors on the secondary market. These agents face a convex cost to participate in this market: when the government or the firms issue more, the funding costs increase as the primary market participants cannot absorb as easily the new funds. This creates an adjustment cost friction:

$$\bar{\Phi}\left(Total\ New\ Issuance_t\right) = \bar{\Phi}\left(\frac{B_t^{crp}}{P_t} + \frac{L_t}{P_t}\right) \tag{11}$$

With $\bar{\Phi}' \geq 0$ and $\bar{\Phi}'' \geq 0$. The functional form for $\bar{\Phi}$ is:

$$\bar{\Phi}(x) \equiv \Phi_0 \frac{x^{\Phi_1+1}}{\Phi_1+1} \exp\left(\frac{\nu_t^{\Phi}}{\Phi}\right), \ \Phi_0 \geq, \ \Phi_1 > 0$$

Where ν_t^{Φ} is a shock to the financing friction and Φ is the steady state value of the first derivative of the friction, which is there as a scaling variable. The shock follows the law of motion:

$$\nu_t^{\Phi} = \rho^{\Phi} \nu_{t-1}^{\Phi} + \varepsilon_t^{\Phi}$$

The primary market participants sell immediately on the secondary market the bonds they purchased on the primary market at price q_t^t for the government bond (secondary market price at time t for a bond issued in time t), and at price q_t^{crp} for the corporate bond. The profit maximization of these agents is given by:

$$\max_{b_t^{crp}, l_t} \ q_t^{crp} b_t^{crp} + q_t^t l_t - \left(b_t^{crp} + l_t\right) - \bar{\Phi}\left(b_t^{crp} + l_t\right) \tag{12}$$

The problem is concave, so the solution can be found by taking the first order conditions:

$$\begin{aligned} q_t^{crp} &= 1 + \Phi_t \\ q_t^t &= 1 + \Phi_t \end{aligned}$$

where we define the primary market friction $\Phi_t \equiv \frac{\partial \bar{\Phi}\left(b_t^{crp}+l_t\right)}{\partial l_t} = \frac{\partial \bar{\Phi}\left(b_t^{crp}+l_t\right)}{\partial b_t^{crp}}$ in a compact form. In Appendix B, I propose two isomorphic microfoundations for this primary market friction, relaying on specialized investors in the primary market. The first one assumes a moral hazard problem for the primary dealer in a similar spirit to Gabaix and Maggiori (2015). The second one assumes risk averse arbitrageurs in the spirit of Vayanos and Vila (2021). I specify a primary market friction in a reduced form[27] as in equation (11) rather than with a particular microfoundation to highlight the key transmission mechanism. What is crucial is that a higher overall issuance increases interest rates, irrespective of the particular microfoundation. Therefore, if the government issues more debt, interest rates for the government and the corporate sector will both increase. As I show in Appendix B, the macroeconomic implications are identical if the underlying reason comes from a moral hazard problem for primary dealers or from risk averse arbitrageurs.

[27] Examples in the literature of reduced form debt adjustment frictions in macroeconomic models include Greenwald, Krainer and Paul (2020) and Morelli, Ottonello and Perez (2019) among others.

6.3 Households

Households enjoy consumption goods C_t and dislike working hours H_t. They optimization problem is the following:

$$\max_{\{C_t, H_t, B_t^{crp}, B_t^{mp}, \{D_t^{t-j}\}_{j=0}^{\infty}\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} - \chi \frac{H_t^{1+\eta}}{1+\eta} \right] \tag{13}$$

They can invest in three separate sets of debt instruments:

- a nominally risk free monetary policy bond B_t^{mp} at rate R_t^{mp} which is in zero net supply and used only for conducting monetary policy,
- a corporate debt claim B_t^{crp} issued by corporations to finance investments, which pays a real risk free return R_t^{crp} and can be purchased on the secondary market at price q_t^{crp},
- a set of government bonds in the secondary market. D_t^{t-j} is the nominal quantity of the government bond issued $t-j$ periods ago and purchased in period t, with $j \geq 0$ and q_t^{t-j} and R_{t-j}^{new} are the corresponding price and coupon rate respectively.

The households earn wage W_t, receive profits Π_t from firm producers, and pay taxes T_t. The nominal budget constraints in a given period is:

$$P_t C_t + B_t^{mp} + q_t^{crp} B_t^{crp} + \sum_{j=0}^{\infty} q_t^{t-j} D_t^{t-j} + P_t T_t = W_t H_t + P_t \Pi_t + \tag{14}$$

$$B_{t-1}^{mp}(1 + R_{t-1}^{mp}) + B_{t-1}^{crp}(1 + R_{t-1}^{crp}) \frac{P_t}{P_{t-1}} + \sum_{j=1}^{\infty} ((1-\delta^d) q_t^{t-j} + R_{t-j}^{new} + \delta^d) D_{t-1}^{t-j}$$

As shown in Appendix G, the solution to the household problem can be characterized by four equations: a labor supply choice, an Euler equation for the monetary policy bond, an Euler equation for the corporate bond, and an Euler equation for the newly issued government bond. The convenient geometric nature of government bonds allows to have only one Euler equation for government debt rather than having to keep track of each past vintage of bonds. This simplifies the equilibrium computation substantially. Since each bond vintage affects the equilibrium due to its impact on the primary market friction, one would in principle need otherwise to keep track of all vintages of public debt. Substituting in the primary market friction from the primary market participants we obtain the following four conditions:

$$C_t^{-\sigma} w_t = \chi H_t^{\eta} \tag{15}$$

$$1 = \mathbb{E}_t \left[\beta \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{(1 + R_t^{mp})}{\pi_{t+1}} \right] \tag{16}$$

$$1 = \mathbb{E}_t \left[\beta \left(\frac{C_{t+1}}{C_t} \right)^{-\sigma} \frac{(1 + R_t^{crp})}{1 + \Phi_t} \right] \tag{17}$$

$$\frac{(1 + \Phi_t)}{(\delta^d + R_t^{new})} = (1 + R_t^{mp})^{-1} + \mathbb{E}_t \left[\beta \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}(\pi_{t+1})} (1 - \delta^d) \frac{(1 + \Phi_{t+1})}{(\delta^d + R_{t+1}^{new})} \right] \tag{18}$$

Equation (18) shows that the interest rate on newly issued bonds today R_t^{new} depends on the current primary market frictions, on current monetary policy rates, on the expected bond interest rates tomorrow and on tomorrows frictions in the primary market. The weight on future market conditions is directly proportional to the maturity structure. As δ^d decreases, the weight on future market conditions becomes more important. This can be seen clearly by rewriting the right-hand-side of equation (18) as a weighted average of notional nominal zero coupon bonds not affected by the primary market friction[28] where the weight is a geometrically decaying function of the duration parameter:

$$\frac{(1 + \Phi_t)}{(\delta^d + R_t^{new})} = \sum_{j=1}^{\infty} (1 - \delta^d)^{j-1} \left[1 + R_t^{zerocoupon,t,t+j} \right]^{-j}$$

Public Debt Pricing and Duration to GDP. Next, I combine the pricing decision by the household, the solution to the problem of the primary market participants, and the public debt structure. This allows to characterize compactly the behavior of the secondary market price of public debt and show the mapping that duration-to-GDP allows between measuring insurance against interest rate risks from a market value approach and savings in debt servicing costs.

Lemma 2 *If public debt has a geometric principal structure with fixed nominal rates and its law of motion can be described by* (4), (5), *and* (6), *primary market participants solve* (12), *and households maximize utility* (13) *subject to* (14)*; then, the secondary market price* q_t^d *of the overall debt stock* D_t *is:*

$$q_t^d = \frac{(\delta^d + R_t^{ave})}{(\delta^d + R_t^{new})} (1 + \Phi_t) \tag{19}$$

Appendix G.1.3 presents the proof by using the Euler equations for long bonds and the aggregate

[28] I define the annualized yield on these zero coupon bonds as the annualized yield equal to the expectation of the j periods ahead nominal SDF, $\left[1 + R_t^{zerocoupon,t,t+j} \right]^{-j} \equiv \mathbb{E}_t \left[\prod_{k=1}^{j} \left(\frac{1}{\pi_{t+k}} \right) \beta^j \frac{C_{t+j}^{-\sigma}}{C_t^{-\sigma}} \right]$

structure of public debt. Equation (19) shows how the secondary market price of overall debt depends on the primary market friction and on the difference between the average interest rate and interest rate on newly issued debt. Specifically, if the current rate is relatively higher than the legacy one, the price of government debt will decline. It will decline proportionally more the higher maturity public debt is. This mirrors, on the secondary market valuation side of public debt, the key channel of fixed rate long debt insurance. When the government has more long term debt and interest rates increase, investors lose, whereas the opposite happens when rates decline. If maturity is short the secondary market price of public debt becomes simply equal to the primary market friction, as for corporate debt.

