Optimal public debt indexation in advanced economies

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Abstract

This paper examines the cross-country heterogeneity in the share of advanced economies' inflation-linked (IL) debt when governments, taking inflation as given, issue IL debt and nominal debt and aim to minimize tax distortions, debt investors are risk-neutral, and nominal debt carries a convenience premium. The optimal IL debt share increases in the level and the variance of inflation, decreases in the correlation between government spending and inflation, and, for a fixed level of debt, decreases in the nominal debt's convenience premium. Data between 1995 and 2018 for 14 advanced economies that issue IL debt exhibit cross-country correlations in line with the model's comparative statics about inflation. The model's welfare analysis suggests that nominal debt's convenience premium can explain the relatively low public debt indexation in most advanced economies.

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1 Introduction

Between 1995 and 2018, advanced economies issued, on average, 10% of their total public debt linked to inflation. However, countries' reliance on this type of asset is highly uneven. For example, the United Kingdom or Israel issued almost a quarter of their public debt in this manner, whereas Japan or Korea issued only about 1%.

This paper proposes a model to examine the cross-country heterogeneity in inflation-linked (IL) debt in advanced economies and brings the model's predictions to the data. The elements of the model are the following. First, governments need to finance an uncertain stream of government spending. Second, to finance their spending, they issue IL debt and nominal debt taking inflation as given and aiming to minimize tax distortions. Third, domestic debt investors are risk-neutral, but nominal debt carries a convenience premium due to unique attributes investors attach to nominal debt and not to IL debt (Fleckenstein et al. 2014).

Fleckenstein et al. (2014) uncovers significant mispricing between nominal debt and IL debt in the US. Their interpretation is that the attributes of safety and liquidity Krisnamurthy and Vissing-Jorgensen (2012) find that apply to public debt only apply to nominal securities, bringing down the nominal yields but not the IL yields. This finding is not exclusive to the US. For a larger sample of advanced economies, Ermolov (2021) finds that, at medium-term maturities, IL debt is more expensive to issue than nominal debt due to an illiquidity premium.

The literature that considers IL debt a commitment device for governments tempted to inflate away their nominal debt predicts that nominal rates are higher than IL rates due to an inflation risk premium. Furthermore, in that view, governments increase inflation in bad times, thereby decreasing the real burden of their nominal debt during crises (Du et al. 2020, Engel and Park 2022). However, inflation often increases in good times in advanced economies.

This paper, therefore, proposes a risk-sharing perspective to analyse IL debt in advanced economies, similar to that of Bohn (1988), Calvo and Guidotti (1990), Barro (1997), and Missale (1999), extended with a liquidity motive to issue nominal debt as in Greenwood et al. (2015).

According to the model presented in this study, when governments issue both nominal and IL debt, the optimal IL debt share increases in the level and the variance of inflation and decreases in the correlation between government spending and inflation. The intuition for each of these comparative statics is as follows. First, the higher inflation is, the higher inflation expectations become, decreasing how much the government collects from issuing nominal debt and increasing the IL debt it needs to issue. Second, if inflation volatility increases, the government moves away from nominal debt, to avoid a more volatile real repayment, thereby decreasing tax distortions. Finally, the government hedges its budget constraint by issuing a higher IL debt share when the correlation between government spending and inflation decreases. Doing so avoids a higher real repayment from nominal debt when the burden from government spending increases.

The last comparative static implies that IL debt is a good hedge for a country with a negative correlation between government spending and inflation. Adding an assumption of countercyclical government spending, the model allows us to conclude that IL debt is an appropriate hedge for countries with procyclical inflation, offering a rationale for countries with procyclical inflation to issue IL debt.

The optimal IL debt share also decreases in the nominal debt's convenience premium for a fixed level of debt. Intuitively, the government issues a higher share of nominal debt if it is more valuable to investors and generates more revenues for the government. A higher convenience premium allows the government to finance itself at a lower interest rate and collect enough revenues to issue less IL debt.

A welfare analysis within the model sheds light on a government's decision whether to increase its IL debt issuance or not. The government compares the welfare gain from increasing its IL debt, thereby decreasing its illiquidity, against giving up the lower borrowing costs of nominal debt. A back-of-the-envelope calibration shows that the welfare gain is substantially smaller than the nominal debt's convenience premium.

Data between 1995 and 2018 for 14 advanced economies that issue IL debt show evidence consistent with some of the model's comparative statics. The cross-country correlations between the average IL debt share and inflation and between the average IL debt share and the standard deviation of inflation are positive and sizable.

The remainder of the paper is structured as follows. Section 2 highlights the paper's contribution to the earlier literature. Section 3 presents relevant stylized facts about IL debt and inflation's cyclical properties in the advanced economies from the study's sample. Section 4 describes the model, presents and tests the key comparative statics on the share of IL debt, and lays out the welfare analysis. Lastly, Section 5 concludes the paper.

2 Contribution to the literature

This study is related to several strands of the literature. First, it is related to the risk-sharing literature on IL debt and the references cited in the introduction. This study complements this literature by adding a convenience premium to nominal debt, as Greenwood et al. (2015), which generates an empirically relevant pricing difference between IL debt and nominal debt, and by bringing the model's predictions to the recent IL debt data of advanced economies. Samuelson (1988) studies IL debt against real money balances in an environment where real money balances enter the consumers' utility function, and the government chooses public spending, the interest rate on IL debt, and lump-sum tax revenues. Instead, in this study, the government chooses between IL debt and nominal debt and taxing has a distortionary quadratic cost, resulting in pros and cons of IL debt not found in Samuelson (1988). More recently, Westerhout and Beetsma (2019) and Westerhout (2020) have studied the stabilization properties of IL debt. The former authors study them in the presence of fiscal constraints, and the latter studies optimal indexation in the presence of countercyclical monetary policy when nominal debt carries an inflation risk premium. In contrast, this study abstracts from fiscal constraints since many advanced economies do not have any and, instead of an inflation risk premium in nominal debt, considers an illiquidity premium in IL debt.

Second, this study is related to the literature on IL debt as a commitment device for countries (Persson et al. 1987, 2006, Diaz-Gimenez et al. 2008, Alfaro and Kanczuk 2010, Sunder-Plassmann 2020). Unlike those papers, in this study, the government takes inflation as given and chooses the optimal IL debt share to minimize tax distortions, an approach that aligns better with countries with independent central banks.

Third, it is related to the literature on cross-country heterogeneity in public debt composition. A lot of this work is empirical and focuses on public debt's currency denomination in emerging economies (Eichengreen et al. 2002, Hausmann and Panizza 2003, Burger and Warnock 2006, Claessens et al. 2007, Ogrokhina and Rodriguez 2018, Engel and Park 2022). These papers find that, among others, country size, exchange rate regimes, inflation level and volatility, creditor protection, and inflation-targeting regime matter. Mehl and Reynaud (2010) broadens the scope of the assets studied to short-term maturities and IL debt but still limits the analysis to emerging economies. They conclude that only inflation impacts all types of risky assets. Economic size, fiscal soundness, and breadth of domestic investor size are also important for certain risky assets, particularly for IL debt. In contrast, this paper investigates IL debt in advanced economies and focuses on the relevant explanatory variables from an optimal public debt indexation model. Gomez-Gonzalez (2021) studies the drivers of IL debt in advanced and emerging economies but also takes an empirical approach instead of deriving the relevant variables from a model.

