Treasury Supply, Relative Convenience Yields and Exchange Rates*

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Abstract

The fiscal sustainability of US public debt depends crucially on the convenience yield, the premium that investors pay to hold US Treasuries. Theoretically, equilibrium government debt supply is negatively associated with the convenience yield, which is also linked to the exchange rate through interest parity. However, the existing literature offers only correlational evidence, disregarding the active choice of debt issuance by the government. Using a simple open-economy model with optimal debt supply and liquidity preference for Treasuries, we show that outward shifts in debt supply reduce the convenience yield through dollar depreciation. Conversely, changes in liquidity preference generate positive comovements between debt supply, currency appreciation, and convenience yields. As a result, estimation strategies, like OLS, that fail to disentangle Treasury supply and demand shocks result in an understatement of the yield elasticity of Treasury demand, and of the impact of Treasury supply shocks on exchange rates. We confirm the predicions of our model via local projections using an instrument based on Treasury futures price changes following auction announcements. An unexpected rise in US Treasury supply lowers the convenience yield and depreciates the dollar against G10 currencies by up to three times more than previously esimated.

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1 Introduction

In times of historically high government debt, when the US government relies heavily on debt financing to support massive spending in the wake of the COVID-19 pandemic, understanding the simultaneous impact of debt issuances on exchange rates and the convenience yield *vis-à-vis* foreign government bonds takes on paramount importance.

The issuance of US Treasury debt—the global safe asset—is not a mere domestic policy decision; its effects being felt globally, it is a key element of global financial stability. Changes in Treasury yields impact the perceived risk-free rate, triggering adjustments in financial asset valuations worldwide, as highghlited in the Global Financial Cycle literature (e.g., Miranda-Agrippino and Rey, 2020, 2022). Simultaneously, fluctuations in exchange rates due to Treasury supply shocks have implications for global trade and investment flows, affecting the competitive position of US exports and the cost of dollar-denominated debt for emerging economies.

From a policy standpoint, these dynamics are even more critical. As elucidated in Van Nieuwerburgh et al. (2021), the fiscal sustainability of the growing US public debt relies crucially on the willingess of foreign investors to pay a premium for US Treasuries. Therefore, assessing fiscal capacity in the US requires appropriately estimating the yield sensitivity of investor's demand, in particular in response to an increase in public debt. Likewise, the ability of the US Treasury to fulfill its mandate—to issue debt at the lowest cost to the government—also hinges on it capacity to anticipe market reactions accurately.

Yet, studies on the relationship between Treasury supply, convenience yields and exchange rates have focused almost exclusively on the demand side. Empirical analyses routinely treat the observable outstanding amount of US Treasuries as an exogenous variable (e.g., Du et al., 2018), while theories linking convenience yields and exchange rates tend to take the supply of debt either as fixed, or changing automatically in response to a postulated tax rule (e.g. Valchev, 2020).

However, governments can and do take into account price incentives when deciding the quantity of debt to issue. Within the bounds imposed by their intertemporal budget constraint, lower interest rates can induce tilting government funding towards debt, especially if Ricardian equivalence does not hold. In fact, the low-interest rate environment of the 2010s sparked a lively academic debate on the incentives for government to issue debt to finance expenditure and roll-over previous borrowing, and on the sustainability thereof[1].

[1] See for example Blanchard (2019), Jiang et al. (2019), Reis (2021), Mehrotra and Sergeyev (2021), Brunnermeier et al. (2022) Mankiw (2022)

The convenience yield itself is a determinant of the attractiveness of debt issuance: Choi et al. (2022) show that if foreigners derive a non-monetary payoff from holding US Treasuries, the difference between the yield of Treasuries and that of corporate bonds represents the marginal benefit in the optimality condition for debt in the government's Ramsey problem. They also provide evidence that the US acts as a monopolist, exploiting market power and hence restricting the global safe asset supply. While we do not explore strategic behaviour in this paper, this line of argument does lend additional support to the idea that the debt supply decision is not divorced from price considerations.

In this paper, we aim to construct a unified theoretical framework that can effectively analyze the dynamics between Treasury supply, the convenience yield, and exchange rates. We then propose to empirically test the key implications of this framework. This dual approach allows us not only to deepen our understanding of the impact of Treasury debt issuance, but also to validate these insights against empirical evidence.

A simple, deterministic two-country general equilibrium model illustrates the interplay between supply and demand of US Treasuries and frames our empirical analysis. US Treasuries offer a non-monetary liquidity payoff that generates an endogenous and time-varying convenience yield relative to foreign bonds. The convenience yield adjusts to changes in debt supply and liquidity preferences in equilibrium through the nominal exchange rate. The first testable implication of our model is that an increase in debt supply causes a drop in the convenience yield and an immediate depreciation of the US dollar, followed by an appreciation.

We also analyse the Ramsey-optimal choice of government bond issuance, which depends on the marginal cost of issuing debt and on its marginal benefit, which equals the convenience yield. As a result, the debt supply schedule is upward-sloping in the convenience yield, which introduces a positive correlation between debt supply, convenience yields and exchange rates in response to higher liquidity preference. The second testable implication of our model is that any regression of convenience yields and exchange rates on measures of Treasury supply will suffer from endogeneity, as it cannot be determined *a priori* whether the observed price-quantity pairs are the results of shifts in the demand or the supply curves. As a consequence, the estimated coefficient on the quantity of debt will be attenuated towards zero.

We address this endogeneity issue with a high-frequency instrumental variable *à la* Phillot (2021). The intuition behind the instrument is the following: if the futures market prices in all relevant information, as per the efficient market hypothesis

(Malkiel and Fama, 1970), changes in Treasury futures prices in a tight window around auction announcements are caused by an unexpected changes in the supply of Treasuries. The strategy is complementary to that of Gorodnichenko and Ray (2017), who use instead futures price changes around the auction itself to tease out Treasury demand shocks.

Firstly, we examine the immediate impact of unexpected changes in the outstanding amount of US Treasuries on the daily US dollar exchange rate and the convenience yield relative to other G10 currencies between February 2001 and January 2020 via a 2SLS procedure. First-stage statistics validate our set of instruments both in terms of relevance and overidentifying restrictions. Second-stage results indicate that a median-sized US Treasury supply shock translates into a same-day decrease of the US relative convenience yield of about 0.65 basis points and a depreciation of the US dollar of about 19 basis points. Notably, the effects otherwise reported by OLS are much smaller and not statistically significant.

Secondly, we investigate the evolution and persistence of these effects. A local-projection instrumental-variable model shows that the drop in the convenience yield reaches up to 3 basis points and is persistent, i.e. statistically significant, over a 12-week horizon. On the other hand, the US dollar depreciation documented in the daily exercise lasts for a week and reverses into a statistically significant appreciation, reaching more than 50 basis points four weeks after the impact before vanishing four weeks later.

Finally, to illustrate how our instrumental variable approach solves the endogeneity problem that emerges naturally in our theoretical framework, we replicate the panel-data analysis of the relationship between the outstanding amount of US Treasuries and the convenience yield in Du et al. (2018). Our IV approach documents that a one percentage-point increase in US debt-to-GDP causes a 2.90 basis points decrease in the 5-year US relative convenience yield. Importantly, this coefficient is two times as large as its OLS equivalent.

Together, these empirical findings corroborate both of the testable implications of our model. First, truly unexpected increases in the outstanding amount of US Treasury debt do seem to cause an immediate US dollar depreciation followed by an appreciation, as well as a decline in the US convenience yield, relative to a panel of G10 currencies. Second, the downward bias OLS estimates exhibit in all three approaches is consistent with the presence of a positive correlation between Treasury quantity and convenience yield introduced by demand shocks along an upwards-sloping supply curve, which is left unaccounted for in the absence of a clean identification strategy for Treasury supply shocks.

Related Literature.—A long-standing literature analyses the theoretical foundations of the observed premium, or convenience yield, of US Treasuries with respect to various comparable assets (Longstaff, 2004, Krishnamurthy and Vissing-Jorgensen, 2012, Nagel, 2016), motivating a downward-sloping demand curve for US Treasuries. We follow their approach by modeling the convenience yield with an additional term in households' utility function that depends on Treasury holdings. More recently, a series of papers provides theoretical frameworks linking convenience yields and exchange rate dynamics through demand-side effects (Engel and Wu, 2018, Jiang et al., 2020, Kekre and Lenel, 2021, Jiang et al., 2021). Our studies contributes to this strand of the literature by highlighting the role of an upward-sloping supply curve of US Treasuries.

There is also a related literature on the optimal supply of government debt, modelling the benefit to households via a variety of mechanisms such as collateral constraints and liquidity (Aiyagari and McGrattan, 1998, Woodford, 1990, Angeletos et al., 2016). We contribute by building a model in which the benefit is motivated by a different channel: issuing debt frees up resources, previously tied up in taxation, to invest in foreign bonds, which pay a higher yield due to the liquidity payoff of Treasuries enjoyed by foreign households.

The papers closest to our theoretical model are Valchev (2020) and Choi et al. (2022). The former shows that time-varying convenience yields arise in a simple endowment economy with bonds in the utility function, and that monetary-fiscal policy interactions generate non-monotonic dynamics in the exchange rate. The demand-side of our theoretical model is similar, but we restrict US household to hold only foreign bonds. The most significant difference arises from the government debt supply side. Valchev (2020) imposes a linear rule for taxes, which then implies a given amount of bonds through the budget constraint. On the other hand, we solve for the bond supply curve deriving from the Ramsey problem of the government. Furthermore, the empirical section of the paper uses raw outstanding amounts of US Treasuries in regressions of convenience yields and exchange rates, subjecting the results to the threat of debt supply endogeneity.

Similarly to our paper, Choi et al. (2022) use a model in which optimal choice of government debt issuance results in an upward-sloping supply curve of US Treasuries. The marginal benefit for the government in their setup is however the Treasury premium with respect to dollar-denominated corporate bonds, instead of foreign government bonds as in our model. Furthermore, we study the dynamics of exchange rates, while Choi et al. (2022) focus only on the real implications of under-provision of safe assets in a regime of monopolistic supply.

Other papers have investigated empirically the interplay between Treasury supply, relative convenience yields and exchanges rates.[2] Du et al. (2018) propose a measure of relative convenience yields based on Treasury yield covered interest rate (CIP) deviations and find that it decreases when government bond supply increases. Engel and Wu (2018) contend that relative convenience yields are significantly correlated with G10 currency fluctuations. Krishnamurthy and Lustig (2019) find that safe dollar asset supply and demand affect the dollar exchange rate, bond yields, and other aspects of the global financial system.

Our paper builds upon this set of empirical studies by invoking a cleaner identification of Treasury supply, borrowed from Phillot (2021). The latter relates to the well-established literature that aims at identifying macroeconomic "random causes" (Slutsky, 1937), i.e., drivers of business cycle fluctuations (see Ramey, 2016, for a review of the literature on structural shock identification). Phillot (2021) proposes a so-called high-frequency identification strategy of US Treasury supply shocks, exploiting the design of US Treasury auctions. Much like the literature that identifies monetary policy shocks (Kuttner, 2001, Gürkaynak et al., 2005, among others), he interprets changes in US Treasury futures prices around announcements by the US Treasury as surprises about the supply of US debt securities.

We build upon Phillot (2021), whose focus is exclusively on US *domestic* financial outcomes and implement similar local projections (Jordà et al., 2020, 2015, Jordà, 2005) by considering exchange rates and convenience yields as dependent variables to explore the effects of US Treasury supply shocks on *global* macro-financial outcomes. By investigating transmission mechanisms between US Treasury supply shocks and global financial markets, and introducing a theoretical framework to understand these connections, we go beyond a mere addition of exchange rates and convenience yields to his approach.

In a replication of Du et al. (2018) from a Swiss perspective, Benhima and Phillot (2023) report that the OLS supply price elasticity of Swiss relative convenience yields is underestimated by a factor of three relative to an equivalent instrumental approach based on Swiss auction data. Our estimates of this bias in the United States confirm their findings.

The remainder of this paper is organized as follows. Section 2 builds a theoretical framework to illustrate the interplay between supply and demand of US

[2]Note that our paper does not study the relationship between fiscal policy and exchange rates (see, e.g., Monacelli and Perotti, 2010, Ravn et al., 2012, Alberola-Ila et al., 2021). Rather, we evaluate solely shocks to the funding composition of US debt and consider the nominal exchange rate as opposed to the real exchange rate.

Treasuries and provide testable implications. Section 3 investigates this relationship empirically and revisits past evidence using an identification technique based on high-frequency changes in Treasury futures prices surrounding US Treasury announcements. Section 4 concludes.

2 Theoretical Model

2.1 The Setup

The model features two countries: the US, indexed H and the rest of the world (henceforth RoW), indexed F. The environment is deterministic and time is discrete and infinite. Consumers in either economy are endowed with real amounts of an undifferentiated good, with price P_t (P_t^*) in the US (RoW) currency.[3] The law of one price holds with $P_t = S_t P_t^*$ where S_t is the US dollar price of one unit of RoW currency (the US dollar depreciates when S_t increases).

Consumers choose consumption and investment in real government bonds. The US representative household can purchase only foreign bonds, while the RoW household can purchase both foreign and US bonds. This assumption is not meant to represent the actual set of assets available to US investors, but rather a snapshot of the external assets and liabilities position of the country as a whole. Thanks to the status of Treasuries as safe assets, the US can invest at a high yield while borrowing at lower rates, as highlighted by Gourinchas and Rey (2022). In our model, this "exorbitant privilege" stems from foreign households deriving a non-monetary payoff from holding US Treasuries. Following Krishnamurthy and Vissing-Jorgensen (2012), we model the non-monetary payoff as an additional term in RoW households' utility function, which is meant to capture special liquidity or safety characteristics. [4]

The US government finances a fixed amount of spending with a mix of lump-sum taxes levied on US households, and bonds purchased by foreign households. Following Choi et al. (2022), the government solves a Ramsey problem with a convex debt issuance cost to choose the optimal amount of debt.

[3]Hereafter, we denote with superscripts "$*$" variables pertaining to RoW.

