Cryptocurrencies in Emerging Markets: A Stablecoin Solution?

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Abstract

El Salvador's 2021 monetary experiment to make Bitcoin legal tender increases financial inclusion at the cost of a volatile medium of exchange. In this paper we study the macroeconomic effects of introducing Bitcoin in a workhorse small open economy model. The model's baseline calibration predicts a 1 standard deviation decline in Bitcoin prices will cause a peak decline in output and consumption of approximately 1 percent. We study a potential solution to El Salvador's experiment, which is to replace Bitcoin with stablecoins pegged to the USD and backed by dollar reserves. We model a net positive welfare benefit relative to financial autarky for the unbanked population when using stablecoins, but net welfare costs with using a high volatility currency like Bitcoin.

Keywords: Bitcoin, cryptocurrency, exchange rates, international macroeconomics, monetary policy, small open economy, stablecoin

JEL Classifications: F31, G14, G15, G18, G23

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1 Introduction

"The Bitcoin gambit might also be a stalking horse for a longer-term plan to replace the US dollar with a local stablecoin, a cryptocurrency whose value is backed by an external asset." **Editorial Board, Financial Times** (7 September, 2021)[1]

El Salvador's monetary experiment in September, 2021 to mark Bitcoin as legal tender is a watershed moment in the history of the world's first decentralized cryptocurrency. President Nayib Bukele of El Salvador claims it as a solution to increase financial inclusion,[2] a common challenge for an emerging market economy (EME). By providing Bitcoin wallets to a significantly unbanked population, it can be used as an effective savings vehicle and as a store of value for users.

However, there are a number of issues with using Bitcoin from a macroeconomic and financial stability standpoint.[3] First and foremost is Bitcoin's volatility, with daily price changes a order of magnitude higher than fiat currency exchange rates.[4] High volatility in a medium of exchange corresponds to high volatility in the macroeconomy.[5] Users who hold Bitcoin will see wild swings in the value of their savings, which will then lead to fluctuations in consumption and hours worked, and thus cause greater swings in output and inflation. A potential solution to the volatility inherent to Bitcoin is to instead adopt a global stablecoin like Facebook's proposed Diem, a private cryptocurrency typically backed by US dollar reserves. A global stablecoin can transform cross-border payments, make it easier for migrants to send remittances to emerging countries, and bring financial inclusion benefits for the unbanked population (Prasad 2021).

In this paper we study the macroeconomic effects of introducing a digital currency in a workhorse small open economy (SOE) New Keynesian model. Our model will shed light on how the stablecoin solution can bring macroeconomic benefits as a vehicle for consumption smoothing for the unbanked population. We also answer macroeconomic questions on introducing a digital currency: what welfare effects this has; whether monetary policy becomes more or less effective; whether digital currencies buffer or amplify an economy from foreign financial shocks; and whether a flexible exchange rate regime can provide an insulation to digital currency move-

1. https://www.ft.com/content/c257a925-c864-4495-9149-d8956d786310
2. https://www.ft.com/content/c36c45d2-1100-4756-a752-07a217b2bde0
3. These concerns were raised by the IMF in a blog post in late-July 2021.
4. For example, Bitcoin crashed by up to 50 percent on 12 March, 2020, an event known as Black Thursday to the cryptocurrency community, see https://blog.kaiko.com/crypto-black-thursday-under-the-microscope-a86770df5c29.
5. See, for example, the discussion by Taylor (1996) and proceeding work.

ments.

Our SOE model features two types of households: those that only hold domestic currency, and those that only hold Bitcoin.[6] The model also contains a banking sector, which intermediates funding between households and firms. Additionally, we allow banks to raise funds from foreign (global) inter-bank markets. The spread between foreign interest rates and domestic interest rates generates the existence of cross-border interbank borrowing into the domestic economy, as investors search for higher yields.[7] Within this framework, we form a simple process for adjustment of Bitcoin deposits due to valuation effects in Bitcoin. The intuition is as follows. Households need to convert Bitcoin to domestic currency at the time of purchase of consumption.[8] Valuation effects in Bitcoin lead to a change in the purchasing power of household Bitcoin deposits, which affects consumption, labor, and bank lending. A baseline calibration predicts a unit standard deviation decline in Bitcoin prices will cause a peak decline in output and consumption of approximately 1 percent.

Using our model we make four contributions. First, we compute the relative welfare of an economy with Bitcoin to an economy with no Bitcoin deposits, which we denote as *Bitcoin autarky*. When the volatility of the Bitcoin price shock is sufficiently high, the general equilibrium effects of volatile Bitcoin deposits lead to an increase in the volatility of bank lending, firm wages, and an increase in the volatility of consumption and labor. The volatility costs cause a decline in aggregate welfare relative to the Bitcoin autarky economy. Our welfare analysis sheds light on the proposed stablecoin solution; for a sufficiently low volatility of the Bitcoin price shock, we obtain net benefits relative to autarky. Thus, we conjecture that stablecoins can provide an effective mechanism for consumption smoothing. By replacing Bitcoin with a stablecoin, the financial inclusion benefits of providing a savings vehicle to the unbanked population exceed the costs of volatility.

Second, we study the effect of digital currency adoption on monetary policy transmission, which is studied in related work by Ikeda (2020). Interest rate setting by the central bank can, in principle, have real economy effects through adjusting the opportunity cost of lending to firms, households, and its effects on asset prices. As residents of another country shift into the digital currency, the domestic central bank will lose control of monetary conditions and the ability to backstop local financial markets. We test this argument through the lens of our model. Relative to a setting

6. In the case of El Salvador, domestic currency is the Dollar, and the exchange rate is fixed.

7. The foreign interest rate can be proxied by the US Federal Funds Rate.

8. This is facilitated in El Salvador through a number of Bitcoin ATMs that are being built to facilitate easy access of Bitcoin to dollars. See https://www.bloomberg.com/news/articles/2021-08-23/el-salvador-readies-Bitcoin-rollout-with-200-atms-for-conversion for more details.

of Bitcoin autarky, we find the transmission of monetary policy is less effective in the case where Bitcoin deposits are prevalent. The intuition is as follows. An increase in Bitcoin deposits reduces the share of domestic dollar deposits. Therefore, the effect of a monetary policy shock on net worth, leverage, and lending is attenuated when a large fraction of a bank balance sheet is in digital currency.