Finally, this paper builds on the finance literature that studies IL debt's pricing versus that of nominal debt in advanced economies. The references cited in the next section conclude that investors require an illiquidity premium to hold IL debt and that the special attributes of liquidity and safety attached to nominal debt do not apply to IL debt from the investors' perspective. This study complements this literature by studying this literature's implications for optimal public debt indexation.

3 IL debt, inflation behavior, and IL rates

This section presents key facts about advanced economies' IL debt, reports inflation's cyclical properties for these countries, and reviews the finance literature on IL rates.

The study's dataset contains data on IL debt outstanding between 1995 and 2018 for almost all the advanced economies that issue IL debt[1]. The data sources are reported in Table 1 in the Online Appendix. Furthermore, the dataset includes annual data on inflation measured as the percentage change in the logarithm of the gross domestic product (GDP) deflator, the real GDP, and real government consumption since 1955, the earliest a country in the sample started issuing IL debt. The data source for these macroaggregates is the Organisation for Economic Co-operation and Development (OECD) Quarterly National Accounts. Several interesting stylized facts emerge from these data.

The size of the IL debt market of advanced economies has increased substantially in the last 20 years, as shown in Figure 1. In the study's sample, IL debt increased from 51.6 billion US dollars

[1]Only Greece, which started issuing IL debt in 2003 (ECB (2003)), is missing from the sample due to the lack of available data.

in 1995, or 0.01% of total advanced economies' GDP, to 3.4 trillion US dollars in 2018, or 0.14% of total advanced economies' GDP.

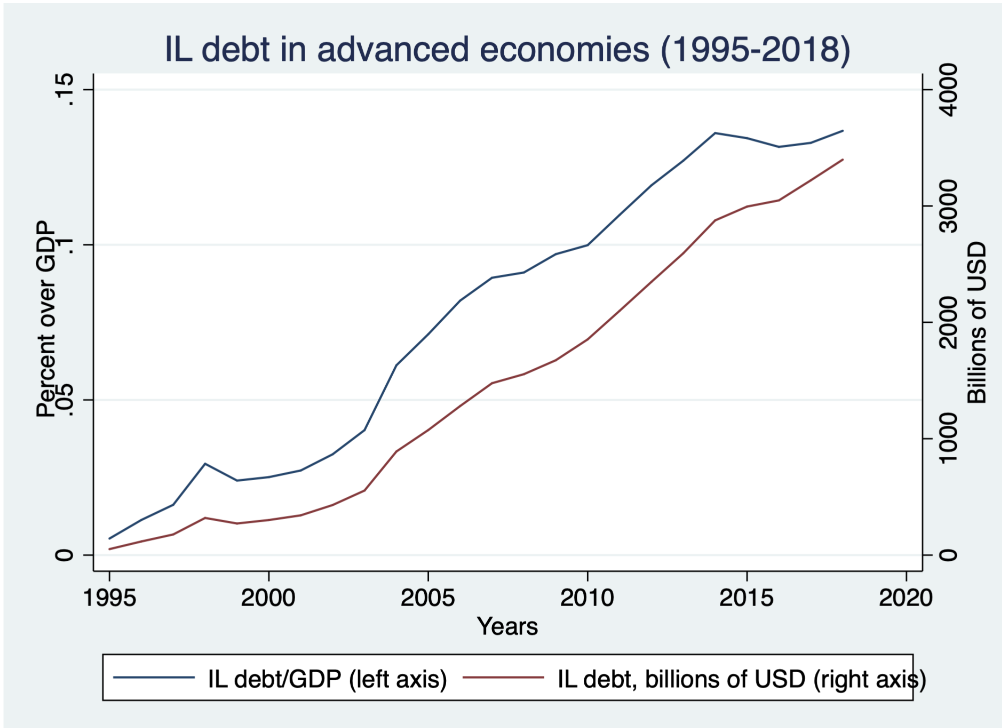

Figure 1: Overall size of the IL debt of advanced economies (in % of total advanced economies' GDP and in billions of US dollars). Sources: See Table 1 in the Online Appendix.

Most countries issue this type of debt at maturities ranging from five to 30 years and link their issuance to the domestic consumer price index (CPI). The exceptions to the second observation are Germany, Spain, the United Kingdom, France, and Italy. Germany and Spain issue their IL debt indexed to the European CPI and the United Kingdom to the retail price index (RPI). France and Italy have two types of IL debt: one indexed to the European CPI and another indexed to their respective domestic CPIs. See Table 3 in the Online Appendix for the maturities each country has issued.

Table 1 lists key facts about the importance of IL debt in the public debt of advanced economies. The second column reports the countries' share of IL debt between 1995 and 2018. On average, between 1995 and 2018, advanced economies issued 10.2% of their total debt linked to inflation. In 2018, countries such as the United Kingdom, New Zealand, and Israel issued more than 20%, and the US issued 10.6%.

IL debt in advanced economies, 1995-2018			
Country	IL debt/debt	Increases in IL debt/debt	Increases in IL debt
Australia	7.2%	2.3	10.7
Canada	4.9%	4.5	8.7
France	10.1%	7.4	22.1
Germany	3.9%	5.8	6.4
Iceland	12.8%	0.3	2.7
Israel	24.1%	0.9	2.0
Italy (€)	6.2%	9.0	14.7
Italy	4.1%	2.2	2.7
Japan	1.0%	3.1	3.4
Korea	1.2%	2.1	4.2
New Zealand	9.4%	3.5	10.8
Spain	3.6%	3.6	4.1
Sweden	13.1%	14.3	13.0
United Kingdom	24.7%	1.1	3.4
United States	8.5%	8.8	42.8
Average	10.2%	4.6	10.1

Table 1: Average share of IL debt between 1995 and 2018. The averages are conditional on the country issuing the type of bond in question. Italy's issuance distinguishes between the issuance indexed to European and Italian inflation. For France, it does not distinguish one type or another. This table also lists the increases in the share of IL debt and total IL debt issued (in number of times). Sources: See Table 1 in the Online Appendix.

Correlation between inflation and GDP	
Country	Subsample, positive IL debt issuance
Australia	11.8%
Canada	37.7%
France	See caption below
Germany	57.8%
Iceland	3.0%
Israel	-16.8%
Italy	-4.5%
Japan	-16.9%
Korea	1.8%
New Zealand	-40.9%
Spain	48.9%
Sweden	-20.2%
UK	-13.3%
US	26.0%

Table 2: Correlation coefficients (as a percentage) between inflation and the first differences of the logarithm of the real GDP for the subperiod in which countries' issuance of IL debt is positive. The subsample depends on the country, with the dates shown in Table 3 in the Online Appendix. Inflation is the domestic inflation for all countries except Germany and Spain, where inflation is the European inflation. For Israel, the correlation is calculated using data from 1970-2018, although it started issuing IL debt in 1955. For France, the correlation is 96.8% but it is calculated using only 1998-2000, the period we know all IL debt was issued linked to French inflation.

Figure 1 in the Online Appendix plots the IL debt share for all countries in the sample and illustrates the results in the third column of Table 1, namely, that all countries in the sample, except Israel and Iceland, substantially increased their IL debt share. As the last row of the third column shows, the share of IL debt increased, on average, by almost five times between 1995 and 2018.