The two Lemmata 1 and 2 are useful intermediate results to arrive to a key proposition of the analytical part of the model. When we have a permanent change in interest rates, a volume metric of duration, *duration-to-GDP* not only measures how much the market value of public debt will change, but also how interest servicing costs change on legacy debt compared to short debt.

Proposition 1 *Take a model where public debt has a geometric principal structure with fixed nominal rates and its law of motion can be described by* (4), (5), *and* (6), *primary market participants solve* (12), *and households maximize utility* (13) *subject to* (14). *If interest rates on newly issued debt increase permanently to* R_t^{new} *then; the duration of the legacy debt stock to GDP,* $Dur_t D_{t-1}/Y_{t-1}^n$, *is a sufficient statistic for two phenomena. First, it measures the decline in the market value of legacy public debt in GDP units. Second, it measures the net present value of interest rate savings that the current maturity of public debt allows on legacy debt compared to a one period debt maturity in GDP units.*

Appendix G.1.4 presents the proof. The equivalence result of this proposition yields a theoretical reason for which duration-to-GDP is the correct measure for the empirical exercise. Irrespective if one is interested on the response of the market value of public debt or on the interest rate servicing costs at book value, this metric is useful for both aims.

6.4 Firms

Final Good Producers. In this economy there is a perfectly competitive sector with final good producers who combine different retail varieties according to a CES aggregator:

$$Y_t = \left(\int_0^1 y_{it}^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

This leads to the demand function for different varieties: $y_{it} = Y_t \left(\frac{P_{it}}{P_t}\right)^{-\varepsilon}$.

Calvo Retailers. Retailers buy a wholesale good at price P_t^w and use it to produce the retail variety y_{it} with a linear technology that maps one to one the wholesale good to the retail variety. As each variety is differentiated they have market power and face a Calvo friction to change prices. Their real marginal cost $\mathcal{S}_t = \frac{P_t^w}{P_t} = \frac{1}{X_t}$ is the real wholesale price. The probability of not being able to reset prices is equal to θ in each period. This leads to a standard New-Keynesian Phillips Curve.

Wholesalers. Wholesalers are perfectly competitive and they combine capital K_{t-1}, household labor H_t, and entrepreneurs labor H_t^e to make the wholesale goods:

$$Y_t = A_t K_{t-1}^{\alpha} H_t^{(1-\alpha)\Omega} (H_t^e)^{(1-\alpha)(1-\Omega)}$$

They sell these goods at nominal price P_t^w to retailers. They pay nominal wage W_t for each unit of household labor, nominal W_t^e for each unit of entrepreneur labor, and real risky return R_t^r to capital owners. The capital share in production is α and Ω is the share of household labor in the overall labor employed by the firm. Technology is stochastic and its process is follows an AR(1) in logs:

$$\frac{A_t}{A} = \left(\frac{A_{t-1}}{A}\right)^{\rho^A} \exp(\varepsilon_t^A)$$

Capital Producers. Capital producers are separate from entrepreneurs and combine investment resources I_t and legacy undepreciated capital $(1-\delta)K_{t-1}$ they purchase from entrepreneurs in order to sell new capital goods with objective function:

$$\max_{\{K_t, I_t, K_{t-1}\}_{t=0}^{\infty}} Q_t K_t - I_t - Q_t^{old}(1-\delta)K_{t-1}$$

These producers face a production with capital adjustment costs:

$$K_t = I_t - \frac{\phi_K}{2}\left(\frac{I_t}{K_{t-1}} - \delta\right)^2 K_{t-1} + (1-\delta)K_{t-1}$$

6.4.1 Entrepreneurs

Entrepreneurs in this economy buy capital from capital producers and invest it in the wholesale firms. They obtain a idiosyncratic return on investments, have linear (risk neutral) utility, and are protected by limited liability. In addition, they also supply inelastically labor to the wholesale firm and obtain a real wage w_t^e. Entrepreneurs exit each period with probability $1-\gamma$ and when they exit they consume the value of their firm (they only consume then). Each entrepreneur j invests capital in the wholesale firms and ex-post she obtains the aggregate return $1+R^k_{t+1}$ multiplied by a idiosyncratic return ω^j_{t+1}. ω^j_{t+1} is distributed according to an iid log-normal with mean one, $\ln(\omega^j_{t+1}) \sim N\left(-\frac{\sigma^2_{\omega,t}}{2}, \sigma^2_{\omega,t}\right)$. I allow for the standard deviation of the idiosyncratic risk to be stochastic and to follow an AR(1) in logs:

$$\frac{\sigma_{\omega,t}}{\sigma_\omega} = \left(\frac{\sigma_{\omega,t-1}}{\sigma_\omega}\right)^{\rho^{\sigma_\omega}} \exp(\varepsilon_t^{\sigma_\omega})$$

This is akin to the risk shock of Christiano, Motto and Rostagno (2014). What is crucial for the derivations of the entrepreneur problem with risk shocks is that the volatility of the realization for next period is known in the current period. The aggregate return is given by:

$$1+R^k_{t+1} = \frac{R^r_{t+1} + Q_{t+1}(1-\delta)}{Q_t}$$

An entrepreneur with wealth N^j_t has to borrow B^j_t at state contingent rate Z^j_{t+1} in order to invest $Q_t K^j_t$. Her balance sheet is:

$$Q_t K^j_t = N^j_t + B^j_t$$

There is costly state verification: only entrepreneurs can observe ex-post ω^j_{t+1}. Lenders pay a monitoring cost μ proportional to the gross return on the invested capital $\mu(1+R^k_{t+1})Q_t K_t \omega^j_{t+1}$. An entrepreneur pays back debt if the return on her investment $(1+R^k_{t+1})Q_t K_t \omega^j_{t+1}$ is higher than the cost of servicing debt $Z^j_{t+1}B^j_t$ otherwise defaults and the lender recovers $(1-\mu)(1+R^k_{t+1})Q_t K_t \omega^j_{t+1}$. There exists a threshold $\bar{\omega}^j_{t+1}$ above which the entrepreneur pays a fixed amount and below which there is a recovery value. The return on a loan is therefore:

$$(1+R^j_{t+1})B^j_t = \begin{cases} Z^j_{t+1}B^j_t & if\ \omega^j_{t+1} \geq \bar{\omega}^j_{t+1} \\ (1-\mu)(1+R^k_{t+1})Q_t K_t \omega^j_{t+1} & if\ \omega^j_{t+1} < \bar{\omega}^j_{t+1} \end{cases}$$

The return on this loan is in expected term (with respect to the idiosyncratic shock) but given a realized return R^k_{t+1}, it must be equal to the outside option of lenders R^{crp}_t (which is the same across all entrepreneurs as there is a large mass of them):

$$(1+R^{crp}_t)(\kappa^j_t - 1) = (1+R^k_{t+1})\kappa^j_t(\Gamma(\bar{\omega}^j_{t+1}, \sigma_{\omega,t}) - \mu G(\bar{\omega}^j_{t+1}, \sigma_{\omega,t}))$$

Where we define leverage as $\kappa_t^j \equiv \frac{Q_t K_t^j}{N_t^j}$ and:

$$\Gamma(\bar{\omega}_{t+1}^j, \sigma_{\omega,t}) \equiv \int_0^{\bar{\omega}_{t+1}^j} \omega f(\omega, \sigma_{\omega,t}) d\omega + \bar{\omega}_{t+1}^j (1 - F(\bar{\omega}_{t+1}^j, \sigma_{\omega,t}))$$
$$G(\bar{\omega}_{t+1}^j, \sigma_{\omega,t}) \equiv \int_0^{\bar{\omega}_{t+1}^j} \omega f(\omega, \sigma_{\omega,t}) d\omega$$
$$F(\bar{\omega}_{t+1}^j, \sigma_{\omega,t}) \equiv \int_0^{\bar{\omega}_{t+1}^j} f(\omega, \sigma_{\omega,t}) d\omega$$