[4]This approach is isomorphic to imposing a cash-in-advance constraint (Feenstra (1986)) or transaction costs (Valchev (2020)).

RoW Households .—The problem of the RoW household is

$$\max_{C_t^*, B_{H,t}^*, B_{F,t}^*} \sum_{s=0}^{\infty} \beta^s [U(C_{t+s}^*) + V(B_{H,t+s}^*)]$$

$$\text{s.t.} \quad C_t^* + B_{F,t}^* + B_{H,t}^* = \left(\frac{S_t}{S_{t-1}}\right)^{-1} \frac{(1+i_{t-1})}{\Pi_t^*} B_{H,t-1}^* + \frac{(1+i_{t-1}^*)}{\Pi_t^*} B_{F,t-1}^* + Y^*,$$

where C_t^* is consumption, $B_{H,t}^*$ and $B_{F,t}^*$ are real holdings of US and RoW bonds, Y^* is the RoW endowment, $1+i_t$ and $1+i_t^*$ are the US and RoW nominal interest rates, and S_t is the nominal exchange rate in terms of dollars per foreign currency, so that an increase of S_t is a dollar depreciation. $\Pi_t^* = P_t^*/P_{t-1}^*$ is gross inflation. $U(C_t)$ and $V(B_{H,t+s}^*)$ are increasing, concave functions representing the utility of consumption and the non-monetary payoff of US Treasuries. The Euler equations for foreign and domestic bonds, respectively, are

$$U'(C_t^*) = \beta \frac{1+i_t}{\Pi_{t+1}^*} \frac{S_t}{S_{t+1}} U'(C_{t+1}^*) + V'\left(B_{H,t}^*\right),$$

$$U'(C_t^*) = \beta \frac{1+i_t^*}{\Pi_{t+1}^*} U'(C_{t+1}^*).$$

Combining these equations, we obtain a modified uncovered interest parity (UIP) condition

$$\underbrace{\frac{1+i_t^*}{\Pi_{t+1}^*} - \frac{S_t}{S_{t+1}} \frac{1+i_t}{\Pi_{t+1}^*}}_{\equiv \phi_t} = \frac{1}{\beta U'(C_{t+1}^*)} V'\left(B_{H,t}^*\right).$$

The left-hand side of the equation is the conventional UIP condition, which is different from zero because of the liquidity benefit provided by US Treasuries, reflected by $V'\left(B_{H,t}^*\right)$ on the right-hand side. We define the wedge in UIP as ϕ_t and refer to it as convenience yield henceforth. Note that since the model features no risk, the UIP deviation is equivalent to the CIP deviation which we use as a proxy for the convenience yield in the empirical analysis.

US Government & Fiscal Policy.—The US government's budget constraint in real terms is

$$B_t^G + T_t = \bar{G} + \frac{B_{t-1}^G}{\Pi_t}(1+i_{t-1}) + \chi(B_{t-1}^G),$$

where B_t^G is the amount of government debt issued in period t, and $\bar{G}$ is a fixed amount of government spending. In line with the empirical analysis, we focus solely on changes in the *composition* of funding of government spending, rather than changes in spending itself. T_t are lump-sum taxes, which adjust in response to changes in B_t^G to satisfy the budget constraint. $\chi(B_{t-1}^G)$ is a cost function that is increasing and convex in the real amount of debt B_{t-1}^G.

The choice of the cost function $\chi(B_{t-1}^G)$ in the model may appear ad-hoc at first glance. However, it can be justified as a convenient representation of distortionary costs associated with financing debt repayments through taxation. This approach is common in the literature, and is used for example in Choi et al. (2022) and Gorton and Ordonez (2022). Another interpretation of this cost function is that it captures the costs associated with expanding the US government's balance sheet. This route is taken by Hall and Reis (2015) and Greenwood et al. (2016), wherein issuing debt incurs expenses related to interest rate risk and asset purchases. Then, $\chi(B_{t-1}^G)$ in our model can be thought of as a catch-all term for any frictions associated with increasing sovereign debt that are not explicitly modelled.

The government chooses the optimal amount of debt issued B_t^G to maximise the US household's utility, subject to the government's budget constraint and to the household problem's optimality conditions, taking interest rates as given. ,[5]

We show in Appendix A that this Ramsey problem can be formulated as

$$\max_{C_t, A_t, B_t^G} \sum_{s=0}^{\infty} \beta^s U(C_{t+s})$$

$$\text{s.t.} \quad C_t + A_t + \bar{G} = \frac{1+i_{t-1}^*}{\Pi_t}\frac{S_t}{S_{t-1}} A_{t-1} + \phi_{t-1} B_{t-1}^G - \chi(B_{t-1}^G) + Y,$$

where we define $A_t \equiv B_{F,t} - B_t^G$ as net foreign assets. The optimality conditions of this problem are

$$U'(C_t) = \beta \frac{1+i_t^*}{\Pi_{t+1}} \frac{S_{t+1}}{S_t} U'(C_{t+1}),$$

$$\phi_t = \frac{\partial \chi(B_t^G)}{\partial B_t^G}.$$

The first condition is the Euler equation for US households. The second one is a static optimality condition stating that the convenience yield ϕ_t equals the marginal cost of issuing a unit of real debt $\frac{\partial \chi(B_t^G)}{\partial B_t^G}$. By issuing a unit of debt, the government commits to pay the US interest rate i_t, but at the same time reduces

[5]Note that, unlike Choi et al. (2022), we assume that the US government is a price taker and does not exploit its monopolistic power to extract a rent from US bond holders. In other words, it does not internalize the effect of B_t^G on ϕ_t. If it did, an under-provision of government bonds would occur, but the mechanisms highlighted in this paper would still hold.

by one unit the lump sum taxes levied on households. Since US households can invest only in foreign bonds, the marginal opportunity cost of taxation is equal to the RoW interest rate i_t^*. Thus, the difference between the interest rate on RoW and US bonds expressed in the same currency, i.e. the convenience yield, is the relevant marginal benefit for the choice of issuing debt.

Monetary policy . — We examine the equilibrium under a fully flexible exchange rate policy with fixed nominal interest rates, so that the convenience yield can adjust through the exchange rate only, thus bringing the core mechanism of the paper into stark relief.

In the US, we fix the nominal interest to a constant, arbitrary level

$$i_t = i \quad \forall t.$$

The nominal interest rate does not affect the real rate, which is fixed at $\frac{1-\beta}{\beta} - \frac{V'(B^G)}{\beta U'(C^*)}$ due to constant endowments. Thus, all adjustments in the equilibrium US real interest rate occur through US inflation only. The modified UIP condition on the other hand adjusts through the nominal exchange rate, which is linked to inflation by virtue of the LOP.

In the RoW, the real interest rate is fixed at $\frac{1-\beta}{\beta}$ due to constant endowments. Therefore, by letting the nominal interest rate be

$$i_t^* = \frac{1-\beta}{\beta} \quad \forall t,$$

$\Pi_t^* = 1$ obtains in equlibrium. A consequence is that $\Pi_t = \frac{S_t}{S_{t-1}}$, as can be seen by combining the LOP for periods t and $t+1$.

2.2 Equilibrium

An equilibrium in this economy is characterized by an allocation $\{C_t, C_t^*, B_{H,t}^*, B_t^G, B_{F,t}, B_{F,t}^*\}$ and prices $\{\Pi_t, \Pi_t^*, S_{t+1}/S_t, i_t, i_t^*\}$ such that

1. Given prices, the allocation satisfies the optimality condition and budget constraint of the RoW household.
2. Given prices, the allocation satisfies the optimality condition and budget constraint of the US government's Ramsey problem.
3. Markets for goods, US government bonds and RoW government bonds clear:
   - Goods: $C_t + C_t^* = Y + Y^* - \bar{G}$,
   - US government bonds: $B_{H,t}^* = B_t^G$,

– RoW government bonds: $B_{F,t} + B^*_{F,t} = \bar{B}_F$,

where $\bar{B}_F$ is the supply of foreign bonds. Note that in this equilibrium US and RoW consumption C and C^* are constant. Real interest rates are constant because endowments are fixed, so it follows from the US and RoW Euler equation for RoW bonds that $C_t = C_{t+1} = C$, and $C^*_t = C^*_{t+1} = C^*$.

Therefore, the only variables that are not constant over time in equilibrium are US Treasury supply B^G_t, US inflation and the exchange rate, which in turn causes the convenience yield ϕ_t to vary. The rationale for these modelling choices is to provide an environment that is as simple as possible, while maintaining the core mechanisms of liquidity preference for US Treasuries and debt supply choice. As real variables are fixed, with the exception of B^G_t, the model is meant to capture a within-quarter environment. Each period can be conceptualised as a week, in keeping with the timing of the local projections in section 3. Note that US Treasury auctions are held at a frequency of several per month, which justifies our assumption of B^G_t varying within a quarter. The equilibrium dynamics are then described by two equations: the modified UIP condition derived from the RoW household's optimisation, and the bond supply schedule implied by the government's Ramsey problem.

We now turn to analyse the effects of shifts in the debt supply curve and in the household's liquidity preference on the convenience yield and exchange rate.[6] In order to obtain an analytical solution of the model and a graphical representation of the equilibrium, we assume the following convenient functional forms

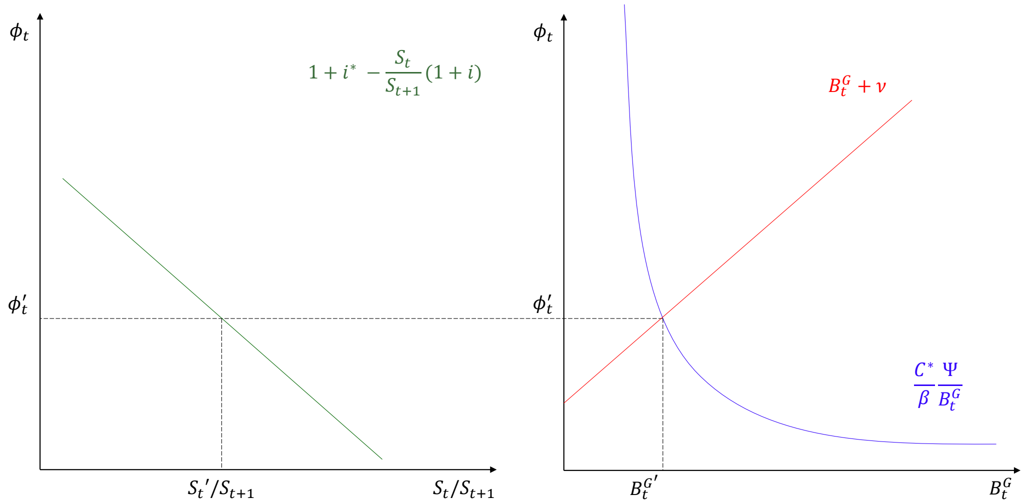
$$U(x) = log(x), \qquad V(x) = \Psi log(x), \qquad \chi(x) = x^2/2 + \nu x,$$

where $\Psi > 0$ is a parameter regulating the relative weight of bonds within the utility function that can be interpreted as liquidity preference, and $\nu > 0$ is a parameter regulating the constant component of the marginal cost of debt issuing. Conceptually, ν plays the same role as the identified Treasury supply shock does in our empirical analysis, with an increase in ν corresponding to a negative supply shock. However, the theoretical model is deterministic, so ν is to be interpreted as a shifter for the supply curve rather than a shock. Note that the results of the model do not hinge on these specific functional forms, but only on $U(x)$ and $V(x)$ being separable, increasing and concave, and on $\chi(x)$ being increasing and convex.

With these functional forms, the US bond supply schedule and the modified UIP

[6] Note that we consider permanent changes to parameters that result in changes to both *steady-state* values and *equilibrium* values. For all variables that are fixed at the steay state in the equilibrium, such as consumption, the two coincide.

Figure 1. Equilibrium Debt, Convenience Yield and Exchange Rates



condition yield two equilibrium equations

$$\phi_t = B_t^G + \nu, \qquad \text{(1a)} \qquad\qquad \phi_t = \frac{C*}{\beta}\frac{\Psi}{B_t^G}. \qquad \text{(1b)}$$

We can then solve for the equilibrium values of ϕ_t and B_t^G as a function of parameters

$$\phi_t = \frac{1}{2}\left(\nu + \sqrt{\nu^2 + 4\frac{C^*\Psi}{\beta}}\right), \qquad B_t^G = \frac{1}{2}\left(\sqrt{\nu^2 + 4\frac{C^*\Psi}{\beta}} - \nu\right).$$

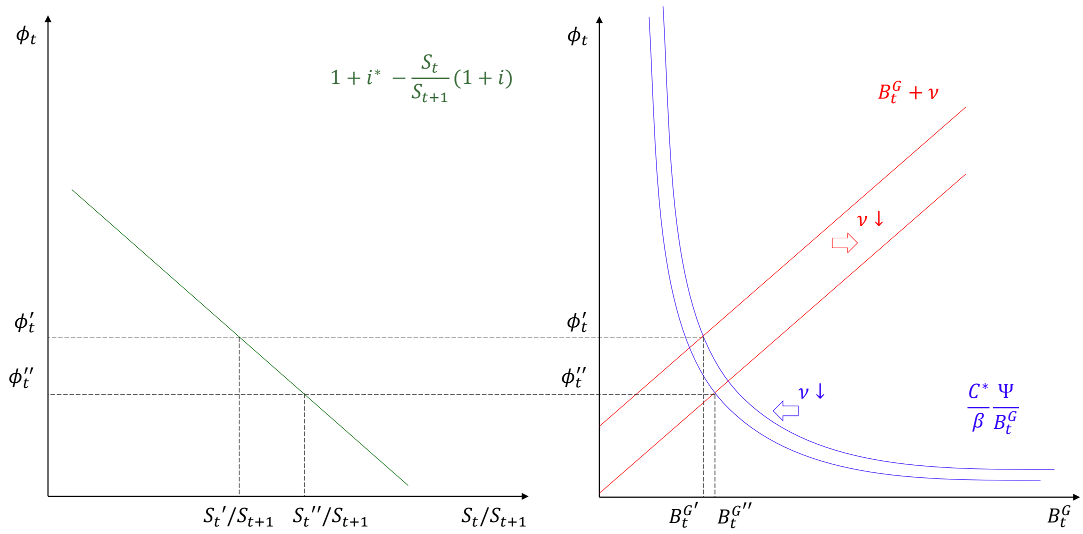
The two latter equations tell us that the convenience yield ϕ_t and the optimal level of US debt B_t^G depend in equilibrium on the two parameters of interest, namely the marginal cost of debt issuance ν, and the preference for liquidity Ψ.