Finally, the fourth column in Table 1 shows that the amount of IL debt issued has increased, on average, by 10 times between 1995 and 2018. Most of the countries in the sample started issuing IL debt after 1995, as Table 3 in the Online Appendix shows. Hence, for these countries, the calculation in the third column of Table 1 uses the date countries started issuing IL debt as the start date. Due to the novelty of IL debt in the public debt portfolios of advanced economies, countries started issuing small amounts of this type of debt, hence the large increases.

IL debt can act as a commitment device for governments tempted to inflate away their nominal debt during crises, implying that inflation is countercyclical and that IL debt, not being subject to inflation risk, is cheaper to issue. Both arguments run counter to the data in advanced economies. The remainder of this section analyses each in turn.

First, this section calculates the correlation between the first-differenced logarithm of the real GDP and the inflation for each country in the sample to analyse the cyclicality of inflation. Table 4 in the Online Appendix shows the results of the unit root tests of Im et al. (2003) for panel data with heterogeneous panels and shows that we cannot reject the presence of unit roots for the real GDP, but we can reject the presence of unit roots for inflation. Thus, only the logarithm of the real GDP is in first differences.

Table 2 reports the results for the period for which each of the countries in the sample issue IL debt, according to the information in Table 3 in the Online Appendix. Some countries (i.e., Canada, Germany, Spain, and the United States) exhibit strong inflation procyclicality, and some countries (i.e., New Zealand) exhibit strong inflation countercyclicality.

Second, this section reviews the vast literature in finance that compares nominal rates and IL rates to understand IL rates. Nominal debt, being subject to inflation risk, should exhibit a higher interest rate than IL debt. However, when taking into account expected inflation, the literature concludes that the nominal rates are too low.

When the United States first started issuing Treasury Inflation Protected Securities (TIPS), the TIPS premium was 100 basis points (bps), and it increased to 300 bps during the 2007-2009 financial crisis (D'Amico et al. 2018). During the early 2000s, the TIPS premium gradually declined, and the cost of TIPS issuance became similar to the cost of nominal debt issuance (Dudley et al. 2009, Christensen and Gillan 2011).

Work on countries other than the United States is more limited. The evidence for the United Kingdom shows that IL debt yields behave similarly to the yields of US TIPS: they were high during the 1990s and declined during the early 2000s, before spiking during the financial crisis (Barr and Campbell 1997, Campbell et al. 2009). Finally, Ermolov (2021), using a sample similar to the one in the current study, compares the cost of issuing nominal debt, the inflation risk premium, to the cost of issuing IL debt, the liquidity premium. He finds that, at medium maturities (five to 10 years), IL debt is more expensive to issue than nominal debt is, which was particularly true during the financial crisis.

The consensus is that the increased costs of IL debt issuance vis-à-vis nominal debt constitute a liquidity premium attached to IL debt; investors require compensation for holding a more illiquid asset (Christensen and Gillan 2012). Illiquidity should be interpreted in a broad sense. D'Amico et al. (2018) indicate that the poorer liquidity of IL debt can be due to the asset's novelty, especially when countries are starting to issue IL debt, due to trading costs, financing constraints, or flight-to-safety episodes, such as during the financial crisis.

The TIPS premium is quantitatively significant. Fleckenstein et al. (2014) argue that the US Treasury could have saved millions if it had issued nominal debt instead of IL debt. Devising an arbitrage strategy using Treasury bonds and inflation-swapped TIPS, the authors find that TIPS mispricing averages 54.5 bps and can reach 200 bps. Their interpretation is that investors do not attach nominal debt's safety and liquidity attributes, as found by Krisnamurthy and Vissing-Jorgensen (2012), to IL debt.

To sum up, inflation procyclicality, present in many advanced economies, and IL rates that are too high compared to nominal rates after accounting for expected inflation run counter to an environment where governments lack commitment. Therefore, the model in the next section moves away from lack of commitment models and consists of a model of optimal public debt composition for a given maturity, where the government takes inflation as given and nominal debt carries a convenience premium due to its liquidity.

4 Model

This section describes a stylized model where, when spending is risky, the government issues IL and nominal debt, taking inflation as given and aiming to minimize tax distortions, debt investors are risk neutral, and nominal debt carries a convenience premium.

4.1 Environment

Consider a two-period economy, with time indexed $t = 0, 1$, and a single good. The economy is populated by a unit mass of risk-neutral households that receive one unit of good at $t = 0$ and pay taxes τ_0. They can consume the remainder or invest it in government bonds, which can be nominal (B^N) or IL (B^I). Households pay Q^N to buy the nominal bond, which pays \$1 on date 1, and Q^I to buy the IL bond, which pays one unit of the good on date 1. On date 1, households receive a stochastic endowment Y_1 and pay taxes τ_1.

The price level on date 0, P_0, is normalized to one. The price level on date 1, P_1, is stochastic and correlated with households' endowment on date 1, Y_1. Denoting $P_1 = P(Y_1)$ explicitly states the dependence of the price level on date 1 on output. Note that the gross inflation Π_1 equals $\frac{P_1}{P_0}$ which equals P_1 given the normalization of P_0. The cyclical properties of inflation studied in Section 3 are easy to incorporate into the model: if $P'(Y_1) > 0$, then inflation is procyclical, where $P'(Y_1)$ denotes the derivative of the function $P(.)$. For concreteness, we can think of procyclical inflation as coming from demand shocks that cause a positive comovement between output and inflation.

The utility of a representative household is given by:

$$U = C_0 + E(C_1) + v(B^N) \tag{1}$$

where $v(B^N)$ denotes liquidity services that only nominal debt provides to households. The utility term $v(B^N)$ captures, in reduced form, nominal debt having special safety and liquidity attributes (Krisnamurthy and Vissing-Jorgensen 2012). It is similar to the assumption of short-term safety that short-term bonds are assumed to have in Greenwood et al. (2015). As these authors, I impose $v'(B^N) > 0$ and $v''(B^N) < 0$.

The government needs to finance exogenous levels of (real) spending on date 0 and date 1, G_0 and G_1, respectively. The latter depends on the endowment on date 1, Y_1, and is denoted by $G_1 = G(Y_1)$. The government's budget constraints in nominal terms on dates 0 and 1 are, respectively,

$$G_0 = \tau_0 + Q^N B^N + Q^I B^I \tag{2}$$

$$\tau_1 = P_1 G(Y_1) + B^N + P_1 B^I \tag{3}$$

where, in the second equation, B^I is premultiplied by P_1, since IL debt pays in units of the good on date 1 (see also Alfaro and Kanczuk 2010 and Gomez-Gonzalez 2019).

We assume $G'(Y_1) < 0$, which captures countercyclical government spending, for example, the government increasing public works in bad times or the outlays of certain public programs, such as unemployment insurance or anti-poverty transfers, automatically increasing in bad times. This assumption captures the government's optimal response to the domestic business cycles, albeit in a very reduced-form manner. Furthermore, we assume government spending on date 0 is more than the average government spending on date 1, $G_0 > E[G(Y_1)]$, which ensures that the government borrows on date 0.