These functions represent the expected share of the gross value of the firm going to the lender $\Gamma(\bar{\omega}_{t+1}^j, \sigma_{\omega,t})$, the expected share of the gross value of the firm on which monitoring costs have to be paid $G(\bar{\omega}_{t+1}^j, \sigma_{\omega,t})$, and the probability of default $F(\bar{\omega}_{t+1}^j, \sigma_{\omega,t})$. These functions are characterized in Appendix G with all their derivatives. Notice that the contract with a fixed real rate as an outside option for the entrepreneurs is not necessarily the optimal one as risk neutral entrepreneurs would insure risk averse household investors who face labor income risk, as argued by Carlstrom, Fuerst and Paustian (2016) and Dmitriev and Hoddenbagh (2017) among others. I take the route proposed by Christiano, Motto and Rostagno (2014) and keep this contract out of empirical relevance, as the alternative optimal contracts would have an amount of indexation not seen in the data.[29]

Entrepeneurs maximization problem. Entrepreneurs maximize their expected wealth, protected by limited liability, subject to the participation constraint of the lenders. They choose a combination of leverage κ_t^j and default cut-off $\bar{\omega}_{t+1}^j$:

$$\max_{\{\kappa_t^j, \bar{\omega}_{t+1}^j\}} \mathbb{E}_t \max \left[(1 + R_{t+1}^k) \kappa_t^j N_t^j (\omega_{t+1}^j - \bar{\omega}_{t+1}^j), 0 \right]$$
$$s.t. \quad (1 + R_t^{crp})(\kappa_t^j - 1) = (1 + R_{t+1}^k) \kappa_t^j (\Gamma(\bar{\omega}_{t+1}^j, \sigma_{\omega,t}) - \mu G(\bar{\omega}_{t+1}^j, \sigma_{\omega,t}))$$

Thanks to constant returns to scale in the production function the solution to this problem is the same irrespective of current wealth level N_t^j. This implies that the leverage and threshold choices are the same for each entrepreneur and we can aggregate to a representative entrepreneur. We define the risk spread as ratio of returns as $(1 + s_{t+1}) \equiv \frac{(1+R_{t+1}^k)}{(1+R_t^{crp})}$ and derivatives of the helping functions as $\Gamma_{\omega,t+1} \equiv \Gamma_\omega(\bar{\omega}_{t+1}^j, \sigma_\omega) = \frac{\partial \Gamma(\bar{\omega}_{t+1}^j, \sigma_\omega)}{\partial \bar{\omega}_{t+1}^j}$ and $G_{\omega,t+1} \equiv G_\omega(\bar{\omega}_{t+1}^j, \sigma_\omega) = \frac{\partial G(\bar{\omega}_{t+1}^j, \sigma_\omega)}{\partial \bar{\omega}_{t+1}^j}$. In Appendix G, I show how the entrepreneur choices can be summarized with two

[29] As a robustness check, I show how the model results do not hinge on the outside option being real debt and go through with nominal debt as in Christiano, Motto and Rostagno (2014), that is, results go through when we allow for a Fisherian debt deflation channel for corporate debt, as shown in Appendix H.5.

non-linear conditions:

$$0 = \mathbb{E}_t \left[(1 + s_{t+1})\kappa_t (1 - \Gamma_{t+1}) - \frac{\Gamma_{\omega,t+1}}{\Gamma_{\omega,t+1} - \mu G_{\omega,t+1}} \right] \tag{20}$$

$$\frac{\kappa_t - 1}{\kappa_t} = (1 + s_{t+1})(\Gamma_{t+1} - \mu G_{t+1}) \tag{21}$$

In the first condition, entrepreneurs trade-off expected gains in terms of additional returns to increasing leverage (the first term in square brackets) against the expected cost to increasing default, and therefore increasing funding costs (the second term in square brackets). This condition holds with expectations as leverage is chosen before shocks realize. The second condition is the participation constraint for lenders who are guaranteed a certain return R_t^{crp}. It must hold ex-post, with the choice of the state-contingent threshold to enforce it. Taken together, these conditions imply a *positive monotonic relationship between leverage and the risk spread*.[30]

To finish the description of the entrepreneur sector we need to specify how their wealth and consumption behave. Equation (22) describes the aggregate law of motion of entrepreneurs wealth. Entrepreneurs wealth in the current period is the sum of the return on last period wealth for entrepreneurs who do not exit and the wage that they earn by working at the wholesale firms. Similarly, equation (23) specifies the consumption for the entrepreneurs who exit, who simply consume the current value of their firm. Finally, equation (24) specifies the return on entrepreneurs equity. This return is sensitive to the difference in corporate bond rates and return on capital invested due to their levered position. Moreover, it is lower when monitoring costs are high.

$$N_t = \gamma(1 + R_t^e)N_{t-1} + w_t^e \tag{22}$$

$$C_t^e = (1 - \gamma)(1 + R_t^e)N_{t-1} \tag{23}$$

$$(1 + R_t^e) = \big((R_t^k - R_{t-1}^{crp})\kappa_{t-1} + (1 + R_{t-1}^{crp}) - \mu(1 + R_t^k)\kappa_{t-1}G(\bar{\omega}_t, \sigma_{\omega,t-1})\big) \tag{24}$$

6.5 Central Bank and Market Clearing

The Central Bank sets monetary policy according to a Taylor rule:

$$\left(\frac{1 + R_t^{mp}}{1 + R^{mp}}\right)^{1+R^{mp}} = \left(\frac{1 + R_{t-1}^{mp}}{1 + R^{mp}}\right)^{\rho^{mp}(1+R^{mp})} \left[\left(\frac{\mathbb{E}_t\pi_{t+1}}{\pi}\right)^{\phi_\pi} \left(\frac{Y_t}{Y}\right)^{\phi_Y}\right]^{(1-\rho^{mp})} \exp(\varepsilon_t^{mp}) \tag{25}$$

ρ^{mp} controls the interest rate inertia in the rule, ϕ_Y the response of interest rates to output, and ϕ_π to inflation. ε_t^{mp} is a monetary policy shock with mean zero.

[30] This becomes apparent when linearizing them, as shown in Appendix G.

In order to close the model we need the goods market clearing condition

$$Y_t = C_t + C_t^e + I_t + G_t + \mu G(\bar{\omega}_t, \sigma_\omega)(1 + R_t^k) N_{t-1} \kappa_{t-1}$$

We assume an inelastic labor supply for entrepreneurs: $H_t^e = 1$.

6.6 Equilibrium, Steady State, and Log-linearization

The equilibrium, the steady state, and the log-linearization of the equilibrium conditions around a zero inflation steady state are all presented in Appendix G. An important feature of the linearization is a convention to interpret more directly impulse response functions in light of the empirical results. Debt quantity variables are linearized over steady state GDP so that $\hat{D}_t = \frac{D_t - D}{Y}$ in order to interpret the results as changes in debt over GDP. Indeed, the main economic channel of debt supply goes through a volume effect and a standard percent deviation would not capture it[31].

7 Model Calibration and Results

7.1 Calibration

The calibration of the model is presented in Table 2. Most parameters are standard. β, α, δ, ϕ_K, η, X, and Ω all come from BGG. ϕ_π and ϕ_Y are standard values for a forward looking Taylor rule, with $\phi_Y = 0.125$ implying an increase of 50 basis points in the policy rate following a 1 percent decline in output, in line with the empirical evidence provided by Smets and Wouters (2007) and Herbst and Schorfheide (2015). The monetary policy persistence ρ^{mp} and the price stickiness parameter θ are also in the empirically plausible range of Smets and Wouters (2007) and Herbst and Schorfheide (2015). The inverse of the elasticity of intertemporal substitution σ is equal to 2 which is in the range of empirical estimates surveyed by Attanasio and Weber (2010).

The primary market friction parameter ζ is a key parameter. Andreolli (2021) estimates a range between 9 and 20 basis points using exogenous variation in the supply of public debt. I pick a value of 10 basis points. This corresponds to the impact of a 1 percentage point increase on overall debt over GDP issuance on corporate and government bonds rates. Andreolli (2021) estimates news shocks to the supply of marketable public with a high frequency identification. The paper uses the high frequency government bond future price changes around announcements of the Debt Management Office following budget speeches by the UK Chancellor of the

[31] Interest rate variables are linearized so that $\hat{R}_t^{crp} = R_t^{crp} - R^{crp}$ in order to interpret results as percentage point deviations. This includes the spreads Φ_t and s_t. I log-linearize all other variables so that $\hat{C}_t = \frac{C_t - C}{C}$.