Third, we contribute to the discussion of global financial cycles and the validity of the "Impossible Trinity" (trilemma) in which a small open economy with perfect capital mobility has to choose between a fixed exchange rate or independent monetary policy, but cannot have both.[9] Rey (2015, 2016) argues that the monetary policy trilemma is now a dilemma, as floating exchange rates no longer isolate the domestic economy from the global financial cycle. Our proxy to a global financial cycle shock is an exogenous shock to the foreign interest rate, which can be thought of as a change to the US Federal Funds Rate or changes in the risk assessment of foreign investors (Miranda-Agrippino and Rey 2020).[10] We show that relative to a baseline calibration of a managed float, the adoption of Bitcoin dampens the effects of the global financial cycle.

Finally, we assess whether the type of exchange rate regime matters for the transmission of the Bitcoin price shock. Comparing a fixed and free floating exchange rate regime, we observe that flexible exchange rates provide an effective buffer through a nominal exchange rate depreciation. While the peak decline in output is 1 percent for the baseline specification, the effects are amplified to a peak output decline of 1.5 percent for a rigid fixed exchange rate, and 0.5 percent for a free floating exchange rate regime. The results support the Obstfeld (2015) view that monetary sovereignty does play a role in insulation from foreign shocks to the economy.

The remainder of the paper is structured as follows. In Section 2 we summarize the contributions of our paper to related literature. In Section 3 we outline the background of El Salvador's Bitcoin proposal and the pros and cons of Bitcoin as legal tender. In Section 4 we describe our model and define the equilibrium conditions. Section 5 outlines the results of our baseline specification of a Bitcoin price shock, and conducts additional tests on differences between fixed and flexible exchange rate regimes and a welfare analysis. Section 6 concludes.

9. See Obstfeld, Shambaugh, and Taylor (2005) and Taylor (2007) for a historical discussion of the monetary policy trilemma.

10. See the vast literature on "sudden stops", which go as far back as Calvo (1998), and the issue of the "taper tantrum" caused by Federal Reserve Bank signaling its intention to tighten monetary policy.

2 Related literature

Our model framework borrows elements from SOE models with financial frictions (Aoki, Benigno, and Kiyotaki 2016; Akinci and Queraltó 2019; Gourinchas 2018; Ahmed, Akinci, and Queralto 2021); exogenous terms of trade shocks (Kulish and Rees 2017; Drechsel and Tenreyro 2018); and the costs of dollarization such as in Schmitt-Grohé and Uribe (2001).

The source of financial frictions in our model is based on an incentive compatibility constraint, in which banks need to have sufficient value or else they will abscond with a fraction of foreign deposits, based on Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). This friction is necessary to deviate from Mundell-Fleming-Dornbusch and the UIP condition. We extend the framework in Aoki, Benigno, and Kiyotaki 2016,henceforth ABK, to include an additional set of households that use Bitcoin ("Bitcoin households"), in addition to households that use conventional fiat currency as a medium of exchange. Critically, the Bitcoin households are unbanked, but hold savings in the form of Bitcoin deposits. Bitcoin prices are subject to a price shocks similar to terms of trade and commodity price shocks studied in Drechsel and Tenreyro (2018) in that we assume an exogenous price process for Bitcoin. A crucial difference is that while the effects of commodity prices affect the allocation of commodity producing firms, in our model we motivate Bitcoin price shocks as affecting the saving and consumption behavior of Bitcoin households. The costs of dollarization studied in Schmitt-Grohé and Uribe (2001) are the loss of monetary independence and ability to stabilize prices against the benefit of reducing the probability of a "Peso" shock and a large devaluation of the currency. The authors conduct a welfare analysis and find net welfare effects ranging from 30 to 50 percent above the pre-dollarization regime. We also study welfare effects of Bitcoin adoption relative to the standard of dollarization and flexible exchange rate regimes for different levels of volatility of the Bitcoin price process.

Our work also relates to an emerging literature on the macroeconomic implications of global stablecoins and a Central Bank Digital Currency (CBDC) (Baughman and Flemming 2020; Benigno, Schilling, and Uhlig 2019; Benigno et al. 2019; Ferrari, Mehl, and Stracca 2020; George, Xie, and Alba 2020; Skeie 2019; Ikeda 2020; Kumhof et al. 2021). Benigno, Schilling, and Uhlig (2019) model a two country framework in which a global stablecoin, like that proposed by Facebook's Libra/Diem, is traded freely between both countries. They determine an equilibrium result of synchronization of interest rates across the two countries in which users are indifferent between holding the global currency and the domestic currency. Baughman and Flemming (2020) model the welfare effects of basket-based stablecoins that is a convex weighting of sovereign currencies. They find, in equilibrium, there is low demand for the global stablecoin, and modest welfare effects relative to a dollarization case of 2 percent. Skeie (2019) studies an equilibrium in which the digital currency is susceptible to bank runs. Ferrari, Mehl, and Stracca (2020) find that spillovers are amplified in the presence of a CBDC, and adoption of a CBDC by a foreign currency reduces the effectiveness of the foreign country's monetary policy. Ikeda (2020) models a 2 country economy in which goods are priced in foreign currency. Domestic monetary policy transmission is weakened when prices are denominated in a foreign currency, in line with the dominant currency pricing model developed in (Gopinath et al. 2020). The channel of monetary policy transmission in Ikeda (2020) is expenditure switching; in our paper we offer an alternative channel through having digital currency deposits that are insulated from changes in the policy rate.

Finally, we contribute to a policy discussion on the cost and benefits of introducing Bitcoin as legal tender. Subacci (2021) argues that while Bitcoin enables value transfer without intermediation, the risk of a sudden drop in its price means that migrants and their families back home can never be sure about the amount transferred.[11] While it is potentially useful in EMEs, where an international financial system serves them poorly, the author notes that alternative payment systems like the M-Pesa mobile money service in Africa can be used as a potential alternative to service the unbanked population.[12] Economists at the IMF (Adrian and Weeks-Brown 2021) have opposed the Bitcoin law, noting substantial risks to macro-financial stability, financial integrity, consumer protection, and the environment. Their view is that households and businesses would have very little incentive to price or save in a parallel cryptoasset, such as Bitcoin, as it is too volatile and unrelated to the real economy. If goods and services are priced in both a real currency and a cryptoasset, households and businesses would spend significant time and resources choosing which money to hold as opposed to engaging in productive activities. They also cite the ineffectiveness of monetary policy as central banks cannot set interest rates on a foreign currency, and as a result domestic prices could become highly unstable. The risk of a sudden drop in its price means that migrants and their families back home can never be sure about the amount transferred. In addition, Plassaras (2013) analyzes regulatory concerns with the IMF in being unable to provide financial sup-

11. See, for example, https://www.project-syndicate.org/commentary/risks-of-el-salvador-adopting-Bitcoin-by-paola-subacchi-2021-06.