Raising taxes has a distortionary effect that is quadratic on the real revenue raised each period: $\frac{\tau_0^2}{2}$ on date 0 and $\frac{\tau_1^2}{2P_1}$ on date 1[2] Households' budget constraints in nominal terms on dates 0 and 1 are, respectively,

$$C_0 = 1 - \tau_0 - \frac{\tau_0^2}{2} - Q^N B^N - Q^I B^I \tag{4}$$

$$P_1 C_1 = P_1 Y_1 - \tau_1 - \frac{\tau_1^2}{2P_1} + B^N + P_1 B^I \tag{5}$$

Maximizing equation (1) subject to the two budget constraints above gives the bond prices:

$$Q^I = 1 \tag{6}$$

$$Q^N = E\left(\frac{1}{P_1}\right) + v'(B^N) \tag{7}$$

These expressions are intuitive. IL debt is a safe asset since it pays in units of the good on date 1. The price of nominal debt and, hence, how valuable it is to investors, decreases if, first, (gross) inflation increases, because nominal debt pays \$1 on date 1, which buys less if inflation is high, and, second, if the liquidity services provided by nominal debt decrease.

Because investors are risk-neutral, the nominal debt price does not feature an inflation risk premium. Ermolov (2021) finds that, empirically, the inflation risk premium is large enough to make $Q^N < Q^I$ only at maturities over 20 years. [3]

Absent nominal debt's liquidity services, the difference in the rates of return between nominal debt and IL debt would equal the expected (net) inflation rate. This result goes against the empirical findings that IL rates are too high after accounting for expected inflation, but it is a good

[2] Alternatively, the quadratic cost could be on the tax rate, and the tax base would be the endowment. On date 0, both approaches are identical because the endowment is fixed and equal to 1. On date 1, Section B.2 in the Online Appendix shows that, although the environment is somewhat different, the comparative statics presented in the main body of the paper survive in the alternative setting. Further, if Y_1 were fixed, both approaches are identical too.

[3] See Westerhout (2020) for an analysis of IL debt with an inflation risk premium on the price of nominal debt.

benchmark case for which to solve the model, as the next section does.

4.2 Optimal indexation without the liquidity service of nominal debt

The government maximizes the utility of households, given in equation (1) when $v(B^N) = 0$ for now. Plugging equations (2) and (3) into the expressions for consumption, equations (4) and (5), the latter divided by P_1, yields the following expressions for C_0 and C_1:

$$C_0 = 1 - G_0 - \frac{1}{2}\left(G_0 - Q^N B^N - Q^I B^I\right)^2 \tag{8}$$

$$C_1 = Y_1 - G(Y_1) - \frac{1}{2}\left(G(Y_1) + \frac{B^N}{P(Y_1)} + B^I\right)^2 \tag{9}$$

where the equation for C_1 explicitly states the dependence of P_1 on Y_1.

From equations (8) and (9), it is clear that the government's objective of maximizing $C_0+E(C_1)$ can be rewritten as minimizing (real) tax distortions. Using the changes of variables: $B^N = S^N B$, $B = Q^N B^N + B^I$, and $B^I = (1 - Q^N S^N)B$, where we have imposed $Q^I = 1$ and where S^N denotes the nominal debt share in the total value of debt, and B denotes the total value of debt issued on date 0, we can rewrite the government's problem as follows:

$$min_{B,S^N} \quad \frac{1}{2}\left(G_0 - B\right)^2 + \frac{1}{2}E\left[G(Y_1) + \frac{S^N B}{P(Y_1)} + (1 - Q^N S^N)B\right]^2 \tag{10}$$

This problem's first-order conditions for B and S^N are, respectively, given by:

$$\tau_0 = E\left[\frac{\tau_1}{P(Y_1)}\left(\frac{S^N}{P(Y_1)} + 1 - Q^N S^N\right)\right] \tag{11}$$

$$BE\left[\frac{\tau_1}{P(Y_1)}\left(\frac{1}{P(Y_1)} - Q^N\right)\right] = 0 \tag{12}$$

Substituting τ_1 in equation (12) for its expression in equation (3), operating, and noting that when nominal debt does not provide liquidity services $Q^N = E\left(\frac{1}{P(Y_1)}\right)$, the first-order condition for S^N in equation (12) can be rewritten as:

$$E\left[\frac{G(Y_1)}{P(Y_1)}\right] - Q^N E\left[G(Y_1)\right] + S^N B Var\left[\frac{1}{P(Y_1)}\right] = 0 \tag{13}$$

Section B.1 in the Online Appendix shows the derivations.

Before proceeding, it is worth noting that if, $G(Y_1)$ is constant, then equation (13) reduces to $S^N BVar\left[\frac{1}{P(Y_1)}\right] = 0$ and the optimal nominal debt share equals $S^N = 0$. Indeed, the government wants to isolate the economy from the tax distortions generated by issuing nominal debt, whose real repayment depends on the realization of price level $P(Y_1)$, which is stochastic. There is no benefit to issuing nominal debt in an environment without stochastic government spending on date 1 and nominal debt not serving a liquidity purpose. Because $G(Y_1)$ is stochastic, equation (13) can be rewritten as:

$$Cov\left(G(Y_1), \frac{1}{P(Y_1)}\right) + S^N BVar\left(\frac{1}{P(Y_1)}\right) = 0 \tag{14}$$

which uses the definition for the covariance between two random variables, namely,

$$E\left[\frac{G(Y_1)}{P(Y_1)}\right] = Cov\left(G(Y_1), \frac{1}{P(Y_1)}\right) + E\left[G(Y_1)\right] E\left[\frac{1}{P(Y_1)}\right] \tag{15}$$

Equation (14) shows the key trade-off the government faces. On the one hand, the second term on the left-hand side of this equation captures the cost of issuing nominal debt, increased volatility coming from a real repayment that depends on P_1, which is uncertain. On the other hand, the first term on the left-hand side, if negative, is the benefit of issuing nominal debt. Suppose this covariance is indeed negative [4]. In that case, the real burden of nominal debt, that is, $S^N B/P_1$, decreases when government spending increases, which is beneficial for the government. The idea that the government uses its public debt structure to hedge macroeconomic risks is raised by Bohn (1988), Barro (1997), and Missale (1999).

To see what happens when the covariance between $G(Y_1)$ and the inverse of (gross) inflation is positive, it is useful to solve for S^N in equation (14):

$$S^N = \frac{-Cov\left(G(Y_1), \frac{1}{P(Y_1)}\right)}{BVar\left(\frac{1}{P(Y_1)}\right)} \tag{16}$$

From this equation, it is clear that, if the covariance between $G(Y_1)$ and the inverse of (gross) inflation is positive, the government would want to save in nominal debt on date 1 and finance

[4] A negative covariance between $G(Y_1)$ and $\frac{1}{P(Y_1)}$ implies a positive covariance between $G(Y_1)$ and $P(Y_1)$.

these savings using IL debt. Intuitively, if the inverse of (gross) inflation increases with government spending, then the government would want to have a position on the nominal debt market that pays it, which is what saving in nominal assets entails.

Limiting the analysis to non-negative positions in the two debt instruments implies that, if the covariance is positive, $S^N = 0$ and full indexation is optimal. Indeed, the government wishes to move away from repaying debt, whose real value, $S^N B/P_1$, increases when government spending increases. Nominal debt's liquidity services, studied in subsection 4.4, could be a reason why we do not see full indexation in reality, even in countries with a positive correlation between government spending and the inverse of inflation.