Table 2: Model Calibration

Parameter	Value	Description
β	0.99	Time Preference
α	0.35	Capital Share
δ	0.025	Depreciation Rate
ϕ_K	10	Capital Adjustment
η	1/3	Inverse of the Frish Elasticity
σ	2	Risk Aversion
θ	0.65	Calvo Degree of Price Stickiness
Ω	0.99	Share of Labor Income Accrued to Entrepreneurs
ζ	0.1	Primary Market Friction Elasticity
ϕ_π	1.5	Coefficient of the Taylor Rule on Expected Inflation
ϕ_Y	0.125	Coefficient of the Taylor Rule on Output
τ^T	2	Tax Policy Parameter
δ^d	0.05 or 1	Debt Maturity Parameter
ρ^A	0.999	Persistence of the Technology Process
s^A	0.1	Standard Deviation of the Technology Process
ρ^G	0.95	Persistence of the Government Spending Process
s^G	0.1	Standard Deviation of the Government Spending Process
ρ^{σ_ω}	0.97	Persistence of the Risk Shock Process
s^{σ_ω}	0.1	Standard Deviation of the Risk Shock Process
ρ^Φ	0.5	Persistence of the Primary Market Friction Process
s^Φ	0.1	Standard Deviation of the Primary Market Friction Process
ρ^{mp}	0.8	Smoothing of Monetary Policy Process
s^{mp}	0.1	Standard Deviation of the Monetary Policy Process
κ	2	Leverage
s	0.0025	Risk Spread
Φ	0.0025	Issuing Friction Spread
$F(\bar{\omega}, \sigma_\omega)$	0.0075	Default Rate
$\bar{D}$	1.6	Marketable Public Debt over Quarterly GDP
$\bar{G}$	0.2	Government Expenditures over GDP
X	1/1.1	Inverse of Markups
π	1	Inflation In Steady State

Notes: The first column shows the parameter or steady state value calibrated. The structural parameters for monitoring costs μ, probability of not exiting for entrepreneurs γ, and average standard deviation in idiosyncratic risk for entrepreneurs σ_ω are computed with the aid of structural parameters and calibrated steady state values for the risk spread s, primary market friction spread Φ, leverage κ, and default rate $F(\bar{\omega}, \sigma_\omega)$. Similarly, the structural parameter for the elasticicity of substitution across varieties ε is computed one to one from the steady state value for the inverse of markups X. The calibration proposes two different values for the parameter governing the maturity of public debt δ^d, either the fraction of principal that need to be refinanced each quarter is 1 (one quarter debt), or the fraction of principal that need to be refinanced each quarter is 0.05 (around four years debt, as its historical average).

Exchequer. These announcements are orthogonal to the fiscal policy stance and other confounding factors as the Chancellor already discussed the overall fiscal stance and resulting economic activity projections during the budget speech[32]. Interestingly, similar estimates can be found in studies employing very different methodologies. Greenwald, Krainer and Paul (2020) presents a similar friction as a holding cost of debt (it is specified on the stock of debt but they have

[32]Identification is important in this setting as public debt variations are associated with changes in fiscal policy that can affect directly the macroeconomy, especially as Xu and You (2021) argue, fiscal policy can also have an information effect.

one period bonds only), and their calibration of the exponential parameter of 25 would imply a ζ of 16 basis points. Bigio, Nuño and Passadore (2019) estimate on Spanish sovereign bond data that an increase in one percent over GDP in issuance correlates with a lowering of the primary market price relative to the secondary market price of the same security by 8 to 56 basis points. Lou, Yan and Zhang (2013) show on US treasury data that an increase in one percent over GDP in issuance is associated with 14 to 23 basis points increase in the auction price[33].

For the tax policy response parameter τ^T, I pick a value in the range of empirical estimates presented by Davig and Leeper (2007) and Herbst and Schorfheide (2015). This is also close to the value (1.5) that Eusepi and Preston (2010) use. Specifically, a value of 2 implies that following an increase by 1 percentage point of public debt to GDP, taxes increase by 0.0205 percentage points of GDP. Davig and Leeper (2007) estimate a value of 0.0094 in reduced form with a Markov switching process. A value of 2 implies that following an increase by 1 percent of public debt taxes increase by 0.1516 percent; Herbst and Schorfheide (2015) estimate a 90 percent confidence interval of 0.14 to 0.49 with a structural DSGE Bayesian estimation. My choice puts me slightly on the high side of the reduced form estimates and on the low side of the structural estimates.

I use long run averages for steady state value of government expenditures $\bar{G}$. For the steady state value of public debt $\bar{D}$, I use a value of 40% of annual GDP, which is close to the long-run average of marketable public debt held by the public as shown by Hall and Sargent (2011).

I compare two economies, one with public debt with a Macaulay duration close to its long run average of about 4 years, with $\delta^d = 0.05$ and one with all debt being one period ahead with $\delta^d = 1$.

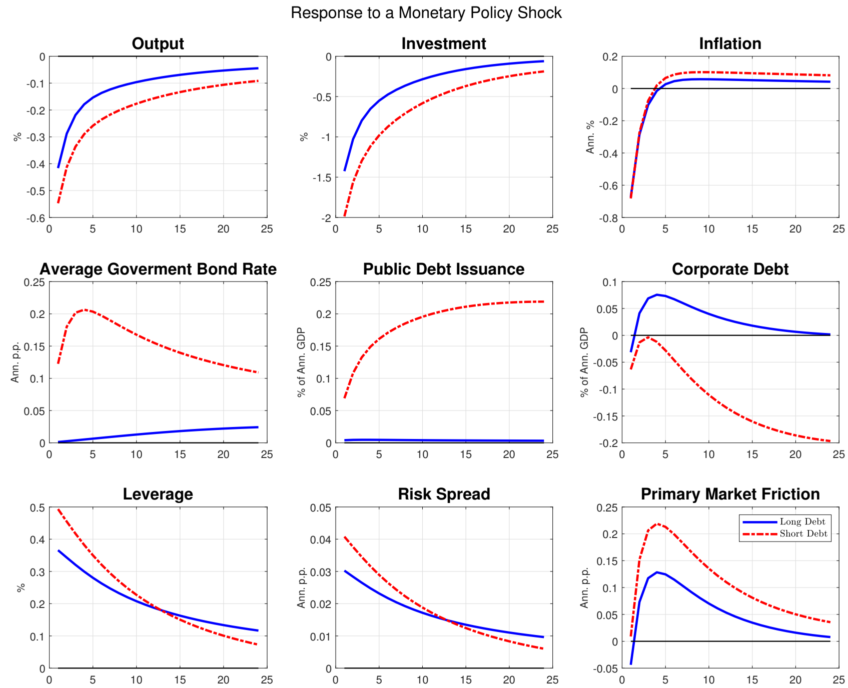
For the financial accelerator, I use the same values as BGG for leverage κ and default rate $F(\bar{\omega}, \sigma_\omega)$. For the steady state spread I assign the same overall value as BGG of 200 basis points on an annualized term, but I split this in half for the risk spread s and the primary market friction spread Φ. The resulting structural parameters are therefore very close to BGG at $\mu = 0.0593$, $\gamma = 0.9816$, and $\sigma_\omega = 0.2705$.[34]

[33] Another papers that provides evidence of a direct crowding-out from government to corporate borrowing is Önder et al. (2021) in the Colombian context. Cole, Neuhann and Ordoñez (2022) show how differences in primary to secondary market prices in Euro Area sovereign borrowers spillover from one country to another.

[34] Note that for the default steady states estimates vary considerably in the literature. If one uses Compustat data the average annual bankruptcy frequency (either Chapter 7 or 11) was 0.96% between 1980 to 2014 from Corbae and D'Erasmo (2017). From S&P data on corporate bonds the average default for all bonds has been 1.48% and for non-financial bonds 1.81% for the period 1981-2019. On the other hand bank lending delinquencies have been much higher than that and data from the Dallas Fed points to an average quarterly delinquency rate of 2.68% for commercial and industrial loans in the period 1987Q1-2020Q2. Glennon and Nigro (2005) estimate for small business loans an average of 17% default rate per loan across its life (and estimate a 4.18% default rate on the first year of life of the loan) in the period 1983-1998.

7.2 Baseline Results

Figure 6: Baseline Model Impulse Response Functions



Notes: The IRFs present the response to an annualized 25 basis points monetary policy shock. The solid blue line presents the IRFs in an economy with the maturity of public debt being at its historical average of around 4 years ($\delta^d = 0.05$). The dot-dashed red line presents the IRFs in an alternative economy with the maturity of public debt being at one quarter ($\delta^d = 1$).