Figure 1 illustrates the equilibrium. The right panel shows the level of the convenience yield that clears the market for US government bonds. The red line is the supply of US debt as per Equation 1a, and the blue curve is the demand thereof by RoW households characterized by Equation 1b. The left panel portrays, for given constant levels of US and RoW nominal interest rates, the simultaneous depreciation required for the modified UIP condition to hold (green line) at the market-clearing level of the convenience yield.

Next, we show both graphically and analytically how this equilibrium is affected by changes in ν and Ψ.

Changes in the Marginal Cost of Debt .—Figure 2 depicts the effects of a drop in ν on the equilibrium values of US government debt, the convenience yield and exchange rate. It corresponds to a reduction in the fixed component of

Figure 2. Marginal Cost of Debt Change



marginal cost of debt issuance, engendering an outward shift of the debt supply curve. As a result, the US government chooses to increase the supply of Treasuries *ceteris paribus*. Since the marginal liquidity value that foreign household derive from US Treasuries is decreasing in the amount held, they will require a higher monetary return to absorb the now higher supply. We define this as "debt supply effect".

In addition, a decrease in ν leads to an inward shift of the Treasury demand curve through an increase in the marginal utility of RoW consumption, which makes holding US debt less attractive at any level of ϕ_t. The decrease in C^* originates through the goods market clearing from a contemporaneous increase in domestic consumption. In turn, the latter is due to subsitution from saving to consumption on the part of US households. As the convenience yield decreases following the first-order expansion in B_t^G, the economy-wide "carry" return from issuing Treasuries and investing in foreign bonds becomes less attractive, and so the US household invests less in foreign bonds and consumes more. We define this mechanism as the "marginal utility effect".

The responses of B_t^G and ϕ_t to a change in ν can be expressed formally as

$$\frac{\partial B_t^G}{\partial \nu} = \frac{1}{4}\left(\nu^2 + 4\frac{C^*\Psi}{\beta}\right)^{-1/2}\left(2\nu + 4\frac{\Psi}{\beta}\frac{\partial C^*}{\partial \nu}\right) - \frac{1}{2},$$

$$\frac{\partial \phi_t}{\partial \nu} = \frac{1}{4}\left(\nu^2 + 4\frac{C^*\Psi}{\beta}\right)^{-1/2}\left(2\nu + 4\frac{\Psi}{\beta}\frac{\partial C^*}{\partial \nu}\right) + \frac{1}{2}.$$

Note that the steady-state level of RoW consumtpion C^* depends on both ν and Ψ, as shown in Appendix B. We can see immediately that $\frac{\partial \phi_t}{\partial \nu} > 0$ for $\frac{\partial C^*}{\partial \nu} > 0$, $\nu > 0$ $\beta > 0$ and $\Psi > 0$. Therefore, a decrease of ν results in a lower ϕ_t. We can confirm this graphically, as the debt supply curve shifts out after a drop in ν, while the debt demand curve shifts inward.

On the contrary, the sign of $\frac{\partial B_t^G}{\partial \nu}$ depends on the relative strengths of the debt supply and marginal utility effects. The latter is mediated by the $\frac{\partial C^*}{\partial \nu}$ term in $\frac{\partial B_t^G}{\partial \nu}$. The condition for $\frac{\partial B_t^G}{\partial \nu} < 0$ requires that the marginal utility effect is sufficiently weak, represented by an upper bound on $|\frac{\partial C^*}{\partial \nu}|$. If that were not the case, the US government would react to the weaker demand for Treasuries by choosing a lower B_t^G than in the original equilibrium. The derivatives $\frac{\partial \phi_t}{\partial \nu}$, $\frac{\partial B_t^G}{\partial \nu}$ and their signs are analysed formally in Appendix D.

As a result of a drop in ν, the economy then moves to a new equilibrium characterized by a lower ϕ_t and, provided that the "debt supply effect" dominates, a higher B_t^G. Interest rates being fixed, the increase in returns from Treasuries will be achieved by an immediate depreciation and a later appreciation of the US dollar, as shown in the left-hand side plot. This theoretical mechanism translates into one simple testable implication which we state next.

Implication 1 *An outward shift in US debt supply reduces the convenience yield through an immediate depreciation and a later appreciation of the US dollar.*

These dynamics are consistent with the correlational evidence in the literature, and with the results of our empirical analysis outlined in Sections 3.3 and 3.4. We contribute by showing that a positive shock to the supply of US Treasuries leads to a reduction of the US convenience yield and an immediate depreciation followed by an appreciation of the US dollar, relative to a panel of G10 currencies, with larger magnitudes than previously estimated.

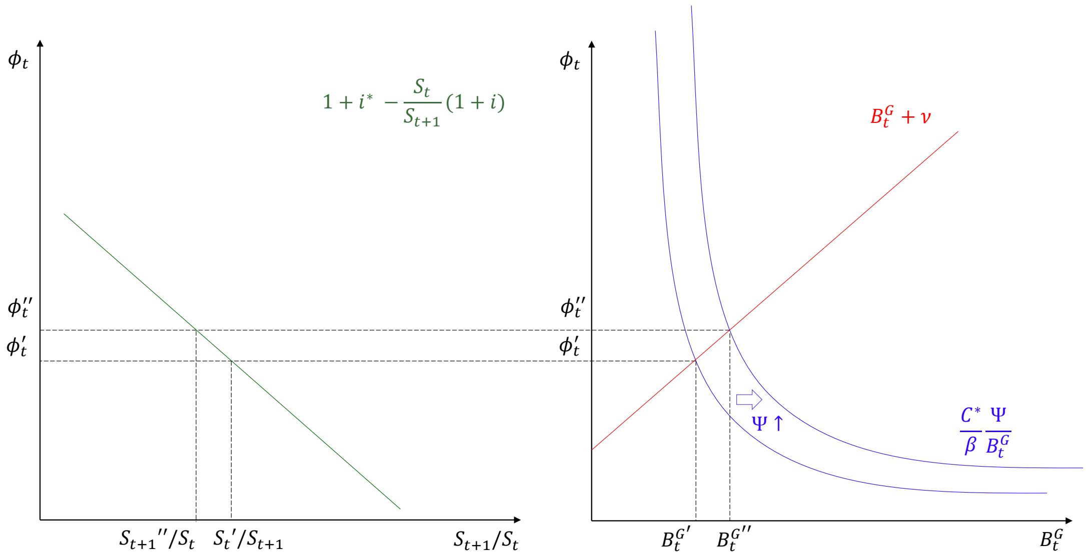
Changes in Liquidity Preference.—An increase in the liquidity preference of RoW households, i.e. an outward demand curve shift, also results in a higher equilibrium amount of US Treasuries, but it is instead associated with a dollar *appreciation* and a *higher* convenience yield.

The responses of B_t^G and ϕ_t to a change in Ψ can be expressed formally as

$$\frac{\partial B_t^G}{\partial \Psi} = \frac{\partial \phi_t}{\partial \Psi} = \frac{1}{4}\left(\nu^2 + 4\frac{C^*\Psi}{\beta}\right)^{-1/2}\left(\frac{4\Psi}{\beta}\frac{\partial C*}{\partial \Psi} + \frac{4C^*}{\beta}\right).$$

The two derivatives are the same, and they are both positive for $\Psi > 1$. This condition ensures that $|\frac{\partial C*}{\partial \Psi}|$ is low enough. In other words, the increase in the

Figure 3. Liquidity Preference Shift



marginal utility of RoW consumption following an increase in Ψ should not be so strong as to reverse the first-order outward shift in US debt demand. In turn, this requires that the parameter Ψ that regulates the marginal liquidity benfit of Treasuries be high enough. We derive this condition formally in Appendix D.

Figure 3 shows that a higher Ψ implies a higher marginal liquidity benefit for a given amount of US Treasuries held. Therefore, RoW households will accept a lower monetary payoff, which causes ϕ_t to increase. The left-hand plot shows that the higher convenience yield is achieved through a contemporaneous dollar appreciation.

The higher convenience yield will then incentivize the US government to issue more debt, due to the higher marginal benefit. If the Treasury supply curve is upward-sloping in the convenience yield, changes in the liquidity preference for US Treasuries introduce a positive correlation between convenience yields, exchange rates and the equilibrium amount of debt. This theoretical mechanism can be summarized in a simple testable implication which we state next.

Implication 2 *Changes in liquidity preference generate positive comovements between US debt supply, US dollar appreciation, and the convenience yield, introducing a bias towards zero in the coefficient of OLS regressions of the convenience yield on Treasury amounts.*

In other words, any empirical analysis that cannot distinguish whether the observed variability in outstanding Treasury amounts, convenience yields and exchange rates is due to changes debt supply or liquidity preference will incur in issues of endogeneity, which we address with an instrumental variable *à la* Phillot (2021) by isolating Treasury supply shocks.

Consistent with this type of endogeneity, we report in Sections 3.3, 3.4 and 3.5 a large downward bias of OLS estimates of the impact of Treasury supply shocks on the US convenience yield and exchange rate, relative to a panel of G10 currencies.

3 Empirical Evidence

Next, in an attempt to corroborate Implications 1 and 2 derived in the previous section, we present empirical evidence concerning the link between Treasury supply, convenience yields, and exchange rates. Our empirical contribution is to characterize how well-identified shocks to Treasury supply impact Treasury premia via currency fluctuations.

Although Du et al. (2018) discuss the long-term link between convenience yields and government bond supply, they do not discuss exchange rate fluctuations. Engel and Wu (2018), on the other hand, relate convenience yields to monthly currency swings, but they employ debt-to-GDP ratios as instruments for Treasury liquidity services. Our theoretical results support the view that government debt does not constitute a viable instrument, for fluctuations in the observed outstanding amount of Treasuries may very well depend on the liquidity services they offer. By invoking a cleaner identification of Treasury supply shocks, this paper aims at improving upon the existing literature.

3.1 Identification

Problem.—It is challenging to empirically measure how changes in the supply of US Treasuries affect global financial markets and macroeconomic outcomes, because linear regressions of exchange rates or relative convenience yields onto US government debt inexorably face endogeneity issues. To see it, consider a flight-to-liquidity episode that leads to an increase in the US relative convenience yield and an appreciation of the US dollar. In other words, there are temporary demand-driven forces that make US debt relatively cheap to finance. Suppose further that the US government is more likely to issue Treasuries during those times when its debt trades at a relatively high convenience yield.[7] Then, a linear regression of that yield onto debt fails to disentangle supply- from demand-driven

[7] In our theoretical framework, government debt issuance relaxes households' budget constraint via less taxes, allowing them to purchase more foreign bonds. The government pays the US interest rate on its borrowing, while households earn the foreign interest rate, converted into dollars, on their RoW bond investment.

factors, reverse causality emerges and estimates are biased downwards. In turn, the link between convenience yields and exchange rates through the UIP transmits this issue to exchange rates too.

To cope with this, we implement an identification strategy of US Treasury supply shocks *à la* Phillot (2021) using Treasury auction data. By interpreting changes in US Treasury futures prices around announcements by the US Treasury as surprises about the supply of US debt securities, we are able to recover shocks between 1998 and 2020. Following is a thorough description of the identification strategy.

Strategy. — The US government finances its debt by issuing Treasuries, whose yield is determined via public auctions. Concurrently, several futures contract on US Treasuries—securities with a settlement price that the buyer agrees to accept delivery of on the settlement date—are being traded on the CBOT since 1977.

According to Phillot (2021), the design of US Treasury auctions offers an ideal set up for shock identification because the details about maturities and volumes of the issued securities are announced several days in advance and come with a report published on the same day. Under the efficient market hypothesis, intraday price variations of US Treasury futures around these announcements reflect surprises.

More formally, let $P_t^{TS,k}$ be the price of a k-year US Treasury and let $F_t^{TS,k}$ be its associated futures price for $k = 2, 5, 10, 30$. Phillot (2021) supposes that, at announcement time t,

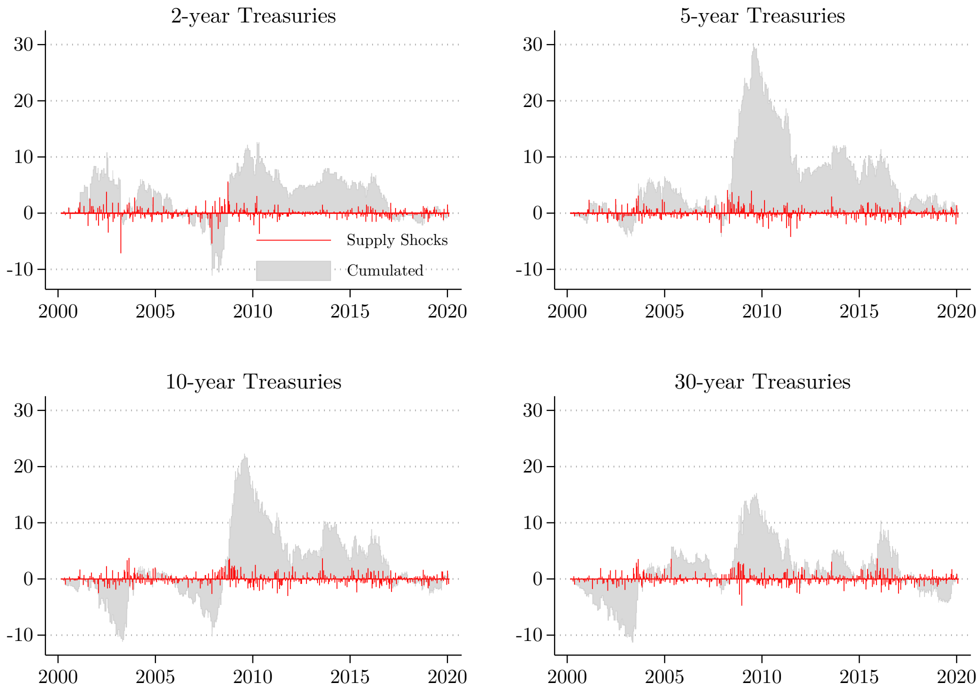
$$F_{t^+}^{TS,k} - F_{t^-}^{TS,k} = -\sigma^k \xi_t^k + u_t^k.$$

In this setting, futures price variations between t^- and t^+ have two drivers: US Treasury supply shocks ξ_t^k, scaled by Treasury demand price elasticity $-\sigma^k$, and a residual u_t. The latter consists of changes in Treasury futures prices that are orthogonal to Treasury supply shocks, such as the release of other macroeconomic news.