To conclude the model's derivation, the total value of debt B equals:

$$B = \frac{G_0 - E\left[G(Y_1)\right]}{2} \tag{17}$$

which is derived from the first-order condition for B in equation (11). Section B.1 in the Online Appendix shows the intermediate steps. Equation (17) is positive due to the parametric restriction imposed that $G_0 > E\left[G(Y_1)\right]$. Plugging equation (17) into equation (16) gives the closed-form solution for S^N, which equals:

$$S^N = \frac{-2Cov\left(G(Y_1), \frac{1}{P(Y_1)}\right)}{Var\left(\frac{1}{P(Y_1)}\right)\left(G_0 - E\left[G(Y_1)\right]\right)} \tag{18}$$

Finally, using the definition of IL debt, $B^I = (1 - Q^N S^N)B$, and the nominal debt price, Q^N, the share of IL debt in the total value of debt, $S^I = B^I/B$, equals:

$$S^I = 1 - E\left(\frac{1}{P_1}\right)S^N \tag{19}$$

The share of IL debt, S^I, increases in expected inflation, as long as $S^N > 0$, that is, if the government borrows in nominal debt. The higher expected inflation is, the less investors value nominal debt, decreasing the government's revenues from issuing nominal debt and forcing it to issue a higher share of IL debt.[5]

[5] Expected inflation affects S^I because the optimal public debt indexation problem solves for the total *value* of debt. If instead of $B = Q^N B^N + B^I$, we define $B = B^N + B^I$, then the well-known Modigliani-Miller theorem holds,

If the government saves in nominal debt and $S^N < 0$, then the share of IL debt decreases in expected inflation. The intuition for the effect of expected inflation reversing is that if the government saves in nominal debt and, as expected inflation increases, its price decreases, the government needs fewer funds to finance the purchase of nominal assets, decreasing IL debt issuance.

Before testing the model's predictions, it is worth noting that adding a maturity dimension to the government's problem would not add any new theoretical insights. Indeed, in an environment where the government has commitment and there is no discounting, the main forces are the ones highlighted so far. On the one hand, intertemporal tax smoothing favors IL debt. On the other hand, low inflation and a positive correlation between government spending and inflation favor nominal debt at all maturities. The exact indexation at different maturities would depend on the inflation levels, inflation volatilities, and the correlations of government spending and inflation in the different periods.

4.3 Comparative statics

This section now analyses and tests some qualitative implications of the model so far. Equations (18) and (19) can be approximated, to a first-order, to the following expressions:

$$\begin{aligned} S^N &\approx \frac{-2Cov\left(G(Y_1), \frac{1}{P(Y_1)}\right) E(P_1)^4}{Var\left(P(Y_1)\right)\left(G_0 - E\left[G(Y_1)\right]\right)} \\ S^I &\approx 1 - \left(\frac{1}{E(P_1)} + \frac{1}{E(P_1)^3} Var(P_1)\right) S^N \\ & \quad 1 + \frac{2Cov\left(G(Y_1), \frac{1}{P(Y_1)}\right) E(P_1)^3}{Var\left(P(Y_1)\right)\left(G_0 - E\left[G(Y_1)\right]\right)} + \frac{2Cov\left(G(Y_1), \frac{1}{P(Y_1)}\right) E(P_1)}{\left(G_0 - E\left[G(Y_1)\right]\right)} \end{aligned}$$

which lead to the following comparative statics:

1. The share of IL debt increases with the variance of inflation when the government borrows in nominal debt.

2. The share of IL debt increases in expected inflation when the government borrows in nominal debt.

3. The share of IL debt increases in the covariance between government spending and the inverse

and expected inflation plays no role since it is priced-in.

of inflation, or, equivalently, decreases in the covariance between government spending and inflation.

If fiscal policy is countercyclical, as the model assumes by imposing $G'(Y_1) < 0$, the last comparative static allows us to determine the countries where IL debt is a better hedge, with either procyclical or countercyclical inflation. Countercyclical fiscal policy implies that government spending increases when output decreases. Furthermore, the optimal nominal debt share increases in the covariance between government spending and inflation. The combination of both observations means that, keeping everything else constant, nominal debt is a good hedge in economies with countercyclical inflation, and, consequently, IL debt is a good hedge for countries with procyclical inflation. Therefore, this model offers a rationale for advanced economies, which often experience procyclical inflation, to issue IL debt if their fiscal policy is countercyclical.

Next, this section presents cross-country evidence consistent with comparative statics 1 to 3 above using the study's dataset. One should always take cross-country correlations with a grain of salt since they are consistent with the model presented in this paper and other models delivering similar predictions. With this caveat in mind, this part presents the above correlations using the study's data.

To test prediction 1 above, Figure 2 shows the share of IL debt against the country's standard deviation of inflation during the period in which each country issues IL debt.[6]. The cross-country correlation between these variables is 65%, aligning with the model's prediction. Excluding Israel and Iceland, which are outliers, the cross-country correlation drops to 39.7%, which is still positive and sizeable. The left-hand side panel of Figure 6 in the Online Appendix shows the scatter plot excluding Israel and Iceland.

To test prediction 2 above, Figure 3 shows the share of IL debt against each country's average inflation during the period in which each country issues IL debt. This test implicitly assumes that, in high inflation countries, expectations of inflation are also high. The cross-country correlation between these variables is 67.4%, also in line with the model's prediction. In this case, excluding Israel and Iceland, again outliers, the cross-country correlation is 56.8%, which is still positive and considerable. The right-hand side panel of Figure 6 in the Online Appendix shows the scatter plot

[6] For Germany, Italy, and Spain, the correlation is calculated using European inflation and applies to the other cross-country correlations

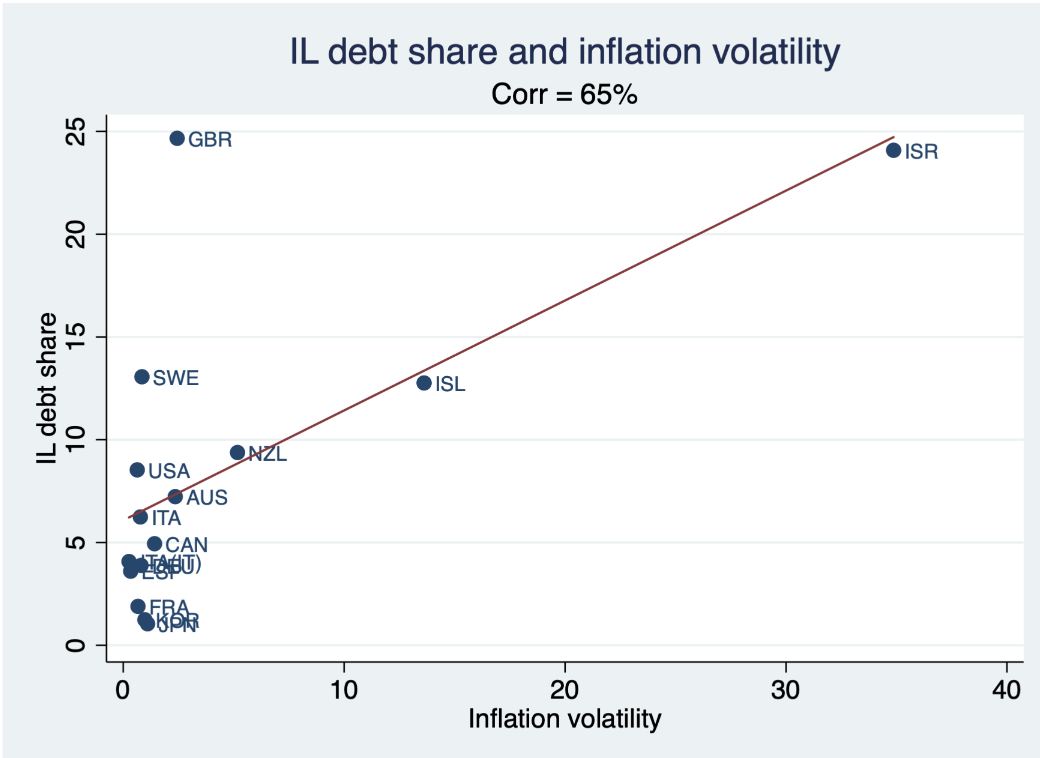

Figure 2: IL debt share against inflation volatility

excluding Israel and Iceland.