The Impulse Response Functions of key variables after a 25 basis points annualized monetary policy tightening are presented in Figure 6. The responses with public debt at its historical duration of around 4 years are described by the solid blue line and the responses in a counterfactual world with only one period public debt by the red dash-dot line. The average responses are similar to a baseline New Keynesian model with a financial accelerator. Output declines on impact by 40 basis points, investment by 1.4 percent, inflation by 65 basis points, the risk spread increases by about 4 basis points[35].

If we turn to the responses of the public debt, in the blue line case (historical duration), we see that the average interest rate on government debt increases mildly, as does public debt issuance. This happens for two reasons: the main one is that all legacy debt has its rate fixed and does not need to be refinanced, a second reason is that rates further on the yield curve respond less than short rates, so overall the interest rate on newly issued long debt respond weakly to the temporary nature of a monetary policy shock. Finally, the primary market friction increases by 0.1 percentage points. This is due to higher corporate issuance as the government

[35]The model implies a general equilibrium semi-elasticity of investment to the nominal corporate bond rate of 2.2 on impact, compared with average empirical estimates slightly above 2 from Ottonello and Winberry (2020) and Cloyne et al. (2018).

does not need to refinance. This implies that the path of the primary market friction follows the sign and path of corporate debt in the long debt scenario.

I now turn to the differential impact under a counterfactual low debt maturity scenario[36] presented in the red dot-dashed line. The key difference with the long-debt case is that, in this scenario, the government borrowing profile is not insured against the interest rate increase. As the average interest rate is equal to the interest rate on newly issued government bonds, we can see that it increases by the same order of magnitude as the 25 basis points monetary policy shock. Consequently, the government needs to borrow more than 0.2 percent of GDP each quarter, a non negligible number for a small temporary monetary policy shock, which is in line with the empirical evidence presented in the first row of Figure 3. This higher issuance is what sets in motion the higher primary market friction; and from there the economic effect unfolds as in a standard financial accelerator investment channel of monetary policy. The entrepreneur is hit by higher borrowing costs which lower her net worth and increase her leverage and risk profile. This in turn makes her borrow and invest less, resulting in lower output.

A few features of this model are worth pointing out. First, this insurance channel does not have a strong impact on inflation, with inflation responding in a similar manner under the two maturity regimes, in line with the empirical results. The technical reason is that markups drive inflation in the New Keynesian Phillips Curve and, with multiple factors of production, there is not a one-to-one mapping from output to markups. The difference in output across the two regimes is offset by the change in the marginal productivity of capital. Intuitively, when public debt has a shorter maturity, the primary market works less well. Therefore, a change in interest rate hits more strongly the return on capital (because of the effect on the entrepreneurs worth) and output (because of investment), but less so markups, so that inflation behaves in a similar way in the two regimes.

The second feature pertains to the response of corporate debt under the two regimes. The model provides a testable implication on the relative response of corporate debt under the two regimes, not on the absolute response. The prediction is that corporate debt responds more negatively under a low maturity regime due to crowding-out from the primary market friction following higher issuance by the government. On the other hand, the absolute response depends on the parametrization. The reason is that, following a contractionary monetary policy shock, entrepreneurs net worth declines but leverage increases, making the absolute response of corporate debt ambiguous. In the current calibration, under a long debt regime, corporate debt increases, similarly to the original BGG paper. Despite not being a discriminating prediction, the empirical results support the sign of the responses of corporate debt under the two regimes presented in Figure 6. In the fourth row of Figure 3, the unconditional response of corporate debt issuance has a positive point estimate and the response under a low duration regime is

[36]This is counterfactual in the data, not in most macroeconomic models!

strongly negative[37].

Overall, output responds 13 basis points more under a low maturity regime, corresponding to a 31% stronger effect of monetary policy[38]. This happens with a relatively moderate increase in the spread corporate pays over the risk free rate, of less than 10 basis points. Moreover, as in the empirical results, the difference in investment response across maturity regimes is higher than the difference in output. Therefore a seemingly small primary market friction has relatively large macroeconomic effect, something we explore in more details below.

I compare the results from this theoretical exercise with the empirical ones. In Appendix D.9, I compute the difference between duration to GDP at its historical mean against a theoretical duration to GDP with an hypothetical quarterly debt. This allows to interpret the no-interaction coefficient $\beta_{1,h}$ as the response to a monetary policy shock if only quarterly maturity debt were issued. If we normalize the response of a contractionary monetary policy shock that increases the Fed funds rate by 25 basis points (by dividing by 4 the coefficient from the LP-IV), we can see that at the unconditional peak effect, monetary policy reduces industrial production by 61% more under a quarterly debt scenario, or 26 basis points. This means that the structural model can explain more than 50% of the percentage difference, highlighting the importance of the financial channel, but implying that other channels could also have a role. The model has the benefit of matching all the relative empirical responses which other channels cannot as discussed in Section 5. Specifically, following a contractionary monetary policy shock, under a longer duration, output, investment, and corporate debt are higher, inflation is about the same, and public debt issuance, leverage, and the relative price of corporate debt are lower.

7.3 Complementary between the Financial Accelerator and the Primary Market Friction

In order to generate the differential impact of monetary policy under public debt maturity regimes one needs both the financial accelerator and the primary market friction. In this subsection and in Table 3, I show how complementarity between the two frictions is key for the results. This complementarity highlights how small frictions on the primary market, can have a small direct (partial equilibrium) effect but a large indirect (general equilibrium) effect, because it interacts with the financial accelerator.

[37] Greenwald, Krainer and Paul (2020) provide independent empirical evidence that corporate debt on average can increase following a contractionary shock.

[38] Appendix H.1 presents the results for the whole set of impulse response functions. In Appendix H.2, I show that the results are robust to varying the calibration of the parameters and, in Appendix H.3, I show that the change in monetary policy strength is approximately linear in the maturity parameter δ^d. In Appendix H.4, I shows how studying a monetary policy shock with the same variance across maturity regimes yields similar outcomes as studying a monetary policy shocks with induces the same change in the endogenous monetary policy rate across regimes.

In a version of the model without the primary market friction, that is ζ is zero, the maturity structure of public debt does not matter. This is by assumption as we assumed no distortive taxation and a representative consumer in order to single out the financial market channel of transmission, this can be seen in the first row of Table 3.

Turning off the financial accelerator is more involved as the standard setting has three ingredients: limited liability, monitoring costs, and no equity issuance. If we eliminate all three we would get back to the Modigliani-Miller irrelevance of the capital structure. However, with a primary market friction on debt but not on equity we would get only equity financing, assuming that the primary market friction hits only debt issuance. For this reason, I shut off completely the entrepreneur sector. I assume that all the capital stock is financed with corporate debt which is hit by the primary market friction. Operationally, I set $\hat{\kappa}_t$, $\hat{s}_t$, $\hat{\omega}_t$, $\hat{N}_t$, and $\hat{R}^e_t$ all to zero and set $\mathbb{E}_t(\hat{R}^k_{t+1}) = \hat{R}^{crp}_t$. In this case, the risk absorption rests on the household, there is no entrepreneurial sector to absorb ex-post aggregate risk. But due to the certainty equivalence at a first order approximation it is not priced in the corporate debt rate. Note that I am stacking the cards against a complementary between the financial accelerator and the primary market friction, as here all the capital stock is subject to the primary market friction since there is no equity financing (in the baseline 50% of the capital stock is backed by equity). The resulting outcome shows the complementarity between the two frictions: the percentage difference in output across maturities is 12%, or 1.4 basis points on impact as shown in the row column of Table 3. The reason is that there is no agent with limited risk bearing capacity whose wealth is hit by higher interest costs when the government is issuing more debt[39].

Finally, in the third row of Table 3 we can see that the baseline theoretical result is higher than the sum of the two above. The financial friction increases funding costs which increases the probability of default and this feeds back into the cost of funds. Because it determines how much one can borrow, the financial accelerator friction magnifies the financing channel friction, which affects the cost of funds. The general equilibrium effects of this complementarity are non trivial.

7.4 Maturity is Key

The key driving force for the results is the variation in the volume of new public debt issued following a monetary policy shock. A natural question therefore is whether the maturity structure

[39] From this exercise, we see that the complementarity in the two frictions relies on the risk bearing capacity of the entrepreneur. As additional evidence, I show an intermediate case of financial accelerator. I keep limited liability and no equity issuance but I make bankruptcy costless, that is, I turn off monitoring costs ($\mu = 0$) and keep the same values of the other structural parameters (γ and σ_ω). The percentage difference in output is 13%, or 5 basis points on impact across maturity regimes. The absence of bankruptcy costs mutes the impact of the government additional issuance under a low maturity case as higher leverage does not feed into higher borrowing costs.