12. We expand on this argument in Section 3, where we discuss the costs and benefits of the Bitcoin experiment in increasing financial inclusion.

port through emergency loan provisions if the financial crisis is due to legal tender in Bitcoin.

3 Background: El Salvador's Bitcoin experiment

3.1 Financial inclusion, remittances, and FDI

El Salvador's recent law to make Bitcoin legal tender took effect on September 7th, 2021 [13] There are three potential benefits of adopting a digital currency as legal tender. The first benefit is financial inclusion, with estimates from the World Bank put up to two thirds of El Salvador's population without a bank account.[14] Under the new regime, each individual can own a government sponsored Chivo digital wallet and is eligible for $30 US in Bitcoin. El Salvador has installed a number Bitcoin ATMs, allowing its citizens to convert the cryptocurrency into US Dollars.[15] In addition to the creation of wallets and ATMs, El Salvadorian banks are also pursuing regulations to encourage the use of Bitcoin wallet services in banking. Banco Central de Reserva (BCR) has published a report outlining rules for commercial banks to offer Bitcoin products, such as digital wallets, in which banks must apply to the central bank for authorization.[16]

A second potential benefit of a digital currency is in reducing remittance costs. According to the World Bank, El Salvador is one of the most dependent countries on remittances which total 25 percent of GDP.[17] The reduction of remittance costs can yield welfare benefits. For example, a study conducted by Aycinena, Martinez, and Yang (2010) finds that a $1 US reduction in fees led migrants to send $25 US more remittances per month.[18] Hanke, Hanlon, Chakravarthi, et al. (2021) quantifies remittance fees of Bitcoin relative to conventional banking methods. The authors estimate remittance fees for using banking services at 4 percent, and Bitcoin are estimated at a minimum of 5 percent, with the addition of network fees and other costs of safety and security of the payment network. Therefore, the success of the Bitcoin experiment in reducing remittance costs depends on whether Bitcoin adoption becomes widespread as legal tender. A third potential benefit is through

13. https://www.npr.org/2021/09/07/1034838909/bitcoin-el-salvador-legal-tender-official-currency-cryptocurrency?t=1634944255426
14. https://datatopics.worldbank.org/g20fidata/country/el-salvador
15. See Appendix A.1 for a map of El Salvador's Bitcoin ATMs.
16. For more information on banking regulations, see https://coingeek.com/el-salvador-publishes-draft-regulations-for-banks-handling-btc/.
17. See https://data.worldbank.org/indicator/BX.TRF.PWKR.DT.GD.ZS?locations=SV.
18. See also https://www.bloomberg.com/news/articles/2021-08-23/el-salvador-readies-Bitcoin-rollout-with-200-atms-for-conversion.

encouraging FDI inflows. One early example of a Bitcoin project is "Bitcoin Beach". In 2019, the coastal town of El Zonte adopted Bitcoin as a local currency. The project gave $50 US in Bitcoin to each local family, encouraging the cryptocurrency's adoption by local vendors. The project led to Bitcoin being used to pay for utility bills, health care, food, and other services.[19]

3.2 Stablecoins and mobile payments

For consumers, firms, and banks, the choice of legal tender depends on the network characteristics of the currency and whether it achieves the properties of money as an effective store of value, medium of exchange, and unit of account. The main cost with adopting Bitcoin is that it does not satisfy the store of value function of money, with volatility exceeding fiat-exchange rate movements by an order of magnitude. A poll conducted by the Central American University finds that approximately 67 percent of El Salvadorian participants did not believe that Bitcoin should be legal tender, and more than 70 percent believed the law should be repealed. Significant public pessimism on the Bitcoin law is justified due to the excess volatility of Bitcoin. Within the first day of the Bitcoin law, Bitcoin fell by approximately 10 percent, from $52,000 US to $47,000 US by day's end. Moody's downgraded government debt due to the risk of poor governance and the Bitcoin law.[20] Plotting daily returns from January 2017 to September 2021, we observe a maximum daily return of 19.4 percent and a peak negative daily return of -38.4 percent.

We now turn to a solution: replacing Bitcoin with a stablecoin, a digital currency with sufficiently low volatility. Stablecoins are a class of cryptocurrencies pegged to the US Dollar. Tether and USDC, the largest stablecoins by market cap as of September 2021, account for approximately 90 percent of the stablecoin market.[21] Estimates of volatility based on quarterly returns of Tether/USD and USDC/USD are 0.18 percent and 0.12 percent, respectively, from January 2020 to September 2021. In contrast, volatility of quarterly returns of BTC/USD is 70 percent over the same period.[22] In solving the volatility problem, the financial inclusion benefits a stablecoin brings can help provide an effective savings for El Salvador residents, helping them smooth consumption with net welfare benefits for the macroeconomy.

19. https://www.reuters.com/technology/bitcoin-beach-tourists-residents-hail-el-salvadors-adoption-cryptocurrency-2021-09-07/

20. https://www.coindesk.com/markets/2021/07/31/moodys-lowers-el-salvador-rating-maintains-negative-outlook-partly-due-to-Bitcoin-law/.

21. A global stablecoin, such as Facebook's Diem project is a viable alternative, however as of September 2021 it has not been officially launched.