Figures 7 and 8 in the Online Appendix show that the positive cross-country correlations between the IL debt share and and inflation level and volatility are robust to using the inflation measure used to index (CPI or RPI).

Finally, to test prediction 3 above, Figure 4 shows the share of IL debt against the country's correlation between real government spending and inflation during the period in which each country issues IL debt. The cross-country correlation between these variables equals -29.4%, negative like the model predicts but small.

Some observations are consistent with IL debt acting as a hedging financial instrument for the government's budget constraint. Spain, where government spending and inflation are positively correlated, issues less of its public debt linked to inflation. It has less to gain from issuing IL debt because, given the correlation between government spending and inflation, the real burden from nominal debt decreases when government spending is high. Countries such as Sweden, Israel, and the United Kingdom, where government spending and inflation are negatively correlated, issue

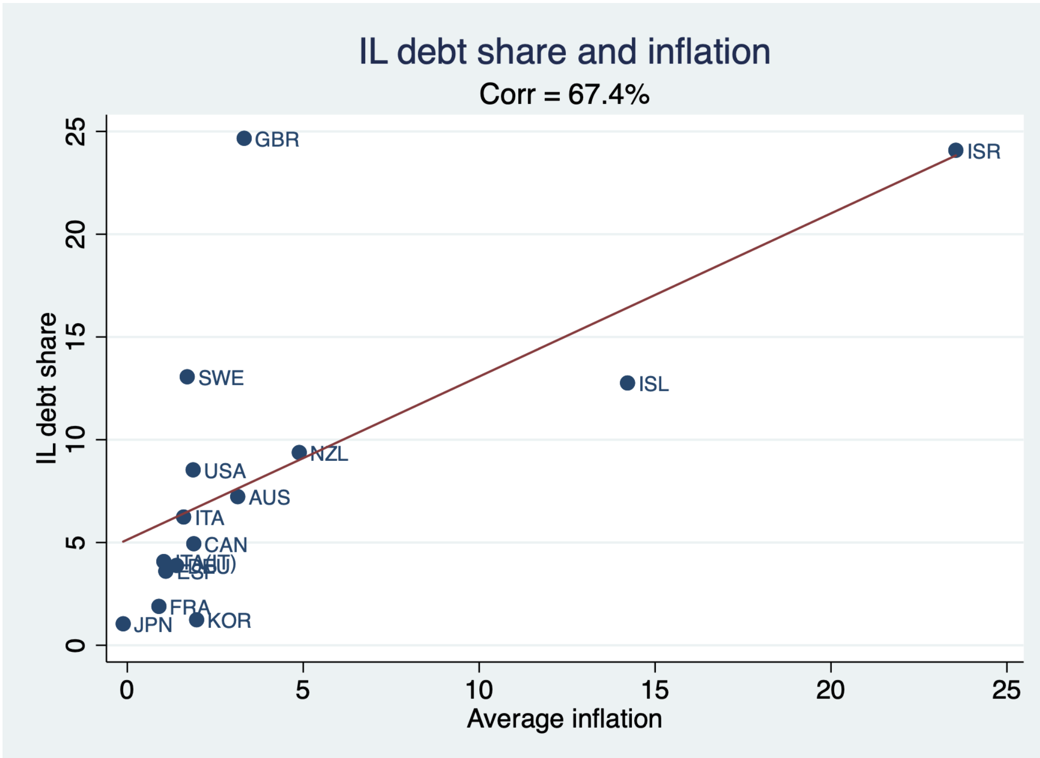

Figure 3: IL debt share against inflation

more of their public debt linked to inflation. These countries have more to gain from issuing IL debt because their government spending behavior implies that the real burden of their nominal debt increases with government spending. However, no strong pattern emerges.

In the context of the model presented so far, in countries where government spending and inflation are negatively correlated, issuing all public debt linked to inflation is optimal. A possible explanation for not seeing this in reality is nominal debt's liquidity services to investors. The following section studies optimal public debt indexation in this case.

4.4 Optimal indexation with nominal debt's liquidity service

This section now turns to the government's utility maximization problem when $v(B^N) > 0$. The choice variables remain B and S^N, and the government solves:

$$max_{S^N,B} \quad 1-G_0-\frac{1}{2}\left(G_0-B\right)^2+v(S^N B)+E\left[Y_1-G(Y_1)-\frac{1}{2}\left(G(Y_1)+\frac{S^N B}{P(Y_1)}+(1-Q^N S^N)B\right)\right]^2 \tag{20}$$

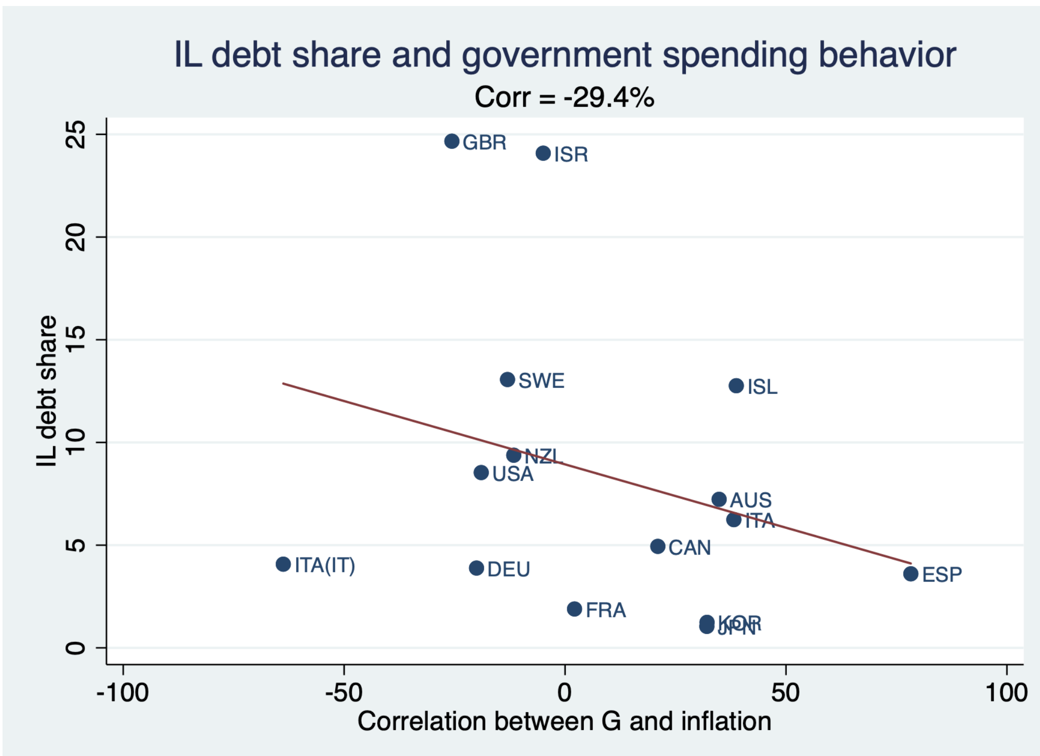

Figure 4: IL debt share against the correlation between real government spending (G) and inflation scatterplot

or, equivalently,

$$max_{S^N,B} \quad -\frac{1}{2}\left(G_0 - B\right)^2 + v(S^N B) - E\left[\frac{1}{2}\left(G(Y_1) + \frac{S^N B}{P(Y_1)} + B - E\left(\frac{1}{P(Y_1)}\right) S^N B - v'(S^N B) S^N B\right)\right]^2 \tag{21}$$

where the second equation drops the elements that are independent of policy and explicitly states that Q^N depends on the amount of nominal debt issued.