There is a trade off in picking the length of the time window (t^-, t^+). As argued by Nakamura and Steinsson (2018), a longer time window allows for capturing more detailed dynamics, yet it comes at the cost of potential confounding factors and noise contamination. In other words, shorter windows restrict the effects of u_t but generate instruments of little statistical power.

We chose a 15-minute window following the announcement so as to minimize the influence of cofounding factors while preserving a satisfying level of relevance for the instrumental variable exercise detailed below. Thus, our four Treasury supply shocks series $\{-\hat{\xi}_t^k\}_{k=2,5,10,30}$ are simply the 15-minute Treasury futures (inverse)

Figure 4. US Treasury Supply Shocks, 1998–2020



Source: Own calculations based on Phillot (2021).

returns following the announcements.[8]

3.2 Data

We now turn to describing the data used in our empirical approach.

US Treasury Supply Shocks.—Announcements about US Treasury auctions are summarized in reports available on `TreasuryDirect.com`. Intraday data on US Treasury futures prices are provided by CQG. As mentioned above, we consider a 15-minute window following report official releases to compute the shocks.

Figure 4 displays the series of shocks stemming from the identification strategy outlined above. The solid red spikes show the Treasury supply shocks $\hat{\xi}_t^k$ and the shaded areas show their running sums. For comparability, the shock series have been z-normalized. As a result, they have a zero mean and sum to zero.

Our measure of changes in Treasury supply at the daily frequency, which we instrument using the series of shocks depicted in Figure 4, is the net cash operation that reads on the US Treasury auction announcement reports. It corresponds to

[8] Phillot (2021), on the other hand, employs a 30-minute window. Unfortunately, using a 30-minute window results in weak instruments across most specifications, unlike the use of a 15-minute window. In other words, prolonging the window by 15 minutes introduces too much noise. Still, the conclusions outlined in the paper are less robust yet consistent under the 30-minute window. See Appendix F for a discussion.

the sum of the dollar amounts of 2-, 5-, 10- and 30-year soon-to-be-auctioned Treasury securities, minus the dollar amounts of soon-to-mature 2-, 5-, 10- and 30-year Treasury securities.

Relative Convenience Yields.—As outlined in Section 2, the relative convenience yield is a premium investors are willing to forego on their holdings of one country's Treasuries for the liquidity services they provide, relative other countries' Treasuries. In our theoretical framework, the relative convenience yield is a wedge in the UIP condition for government bonds. In the absence of uncertainty, UIP deviations are equivalent to CIP deviations.

Du et al. (2018) (based upon Du and Schreger, 2016) propose a measure of relative convenience yields based on CIP deviations, which they define as the yield difference between one country's government bond and US Treasuries, once cash-flows are hedged into that country's currency. In particular, letting $\iota^k_{t,j} - \iota^k_{t,US}$ be the time-t k-year own-currency government bond yield differential between country j and the US, and $\rho^k_{t,j}$ be the logarithm of the time-t k-year market-implied forward premium to hedge currency j against the US dollar, they define CIP deviations $\Phi^k_{t,j}$ as

$$\Phi^k_{t,j} = \iota^k_{t,j} - \iota^k_{t,US} - \rho^k_{t,j}.$$

Moreover, they argue that CIP deviations between country j and the US are mainly driven by their relative convenience yield $\phi^k_{t,j}$, their relative default risk $\kappa^k_{t,US}$, and risk-free CIP deviations $\tau^k_{t,j}$ caused by financial frictions

$$\Phi^k_{t,j} \approx \phi^k_{t,j} - \kappa^k_{t,US} + \tau^k_{t,j},$$

such that relative convenience yields are well approximated by CIP deviations on government bonds, once relative default risk and CIP deviations on risk-free rates are taken into account. In our empirical exercise, we use their measure of convenience yields, which is available at daily frequencies for all G10 currencies (Australia, Canada, Denmark, Germany, Japan, New Zealand, Norway, Sweden, Switzerland, the United Kingdom, and the United States) and for bond maturities ranging from 3 months to 10 years.[9]

Using $\Phi^k_{t,j}$ as a proxy for $\phi^k_{t,j}$ assumes frictionless foreign exchange swap markets and default-free government bonds.[10] As a result, it abstracts from CIP deviations in FX markets and relative credit spreads. The former can be proxied using CIP deviations on observed risk-free rate proxies and the latter using credit default swaps (CDS) on sovereign credit, both of which can be found on Refinitiv Datas-

[9]The data is available at `https://sites.google.com/view/jschreger/CIP`.

[10]According to Du et al. (2018), this assumption is sound for developed economies.

tream. Unfortunately, CDS are not available before the Global Financial Crisis. As a result, we only control for market frictions in what follows and discuss the robustness of our results to controlling for sovereign credit risk in Appendix E.

Finally, unless stated otherwise, CIP deviations are averaged along their maturity dimension (k). The panel structure at the day-currency-level (t, j) on the other hand is exploited.

Financial & Macro Variables. — The financial variables used in the daily regression and the weekly local projections along with convenience yields are exchange rates and a set of controls. The latter are central banks policy rate differentials, MSCI stock market indices, WTI crude oil futures and gold futures prices, as well as the VIX.

Data on central banks policy rates come from the IMF ("International Financial Statistics" dataset), those on the VIX from the website of the Federal Reserve Economic Data (FRED), and the rest from Refinitiv Datastream. This daily sample covers the period between 2001 and 2020.

The macroeconomic variables deployed in the replication exercise of the quarterly panel-data analysis from Du et al. (2018) are debt-to-GDP ratios net of central banks' holdings, central banks policy rates, the VIX and real GDPs. Their sources are respectively the IMF ("Sovereign Debt Investor Base for Advanced Economies" and "International Financial Statistics" datasets), Refinitiv Datastream, FRED, and the OECD ("Quarterly National Accounts"). This quarterly sample covers the period between 2004 and 2020.

3.3 Daily Regression

The first piece of empirical evidence we produce in this paper is a characterization of the impact of unexpected changes in the observable outstanding amount of US Treasuries on the US dollar exchange rate and the US convenience yield *vis-à-vis* other G10 currencies on a daily basis.

The goal is threefold. First, inspecting the first-stage statistics of the 2SLS procedure informs us on our instrument's performance. Second, once our instrument is deemed valid, the daily regressions provide a clear picture on the extent to which our instrument solves endogeneity issues associated with OLS. Third, the second-stage results do not only uncover the immediate effects of Treasury supply shocks, but also guide the subsequent weekly estimations in terms of the variables worth controlling for.

Methodology. — We estimate two separate baseline pooled regressions on daily changes in Treasury supply ΔB_t^G of daily changes in the US convenience yield relative to country j, $\Delta\phi_{t,j}$, and daily log-changes in the US dollar exchange rate *vis-à-vis* currency j, $\Delta\log(S_{t,j})$

$$\Delta\phi_{t,j} = \beta_0 + \beta_1\Delta B_t^G + \beta_2\Delta\log(S_{t,j}) + v_{t,j}, \tag{2}$$

$$\Delta\log(S_{t,j}) = \gamma_0 + \gamma_1\Delta B_t^G + \gamma_2\Delta\phi_{t,j} + w_{t,j}. \tag{3}$$

The coefficients of interest in Equation 2 and 3 are β_1 and γ_1, for they respectively measure the contemporaneous effect in basis points of an increase in Treasury supply on relative convenience yields and exchange rates.[11]

As argued before, the OLS estimation of Equation 2 and 3 suffer from endogeneity. Phillot (2021) argues that the four series of Treasury supply shocks $\{-\eta_t^k\}_{k=2,5,10,30}$ are valid instruments for ΔB_t^G. The results shown in this paper therefore come from the 2SLS estimation of these two Equations.

Albeit parsimonious, these two models will arguably fail to account for a substantial part of the variability in convenience yields and exchange rates movements. In particular, one might be worried about the importance of cross-currency heterogeneity, macroeconomic low-frequency factors and other relevant financial market outcomes.

As a result, in what follows, we supplement Equation 2 and 3 with country fixed effects, year fixed effects as well as set of controls. These are (daily changes of) US and country j stock market price indices, policy rate differentials between the US and country j, the VIX, gold and oil prices, endogenous changes in expectations about future monetary policy (measured as 15-minute changes in Fed funds futures prices around Treasury announcements), risk-free CIP deviations.[12] We also include dummies that take on the value one on days when an auction is either open for bidding, or held.

The inclusion of central bank policy rate differentials is meant to reflect the relative stance of monetary policy and capture exchange rate fluctuations pertaining to excess currency returns, as predicted by the UIP which our theoretical framework features. On the other hand, stock market indices and the VIX, beyond being

[11] Although our results are robust to excluding them, including $S_{t,j}$ and $\phi_{t,j}$ in the two regressions is important if one thinks that Treasury supply, convenience yields and exchange rates admit an infinite vector MA representation whereby structural shocks to one variable affects the others contemporaneously.

[12] Risk-free CIP deviations control for frictions on the swap markets, one of two potential drivers of relative convenience yields according to Du et al. (2018). The other one, relative credit risk, is accounted for by Table A1 in Appendix E.

Table 1. On-Impact Effects of Treasury Supply Shocks

	Convenience Yield			Exchange Rate		
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	IV	OLS	IV	IV
ΔB_t^G (abs. median)	-0.0404	-0.635*	-0.668**	2.232***	30.54***	18.85***
	(0.0392)	(0.371)	(0.317)	(0.792)	(8.455)	(6.351)
$\Delta \log(S_t)$ (bp.)	-0.0319***	-0.0309***	-0.0248***			
	(0.00612)	(0.00615)	(0.00605)			
$\Delta\phi_t$ (bp.)				-4.840***	-4.694***	-5.005***
				(0.936)	(0.939)	(1.253)
Observations	49810	49810	48460	49810	49810	48460
Effective F-stat		13.3	17.3		13.3	17.3
$\hookrightarrow$ Critical Value		12.8	12.5		12.8	12.5
Hansen J-stat p-val.		0.31	0.24		0.71	0.18
Lags	No	No	Yes	No	No	Yes
Fixed Effects	No	No	Yes	No	No	Yes
Controls	No	No	Yes	No	No	Yes

Robust standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

indicators of investor sentiment and uncertainty, should capture the previously documented short-term interdependency of stock prices and exchange rates (Nieh and Lee, 2001). Finally, adding commodity prices should not only proxy inflation expectations but also explain some degree of exchange rate variations for so-called commodity currencies, i.e., the Australian, the Canadian, and the New-Zealand dollar (Chen and Rogoff, 2003).

It is noteworthy that these two regressions are equivalent to a zero-horizon instrumental variable local projection applied to panel data. Following Montiel Olea and Plagborg-Møller (2021), we augment Equation 2 and 3 with the two lags of all the financial variables (including the dependent variables) and compute standard errors that are robust to the presence of arbitrary heteroskedasticity.[13]

Results.—Table 1 displays the results stemming from the estimation of Equation 2 and 3. The elements of columns 1 to 3 pertain to convenience yields, and those of columns 4 to 6 pertain to exchange rates. Columns 1 and 4 contain the OLS estimates, while columns 2 and 5 contain the IV estimates of the baseline model described by Equation 2 and 3. Columns 3 and 6 show the IV estimates when the above-mentioned controls are included.

Looking at the bottom of Table 1, one finds a set of important statistics. First, our sample, by covering the period between February 2001 and January 2020 for 10

[13]Table A2 from Appendix E reports the estimates that are robust to both arbitrary heteroskedasticity and arbitrary autocorrelation. The statistical significance of our results is unchanged.

countries, amounts to nearly 50'000 business days. Second, our set of instruments appears relevant, as all the computed robust F-statistics (Olea and Pflueger, 2013) are above critical values.[14] In all cases, the Hansen J-statistic reflects a p-value exceeding conventional confidence levels, preventing us from rejecting the joint null hypothesis that the instruments are valid.

The first row of coefficients are to be interpreted as the contemporaneous effect of a change in Treasury supply on convenience yields and exchange rates. To recover interpretability, Treasury supply changes are scaled to be the size of an absolute median increase, i.e., \$13 billions.

Upon examination of the convenience yield, we note that OLS regression is unable to establish a statistically significant reduction in the US convenience yield following an increase in Treasury supply. On the contrary, the IV coefficients provided in column (2) indicate that, on impact, unexpected median-sized Treasury supply increases result in a decline of approximately 0.65 basis points in the US convenience yield, relative to G10 currencies. This latter observation suggests that our model is susceptible to omitted variable bias in the absence of an instrument, consistent with Implication 2. The inclusion of additional controls in column (3) does not affect these findings.

Secondly, concerning exchange rates, our analysis shows that Treasury supply shocks lead to a significant 2.2 basis point depreciation of the US dollar on impact, as indicated by OLS. However, this effect is substantially underestimated by OLS, as our IV approach yields a much higher figure of 30.5 basis points. After adding the controls, we estimate that a median-sized surprise increase in Treasury supply results in an immediate depreciation of the US dollar by approximately 18.9 basis points.

Taken together, these results align with Implications 1, at least qualitatively speaking. In terms of their magnitude, on the other hand, these on-impact effects are fairly small. Indeed, the standard deviation of changes in convenience yields and exchange rates is 5.6 and 68.7 basis points respectively. Hence, their immediate response to debt supply shocks lies within the range of a tenth to a third of a standard deviation.