22. Bitcoin, Tether and USDC returns are documented in Appendix A.1.

For stablecoins to become legal tender in emerging markets, stablecoins need to be appropriately regulated to be fully collateralized at all times.[23] Regulations may require stablecoin issuers to be required to meet strict capital requirements to ensure full collateralization. This includes stablecoin deposits backed by government schemes such as deposit insurance, liquidity support by the central bank, and redemption fees in response to peg discounts – as discussed in Routledge and Zetlin-Jones (2021) – are policies that can be used to ensure stability of the peg.[24]

4 The model

We build a small open economy model equipped with a banking sector and cross-border interbank borrowing as one of the funding sources for domestic banks. Our setup is fundamentally based on seminal work in the New Keynesian dynamic stochastic general equilibrium (DSGE) literature such as Clarida, Galí, and Gertler (1999), Christiano, Eichenbaum, and Evans (2005), and Smets and Wouters (2007). We build on this foundation by including SOE features from Galí and Monacelli (2005), ABK, and Akinci and Queraltó (2019).[25]

Our model features a banking sector which can hold cryptocurrency balances – in the form of Bitcoin – and raise funds from both domestic households and international banking sectors, albeit with foreign exchange risk and some efficiency cost. For example, a rise in foreign interest rates charged on cross-border interbank borrowing causes an immediate rise in borrowing costs and leads to a reversal of interbank borrowing. Open economy features in the model we present are also contain elements of Gertler, Gilchrist, and Natalucci (2007) (GGN), which provide similar intuition on the interaction between monetary policy, exchange rate regimes,

23. Stablecoins have faced scrutiny from regulators due to concerns on the potential of run-risk and speculative attacks. This is in part due to stablecoins being backed by illiquid assets that make it difficult for the issuer to meet mass redemption. For example, statements provided by Tether show that the stablecoin is backed at most of 75.6 percent by liquid assets, which include commercial paper, fiduciary deposits, T-bills, and cash reserves. Quarterly statement released by Tether Ltd on breakdown of reserves. Statement issued on May 13th, 2021 on Tether's twitter account. Available at https://twitter.com/Tether_to/status/1392811872810934276

24. An alternative that can be used instead of a stablecoin is a mobile payment platform. In Kenya, the biggest phone company developed M-Pesa, a texting-based system for storing and sending money. A study by Suri and Jack (2016) found M-Pesa's sudden takeoff had lifted 194,000 households, or 2 percent of Kenyan households, out of poverty. Critically, they found changes in financial behavior increased financial resilience and saving.

25. The primary difference between the ABK and Akinci and Queraltó (2019) models is that the former is a small-open economy setup, while the latter is a two-country setup. ABK also restrict their analysis to capital controls, while Akinci and Queraltó (2019) consider the effect of exchange rate regimes during global financial cycles.

and the influence of financial crises.[26]

4.1 Households and workers

The representative household contains a continuum of individuals, each of which are of type $i \in \{b, h, c\}$. Bankers ($i = b$) and regular workers ($i = h$) share a perfect insurance scheme, such that they each consume the same amount of real output. However, Bitcoin workers ($i = c$) are not part of this insurance scheme, and so their consumption volumes are different from bankers and regular workers.

The problem for regular workers is the following. They choose consumption, C_t^h, labor supply, L_t^h, equity holdings in firms, K_t^h, and deposits held at the bank, D_t,[27] to maximize the present value discounted sum of their expected utility,

$$\max_{C_t^h, L_t^h, K_t^h, D_t} \mathbb{E}_t \left[\sum_{s=0}^{\infty} \beta^s \ln \left(C_{t+s}^h - \frac{\zeta_0}{1+\zeta} (L_{t+s}^h)^{1+\zeta} \right) \right], \tag{1}$$

subject to their period budget constraint,

$$C_t^h + Q_t K_t^h + \chi_t^h + D_t = w_t^h L_t^h + \Pi_t^P + (z_t^k + \lambda Q_t) K_{t-1}^h + \frac{R_{t-1}}{\Pi_t} D_{t-1}, \tag{2}$$

where Q_t is the equity price in terms of final goods; $\chi^h(K_t, K_t^h)$ are portfolio management costs of regular workers in the household; w_t^h are real wages of regular workers in terms of final goods; Π_t^P are real profits earned by the household from the production of intermediate goods, production of investment goods, and banking;

26. Notable differences between GGN and the model we present include, but are not limited to: (i) GGN does not introduce a banking sector, and the households directly play a role in borrowing from foreign banks. In contrast, we describe a rich banking sector which plays a role in intermediating cross-border interbank borrowing to local entrepreneurs.
(ii) GGN consider 300 basis point increases in the country risk-premium as an external shock to the domestic small-open economy. In contrast, we examine the influences of an 100 basis point rise in the foreign interest rate which determines the borrowing costs for cross-border interbank borrowing.
(iii) GGN do not provide quantitative responses of the foreign borrowing in the face of external shocks, while we provide a full description of the response of cross-border interbank borrowing to external shocks.
In spite of these differences, we provide the same intuition as GGN: Countries in the position of having to defend an exchange rate peg are more likely to suffer severe financial distress. It is noteworthy that both GGN and this paper suggest small-open economy models that describe sudden stop episodes which are atypical to most of the literature which have occasionally binding constraints (such as in Mendoza (2010)).

27. Technically, the household chooses nominal deposits, D_t^n, which are deflated by the domestic consumer price index, P_t:

$$D_t = \frac{D_t^n}{P_t}.$$

z_t^k is the rental rate of capital; $R_t = 1 + i_t$ is the gross nominal interest rate; and $\Pi_t = \frac{P_t}{P_{t-1}} = 1 + \pi_t$ is the gross domestic inflation rate, where P_t is the domestic price level. The parameters β, ζ_0, ζ, and λ are the household's discount factor, inverse-disutility from labor supply parameter, the Frisch elasticity of labor supply, and one minus the depreciation rate of capital, respectively. The preferences used in (1) are of the Greenwood-Hercowitz-Hoffman form in order to shutoff the income effect on labor supply.

The first-order conditions (FOCs) for labor, savings in equity, and deposits which emerge from the regular worker's problem are:

$$w_t^h = \zeta_0 (L_t^h)^{\zeta}, \tag{3}$$

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1}^h \frac{z_{t+1}^k + \lambda Q_{t+1}}{Q_t + \varkappa^h \frac{K_t^h}{K_t}} \right], \tag{4}$$

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1}^h \frac{R_t}{\Pi_{t+1}} \right], \tag{5}$$

where the parameter $\varkappa^h$ is an efficiency cost arising from regular workers financing firms, while $\Lambda_{t,t+1}^h$ is the stochastic discount factor of the household and is defined as

$$\Lambda_{t,t+1}^h = \beta \mathbb{E}_t \left[\frac{C_t^h - \frac{\zeta_0}{1+\zeta}(L_t^h)^{1+\zeta}}{C_{t+1}^h - \frac{\zeta_0}{1+\zeta}(L_{t+1}^h)^{1+\zeta}} \right]. \tag{6}$$