Table 3: Complementarity Between the Financial Accelerator and the Primary Market Friction.

Percent Difference in Output Response High-Low Maturity	
No Primary Market Friction	0%
With Primary Market Friction and No Financial Accelerator	12%
With Primary Market Friction and Financial Accelerator	31%

Notes: This table shows how much more effective is monetary policy on output on a short maturity regime compared to a long maturity regime. In the first experiment, the comparison is in a case without the primary market friction. The second experiment shuts off the financial accelerator and keeps the primary market friction, this is achieved by setting $\mathbb{E}_t(\hat{R}^k_{t+1}) = \hat{R}^{crp}_t$ and setting to zero all entrepreneurs related variables as leverage, risk spread, entrepreneurs wealth, default threshold, and return on equity. The experiment presented in the third row is the baseline model with both the financial accelerator and the primary market friction present.

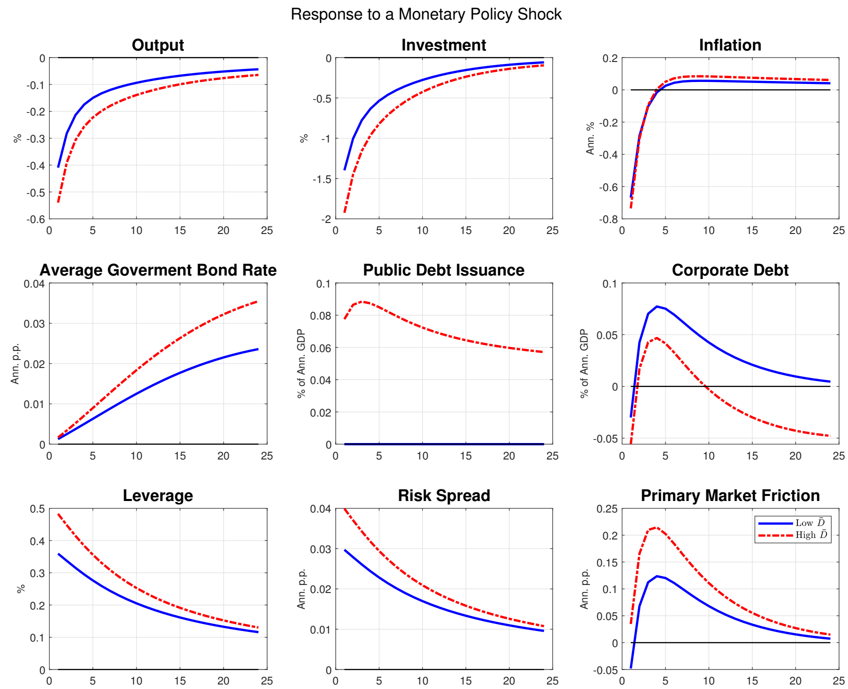
of public debt is crucial or only a change in the stock of public debt would suffice to generate the results. At a qualitative level an increase in the stock of public debt holding maturity constant has the same effect as lowering the maturity structure holding the debt stock constant: they would both make monetary policy more effective on output. However, to reach the same quantitative effect the increase in public debt needed to match the results with maturity would be implausibly high: to achieve a 30% higher effectiveness of monetary policy we would need to go from 0% public debt over annual GDP to 700% public debt over annual GDP, while holding maturity at its historical average of 4 years, as shows in Figure 7. The same result can be achieved by lowering maturity from 4 years to 1 quarter holding marketable public debt at its historical average of 40%. This is an important result: *crowding out non financial firms comes not so much from high debt levels but from large roll-overs of short maturity debt*: this is the gross issuance flow that matters.

8 Conclusion

This paper shows that the effect of monetary policy on output is greatly attenuated when public debt has a long maturity. Going from the average historical duration of US debt to very short term debt *doubles* the impact of a rise of the policy rate on output. In contrast, the transmission mechanism on inflation is not affected much by the maturity structure. The same results hold for the United Kingdom, which has a very different maturity time profile than the United States. After providing a novel narrative account of the political and legal constrains that affected maturity choices, numerous robustness checks, and an exploration of different possible channels, this paper shows that these striking facts can be explained by the *financing channel* of monetary policy transmission.

Long maturity debt acts as an insurance mechanism. Following a contractionary monetary policy shock the government experiences the equivalent of an insurance payout as it does not

Figure 7: Model Impulse Response Functions with Different Public Debt Levels



Notes: The IRFs present the response to an annualized 25 basis points monetary policy shock. The solid blue line presents the IRFs in an economy with no public debt to GDP in steady state. The dot-dashed red line presents the IRFs in an economy with high public debt to GDP in steady state (700%). In both scenarios, the maturity of public debt is at its historical average of around 4 years ($\delta^d = 0.05$).

need to refinance debt at the new higher rate. It does not react directly to this payout with more discretionary spending but instead borrows relatively less. In presence of even a small financial friction on the primary debt issuance market, this leads to higher corporate borrowing and investment and lower spreads: there is less crowding-out. This is a quantitatively important effect and the implications for monetary policy transmission are large.

A standard financial accelerator model à la Bernanke, Gertler and Gilchrist (1999) with a government issuing fixed rate long dated debt and a friction on the primary market for debt issuance can account for the results. A key parameter to calibrate is the primary market friction. I rely on Andreolli (2021) which provides estimates of the pure effect of shocks to the public debt supply using high frequency identification around Debt Management Office announcements. Despite being small in magnitude, this primary market friction matters and is at the root of the *financing channel* of monetary policy transmission.

When interest rate increases, the small primary market financial friction increases funding costs, which raises the probability of default and this feeds back into the cost of funds. Because it determines how much one can borrow, the financial accelerator friction magnifies the financing channel friction, and in turn affects the cost of funds. The general equilibrium effects of this complementarity are non trivial.

The maturity structure itself is key to explain the results. As explained, going from the average historical duration of US debt to very short term debt *doubles* the impact of a rise of the policy rate on output. To obtain the same quantitative difference in responses to a monetary policy by varying only the stock of debt, fixing its maturity at its historical mean, one would need to go from a public debt of 0 to over 700% of GDP. This is an important result: crowding out non financial firms comes not so much from high debt levels but from large roll-overs of short maturity debt. It is the gross issuance flow that matters, i.e. the *financing channel*.

The maturity of public debt can provide useful risk management tool for policy makers and can help in the coordination between the fiscal and the monetary policy makers. If governments push upward the maturity of their debt when interests are low, they can make it easier for central banks to react against sudden increases in inflation.

More generally, while I focus in this paper on variation in interest rates coming from monetary policy shocks, the role for maturity structure of public debt presented here would work for interest rate changes coming from other sources. With long maturity debt, a government will be insured from interest rate increases and will suffer from interest rate declines. In the past 30 years interest rates have been declining across the rich world. This implies that, government borrowers who borrow relatively longer, as European ones, did not benefit from interest rate declines as much as sovereign borrowers with shorter profiles, as the United States. In light of the results of this paper on the financing channel, this can spill over to the corporate sector. Similarly, this financing channel can account for some of the heterogeneity in transmission of US rate increases to emerging markets, with borrowers with shorter sovereign debt maturities being affected relatively more than those with longer dated debt.

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A A Brief History of Public Debt Maturity Choices in the US

Objectives. The Treasury has chosen the maturity of public debt with two generally conflicting objectives in mind. On one hand, the Treasury tries to keep funding costs as low as possible, and this generally pushes the debt toward shorter maturities as the yield curve is generally upward sloping. On the other hand, the treasury tries to minimize some notion of rollover and interest rate risk, thereby pushing towards a higher maturity. The official objective of the US Office of Debt Management is: "Fund the government at the least cost to the taxpayer over time", and among the strategies we find: "Maintain manageable rollovers and changes in interest expense" (see Office of Debt Management, 2020).[40]

The relative importance of these competing aims has shifted, giving rise to a time series variation in the maturity structure of public debt. But importantly for this paper, the changes in the maturity regimes were taken for reasons that do not pertain to monetary policy choices or to factors determining the strength of monetary policy. **The determinants of maturity choice are exogenous with respect to monetary policy, they are slow moving and for a large part of the sample are determined by legal restrictions.**

I now review the main historical developments relevant for the maturity of public debt in the US. We can see clearly the slow moving debt management choices with the Macaulay duration at Face Value in the right panel of Figure C.2.