This problem's first-order conditions for B and S^N are, respectively, given by:

$$\begin{aligned} \tau_0 + v'(S^N B) S^N &= E\left[\frac{\tau_1}{P(Y_1)}\right] + \qquad (22) \\ & E\left[\frac{\tau_1}{P(Y_1)} S^N \left(\frac{1}{P(Y_1)} - E\left(\frac{1}{P(Y_1)}\right) - v'(S^N B) - v''(S^N B) S^N B\right)\right] \\ v'(S^N B) &= E\left[\frac{\tau_1}{P(Y_1)}\left(\frac{1}{P(Y_1)} - E\left(\frac{1}{P(Y_1)}\right) - v'(S^N B) - v''(S^N B) S^N B\right)\right] \qquad (23) \end{aligned}$$

Section B.3 in the Online Appendix shows that the previous first-order conditions can be rewritten as:

$$B = \frac{G_0 - E\left(G(Y_1)\right)}{2 - v'(S^N B) S^N} \tag{24}$$

$$\begin{aligned} v'(S^N B) + \tau_0 \left(v'(S^N B) + v''(S^N B) S^N B\right) + S^N B v'(S^N B)\left(1 + v'(S^N B)\right) = \\ Cov\left(G(Y_1), \frac{1}{P(Y_1)}\right) + S^N B Var\left(\frac{1}{P(Y_1)}\right) \end{aligned} \tag{25}$$

where the first of these equations gives an implicit equation for B. If holding nominal debt has no direct utility, $v'(B^N) = 0$, equation (24) becomes equation (17). If $v(S^N B) = \gamma f(S^N B)$, where $f(.)$ satisfies $f'(.) > 0$ and $f''(.) < 0$, the following proposition holds.

Proposition 1 *The total value of debt, B, increases in the liquidity services of nominal debt, parametrized by γ.*

Proof. Substituting function $v(.)$ for function $\gamma f(.)$, equation (24) becomes:

$$B = \frac{G_0 - E\left(G(Y_1)\right)}{2 - \gamma f'(S^N B) S^N}$$

Differentiating implicitly this equation with respect to γ and solving for $\partial B/\partial\gamma$ gives:

$$\frac{\partial B}{\partial \gamma}=\left[1-\frac{G_0-E\left(G(Y_1)\right)}{\left(2-\gamma f'(S^N B)S^N\right)^2}\gamma(S^N)^2 f''(S^N B)\right]^{-1}\frac{G_0-E\left(G(Y_1)\right)}{\left(2-\gamma f'(S^N B)S^N\right)^2}f'(S^N B)S^N$$

This expression is positive under the parametric restriction that $G_0-E\left(G(Y_1)\right)>0$. Because $f''(.)<0$ and $G_0-E\left(G(Y_1)\right)>0$, the term between squared brackets is positive. Furthermore, because $f'(.)>0$ the second term is also positive. ■

Equation 25) gives an implicit equation for S^N. The right-hand side of this equation contains the same terms as condition (14) and the forces are thus identical to the ones there: higher variance of inflation and a negative covariance between government spending and inflation makes IL debt more attractive for the government. The left-hand side of equation (25) indicates three benefits in favor of issuing nominal debt stemming from the liquidity services of nominal debt. The first summand is the direct marginal benefit of money services provided by nominal debt. The second and third summands capture the government's benefit when it can finance itself at a lower interest rate. These two benefits are also presented by the model of Greenwood et al. (2015). The fourth and fifth summands capture the lower burden from IL debt, because a higher price for nominal debt decreases the government's repayment to IL debt investors, $B^I=(1-Q^N S^N)B$, lowering tax distortions.

The expression for the IL debt share is

$$S^I=1-\left(E\left(\frac{1}{P_1}\right)+\gamma f'(S^N B)\right)S^N \tag{26}$$

where B and S^N are the solutions to equations (24) and (25).

From equations (24) to (26), the following proposition holds.

Proposition 2 *The share of IL debt, S^I, increases in expected inflation as long as $S^N>0$.*

Proof. First, from equations (24) and (25), note that S^N and B do not depend on the level of inflation. Indeed, $\tau_0=G_0-B$ and the remaining terms do not contain the level of inflation. Then, from equation (26) it is clear that that the higher inflation is, the lower the expectation of the inverse of inflation becomes, which increases S^I due to the negative sign premultiplying $E\left(\frac{1}{P_1}\right)$. ■

With a similar approach to that of Greenwood et al. (2015), namely, abstracting from the lower tax distortions and the lower burden from IL debt in equation (25)[7], the following propositions hold.

Proposition 3 *Abstracting from lower tax distortions and the lower burden from IL debt, the share of nominal debt, S^N, decreases in the covariance between government spending and the inverse of inflation.*

Proof. Differentiating implicitly equation (25) with respect to $Cov\left(G(Y_1), \frac{1}{P(Y_1)}\right)$ yields

$$\frac{\partial S^N}{\partial Cov\left(G(Y_1), \frac{1}{P(Y_1)}\right)} = -B^{-1}\left(Var\left(\frac{1}{P(Y_1)}\right) - \gamma f''(S^N B)\right)^{-1}$$

Because $f''(.) < 0$, the term to the power of -1 in the derivative is positive. Hence, the equation is negative because a negative sign premultiplies it. ■

Proposition 4 *Abstracting from lower tax distortions and the lower burden from IL debt, the share of nominal debt, S^N, decreases, to a first-order approximation, in the variance of inflation.*

Proof. Substituting function $v(.)$ for function $\gamma f(.)$, equation (25) can be written, to a first-order, as:

$$\gamma f'(S^N B) = Cov\left(G_1, \frac{1}{P_1}\right) + S^N B \frac{Var(P_1)}{E(P_1)^4} \tag{27}$$

Differentiating implicitly this equation with respect to $Var\left(P(Y_1)\right)$ yields:

$$\frac{\partial S^N}{\partial Var(P_1)} = -S^N B \left[Var(P_1) - \gamma f''(S^N B) E(P_1)^4\right]^{-1} \tag{28}$$

As before, because $f''(.) < 0$, the term to the power of -1 is positive. Hence, as long as the government is issuing nominal debt and not saving in nominal debt, that is, $S^N > 0$, this equation is negative because a negative sign premultiplies it. ■

[7] Specifically, we abstract from the second to fifth summands from the left-hand side in equation (25) and focus only on the direct liquidity services from nominal debt: $v'(S^N B)$.