Bitcoin workers also supply their labor to firms for a wage, however their only vehicle for intertemporal savings is to hold Bitcoin balances. Their problem is:

$$\max_{C_t^c, L_t^c, B_t} \mathbb{E}_t \left[\sum_{s=0}^{\infty} \beta^s \ln \left(C_{t+s}^c - \frac{\zeta_0}{1+\zeta} (L_{t+s}^c)^{1+\zeta} \right) \right], \tag{7}$$

subject to period budget constraint,

$$C_t^c + B_t = w_t^c L_t^c + \frac{R_{t-1}^c}{\Pi_t} B_{t-1}, \tag{8}$$

where B_t is real Bitcoin holdings in terms of domestic quantities.[28] We assume that Bitcoin workers choose the amount of Bitcoin to hold in proportion to its expected appreciation, Π_{t+1}^c:

$$B_t = \bar{B} \mathbb{E}_t \left[\Pi_{t+1}^c \right], \tag{9}$$

28. Specifically, we define

$$B_t = P_t^c B_t^N,$$

where P_t^c is the price level of Bitcoin and B_t^N are nominal Bitcoin holdings.

where we simply define the period t appreciation of Bitcoin as:

$$\Pi_t^c = \frac{P_t^c}{P_{t-1}^c} = 1 + \pi_t^c.$$

The FOCs that arise from the Bitcoin worker problem are

$$w_t^c = \zeta_0 (L_t^c)^{\zeta}, \tag{10}$$

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1}^c \frac{R_t^c}{\Pi_{t+1}} \right], \tag{11}$$

where the stochastic discount factor of the Bitcoin worker is defined as:

$$\Lambda_{t,t+1}^c = \beta \mathbb{E}_t \left[\frac{C_t^c - \frac{\zeta_0}{1+\zeta}(L_t^c)^{1+\zeta}}{C_{t+1}^c - \frac{\zeta_0}{1+\zeta}(L_{t+1}^c)^{1+\zeta}} \right]. \tag{12}$$

The interaction between workers and bankers within the representative household is as follows. We normalize the composition of workers and bankers such that their combined population is a unit density. Let σ denote the continuation probability of a banker remaining in employment through to the next period, such that she may retire with probability $1-\sigma$ in each period. The number of bankers retiring in each period is matched by the number of workers transitioning into banking, and thus the population of workers and bankers is stable. A retiring banker transfers her franchise value – or remaining net worth – as a dividend to the household, and new bankers receive fraction γ of total assets from the household as initial funds.

As mentioned, regular workers can directly purchase equity in domestic firms, but with an efficiency cost – relative to a banker purchasing equity – given by the following expression:

$$\chi_t^h = \frac{\varkappa^h}{2} \left(\frac{K_t^h}{K_t} \right)^2 K_t, \tag{13}$$

where K_t is the aggregate capital stock. Regular workers can also save their earnings in the form of bank deposits, which are nominal, short term, and non-contingent, and earn a nominal return of R_t.

Regular workers cannot access foreign savings directly, and foreign households cannot directly hold domestic capital. All interactions between domestic equity markets and foreign households must be intermediated by the domestic banking sector. This of course implies that the domestic banks are exposed to foreign exchange rate risk. Figure 1 provides an overview of agents and flows in this model.

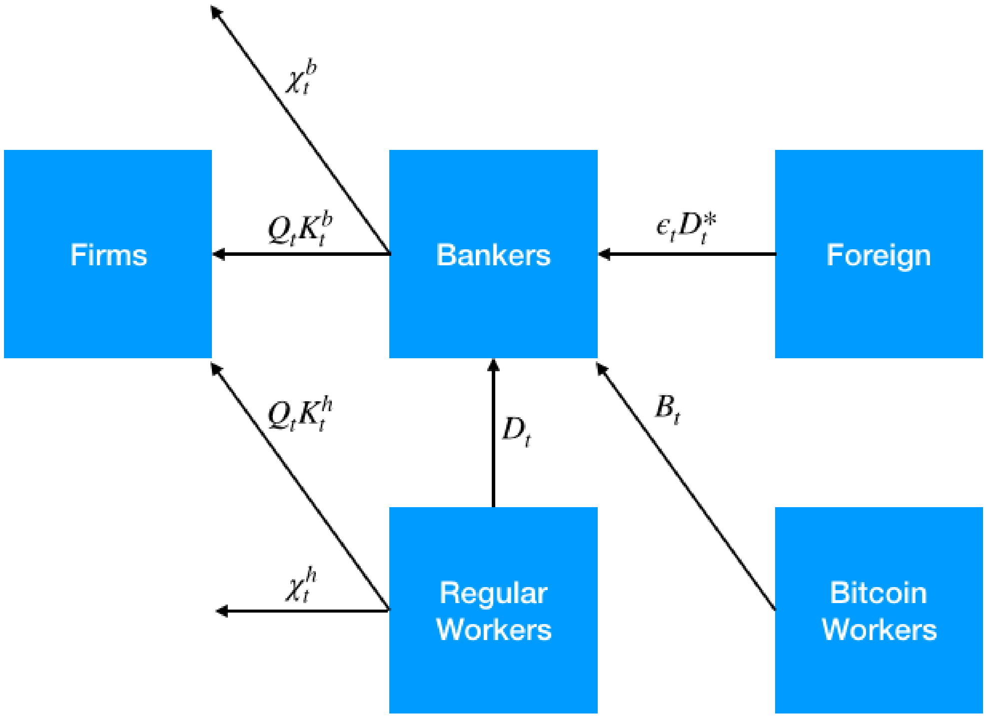


Figure 1: Graphical illustration of the model

4.2 Banks

A banker will finance her capital investments, of market value $Q_tk_t^b$, by receiving deposit funds from regular workers in domestic currency, d_t, Bitcoin deposits from Bitcoin workers, b_t, and from foreign households in foreign currency, $\epsilon_t d_t^*$. The banker faces exchange rate risk, and the real exchange rate is defined as

$$\epsilon_t = \frac{E_t P_t^*}{P_t}, \tag{14}$$

where E_t is the nominal exchange rate defined as the quantity of domestic currency units per one unit of foreign currency.[29] While bankers can invest in domestic firms costlessly – unlike workers – they incur an efficiency cost from taking in deposits from foreign households, defined by the following expression:

$$\chi_t^b = \frac{\varkappa^b}{2} x_t^2 Q_t k_t^b, \tag{15}$$

where $\varkappa^b > 0$ is a foreign borrowing cost parameter and $Q_tk_t^b$ is the asset holding of a banker.[30] x_t is the fraction of a banker's assets financed by foreign borrowing and