The modern debt management framework in the US started before the estimation sample, following the Treasury-Fed accords of 1951, when the Fed became independent in setting monetary policy and the Treasury took charge of debt management. After a brief period of coordination between the Treasury and the Fed with operation Twist, where the Fed intervened in long dated debts to flatten the yield curve, the Fed moved to a policy of intervention only on the short rate in the mid 60s. This followed the consensus that the policy did not work as expected as argued by Modigliani and Sutch (1966). This sealed the independence of the two institutions in the period under study.

The interest rate ceiling law period. In the earlier part of the sample, up to the mid 70s, we can see a constant decline in the maturity of debt. This was happening due to a shortening of the securities issued as a law forbade the Treasury from issuing bonds with interest rates

[40] During our entire sample, officials express a dual objective function as documented by Greenwood et al. (2014). In 1998 the Assistant Secretary of the Treasury for Financial Markets Gary Gensler argued at the House committee on Ways and Means that the objective of debt management is "achieving the lowest cost financing for the taxpayers", and "a balanced maturity structure also mitigates refunding risks". In 2008, Director of the Office of Debt Management Karthik Ramanathan also argued for achieving the "lowest cost of financing over time" and to "spread debt across maturities to reduce risk".

above 4.25%. This law was instituted in 1918 (see p. 635 Friedman and Schwartz, 1963) and was not binding for a long time as interest rates were low. In the early 60s, Friedman and Schwartz (1963) argued that the ceiling might constraint the maturity choices of the Treasury and that a possible repeal was a point of political debate. The ceiling became binding from the mid 60s on longer date bonds, effectively pushing the Treasury to lower maturities (the law applied to bonds but not to medium term notes). In a testimony at the Ways and Means House Committee, Secretary of the Treasury John B. Connally, in 1971, expressed how this was a binding constraint for debt management and his desire to lengthen the existing maturity: "Because of the interest rate ceiling, the Treasury has been unable to sell a security maturing in more than seven years since mid-1965. The result has been a substantial and serious piling up of the debt in the short-term area" (see Ways and Means Committee Hearing, 1971).

This law was repealed in steps. Congress approved an initial allowance for $10 billions issuances above the ceiling for bonds maturing in more then 7 years following the 1971 testimony. It then allowed an extension to bonds only maturing in more than 10 years and the increased the allowance to $12 billions in March 1976 (see HR11893, 1976); this coincided with the lengthening on the Face Value duration that we can see in the right panel of Figure C.2 in the late 70s. The allowance was increased several times again, in June 1976 to $17 billion, in 1977 to $27 billion, in 1978 to $32 billion, in April 1979 to $40 billion, in 19 September 1979 to $50 billion, and in 1980 to $70 billion (see references in Garbade, 2015). We can find evidence that the ceiling was binding in political debates throughout the period. In 1982, the Treasury asked, unsuccessfully, to Congress to the repeal the ceiling in order to increase the maturity of public debt: "Treasury has exhausted its $70 billion authority to issue long term bonds and was forced to cancel its regular quarterly issues of 20-year bonds in April and 30-year bonds in May. Treasury believes it must continue to issue bonds to maintain a presence in all maturity sectors of the bond market and to resist shortening the maturity of the public debt" (see Committee on Finance Hearing, 1982).

The ceiling was not repealed, but it raised again following the Treasury request in 1982 to $110 billion; and then again in 1983 to $150 billion, in 1984 to $200 billion, in 1985 to $250 billion, and in 1987 to $270 billion (see references in Garbade, 2015). Finally, the law was repealed in 1988 (see US Treasury, 2021). Throughout the 60s, 70s, and 80s we can see a desire of the Treasury to lengthen the maturity to minimize refinancing risk, restrained by Congress which was more afraid of the high cost of longer maturity debt[41]. The debate and the law ceilings were *exogenous* with respect to the monetary policy actions and its strength in affecting output.

[41] As reported by Shanahan (1971), the chairman of the House Banking Committee, Representative Wright Patman of Texas argued at the Ways and Means Committee "the existence of the 4-1/4 percent interest rate ceiling was the only thing that had kept the Treasury from selling bonds with interest rates as high as 8 per cent and maturities of 30, 40 or even 50 years, during the recent period of tight money".

Focus on costs. Until the interest rate ceiling law was in place, the focus of the Treasury had been increasing the average maturity with the aim of reducing rollover risk. However, the repeal allowed the Treasury to reassess its maturity choices. The push toward longer maturities ended soon after the repeal, with a stronger emphasis on lowering average debt costs in the Treasury. Wessel (1993) argues that the Clinton administration would want to save on debt servicing costs with the reasoning: "the case for the change is straightforward: The interest rate on a 30-year Treasury bond is substantially higher than the rate on a three-month Treasury bill. If the Treasury borrowed less at 30-year rates and more at three-month rates, taxpayers could save billions of dollars". Following a decision to lower the maturity of debt the Secretary of the Treasury Lloyd Bentsen argued: "We have considered this issue very carefully and believe the restructuring of our debt mix, over the long run, is in the best interests of American taxpayers. This action to shorten the maturity of Treasury borrowing will produce real savings on interest costs over time" (see references in Garbade, 2015)[42].

The case for shortening of the average duration to lower borrowing costs kept going until the mid-aughts, with a mechanical increase in Macaulay duration, but not in duration-to-GDP in the late 90s. The strong fiscal surpluses and declining levels of public debt pushed down duration-to-GDP, but initially increased Macaulay duration as the Treasury simply issued lower amounts of new debt, without retiring existing long bonds. The desire the shorten debt maturity was the reason why the Treasury undertook the buyback operations in 2000 and 2001, together with wanting to concentrate issuance in a smaller number of larger issues to maintain liquidity in the Treasuries market (see Garbade and Rutherford, 2007). The Secretary of the Treasury Lawrence Summers made this argument in 1999 for the advantages of the buyback operation: "first, by prepaying the debt we would be able to maintain larger auction sizes than would otherwise be possible. Enhancing the liquidity of Treasuries benchmark securities should lower the governments interest costs over time and promote overall market liquidity. Second, by paying off debt that has substantial remaining maturity, we would be able to prevent what would otherwise be a potentially costly and unjustified increase in the average maturity of our debt" (see Summers, 1999). As part of the commitment to lower the average maturity the Treasury decided to stop issuing 30 years bonds in 2001 (see US Treasury, 2021)[43].

Long maturity strikes back. The intellectual environment shifted again in the mid aughts, this time in favor of long bonds, with a stronger emphasis on rollover risk. The decision to lengthen the maturity started before the financial crisis and the subsequent increase in debt, in a period of relatively strong tax receipts and low federal deficit. The Treasury reintroduced

[42]Note that the yield curve was not particularly steep in the early 90s, in December 1993 the difference between a 10 year and a 3 month Treasury rates was 2.76%. In September 1982, when the Treasury asked Congress to be able to issue longer maturity debt, this spread was 3.85%.

[43]This can be seen graphically in Figure C.3 with the 30 years promises disappearing after 2001.

the 30 years bond in 2006[44] and discontinued the 3 years note in 2007.

The estimation sample ends at the beginning of the financial crisis, but for completeness, I show how the maturity choices of the Treasury continued in the same path. The increase in maturity of Treasury issuances kept increasing following the financial crisis until today. The risk of rollover was emphasized more often. As an example, the Treasury Borrowing Advisory Committee suggested in 2009: "The conclusions were that the potential for inflation, higher interest rates, and roll over risk should be of material concern. In most economic scenarios, lengthening the average maturity of debt from 53 months to 74-90 months was recommended. Committee members commented that while real progress has been made in terms of lengthening the average maturity of US Treasury debt to 53 months [...], more needs to be done in this regard" (see Treasury Borrowing Advisory Committee, 2009). Then again in 2010: "further lengthening of the average maturity should take precedence" (see Treasury Borrowing Advisory Committee, 2010). The push toward higher maturities took shape in a period when the yield curve was relatively steep, with short rates at the zero lower bound, but longer rates still well in positive territory. The Treasury was buying relatively expensive insurance.

Between the 1951 Treasury accords and the QE2 period, there was a strong separation of roles between the Fed and the Treasury. We can directly see this by noticing how close the baseline value and the value for *Also Fed Holdings* are for Macaulay duration and duration-to-GDP in Figure C.2. However, that changed with QE2, when the Fed bought long dated Treasury bonds. In this last period, the two agencies have conflicting objectives (see Greenwood et al., 2014): the Treasury tried to increase the maturity of public debt to minimize rollover risk and the Fed tried to lower the maturity to lower the term premium. The overall duration-to-GDP increases in line with the Treasury objective. However, I exclude this last period also to avoid any potential contamination.