Notwithstanding, the weekly analysis below—computed over a time-period that speaks more adequately to our model—documents effects with a magnitude of greater economic significance as well as a non-negligible degree of persistence.

[14] The critical values are computed under the null hypothesis that the Nagar (1959) bias is greater than 10% of the benchmark with a 95% confidence level.

3.4 Weekly Local Projections

The second piece of empirical evidence we present in this paper is a general picture of the dynamics of exchange rates and relative convenience yields a few weeks following the shocks characterized above. We are particularly interested in knowing how the effects of Treasury supply shocks outlined above evolve within a quarter, for consistency with the timing of the theoretical model, and whether they are persistent.

Methodology.—We estimate the cumulative impulse response functions (IRFs) of relative convenience yields and exchange rates to changes in Treasury supply via the following local projections

$$\phi_{t,j} - \phi_{t-h-1,j} = \beta_{0,h} + \beta_{1,h}\Delta B^G_{t-h} + \beta_{2,h}\Delta \log(S_{t-h,j}) + v_{t,j,h}, \tag{4}$$

$$\log(S_{t,j}) - \log(S_{t-h-1,j}) = \gamma_{0,h} + \gamma_1 \Delta B^G_{t-h} + \gamma_{2,h}\Delta\phi_{t-h,j} + w_{t,j,h}, \tag{5}$$

for $h = 0, ..., 12$.[15] Because we are interested about the dynamic causal effects of US Treasury supply shocks in a time window that speaks to our theoretical framework, we lower our data frequency to the weekly level and compute these IRFs over a horizon of 12 weeks.[16] We take averages for all the financial outcomes (convenience yields, exchange rates, volatility, stock and commodity prices, policy rate differentials, FX swap market frictions), and sums for the auction-related variables (shifts in expectations about monetary policy, auction and bidding dummies).

As argued before, because the OLS estimation of Equation 4 and 5 suffers from endogeneity, we use the four series of Treasury supply shocks $\{-\eta^k_t\}_{k=2,5,10,30}$, summed over each week, as instruments for ΔB^G_t. The results shown below therefore come from their 2SLS estimation.

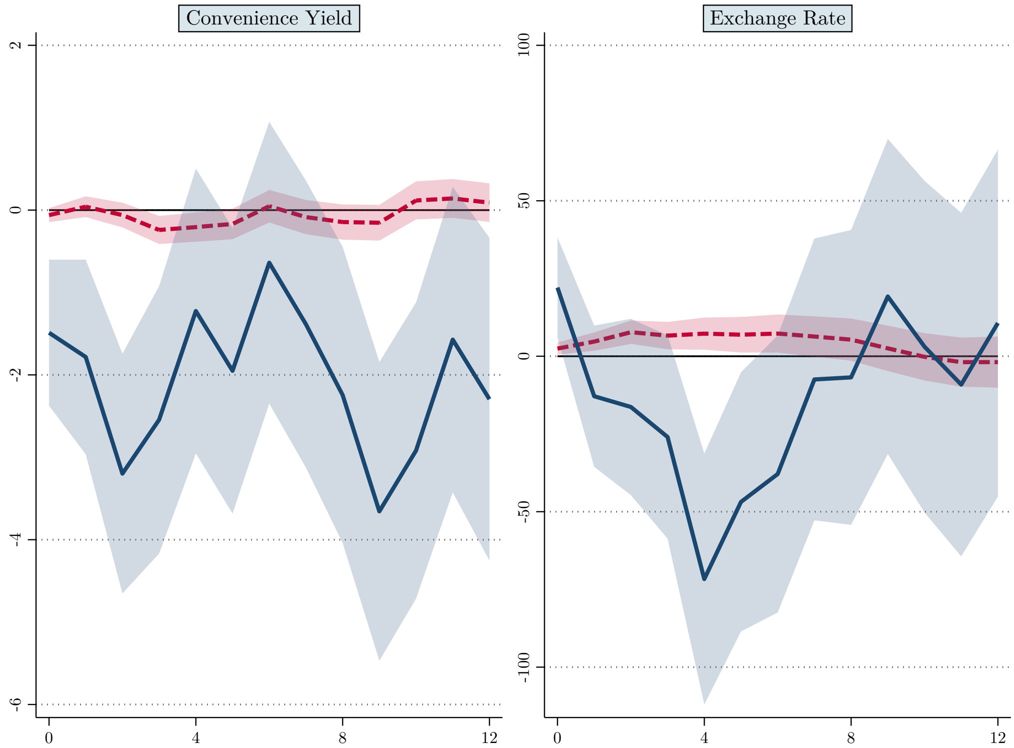
We add the same controls as in the daily regressions described earlier. Again, the confidence intervals that we report are based on a lag-augmented model with standard errors that are robust to heteroskedasticity (Montiel Olea and Plagborg-Møller, 2021).

Results.—Figure 5 displays the IRFs to Treasury supply shocks of convenience yields and exchange rates over a 12-week period (in basis points). The solid blue lines in each subplot displays the cumulative IRF to a 13-billion-dollar positive change in US Treasury supply of the above-mentioned variable stemming from the

[15] Although presented with slight differences from the specification used in Phillot (2021), these local projections are equivalent as they generate cumulative IRFs to Treasury supply shocks.

[16] The results we obtain with weekly data are similar, both qualitatively and quantitatively, to the ones we obtain using daily data over 60 business days. The advantage of weekly IRFs over daily ones lies in their smoothness. See Figure A1 in Appendix E.

Figure 5. IRFs to Treasury Supply Shocks of Convenience Yields and Exchange Rates



Notes: The solid blue lines in each subplot displays the IRF to a 13-billion-dollar positive change in US Treasury supply of the above-mentioned variable stemming from the 2SLS estimation of Equation 4 and 5. The dashed red lines are the estimates of the same object via OLS. Blue and red shaded areas are the respective 90% confidence intervals. The horizontal axis represents weeks from impact. Variables are in basis points.

2SLS estimation of Equation 4 and 5. The dashed red lines are the estimates of the same object via OLS. Blue and red shaded areas are the respective 90% confidence intervals. The horizontal axis represents weeks from impact. Variables can be interpreted in levels as the lines depict cumulative changes, as per Equation 4 and 5.

Concentrating on the IV outcomes for convenience yields, the initial observation is that the daily regression analysis results remain valid. Specifically, our instrumented approach indicates that, upon impact, the US convenience yield relative to G10 currencies experiences a substantial decrease of around 1 basis point. Furthermore, this decline is persistent throughout a quarter, and in some cases, reaches up to 3 basis points. Ordinary least squares (OLS) estimations, despite indicating a significant decrease four weeks after the shock, do not account for the magnitude and persistence of the effects revealed by our instrumental approach.

Concerning exchange rates, our IV local projections show that, similar to our daily regression, Treasury supply shocks lead to an immediate 25 basis points depreciation of the US dollar (USD). Consistently with the modified UIP condition in our theorretical model, the effects of these shocks reverse over time and result in a statistically significant appreciation of the USD, reaching more than 50 basis points four weeks after the impact, before vanishing four weeks later. Meanwhile, OLS estimates show a moderate but statistically significant depreciation of the USD over the same period.

Overall, our empirical findings not only highlight the presence of endogeneity in OLS estimates of IRFs, as per Implication 2, but they also align well with the dynamics prescribed by Implication 1.

3.5 Quarterly Panel-Data Regression

The third piece of empirical evidence we present in this paper is a replication of the panel-data quarterly analysis of the relationship between the outstanding amount of US Treasuries and the convenience yield in Du et al. (2018).

In an empirical study, Benhima and Phillot (2023) previously report that the OLS supply price elasticity of Swiss relative convenience yields is underestimated by a factor of three relative to an equivalent instrumental approach based on Swiss auction data. Here, we address whether the size of this bias is similar for the United States.

Methodology.—As in Du et al. (2018), we regress relative convenience yields at quarterly frequencies onto a set of macroeconomic and financial variables, for the panel of G10 countries between 2004 and 2020.[17]

In particular, we model the US dollar 5-year maturity relative convenience yield as

$$\phi_{t,j}^{5Y} = \beta_0 + \beta_1 \log\left(\tfrac{\text{Debt}}{\text{GDP}}\right)_{US,t} + \beta_2 \log\left(\tfrac{\text{Debt}}{\text{GDP}}\right)_{j,t} + \beta_3' X_{j,t} + \varepsilon_{j,t}, \tag{6}$$

where $\log\left(\tfrac{\text{Debt}}{\text{GDP}}\right)_{US,t}$ and $\log\left(\tfrac{\text{Debt}}{\text{GDP}}\right)_{j,t}$ are the log of the debt net of central banks's holdings as a ratio of GDP at time t for the US and country j respectively, $X_{j,t}$ is a set of controls. Du et al. (2018) consider for $X_{j,t}$ three variables other than currency fixed effects: The US policy rate, country j policy rate and the VIX.

Earlier, we argued that OLS estimates of β_1 from Equation 6 are likely biased downwards due to endogeneity.[18] To cope with this, we instrument the US debt-to-GDP ratio with the first principal component of US Treasury futures returns

[17]Note that one departure from their specification lies in the data coverage, as their sample ranges between 2000 and 2016.

[18]Arguably, β_2 estimates face a similar bias. We unfortunately do not have auction data for the other countries in the sample and therefore interpret our estimates of β_2 with caution.

Table 2. Du et al. (2018) Revisited

	5-Year Convenience Yield					
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	OLS	IV	OLS	IV
$\log(\frac{\text{Debt}}{\text{GDP}})_{\text{US}}$ (pp.)	-0.49***	-3.32***	-0.81***	-1.72	-1.50***	-2.90***
	(0.10)	(1.07)	(0.17)	(1.65)	(0.36)	(1.10)
$\log(\frac{\text{Debt}}{\text{GDP}})_{\text{j}}$ (pp.)	0.04	0.86**	0.02	-0.05	0.11*	0.12*
	(0.07)	(0.41)	(0.08)	(0.13)	(0.06)	(0.07)
Observations	640	640	640	640	640	640
Effective F-stat		9.1		2.1		19.2
↪ Critical Value		15.1		15.1		15.1
Controls:						
↪ Du et al. (2018)	No	No	Yes	Yes	Yes	Yes
↪ Bacchetta et al. (2022)	No	No	No	No	Yes	Yes

HAC robust standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

around announcements, cumulated over quarters and first-differenced. We resort to principal component analysis because it performs better as an instrument for quarterly US debt-to-GDP ratio compared to using the set of four shock series as four separate instruments.

Unfortunately, our instrument's relevance erodes when we restrict ourselves to the above set of controls. Hence, we complement $X_{j,t}$ with additional controls, whose choice is guided by Bacchetta et al. (2022), namely the log of US real GDP, the log of country j real GDP and a quadratic time trend. In order to make our specification as similar as possible with the previously reported daily and weekly evidence, we additionally account for risk-free CIP variations.

Finally, because the error term $\varepsilon_{j,t}$ might very well be autocorrelated and could suffer from heteroskedasticity, we compute HAC robust standard errors (8 lags). Note that unlike Du et al. (2018), we do not resort to cluster-robust standard errors at the country level, since the consistency thereof calls for an infinite number of clusters and that we have only 10 of them (Angrist and Pischke, 2009). Arguably, the ample availability of observations along time dimension on the other hand does not invalidate the use of kernel-robust standard errors.

Results. — Table 2 displays the estimates of Equation 6. Odd-numbered columns present OLS estimates, even-numbered ones present IV estimates. Columns 1 and 2 excludes all types of controls, columns 3 and 4 includes the set of controls used in Du et al. (2018) plus country fixed-effects, while columns 4 and 6 adds the controls suggested by Bacchetta et al. (2022).

Looking at the bottom of Table 2 reveals that our instrument is weak when we do not control for anything (column 2), or only for the VIX and policy rates (column 4). Indeed, the effective F-stats fail to exceed the critical values (95% confidence of a 20% worst-case bias). The resulting coefficients must therefore be interpreted with caution. The instrument's relevance is restored once we control for log-real GDPs and a quadratic trend (column 6), as the effective F-stat is well above its critical value.

In general, both OLS and IV associate government debt with relative convenience yield in a negative fashion. The reported OLS estimates predict that a one pp. increase in US debt-to-GDP weakens significantly the 5-year US relative convenience yield by between 0.49 and 1.50 basis points depending upon the inclusion of control variables. In particular, the effect is largest under the full set of controls, in itself reinforcing the view that statistical models linking Treasury supply to relative convenience yields are prone to committed variable biases.

Our IV approach, on the other hand, report effects that have the same sign, yet with a higher magnitude. Indeed, a one percentage-point increase in US debt-to-GDP causes a decrease in the 5-year US relative convenience yield ranging between 1.72 and 3.32 basis points. Although the specification without control does well in delivering our central result that endogeneity issues prevent OLS to consistently estimate this coefficient, its IV estimate should be interpreted with caution, as it suffers from weak instruments. Adding the restricted set of controls (column 5) does not solve this issue. It is upon the inclusion of the full set of controls (column 6) that our instrument's relevance is restored. The corresponding decrease of roughly 3 basis points in the US relative convenience yield for each percentage-point increase in the US debt as a ratio of GDP is not only highly statistically significant, it is also twice as large a the OLS estimate.

The latter observation is consistent with the OLS coefficient being muddled by the positive correlation between Treasury quantity and convenience yield introduced by demand shocks along an upwardly sloping supply curve, which is unaccounted for in the absence of a clean identification strategy for Treasury supply shocks.

4 Conclusions

In this paper, we develop a comprehensive theoretical framework to examine the interplay among Treasury supply, the convenience yield, and exchange rates. We conduct an empirical examination of the principal implications of this theoretical framework. This dual approach enables us to not only enhance our comprehension of the consequences of Treasury debt issuance for two variables of high relevance for market participants and policymakers alike, but also to validate these insights against empirical evidence.