Proposition 5 *Abstracting from lower tax distortions and the lower burden from IL debt, the share of nominal debt, S^N, for a given level of debt B, increases in the liquidity services of nominal debt, parametrized by γ.*

Proof. Differentiating implicitly equation (25) with respect to γ yields

$$\frac{\partial S^N}{\partial \gamma} = B^{-1} f'(S^N B) \left(Var\left(\frac{1}{P(Y_1)} \right) - \gamma f''(S^N B) \right)^{-1}$$

Because $f''(.) < 0$, the term to the power of -1 is positive and the equation is positive because $f'(S^N B) > 0$. [8] ■

Considering liquidity services in nominal debt leaves the comparative statics between the share of IL debt and expected inflation, the variability of inflation, and the correlation between government spending and inflation unchanged. Additionally, the model with liquidity services in nominal debt features a new comparative static about the convenience premium and the nominal debt share for a given level of debt. Testing this comparative static is problematic since, in reality, B is not fixed, and the total amount of nominal debt issued affects the nominal debt's convenience premium. The more nominal debt countries issue, the higher its liquidity and convenience premium, raising reverse causality concerns in a test of proposition 5.

For example, according to Ermolov (2021)'s calculations, the UK's IL debt versus nominal issuance costs after 2004 is 0.29%. For the US, this number is 0.42%. From the model's perspective, IL debt is more expensive to issue in the US, implying that US nominal debt has a higher convenience premium. In line with the model's predictions, after 2004, the US issued a lower IL debt share (10.4%) than the UK (24.7%). However, the US nominal debt outstanding is much larger than the UK nominal debt outstanding, which could drive nominal debt's issuance costs down by increasing its liquidity and convenience premium.

Given the limitations of comparing liquidity premia and IL debt shares in the data, the following section explores the liquidity premium further using welfare analysis.

[8] Notice that proposition 5 requires B to be fixed. This restriction is necessary because an increase in γ has an unambiguously positive effect on the total nominal debt issued, $S^N B$, but not on the nominal debt share, S^N. However, for a given level of debt, the effect of γ on the nominal debt share is positive and unambiguous, as the proposition shows.

4.5 Welfare analysis

This section compares domestic welfare under the optimal public debt indexation in the two versions of the model (with and without nominal debt's liquidity services), ignoring the utility term associated with the convenience premium. A back-of-the-envelope calibration for this difference quantifies the welfare gain of increasing IL debt issuance and, consequently, increasing IL debt's liquidity. This welfare gain should be traded-off against the cost of increasing IL debt issuance, namely, giving up the lower nominal debt cost.[9]

Section B.4 in the Online Appendix shows that abstracting from the lower tax distortions and the lower burden from IL debt, the difference between the welfare in the model with nominal debt's liquidity services (W_γ) and the welfare in the model without liquidity services (W) equals:

$$W_\gamma - W = (G_0 - E(G_1))(B_\gamma - B) - B_\gamma^2 - B^2 - \frac{S_\gamma^N B_\gamma}{2} v'(S_\gamma^N B_\gamma) \left[1 - S_\gamma^N B_\gamma v'(S_\gamma^N B_\gamma) - E(G_1) - B_\gamma\right] \tag{29}$$

where B denotes the optimal level of debt in the model without nominal debt's liquidity services (given in equation 17), B_γ denotes the optimal level of debt in the model with nominal debt's liquidity services (given implicitly in equation 24), and S_γ^N denotes the optimal share of nominal debt in the latter model (given implicitly in equation 25)).

To get a rough sense of equation (29)'s magnitude, we make the following assumptions. First, we impose $B = 1$ to calculate the welfare difference for a given level of debt. Second, although $B_\gamma > B$ by proposition 1, we make them equal, which assumes that the changes in IL debt are small. Third, the empirical evidence on advanced economies' IL debt issuance shows that, on average, S^N equals 90% (or 0.9). Fourth, in line with the finance literature's estimates, we make the convenience premium, $v'(s_\gamma^N B_\gamma)$, equal to 100 bps, on the lower end of the estimated 54 bps to 200 bps range (Fleckenstein et al. 2014). Finally, we set $E(G_1) = 0.5$, which uses equation 17, $B = 1$, and imposes $G_0 = 2.5$. A way to think about this choice is that half of the total value of debt comes from future government spending. Under the described calibration, the benefit of increasing IL debt issuance, $W_\gamma - W$, equals 0.027. However, the cost is substantially higher (100 bps or 0.1).

[9] Increasing the IL debt issuance would presumably decrease IL debt's borrowing costs, but the exercise assumes small increases in IL debt issuance. In other words, it is a local analysis around the current IL debt issuance.

To sum up, considering a convenience premium on nominal debt adds another benefit in favor of issuing more of it: the liquidity services it provides to investors and the lower cost of financing for the government. A back-of-the-envelope calculation suggests that giving up nominal debt's convenience premium might be an order of magnitude larger than the welfare gain from increasing IL debt issuance for advanced economies, offering a reason why IL debt issuance is low in most advanced economies.

5 Conclusions

Between 1995 and 2018, the size of the IL public debt issuance of advanced economies increased considerably, but the popularity of this type of asset is highly uneven across countries. Models that interpret IL debt as a commitment device for governments tempted to inflate away their real public debt burden are unsuitable for countries with independent central banks. Furthermore, the cyclicality of inflation in many advanced economies and IL rates' behavior runs counter to the predictions made by this type of model. This paper offers a risk-sharing perspective on IL debt extended with a liquidity motive to issue nominal debt.

Through the lens of the study's model, IL debt has three advantages from the government's point of view: first, it avoids a volatile real repayment; second, its price is not eroded by inflation expectations; and, third, it is a good hedge for government budget constraints when public spending and inflation are negatively correlated. If government spending is countercyclical, the last advantage also implies that IL debt is preferable for countries with procyclical inflation. Instead, if public spending and inflation are positively correlated, IL debt is a poor hedge for the government's budget constraint, and nominal debt is preferable.

Nominal debt is also preferable when it provides investors liquidity services, as the nominal IL rate differentials suggest. In this environment, the benefits of nominal debt comprise not only the benefits of direct liquidity, but also increased government revenues from issuing nominal debt. The liquidity services of nominal debt allow a government to finance itself at a lower rate and to collect enough revenues to issue less IL debt.

Welfare analysis within the model suggests that nominal debt's liquidity services have the potential to explain low public debt indexation in advanced economies. A back-of-the-envelope calculation shows that the welfare gain of increasing IL debt issuance is an order of magnitude smaller than the nominal debt's convenience premium, which quantifies the cost-saving a government would give up by switching from nominal to IL debt.

The data on the IL debt issuance and other macroaggregate data of advanced economies support the model's comparative statics about inflation. The data show that countries with higher and more volatile inflation issue more of their public debt linked to inflation.

Two forces prevent public debt indexation in the model: a positive correlation between government spending and inflation and the liquidity services of nominal debt. The paper's welfare analysis suggests that understanding these services further is a promising avenue for future research and of practical relevance to public debt management. Including an endogenous component in government spending, in addition to the automatic stabilizing component in this paper, will certainly add a relevant dimension to the optimal public debt indexation problem.

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