To summarize, this narrative account of the maturity choices shows how the Treasury chose the debt composition *exogenously* with respect to the monetary policy cycle. In the period up to 1988, the Treasury was directly constrained by the 4.25% interest rate ceiling law in its maturity choices. From 1993 the trade-off calculation shifted toward costs pushing towards shorter maturities, and then again, in 2005 it shifted back toward rollover risk and toward longer maturities.

[44] The Treasury Borrowing Advisory Committee, the advisory committee of private institutions who buy government debt, remarked in their quarterly report in April 2005: "reintroducing 30-year bonds would serve to mitigate rollover risk given large maturities in coming years" (see Treasury Borrowing Advisory Committee, 2005).

B Microfoundation of the Primary Market Friction

In this section I propose two possible microfoundations to the primary market friction. The key idea underlying both microfoundations is based upon some degree of market segmentation. The primary market for government and corporate debt can be accessed only by specialized players. In the real world, they would be primary dealers and desk in investment banks dealing with underwriting and placing bonds.

B.1 Risk-Averse Arbitrageurs

The first microfoundation is based on risk averse primary market participants. These agents are risk averse and live for one initial sub-period, akin to the Vayanos and Vila (2021) arbitrageurs. They are selected out of the households, buy newly issued government debt l and newly issued corporate debt crp on the primary market with either equity e_t or riskless debt b_t and they subsequently sell it to the secondary market at price $q^i_{t+\Delta}$ for $i = \{l, crp\}$. There is a technological constraint that forces them to bid in advance of knowing the final secondary market price.

The consequence of these assumptions is that the primary market price is generally lower than the secondary market price. This is a reward for risk taking for these specialized investors. One can find evidence of this outcome empirically. Primary dealers both for government and private bonds must use their own balance sheet to provide liquidity in the secondary market for such securities because of contractual obligations. This is a well known phenomenon in issuance for most market based financial instruments even for very liquid government bond auctions as discussed in Duffie (2010). Lou, Yan and Zhang (2013) document this *auction cycle* for US treasuries and Eisl et al. (2019), Beetsma et al. (2016), Sigaux (2018), Bigio, Nuño and Passadore (2019) for Eurozone sovereign issuers. All these papers relate this empirical finding to segmented primary markets and limited risk bearing capacity of these investors.

These agents have mean-variance utility on their terminal value of wealth $e_{t+\Delta}$ with absolute risk aversion a.

$$\max_{b_t, b_t^{crp}, l_t} \mathbb{E}_t \left[e_{t+\Delta} \right] - \frac{a}{2} \mathbb{V}ar_t \left[e_{t+\Delta} \right]$$

Their two sub-periods budget constraints are:

$$\begin{aligned} e_t &= b_t + b_t^{crp} + l_t \\ e_{t+\Delta} &= b_t + q^{crp}_{t+\Delta} b^{crp}_{t+\Delta} + q^l_{t+\Delta} l_{t+\Delta} \end{aligned}$$

Where I assume for simplicity that the sub-period is short enough for the riskless asset to not earn any interest. All the results go through with a non-zero interest as well, at the cost of added notation without any further insight. We can consolidate the two budget constraint into one by substituting in for the riskless debt:

$$e_{t+\Delta} = e_t + (q^l_{t+\Delta} - 1)l_{t+\Delta} + (q^{crp}_{t+\Delta} - 1)b^{crp}_{t+\Delta}$$

Which has the intuitive interpretation that the investor can trade-off risky capital gains in the primary markets for the riskless debt. Before solving the problem, we can define the joint second moments of the capital gains as $\sigma_{l,crp} = \mathbb{C}ov_t(q^l_{t+\Delta} - 1, q^{crp}_{t+\Delta} - 1)$ for the covariance between the government and corporate debt capital gains, and similarly for the variances. We can rewrite the variance of terminal wealth: $\mathbb{V}ar_t\left[e_{t+\Delta}\right] = \sigma^2_l l^2_t + \sigma^2_{crp}(b^{crp}_t)^2 + 2\sigma_{l,crp} l_t b^{crp}_t$. With this expression, we can plug it into the objective function and solve for the optimal allocation:

$$\frac{\partial}{\partial l_t} : \mathbb{E}_t\left[q^l_{t+\Delta} - 1\right] = a\left[\sigma^2_l l_t + \sigma_{l,crp} b^{crp}_t\right]$$
$$\frac{\partial}{\partial b^{crp}_t} : \mathbb{E}_t\left[q^{crp}_{t+\Delta} - 1\right] = a\left[\sigma_{l,crp} l_t + \sigma^2_{crp} b^{crp}_t\right]$$

For a given volatility process of the returns to the capital gains this links the quantity of debt to the risk premia associated with participating in the primary market. Note that this creates a mapping from public debt quantity supplied to the corporate debt price and this mapping is $a\sigma_{l,crp}$. With the additional assumption that $\sigma^2_{crp} = \sigma^2_l = \sigma_{l,crp}$, that is, perfect correlation of returns and same variance, then the two risk premia are identical and are exactly equal to $\hat{\Phi}_t$ in the linearized model. Moreover, $a\sigma_{l,crp}$ becomes equal to ζ.

This microfoundation shows how we can rationalize the primary market friction with the widely used framework of risk averse arbitrageurs in segmented market. However, this is only one such possibility to achieve it and the results do not hinge on its specifics. In order to show the generality of the primary market friction, in the next subsection, I propose another microfoundation isomorphic to this one.

B.2 Moral Hazard

As an alternative microfoundation I employ the framework presented by Gabaix and Maggiori (2015): a moral hazard problem whereby the primary market dealers can abscond a fraction Γb_t of the total borrowing from the lender. This is similar to Kiyotaki and Moore (1997) with the addition that the fraction absconded can depend on the size of the balance sheet of the dealers, to highlight the role of financial complexity.

In this framework, the setting is as in the first microfoundation with the simplifying assumptions of linear utility and no initial equity. We can proceed by splitting the problem in two steps. The first step is the choice of the balance sheet b_t. The second step is the choice of what type of debt to buy. To this aim, I define the return on total assets $q^A_{t+\Delta} \equiv \frac{q^l_{t+\Delta} l_t + q^{crp}_{t+\Delta} b^{crp}_t}{b_t}$. The first step of the problem of the primary market participant can be written as a choice of the borrowing level:

$$\max_{b_t} \mathbb{E}_t \left[(q^A_{t+\Delta} - 1) b_t \right]$$
$$s.t.\ b_t \leq (1 - \Gamma b_t) \mathbb{E}_t \left[q^A_{t+\Delta} b_t \right]$$

That is, the objective of the agent is to maximize the expected value of the net return on assets. The problem is subject to total borrowing being at most the fraction not absconded of the expected terminal value of the firm. As the objective function is linear and the constraint is concave in b_t the constraint binds and we can find the optimal size by solving the constraint for the positive solution of b_t:

$$\frac{1}{\mathbb{E}_t \left[q^A_{t+\Delta} \right]} = 1 - \Gamma b_t$$
$$b_t = \frac{1}{\Gamma} \frac{\mathbb{E}_t \left[q^A_{t+\Delta} \right] - 1}{\mathbb{E}_t \left[q^A_{t+\Delta} \right]}$$

This expression has intuitive sense. The size of the balance sheet will be lower the higher the fraction of divertable output and the lower the expected return on investing in the primary market. The overall return is linear in the returns in the corporate and government debt, therefore, to have investment in both the return must be the same in equilibrium. In addition, an increase in government debt quantity has the same impact on the price of both government and corporate debt, and vice-versa.

$$\frac{\mathbb{E}_t \left[q^l_{t+\Delta} \right] - 1}{\mathbb{E}_t \left[q^l_{t+\Delta} \right]} = \Gamma (b^{crp}_t + l_t)$$
$$\frac{\mathbb{E}_t \left[q^{crp}_{t+\Delta} \right] - 1}{\mathbb{E}_t \left[q^{crp}_{t+\Delta} \right]} = \Gamma (b^{crp}_t + l_t)$$

These expressions again map directly to the primary market friction presented in the model. The message from the two microfoundations is that the relationship between debt quantities and prices in the primary market arise from a variety of standard models in macroeconomics and finance. Moreover, the exact nature of the friction does not matter per se.

Appendix References

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