We construct a simple two-country model to uncover the dynamics of supply and demand for US Treasuries. Our model describes how US Treasuries, as a result of a liquidity payoff derived by foreign investors, generate an endogenous and time-varying convenience yield relative to foreign bonds characterized by a wedge in the UIP condition. In turn, because US government debt issuance, for a given spending, relaxes households' budget constraint via less taxes, it allows them to purchase more foreign bonds and pocket the convenience yield—the marginal debt issuance benefit. As a result, the debt supply schedule is upward-sloping in the convenience yield because the government solves a Ramsey problem with a convex debt issuance cost. The framework reveals how the US convenience yield and exchange rate respond to changes in the marginal cost of debt issuance and shifts in liquidity preference.

An essential part of our theoretical discussion is the unveiling of two testable implications. Firstly, an increase in debt supply instigates a reduction in the convenience yield and an immediate depreciation of the US dollar followed by an appreciation. Secondly, as the US government faces incentives to issue debt in times when the US convenience yield is high, regression analyses of convenience yields and exchange rates onto US Treasury supply measures may suffer from endogeneity.

In a set of empirical exercises, we address these testable implications using an instrumental variable approach, thus tackling the endogeneity issue. In particular, we exploit the US Treasury auction design to elicit US Treasury supply shocks measuring intraday US Treasury futures price changes around announcements by the US Treasury. Because they reflect surprises to the supply of US Treasury securities, these futures prices changes qualify as valid instruments.

Crucially, the empirical results corroborate our model's testable implications. We demonstrate how unexpected increases in US Treasury supply lead to immediate depreciation of the US dollar followed by an appreciation, as well as a decline in the US convenience yield, relative to other G10 currencies between 2001 and 2020. Our findings also shed light on the downward bias exhibited by OLS estimates, demonstrating the presence of a positive correlation between US debt supply, the US relative convenience yield, and US dollar appreciation introduced by demand shocks, consistent with an upward-sloping US debt supply schedule.

The implications of these findings are twofold. They can inform policy discussions, given the significance to the global financial system of the US dollar and the liquidity and safety attributes of US Treasury securities, whereby the US enjoys a currency hegemony and an exorbitant privilege.[19] Additionally, they contribute to the literature, as mischaracterizations of government debt management strategy could arise from biased estimates of the impact of Treasury supply on the convenience yield, with important repercussions on the US debt sustainability and fiscal capacity.[20]

Our paper sets the stage for exciting further research. First, incorporating Treasury demand shocks into the empirical analysis, which could offer empirical verification of the conjecture that the US government solves a Ramsey-like optimal debt issuance problem. Second, introducing production under uncertainty, non-tradable goods, and active monetary policy regimes may refine results and help quantitatively test our predictions. Last but not least, developing an accurate dichotomy of Treasury supply shocks from changes in government spending versus changes in the composition of funding could elucidate the "exchange rate appreciation puzzle", by revealing conditions under which the convenience yield drop following a rise in debt supply can reconcile the observed exchange depreciation in response to an expansionary fiscal shock.

[19]See Gourinchas et al. (2019) for a recent discussion.

[20]See, e.g., Mian et al. (2021) and Jiang et al. (2022) for recent contributions.

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A US government Ramsey problem

The problem of the US household is

$$\max_{C_t, B_{F,t}} \sum_{s=0}^{\infty} \beta^s U(C_{t+s})$$

$$\text{s.t.} \quad C_t + B_{F,t} + T_t = \frac{1+i^*_{t-1}}{\Pi_t} \frac{S_t}{S_{t-1}} B_{F,t-1} + Y.$$

The resulting Euler equation for RoW bonds is

$$U'(C_t) = \beta \frac{1+i^*_t}{\Pi_{t+1}} \frac{S_{t+1}}{S_t} U'(C_{t+1}).$$

By substituting the T_t in the household's budget constraint using the government's budget constraint, the Ramsey problem of the US government is

$$\max_{C_t, B_{F,t}, B^G_t} \sum_{s=0}^{\infty} \beta^s U(C_{t+s})$$

$$\text{s.t.} \quad C_t + B_{F,t} + \bar{G} + \frac{B^G_{t-1}}{\Pi_t}(1+i_{t-1}) + \chi(B^G_{t-1}) - B^G_t = \frac{1+i^*_{t-1}}{\Pi_t} \frac{S_t}{S_{t-1}} B_{F,t} + Y$$

$$U'(C_t) = \beta \frac{1+i^*_t}{\Pi_{t+1}} \frac{S_{t+1}}{S_t} U'(C_{t+1})$$

Now consider a modified problem in which only the first constraint is present. The combined FOCs for C_t and $B_{F,t}$ yield the RoW bonds Euler equation, which appears as the second constraint in the original problem. Therefore, the Euler equation constraint is redundant, and we can write the Ramsey problem as in section 2.1.2 by removing the Euler equation and re-writing the budget constraint as a function of net foreign assets $A_t \equiv B_{F,t} - B^G_t$.

B Steady State

We solve the model assuming that domestic and foreign interest rates remain fixed at their zero-inflation steady-state values. In this appendix, we provide the solution for such steady state under the functional form assumptions made in section 2.2.

Given the zero-inflation assumption, at the steady state $\Pi = 1$, $\Pi^* = 1$. Therefore, given LOP and the assumption of $P_t^* = 1$, without loss of generality as P_t^* is indetermiante, it follows that $S = 1$.

The domestic and ROW households' Euler equations for foreign bonds at the steady state imply

$$i^* = \frac{1-\beta}{\beta}.$$

The ROW household's Euler equation for domestic bonds at the steady state implies

$$i = \frac{1-\beta}{\beta} - \frac{\Psi}{\beta B^G} C^*.$$

From the goods market clearing condition, we can express C^* as a function of C and exogenous variables

$$C^* = Y + Y^* - \bar{G} - C.$$

Substituting i and C^* in the ROW household's budget constraint evaluated at the steady state and exploiting the foreign government bond market clearing condition $B_{F,t} + B_{F,t}^* = \bar{B}_F$, we obtain

$$(1 + \frac{\Psi}{\beta})C + \frac{1-\beta}{\beta} B^G + \frac{1-\beta}{\beta} B_F^* - (1 + \frac{\Psi}{\beta})(\beta Y - \bar{G}) - \frac{\Psi}{\beta} Y^* = 0. \tag{7}$$

By substituting T from the domestic government's budget constraint into the domestic household's budget constraint at the steady state, and exploiting the market clearing condition for the foreign bond, we can also express it as an equation in B^G, B_F^* and C

$$\frac{\beta+\Psi}{\beta} C + \frac{\beta+\Psi}{\beta} \bar{G} + \frac{1-\beta}{\beta}(B^G - \bar{B}_F + B_F^*) - \frac{\Psi}{\beta} Y^* - \frac{\beta+\Psi}{\beta} Y + \frac{B^{G2}}{2} + \nu B^G = 0 \tag{8}$$

Furthermore, the first-order condition of the domestic government at the steady state reads

$$\frac{\Psi}{\beta B^G}(Y + Y^* - \bar{G} - C) = B^G + \nu. \tag{9}$$

Therefore, we can solve for B^G, B_F^* and C, through equations 7, 8 and 9.

This process results in a quadratic equation in B^G:

$$\frac{B^{G2}}{2} + B_G\nu + \left(1 - \frac{1}{\beta}\right) B_F = 0$$

It has two real solutions for $\beta \in (0, 1)$:

$$B_1^G = \frac{\sqrt{\beta\left(2\bar{B}_F\left(1-\beta\right) + \beta\nu^2\right)} - \beta\nu}{\beta},$$

$$B_2^G = \frac{\sqrt{\beta\left(2\bar{B}_F\left(1-\beta\right) + \beta\nu^2\right)} + \beta\nu}{\beta}.$$

Note that for $\beta \in (0, 1)$, $B_2^G > 0$. Consistently with our approach for the dynamic equilibrium, we want restrict our attention to a unique positive value of steady-state US government debt. Therefore, we impose $B_1^G < 0$, which holds for $\bar{B}_F \in [\frac{\beta\nu^2}{2(\beta-1)}, 0)$, and choose $B^G = B_{G,2} > 0$. A positive steady-state supply of Treasuries then requires a negative $\bar{B}_F$, implying that the RoW government is a net creditor in the steady state.

We can then solve for C and B_F^* as a function of B^G.

$$B_F^* = \frac{\beta}{\beta - 1}\left(Y^* - \frac{\beta(1+\Psi)}{\Psi}B^{G2} + \frac{\Psi(1-\beta) - \beta^2\nu(1+\Psi)}{\Psi\beta}B^G\right)$$

$$C = Y + Y^* - \bar{G} - \frac{\beta}{\Psi}B^{G2} - \frac{\beta\nu}{\Psi}B^G$$

By substituting B^G, B_F^* and C into the ROW Euler equation, goods market clearing and ROW bond market clearing conditions, respectively, we find i, C^* and B_F.

C Equilibrium Existence and Uniqueness

Combining the two equilibrium equations, we are left with a quadratic equation that expresses ϕ_t as a function of parameters

$$\phi_t^2 - \nu\phi_t - \frac{C^*\Psi}{\beta} = 0$$

This equation has two solutions:

$$\phi_{1,t} = \frac{\nu - \sqrt{\nu^2 + 4\frac{C^*\Psi}{\beta}}}{2}, \qquad \phi_{2,t} = \frac{\nu + \sqrt{\nu^2 + 4\frac{C^*\Psi}{\beta}}}{2}.$$

First, note that $\nu^2 + 4\frac{C^*\Psi}{\beta} > 0 \, \forall \Psi > 0, \beta > 0, C^* > 0$. Therefore, $\phi_{1,t}$ and $\phi_{2,t} \in \mathbb{R}$ everywhere in the region of interest of the parameter space.

The model then features two equilibria, characterized by $\phi_{1,t}$ and $\phi_{2,t}$. For $\nu > 0, \Psi > 0, \beta > 0, C^* > 0$, we have $\phi_{2,t} > 0$, so an equilibrium with a positive convenience yield exists. Consider the sign of $\phi_{1,t}$. The condition for $\phi_{1,t} > 0$ is

$$\nu - \sqrt{\nu^2 + 4\frac{C^*\Psi}{\beta}} > 0 \iff \frac{C^*\Psi}{\beta} < 0.$$

This condition never holds for $\Psi > 0, \beta > 0, C^* > 0$. Therefore, $\phi_{1,t} < 0$ in the region of interest of the parameter space. By 1b, $\phi_{1,t} < 0 \implies B_{1,t}^G < 0$, so the convenience yield can only be negative in equilibrium if the US government is a net creditor. Our proxy for the convenience yield, that is observed CIP deviations for US government bonds, can take positive or negative values depending on currencies, but we discard the negative convenience yield equilibrium in our model because of the counterfactual implication of negative equilibrium levels of US government debt.[21]

We are then left with the equilibrium characterized by $\phi_{2,t}$ since $\nu^2 + 4\frac{C^*\Psi}{\beta} > 0$, $\phi_{2,t} > 0$ and, by 1b, $B_{1,t}^G > 0$. Therefore, what is presented in the main body of the paper is the unique equilibrium characterized by positive values of the convenience yield and the US debt level.

[21]See Sushko et al. (2016) for a discussion on the determinants of CIP deviation signs.

D Derivations for Comparative Statics

In this appendix we derive the formal conditions for the signs of $\frac{\partial \phi_t}{\partial \nu}$, and $\frac{\partial \phi_t}{\partial \Psi}$.

D.1 Steady-State Derivatives

We start by calculating useful derivatives of steady-state variables and determining their sign.

First, consider the derivative of US government debt supply $B_{G,t}$ with respect to ν at the steady state

$$\frac{\partial B^G}{\partial \nu} = 1 + \frac{\beta \nu}{\sqrt{\beta\left(\beta \nu^2 + 2\bar{B}_F(1-\beta)\right)}}. \tag{10}$$

The derivative of $B_{G,t}$ with respect to ν at the steady state

Note that $\frac{\partial B^G}{\partial \nu} > 0$ for $\nu > 0$ and $\beta \in (0,1)$.

Let us then turn to domestic consumption. Note that by goods market clearing, $C^* = Y + Y^* - \bar{G} - C$, so $\frac{\partial C^*}{\partial \nu} = -\frac{\partial C}{\partial \nu}$ and $\frac{\partial C^*}{\partial \Psi} = -\frac{\partial C}{\partial \Psi}$.

We have

$$\frac{\partial C}{\partial \Psi} = \frac{\beta B^G(B^G + \nu)}{\Psi^2},$$

so $\frac{\partial C}{\partial \Psi} > 0$ and $\frac{\partial C^*}{\partial \Psi} < 0$ for $\beta \in (0,1)$, $\nu > 0$ and $\Psi > 0$.

We also have

$$\frac{\partial C}{\partial \nu} = -\frac{\beta}{\Psi}\frac{\partial B^G}{\partial \nu}(2B^G + \nu),$$

so $\frac{\partial C}{\partial \nu} < 0$ and $\frac{\partial C^*}{\partial \nu} > 0$ for $\beta \in (0,1)$, $\Psi > 0$ and $\frac{\partial B^G}{\partial \nu} > 0$.

D.2 Comparative Statics

We will now use the results derived above to establish signs for the derivatives presented in the comparative statics in Sections 2.2.1 and 2.2.2.

To ensure that a decrease in ν results in a higher equilibrium level of US debt, we set

$$
\begin{aligned}
&\frac{\partial B_t^G}{\partial \nu} < 0 \\
\iff &\frac{1}{4}\left(\nu^2 + 4\frac{C^*\Psi}{\beta}\right)^{-1/2}\left(2\nu + 4\frac{\Psi}{\beta}\frac{\partial C^*}{\partial \nu}\right) - \frac{1}{2} < 0 \\
\iff &\left(\nu^2 + 4\frac{C^*\Psi}{\beta}\right)^{-1/2}\left(2\nu + 4\frac{\Psi}{\beta}\frac{\partial C^*}{\partial \nu}\right) < 2 \\
\iff &\frac{\partial C^*}{\partial \nu} < \frac{\beta}{2\Psi}\left(\left(\nu^2 + \frac{4\Psi}{\beta}C^*\right) - \nu\right).
\end{aligned}
$$

For $\frac{\partial C^*}{\partial \nu} > 0$, this condition requires that RoW consumption does not react too strongly to the increase in ν, so that the marginal utility effect does not dominate the debt supply effect.