29. Thus, an increase (decrease) in ϵ_t and E_t is a domestic currency depreciation (appreciation).

30. The quadratic adjustment costs χ_t^h and χ_t^b can also be thought of as a method to close the model, as explained in Schmitt-Grohé and Uribe (2003).

is defined as:

$$x_t = \frac{\epsilon_t d_t^*}{Q_t k_t^b}. \tag{16}$$

Additionally, as the banker offers Bitcoin wallet services to Bitcoin workers,[31] we define x_t^c as a banker's Bitcoin deposit leverage ratio:

$$x_t^c = \frac{b_t}{Q_t k_t^b}. \tag{17}$$

Bankers aim to build up their own net worth or franchise value, n_t, until retirement. As mentioned, when a banker retires, she brings her net worth back to the household in the form of a dividend.[32] Thus, a banker will seek to maximize her bank's franchise value, $\mathbb{V}_t^b$, which is the expected present discount value of future dividends:

$$\mathbb{V}_t^b = \mathbb{E}_t \left[\sum_{s=1}^{\infty} \Lambda_{t,t+s} \sigma^{s-1} (1-\sigma) n_{t+s} \right], \tag{18}$$

where n_{t+s} is the net worth of the bank when the banker retires at date $t+s$ with probability $\sigma^{s-1}(1-\sigma)$. So, a banker will choose quantities k_t^b, d_t, and d_t^* to maximize expression (18).[33]

A financial friction inline with Gertler and Kiyotaki (2010) is used to limit the banker's ability to raise funds, whereby the banker faces a moral hazard problem: the banker can either abscond with the funds she has raised from domestic and foreign depositors, or the banker can operate honestly and pay out her obligations. Absconding is costly, however, and so the banker can only divert a fraction, Θ, of assets she has accumulated:

$$\Theta(x_t, x_t^c) = \frac{\theta_0 + \theta_0^c}{\exp(\theta x_t)\exp(\theta^c x_t^c)}, \tag{19}$$

where we assume that $\{\theta_0, \theta_0^c, \theta, \theta^c\} > 0$. Thus, following Gertler and Kiyotaki (2010), we assume that as the banker raises a greater proportion of her funds from

31. See, for example, the central bank of El Salvador publishing draft regulations on banks handling Bitcoin deposits.

32. As done in ABK, this retirement assumption is made so as to avoid banks being able to accumulate retained earnings, evading any financing constraints or obligations to creditors.

33. Note that we make the simplifying assumption that each individual banker exogenously accepts Bitcoin deposits, b_t, directly in proportion to the population of bankers and total Bitcoin holdings. In other words, in aggregate, the total sum of individual Bitcoin deposits at each j-th bank, $b_t(j)$, is equal to aggregate Bitcoin deposits, B_t:

$$\sum_{j=1}^{\infty} b_t(j) = B_t.$$

international financial markets and Bitcoin deposits, she can abscond a smaller proportion of her assets.

The caveat to absconding, in addition to only being able to take a fraction of assets away, is that it takes time – i.e., it takes a full period for the banker to abscond. Thus, the banker must decide to abscond in period t, in addition to announcing what value of d_t she will choose, prior to realizing next period's rental rate of capital. If a banker chooses to abscond in period t, its creditors will force the bank to shutdown in period $t+1$, causing the banker's franchise value to become zero.

Therefore, the banker will choose to abscond in period t if and only if the return to absconding is greater than the franchise value of the bank at the end of period t, $\mathbb{V}_t^b$. It is assumed that the depositors act rationally, and that no rational depositor will supply funds to the bank if she clearly has an incentive to abscond.[34] In other words, the bankers face the following incentive constraint:

$$\mathbb{V}_t^b \geq \Theta(x_t, x_t^c) Q_t k_t^b, \tag{20}$$

where we assume that the banker will not abscond in the case of the constraint holding with equality.

4.2.1 Bank balance sheet

Table 1 represents the balance sheet of a typical banker, and so we can write the following balance sheet constraint that the banker faces:

$$\left(1 + \tau_t^K + \frac{\varkappa^b}{2} x_t^2\right) Q_t k_t^b = d_t + (1 - \tau_t^{D^*}) \epsilon_t d_t^* + (1 + \tau_t^N) n_t + (1 - \tau_t^c) B_t. \tag{21}$$

34. Consider a simple Gertler and Kiyotaki (2010) setup absent of inflation and foreign deposits. Recall that the banker seeks to maximize profits and that it will choose to abscond if and only if:

$$\underbrace{R^k(d+n) - Rd}_{\text{Profit from operating honestly}} < \underbrace{\Theta R^k(d+n).}_{\text{Absconding payoff}}$$

If the banker wants to abscond, she will set her demand for deposits such that the above inequality holds, or,

$$R > \frac{(1-\Theta)R^k(d+n)}{d}.$$

In other words, if a banker signalled that she intended to default, then the return that the worker would receive from depositing with other banks would be greater than the return they would earn by depositing with the absconding banker. Therefore, an absconding banker would receive no deposits, and so an optimizing banker would not choose to abscond.

Assets	Liabilities + Equity
Loans $Q_t k_t^b$	Deposits d_t
Management costs χ_t^b	Bitcoin deposits b_t
	Foreign debt $\epsilon_t d_t^*$
	Net worth n_t

Table 1: Bank balance sheet

Additionally, we can write the flow of funds constraint for a banker as

$$n_t = (z_t^k + \lambda Q_t) k_{t-1}^b - \frac{R_{t-1}}{\Pi_t} d_{t-1} - \frac{R_{t-1}^*}{\Pi_t^*} \epsilon_t d_{t-1}^* - \frac{R_{t-1}^c}{\Pi_t} b_{t-1}, \tag{22}$$

noting that for the case of a new banker, the net worth is the startup fund given by the household (fraction γ of the household's assets).

4.2.2 Rewriting the banker's problem

With the constraints of the banker established, we can proceed to write the banker's problem as:

$$\max_{k_t^b, d_t, d_t^*} \mathbb{V}_t^b = \mathbb{E}_t \left[\Lambda_{t,t+1} \left\{ (1-\sigma) n_{t+1} + \sigma \mathbb{V}_{t+1}^b \right\} \right],$$

subject to the incentive constraint (20) and the balance sheet constraint (21).