To ensure that the increase in the marginal liquidity preference of RoW households results in a higher convenience yield and equilibrium level of US debt, we set

$$
\begin{aligned}
&\frac{\partial \phi_t}{\partial \Psi} > 0 \iff \frac{\partial B_{G,t}}{\partial \Psi} > 0 \\
\Psi \iff &\frac{1}{4}\left(\nu^2 + 4\frac{C^*\Psi}{\beta}\right)^{-1/2}\left(\frac{4\Psi}{\beta}\frac{\partial C^*}{\partial \Psi} + \frac{4C^*}{\beta}\right) > 0 \\
\iff &\frac{4\Psi}{\beta}\frac{\partial C^*}{\partial \Psi} + \frac{4C^*}{\beta} > 0 \\
\iff &\frac{4\Psi}{\beta}\frac{-\beta B^G(B^G+\nu)}{\Psi^2} + \frac{4C^*}{\beta} > 0 \\
\iff &\frac{\beta B^G(B^G+\nu)}{\Psi^2} < \frac{\beta B^G(B^G+\nu)}{\Psi} \\
\iff &\Psi > 1,
\end{aligned}
$$

where we substitute in C^* as a function of B^G and we use $\frac{\partial C}{\partial \Psi} = -\frac{\partial C^*}{\partial \Psi}$. This condition requires that the is strong enough that the outward shift in the debt demand curve engendered by a higher Ψ is not undone by the concurrent increase in the marginal utility of consumption due to $\frac{\partial C^*}{\partial \Psi} < 0$.

Table A1. Relative Credit Risk

	Convenience Yield			Exchange Rate		
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	IV	OLS	IV	IV
ΔB_t^G (abs. median)	-0.0404	-0.635*	-0.703**	2.232***	30.54***	18.45***
	(0.0392)	(0.371)	(0.318)	(0.792)	(8.455)	(6.249)
$\Delta \log(S_t)$ (bp.)	-0.0319***	-0.0309***	-0.0241***			
	(0.00612)	(0.00615)	(0.00605)			
$\Delta\phi_t$ (bp.)				-4.840***	-4.694***	-4.831***
				(0.936)	(0.939)	(1.249)
Observations	49810	49810	48460	49810	49810	48460
Effective F-stat		13.3	17.6		13.3	17.6
$\hookrightarrow$ Critical Value		12.8	12.6		12.8	12.6
Hansen J-stat p-val.		0.31	0.24		0.71	0.20
Lags	No	No	Yes	No	No	Yes
Fixed Effects	No	No	Yes	No	No	Yes
Controls	No	No	Yes	No	No	Yes

Robust standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

E Robustness

E.1 Daily Analysis

Relative Credit Risk.—One limitation of our convenience yield metric is that it presupposes frictionless foreign currency swap markets and default-free government bonds. As a consequence, it abstracts from risk-free CIP deviations and relative credit spreads. Thus, we use CIP deviations on observed risk-free rate proxies in the study to approximate the former. Du et al. (2018) advise employing sovereign CDS for the latter. But, owing to the shortage of CDS data, we do not include it in our benchmark findings.

Table A1 re-estimates the figures in Table 1, by controlling for prices of CDS of both the US and country j. In order to avoid dropping half of the observations compared to our benchmark regressions, we set CDS prices to zero for all countries in the period prior to the Global Financial Crisis. Although this might seem a strong assumption, it is guided by the documented fact that prior to the crisis, credit spread differentials were a negligible a driver of our measure of relative convenience yields (Du et al., 2018).

By construction, only columns (3) and (6) of Table A1 contain alternative estimates. If anything, controlling for relative credit risk amplifies the reaction of relative convenience yields to Treasury supply shocks. Indeed, the estimated coefficient decreases from 0.668 to 0.703 basis points, the latter coefficient remaining

Table A2. Heteroskedasticity and Autocorrelation-Robust Standard Errors

	Convenience Yield			Exchange Rate		
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	IV	OLS	IV	IV
ΔB_t^G (abs. median)	-0.0404	-0.635*	-0.668**	2.232***	30.54***	18.85***
	(0.0392)	(0.366)	(0.315)	(0.784)	(8.345)	(6.397)
$\Delta \log(S_t)$ (bp.)	-0.0319***	-0.0309***	-0.0248***			
	(0.00673)	(0.00677)	(0.00655)			
$\Delta\phi_t$ (bp.)				-4.840***	-4.694***	-5.005***
				(1.029)	(1.039)	(1.366)
Observations	49810	49810	48460	49810	49810	48460
Effective F-stat		13.1	17.1		13.1	17.1
$\hookrightarrow$ Critical Value		12.6	12.3		12.6	12.3
Hansen J-stat p-val.		0.31	0.24		0.70	0.19
Lags	No	No	Yes	No	No	Yes
Fixed Effects	No	No	Yes	No	No	Yes
Controls	No	No	Yes	No	No	Yes

HAC robust standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

highly statistically significant.

The immediate US dollar depreciation obtained from the benchmark results on the other hand, though it is conserved, is somewhat smaller. An unexpected median-sized increase in US Treasury supply, controlling for CDS prices, leads to a statistically significant depreciation of 18.45 basis points (18.85 basis points in the benchmark).

Autocorrelation-Robust Standard Errors.—In the benchmark daily regressions whose estimates are displayed in Table 1, we compute standard errors that are robust to arbitrary heteroskedasticity, as suggested by Montiel Olea and Plagborg-Møller (2021). Nonetheless, computing heteroskedasticity and autocorrelation consistent (HAC) standard errors instead is a reasonable alternative.

Thus, Table A2 informs on the significance of the same coefficients under HAC standard errors. The resulting minor variations in the estimated standard errors leaves all the conclusions drawn in the paper unchanged.

CIP Deviations on 2-, 5- and 10-Year Treasuries.—Our measure of US Treasury supply is the net operation that the US Treasury plans on achieving with an upcoming auction. Since our instrument is based on Treasury futures prices, and that these futures only exist for the 2-, 5-, 10- and 30-year bonds, this measure of supply considers the auctions of securities with one of these four maturities exclusively. Yet, in benchmark regressions, we average relative convenience yields along the maturity dimension, although the latter ranges from 3 month to 10

Table A3. CIP Deviations on 2-, 5- and 10-Year Treasuries Only

	Convenience Yield			Exchange Rate		
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	IV	OLS	IV	IV
ΔB_t^G (abs. median)	-0.0495	-0.987***	-0.897***	2.191***	29.90***	17.81***
	(0.0330)	(0.370)	(0.290)	(0.790)	(8.404)	(6.370)
$\Delta \log(S_t)$ (bp.)	-0.0277***	-0.0262***	-0.0280***			
	(0.00542)	(0.00547)	(0.00516)			
$\Delta \phi_t$ (bp.)				-9.200***	-8.829***	-10.10***
				(1.831)	(1.818)	(1.871)
Observations	49714	49714	48390	49714	49714	48390
Effective F-stat		13.2	17.2		13.2	17.2
$\hookrightarrow$ Critical Value		12.8	12.5		12.8	12.5
Hansen J-stat p-val.		0.00	0.00		0.69	0.21
Lags	No	No	Yes	No	No	Yes
Fixed Effects	No	No	Yes	No	No	Yes
Controls	No	No	Yes	No	No	Yes

Robust standard errors in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

years.

What does that mean for our estimates $\hat{\beta}_1$? In theory, our benchmark estimates (in absolute terms) ought to be taken as lower bounds. This is because they fail to account for the variability in CIP deviations at maturities outside our supply measure that are, in truth, associated with Treasury supply shocks.

One natural robustness check therefore consists in considering CIP deviation on government bonds at maturities that match our supply measure. In particular, we re-estimate the coefficients from Table 1 using the average relative convenience yield for 2-year, 5-year and 10-year bonds. Table A3 displays the results.

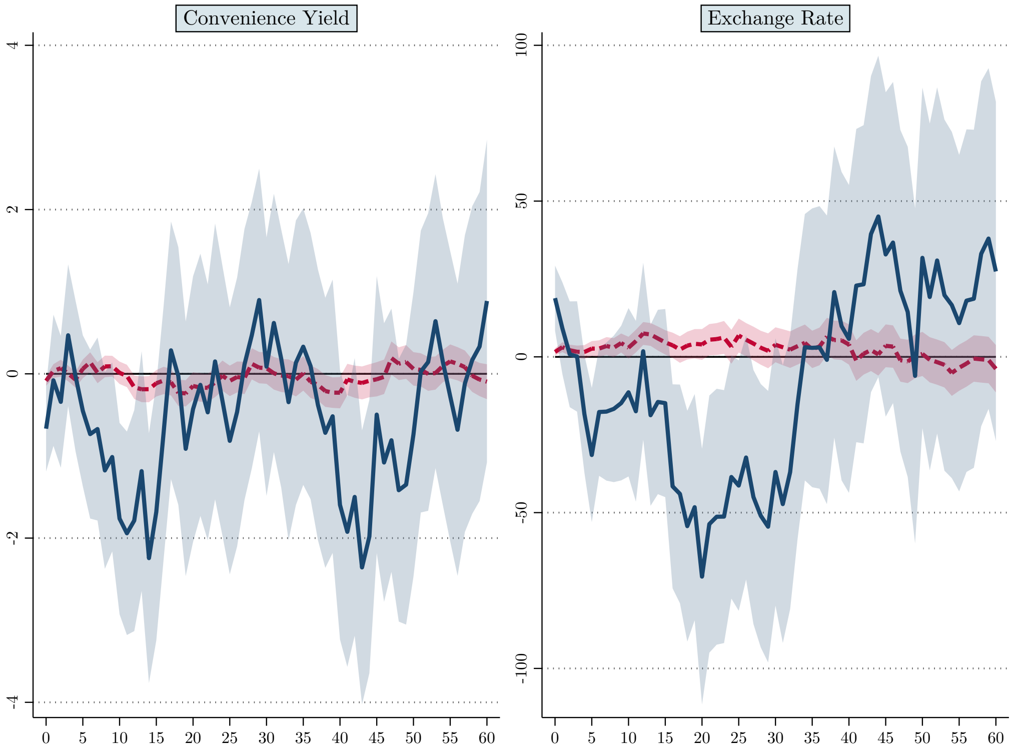
As expected, the magnitude of the effect of Treasury supply shocks on relative convenience yields is larger. Our instrumental variable approach without control now associates a sudden median-sized increase in Treasury supply with an immediate decrease of the convenience yield of about 1 basis point, with very high statistical significance. Adding lags and fixed effects, and controlling for other important factors leads to an estimate of about 0.9 basis point.

Note that the coefficients for exchange rates are mostly unaffected.

E.2 Weekly Analysis

Long-Term Daily Local Projections. — As a robustness check, we replicate Figure 5 but using the daily sample instead of weekly averages thereof. The results

Figure A1. IRFs to Treasury Supply Shocks of Convenience Yields and Exchange Rates



Notes: The solid blue lines in each subplot displays the IRF to a 13-billion-dollar positive change in US Treasury supply of the above-mentioned variable stemming from the 2SLS estimation of Equation 4 and 5. The dashed red lines are the estimates of the same object via OLS. Blue and red shaded areas are the respective 90% confidence intervals. The horizontal axis represents business days from impact. Variables are in basis points.

are shown on Figure A1.

Qualitatively speaking, all the conclusions drawn in the paper are intact. Quantitatively speaking, although the overall magnitude is preserved, daily local projections produce IRFs that are somewhat more volatile. As a consequence, the estimated impact of Treasury supply shocks on relative convenience yield temporarily returns to a level that is statistically indiscernible from zero between 20 and 40 business days.

Exchange rates on the other hand seem to display an almost identical response to Treasury supply changes, both qualitatively and quantitatively.

E.3 Quarterly Analysis

CIP Deviations on 2-, 5- and 10-Year Treasuries.—Recall that our instrument is the quarterly difference of the first principal component of within-quarter cumulated changes in Treasury futures prices occurring around 2-, 5-, 10-

Table A4. Du et al. (2018) Revisited, 2-, 5- and 10-year Maturities

	5-Year Convenience Yield					
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	OLS	IV	OLS	IV
$\log(\frac{\text{Debt}}{\text{GDP}})_{\text{US}}$ (pp.)	-0.43***	-2.77***	-0.80***	-2.76	-1.59***	-3.00**
	(0.09)	(0.95)	(0.16)	(1.88)	(0.37)	(1.20)
$\log(\frac{\text{Debt}}{\text{GDP}})_{\text{j}}$ (pp.)	0.03	0.70**	-0.03	-0.17	0.04	0.06
	(0.07)	(0.36)	(0.07)	(0.15)	(0.08)	(0.08)
Observations	640	640	640	640	640	640
Effective F-stat		9.1		2.1		19.2
↪ Critical Value		15.1		15.1		15.1
Controls:						
↪ Du et al. (2018)	No	No	Yes	Yes	Yes	Yes
↪ Bacchetta et al. (2022)	No	No	No	No	Yes	Yes

HAC robust standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

and 30-year US Treasury auctions. As a result, it is of interest to reassess the relationship between debt increases and the relative convenience yield, when the latter is measured using maturities that match the instrument.

Table A4 displays the re-estimation of the coefficients from Table 2 using the average relative convenience yield for 2-year, 5-year and 10-year bonds. As can be expected, the conclusions drawn from this refinement of our dependent variable are univocally identical to the ones exposed in the main body of this paper.

If anything, the effects reported in the specification with all the available controls are even larger than in the benchmark, i.e., the one with the strongest instrument. In particular, a 1 percentage-point increase in the US debt-to-GDP ratio is associated with a significant decrease in the relative convenience yield of 3 basis points.

Relative Credit Risk.—As earlier, a natural robustness check consists in controlling for relative credit risk, for the latter is a potential driving force of the CIP deviations on Treasury securities, especially in the period after the Global Financial Crisis.

To this end, Table A5 re-estimates the figures in Table 2, by controlling for prices of CDS of both the US and country j. As before, we set CDS prices to zero for all countries in the period prior to the Global Financial Crisis.