Since $\mathbb{V}_t^b$ is the franchise value of the bank, which we can interpret as a "market value", we can divide $\mathbb{V}_t^b$ by the bank's net worth to obtain a Tobin's Q ratio for the bank denoted by ψ_t:

$$\psi_t \equiv \frac{\mathbb{V}_t^b}{n_t} = \mathbb{E}_t \left[\Lambda_{t,t+1} (1 - \sigma + \sigma \psi_{t+1}) \frac{n_{t+1}}{n_t} \right]. \tag{23}$$

Next, iterate the banker's flow of funds constraint (22) forward by one period, and then divide through by n_t to yield:

$$\begin{aligned} \frac{n_{t+1}}{n_t} &= \left(z_{t+1}^k + \lambda Q_{t+1} \right) \frac{k_t^b}{n_t} - \frac{R_t}{\Pi_{t+1}} \frac{d_t}{n_t} - \frac{R_t^*}{\Pi_{t+1}^*} \frac{\epsilon_{t+1} d_t^*}{n_t} - \frac{R_t^c}{\Pi_{t+1}} \frac{b_t}{n_t} \\ &= \frac{\left(z_{t+1}^k + \lambda Q_{t+1} \right)}{Q_t} \frac{Q_t k_t^b}{n_t} - \frac{R_t}{\Pi_{t+1}} \frac{d_t}{n_t} - \frac{R_t^*}{\Pi_{t+1}^*} \frac{\epsilon_{t+1}}{\epsilon_t} \frac{\epsilon_t d_t^*}{n_t} - \frac{R_t^c}{\Pi_{t+1}} \frac{b_t}{n_t}, \end{aligned}$$

where ϕ_t is the leverage ratio of a bank,

$$\phi_t = \frac{Q_t k_t^b}{n_t}. \tag{24}$$

Rearrange the balance sheet constraint (21) and use the fact that $\epsilon_t d_t^* / n_t = x_t \phi_t$

and $b_t/n_t = x_t^c \phi_t$, to yield the following:

$$\frac{d_t}{n_t} = \left(1 + \tau_t^K + \frac{\varkappa^b}{2} x_t^2\right) \phi_t - \left(1 - \tau_t^{D^*}\right) x_t \phi_t - \left(1 - \tau_t^c\right) x_t^c \phi_t - \left(1 + \tau_t^N\right).$$

Substitute this value for d_t/n_t into the expression for n_{t+1}/n_t, and we get:

$$\begin{aligned}\frac{n_{t+1}}{n_t} = &\left(\frac{z_{t+1}^k + \lambda Q_{t+1}}{Q_t} - (1+\tau_t^K)\frac{R_t}{\Pi_{t+1}}\right)\phi_t + \left(1 + \tau_t^N - \frac{\varkappa^b}{2} x_t^2 \phi_t\right)\frac{R_t}{\Pi_{t+1}} \\ &+ \left[(1-\tau_t^{D^*})\frac{R_t}{\Pi_{t+1}} - \frac{R_t^*}{\Pi_{t+1}^*}\frac{\epsilon_{t+1}}{\epsilon_t}\right] x_t \phi_t + \left[(1-\tau_t^c)\frac{R_t}{\Pi_{t+1}} - \frac{R_t^c}{\Pi_{t+1}}\right] x_t^c \phi_t.\end{aligned}$$

Substituting this expression into (23), yields the following:

$$\begin{aligned}\psi_t &= \mathbb{E}_t\left[\Lambda_{t,t+1}(1-\sigma+\sigma\psi_{t+1})\left\{\begin{array}{r}\left(\frac{z_{t+1}^k+\lambda Q_{t+1}}{Q_t} - (1+\tau_t^K)\frac{R_t}{\Pi_{t+1}}\right)\phi_t + \left(1+\tau_t^N - \frac{\varkappa^b}{2}x_t^2\phi_t\right)\frac{R_t}{\Pi_{t+1}} \\ + \left[(1-\tau_t^{D^*})\frac{R_t}{\Pi_{t+1}} - \frac{R_t^*}{\Pi_{t+1}^*}\frac{\epsilon_{t+1}}{\epsilon_t}\right] x_t\phi_t \\ + \left[(1-\tau_t^c)\frac{R_t}{\Pi_{t+1}} - \frac{R_t^c}{\Pi_{t+1}}\right] x_t^c\phi_t\end{array}\right\}\right] \\ &= \mu_t\phi_t + \left(1+\tau_t^N - \frac{\varkappa^b}{2}x_t^2\phi_t\right)\upsilon_t + \mu_t^* x_t\phi_t + \mu_t^c x_t^c \phi_t,\end{aligned}$$

where we write the Tobin Q ratio for the banker, ψ_t, in terms of $\Omega_{t,t+1}$, the stochastic discount factor of the banker[35]; μ_t, the excess return on capital over home deposits; μ_t^c, the cost advantage of Bitcoin over home deposits; μ_t^*, the cost advantage of foreign currency debt over home deposits or the deviation from real uncovered interest parity (UIP); and υ_t, the marginal cost of deposits:

$$\mu_t = \mathbb{E}_t\left[\Omega_{t,t+1}\left\{\frac{z_{t+1}^k + \lambda Q_{t+1}}{Q_t} - (1+\tau_t^K)\frac{R_t}{\Pi_{t+1}}\right\}\right], \tag{25}$$

$$\mu_t^c = \mathbb{E}_t\left[\Omega_{t,t+1}\left\{(1-\tau_t^c)\frac{R_t}{\Pi_{t+1}} - \frac{R_t^c}{\Pi_{t+1}}\right\}\right], \tag{26}$$

$$\mu_t^* = \mathbb{E}_t\left[\Omega_{t,t+1}\left\{(1-\tau_t^{D^*})\frac{R_t}{\Pi_{t+1}} - \frac{\epsilon_{t+1}}{\epsilon_t}\frac{R_t^*}{\Pi_{t+1}^*}\right\}\right], \tag{27}$$

$$\upsilon_t = \mathbb{E}_t\left[\Omega_{t,t+1}\frac{R_t}{\Pi_{t+1}}\right], \tag{28}$$

$$\Omega_{t,t+1} = \Lambda_{t,t+1}(1-\sigma+\sigma\psi_{t+1}). \tag{29}$$

35. Note that we assume that the stochastic discount factor of the banker is a function of the stochastic discount factor of the regular workers. This is because we assume that Bitcoin workers do not hold domestic currency denominated deposits.