Controlling for relative credit risk erodes the instrument's effective F-statistic in the first stage. It comes as no surprise that once such an important driver of debt supply is controlled for, the power of a daily instrument aggregated at the quarter

Table A5. Du et al. (2018) Revisited, Relative Credit Risk

	5-Year Convenience Yield					
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	OLS	IV	OLS	IV
$\log(\frac{\text{Debt}}{\text{GDP}})_{\text{US}}$ (pp.)	-0.49***	-3.32***	-0.81***	-1.72	-0.98***	-2.46*
	(0.10)	(1.07)	(0.17)	(1.65)	(0.35)	(1.41)
$\log(\frac{\text{Debt}}{\text{GDP}})_{\text{j}}$ (pp.)	0.04	0.86**	0.02	-0.05	0.10	0.11
	(0.07)	(0.41)	(0.08)	(0.13)	(0.08)	(0.08)
Observations	640	640	640	640	640	640
Effective F-stat		9.1		2.1		11.8
$\hookrightarrow$ Critical Value		15.1		15.1		15.1
Controls:						
$\hookrightarrow$ Du et al. (2018)	No	No	Yes	Yes	Yes	Yes
$\hookrightarrow$ Bacchetta et al. (2022)	No	No	No	No	Yes	Yes

HAC robust standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

level is lowered. In any case, the shown coefficients have to be interpreted with caution as they suffer from weak instruments.

The second stage reveals results that are qualitatively similar to the specification used in the paper. Qualitatively speaking, the effects reported are somewhat smaller and of lower statistical significance. Overall, this robustness check confirms the findings highlighted in this paper.

F Alternative Instrument Window

In this appendix, we present an alternative analysis using the 30-minute shock window approach employed by Phillot (2021). While our main analysis in this paper utilized a tighter 15-minute shock window, it is natural to inquire about the differences that would arise if we were to adopt the same instrument as Phillot (2021).

We provide this appendix to offer a comparative perspective on the results obtained from both approaches. Specifically, we comment on the outcomes of the three baseline approaches employed: (i) the on-impact daily analysis, (ii) the weekly local projections over 12 weeks, and (iii) the quarterly replication of Du et al. (2018).

First, it is important to note that the instrument's F-statistics indicate weak instruments in the context of the daily and weekly analysis. Therefore, the results should be interpreted with caution and are presented here for completeness.

Nakamura and Steinsson (2018) argue that while a longer time window allows for capturing more detailed dynamics, it also introduces potential confounding factors and noise contamination. In our analysis, the choice of a 15-minute window strikes a balance between capturing relevant dynamics and minimizing these potential issues. Indeed, it appears that the inclusion of 15 additional minutes in the instrument computation introduces so much noise that it poses a challenge for instrument relevance.

Furthermore, it's worth considering that the analysis in Phillot (2021) involves distinct financial time series compared to our study, which could play a role in the divergent instrument performance we observe. While Phillot (2021) concentrates on domestic financial outcomes, our research centers on global macro-financial variables. Notably, our variables exhibit variation not only over time but also across countries, introducing a panel dimension not present in his paper. As a result, our adoption of the 15-minute window appears to offer a more targeted empirical approach for investigating convenience yields and exchange rates.

Despite these limitations, the analysis using the 30-minute window reveals a negative relationship between the US relative convenience yield and US Treasury supply both on impact (daily) and over the course of 12 weeks, whereby it takes over a month and a half for that effect to become significant. Exchange rates, on the other hand, fail to exhibit a statistically significant relationship with Treasury supply. Over the course of 12 weeks, an immediate currency change cannot be significantly estimated, but a future US dollar appreciation can. As such, it appears that our testable implication 1 can be confirmed by the data with a limited degree of robustness.

Second, for the quarterly analysis, the conclusions remain qualitatively similar, whereby a positive change in debt-to-GDP induces a significant decrease in the US relative convenience yield against a panel of G10 currencies. The relevance of the instrument, when it is cumulated quarterly, seems to perform extremely well (in terms of F-statistcs) while controlling for the same variables as Du et al. (2018). On the other hand, under our preferred set of instruments (Bacchetta et al., 2022), the instrument is weak and the result have to be interpreted with caution. That being said, the estimated coefficient under the latter specification of 8.89 is almost sixfold compared to its OLS equivalent, further demonstrating our testable implication 2.

Nonetheless, it is crucial to recognize the limitations of the presented empirical results. Due to the presence of weak instruments, which reduce the precision and robustness of the estimated coefficients, the findings should be interpreted with caution. Weak instruments not only introduce bias into the parameter estimates, but also produce larger standard errors, thereby lowering the reliability of the reported effects.

Next, we describe the detailed results for the daily, weekly and quarterly analyses under the alternative instrument.

F.1 Daily Analysis

We estimate the same-day effect of changes in US Treasury supply on the convenience yields and exchange rates of the US relative to G10 currencies. The OLS specification is identical to the one used in the main body of the paper, while the IV specification employs the US Treasury futures returns over a 30-minute window around Treasury announcements, as in Phillot (2021).

As can be seen from Table A6, the instrument fails in all specifications to achieve the corresponding critical value. Hence, we face weak instruments and cannot interpret the coefficients as causal effects with a high enough degree of certainty.

Regarding relative convenience yields (columns 1 and 3), we still find a negative relationship with Treasury supply throughout. The only coefficient that is statistically significant in this respect is the one from IV that accounts for the lags, fixed effects, and the set of controls (column 3). Albeit suffering from weak instruments, the estimated coefficient implies that an absolute median increase in Treasury supply leads to a 1 basis-point decrease of the US convenience yield relative to the other currencies in the sample. This effect is significant at the 90%

Table A6. On-Impact Effects of Treasury Supply Shocks, 30-Minute-Window Instrument

	Convenience Yield			Exchange Rate		
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	IV	OLS	IV	IV
ΔB_t^G (abs. median)	-0.0404	-0.454	-0.999*	2.232***	-0.406	-5.745
	(0.0392)	(0.507)	(0.545)	(0.792)	(8.473)	(8.963)
$\Delta \log(S_t)$ (bp.)	-0.0319***	-0.0312***	-0.0244***			
	(0.00612)	(0.00619)	(0.00611)			
$\Delta\phi_t$ (bp.)				-4.840***	-4.854***	-5.376***
				(0.936)	(0.937)	(1.247)
Observations	49810	49810	48460	49810	49810	48460
Effective F-stat		11.1	9.4		11.1	9.4
$\hookrightarrow$ Critical Value		12.2	12.3		12.2	12.3
Hansen J-stat p-val.		0.12	0.45		0.55	0.15
Lags	No	No	Yes	No	No	Yes
Fixed Effects	No	No	Yes	No	No	Yes
Controls	No	No	Yes	No	No	Yes

Robust standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

level. This result is consistent with testable implication 1, further supporting the theoretical framework of the paper.

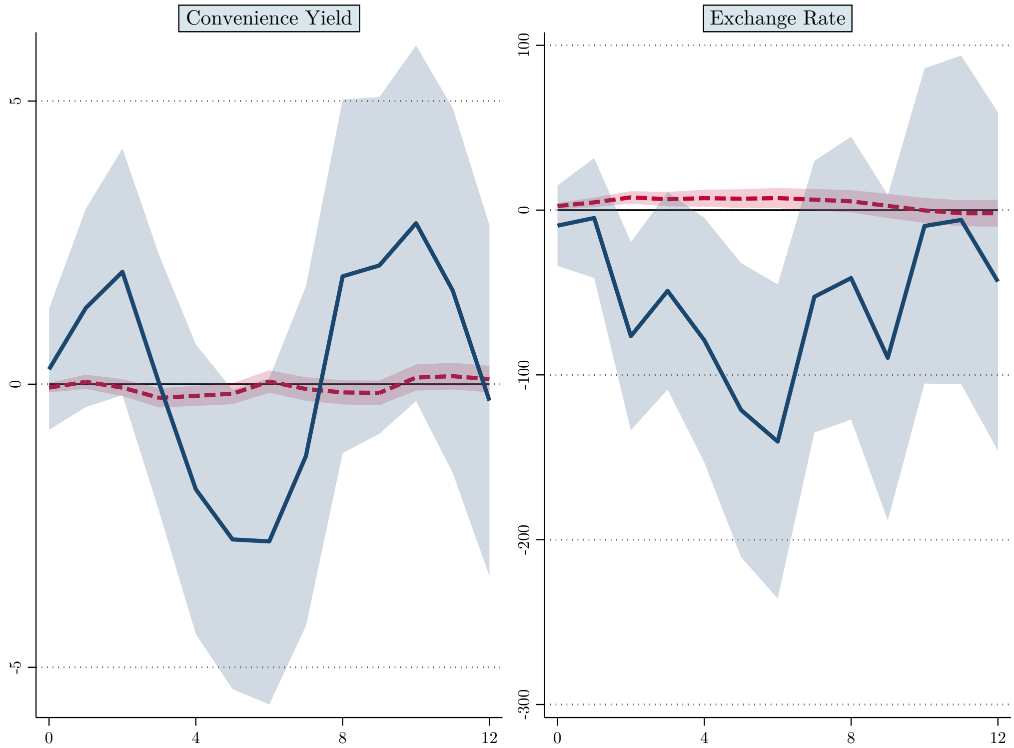
As for exchange rates (columns 4-6), not only do we suffer from weak instruments, but we also find statistically insignificant relationships once Treasury supply is instrumented. Even the coefficients are negative, going against our testable implication 1.

Finally, regarding testable implication 2, our analysis suggests that it can only be supported to the extent that the significant coefficient from column 3 exceeds the statistically insignificant coefficient from column 1. However, the results on exchange rates do not provide additional support for this implication. Therefore, while the findings on relative convenience yields align with testable implication 2, the lack of significant relationships in exchange rates limits the overall support for this testable implication.

F.2 Weekly Analysis

We apply the same methodology as in the main body of the paper, estimating local projections of the dynamic causal effect of Treasury supply shocks on relative convenience yields and the US dollar relative to G10 currencies, but at a weekly frequency. The only difference is that we use the alternative 30-minute window for measuring the instrument, as in Phillot (2021).

Figure A2. IRFs to Treasury Supply Shocks of Convenience Yields and Exchange Rates, 30-Minute-Window Instrument



Notes: The solid blue lines in each subplot displays the IRF to a 13-billion-dollar positive change in US Treasury supply of the above-mentioned variable stemming from the 2SLS estimation of Equation 4 and 5. The dashed red lines are the estimates of the same object via OLS. Blue and red shaded areas are the respective 90% confidence intervals. The horizontal axis represents weeks from impact. Variables are in basis points.

First, similar to the daily analysis, the instrument does not achieve relevance in this exercise. The F-statistic of 7.29 falls below the critical value of 10.27, raising doubts about the validity of the estimates. Despite this limitation, Figure A2 presents the IRFs following a $13 billion increase in US Treasury supply, mirroring the approach in the main body of the paper.

As observed in Figure A2 , there is no significant immediate impact on the US dollar exchange rate and the US convenience yield following the shock. However, after approximately one and a half months, the US relative convenience yield experiences a significant decrease of about 2.5 basis points, which quickly diminishes. Treasury supply shocks seem to cause the US dollar to appreciate by over 100 basis points after one and a half months, with the effect dissipating within a quarter.

The weekly analysis, conducted using this alternative instrument, provides partial confirmation of testable implication 1, aligning with the daily findings outlined above. Treasury supply tends to lead to a future decrease in US convenience yields and a future appreciation of the US dollar, but does not immediately impact these variables. On the other hand, the decoupling of the effect magnitude with the use of this instrument appears to provide supportive evidence for testable implication 2.

However, it is important to note that the weakness of the instrument in this analysis raises concerns about the validity of the approach. As a result, we favor the 15-minute window used in the main body of the paper as a more robust approach for measuring these relationships.

F.3 Quarterly Analysis

In quarterly analysis, we replicate the exercise conducted by Du et al. (2018), which is presented in the main body of the paper. However, we introduce a 30-minute-window instrument for this replication. The results of this replication exercise can be found in Table A7.

Columns 1 and 4 in Table A7 correspond to the same specifications as those in Table 2, as they use identical parameters. On the other hand, columns 2, 3, 5, and 6 incorporate the alternative instrument. It is worth noting that the instrument, represented by the first principal component derived from the four series of daily instruments (cumulated over quarters), performs exceptionally well in both the specification without controls (column 2) and the one with the same controls as used by Du et al. (2018) in their paper (column 3). The F-statistics in these cases greatly exceed their respective critical values, indicating sufficient instrument relevance. However, the same cannot be said for the specification that includes the controls proposed by Bacchetta et al. (2022) (column 6), raising doubts about the validity of the estimates.

The estimated impact of a one percentage-point increase in US debt-to-GDP on the US convenience yield varies between -1.6 and -8.9 basis points, depending on whether and which controls are included in the model.

Under this alternative instrument, the conclusions outlined in the paper remain consistent. Most notably, instrumenting debt-to-GDP ratios using Treasury futures prices changes around announcements by the US Treasury resolves an endogeneity issue, as suggested by testable implication 2. However, it is important to exercise caution when interpreting the figure of 8.8 basis points due to the potential problem of weak instruments.

Table A7. Du et al. (2018) Revisited, 30-Minute-Window Instrument

	5-Year Convenience Yield					
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	IV	OLS	IV	OLS	IV
$\log(\frac{\text{Debt}}{\text{GDP}})_{\text{US}}$ (pp.)	-0.49***	-1.58***	-0.81***	-1.34***	-1.50***	-8.89***
	(0.10)	(0.30)	(0.17)	(0.32)	(0.36)	(3.12)
$\log(\frac{\text{Debt}}{\text{GDP}})_{\text{j}}$ (pp.)	0.04	0.36**	0.02	-0.02	0.11*	0.17*
	(0.07)	(0.14)	(0.08)	(0.08)	(0.06)	(0.09)
Observations	640	640	640	640	640	640
Effective F-stat		52.5		47.0		7.3
↪ Critical Value		15.1		15.1		15.1
Controls:						
↪ Du et al. (2018)	No	No	Yes	Yes	Yes	Yes
↪ Bacchetta et al. (2022)	No	No	No	No	Yes	Yes

HAC robust standard errors in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$