Therefore, we can rewrite the banker's problem as the following:

$$\psi_t = \max_{\phi_t, x_t} \left[\mu_t \phi_t + \left(1 + \tau_t^N - \frac{\varkappa^b}{2} x_t^2 \phi_t \right) \upsilon_t + \mu_t^* \phi_t x_t + \mu_t^c x_t^c \phi_t \right], \tag{30}$$

subject to

$$\psi_t \geq \Theta(x_t, x_t^c)\phi_t. \tag{31}$$

4.2.3 Solving the banker's problem

With $\mu_t, \mu_t^*, \mu_t^c > 0$, the banker's incentive compatibility constraint binds with equality, and so we can write the Lagrangian as:

$$\mathcal{L} = \psi_t + \lambda_t(\psi_t - \Theta(x_t, x_t^c)\phi_t),$$

where λ_t is the Lagrangian multiplier. The FOCs with respect to ϕ_t and x_t are:

$$\frac{\partial \mathcal{L}}{\partial \phi_t} : (1 + \lambda_t) \left[\mu_t + \mu_t^* x_t + \mu_t^c x_t^c - \frac{\varkappa^b}{2} x_t^2 \upsilon_t \right] = \lambda_t \Theta(x_t, x_t^c), \tag{32}$$

$$\frac{\partial \mathcal{L}}{\partial x_t} : (1 + \lambda_t) \left[\varkappa^b x_t \upsilon_t - \mu_t^* \right] = \theta \lambda_t \Theta(x_t, x_t^c), \tag{33}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda_t} : \psi_t = \phi_t \Theta(x_t, x_t^c). \tag{34}$$

Use (34) and substitute into the banker's objective function to yield:

$$\phi_t = \frac{(1 + \tau_t^N)\upsilon_t}{\Theta(x_t, x_t^c) - \mu_t - \mu_t^* x_t - \mu_t^c x_t^c + \frac{\varkappa^b}{2} x_t^2 \upsilon_t}. \tag{35}$$

Then, combine (32) and (33) to write

$$F\left(x_t, \frac{\mu_t}{\upsilon_t}, \frac{\mu_t^*}{\upsilon_t}, \frac{\mu_t^c}{\upsilon_t}\right) = -\frac{\theta \varkappa^b}{2} x_t^2 + \left(\theta \frac{\mu_t^*}{\upsilon_t} - \varkappa^b\right) x_t + \theta \left(\frac{\mu_t}{\upsilon_t} + \frac{\mu_t^c}{\upsilon_t} x_t^c\right) + \frac{\mu_t^*}{\upsilon_t}.$$

Note that $\mu_t, \mu_t^*, \mu_t^c, \upsilon_t > 0$, and so $F(x_t = 0, \dots) > 0$, and thus we can write

$$x_t = \frac{\theta \mu_t^* - \varkappa^b \upsilon_t}{\theta \varkappa^b \upsilon_t} + \sqrt{\left(\frac{\mu_t^*}{\varkappa^b \upsilon_t}\right)^2 + 2\frac{\mu_t^c}{\varkappa^c \upsilon_t} x_t^c + \left(\frac{1}{\theta}\right)^2 + 2\frac{\mu_t}{\varkappa^b \upsilon_t}}. \tag{36}$$

This concludes the problem and optimal choices of the banker.

4.3 Firms

4.3.1 Final good firms

Firms and production in the model are standard, following a New Keynesian Dixit-Stiglitz setup. Final goods are produced by perfectly competitive firms using intermediate goods as inputs into production:

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\eta-1}{\eta}} di \right)^{\frac{\eta}{\eta-1}},$$

where $Y_t(i), i \in [0,1]$, are differentiated intermediate goods and $\eta > 0$ is an elasticity of demand parameter. Final good firms maximize their profits by selecting how much of each intermediate good to purchase, and so their problem is:

$$\max_{Y_t(i)} P_t Y_t - \int_0^1 P_t Y_t(i) di.$$

Thus, as in Blanchard and Kiyotaki (1987), following the FOC of the final good firm problem, intermediate good producers face a downward sloping demand curve for their products:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\eta} Y_t,$$

where $P_t(i)$ is the price for good i, and P_t is the price index for the aggregate economy and is defined as:

$$P_t = \left(\int_0^1 P_t(i)^{1-\eta} di \right)^{\frac{1}{1-\eta}}.$$

4.3.2 Intermediate good producers

Each differentiated intermediate good is produced by a constant returns to scale technology given as follows:

$$Y_t(i) = A_t \left(\frac{K_{t-1}(i)}{\alpha_K} \right)^{\alpha_K} \left(\frac{M_t(i)}{\alpha_M} \right)^{\alpha_M} \left(\frac{L_t^c(i)}{\alpha_c} \right)^{\alpha_c} \left(\frac{L_t^h(i)}{1-\alpha_K-\alpha_M-\alpha_c} \right)^{1-\alpha_K-\alpha_M-\alpha_c},$$

where $K_t(i)$, $M_t(i)$, $L_t^c(i)$, and $L_t^h(i)$ are capital, imports, Bitcoin worker labor, and regular worker labor inputs into production, respectively, by intermediate good producer i, and A_t denotes an aggregate total factor productivity (TFP) process which is assumed to follow a stationary AR(1) process. α_K, α_M, and α_c are input shares for capital, imports, and Bitcoin workers, respectively, and are each assumed to be bound between 0 and 1 such that the share of inputs sum to unity.

The cost minimization problem for each intermediate good producer is:

$$\min_{K_{t-1}(i),M_t(i),L_t^c(i),L_t^h(i)} z_t^k K_{t-1}(i) + \epsilon_t M_t(i) + w_t^c L_t^h(i) + w_t^h L_t^h(i),$$

subject to:

$$\begin{aligned} &A_t \left(\frac{K_{t-1}(i)}{\alpha_K}\right)^{\alpha_K} \left(\frac{M_t(i)}{\alpha_M}\right)^{\alpha_M} \left(\frac{L_t^c(i)}{\alpha_c}\right)^{\alpha_c} \left(\frac{L_t^h(i)}{1-\alpha_K-\alpha_M-\alpha_c}\right)^{1-\alpha_K-\alpha_M-\alpha_c} \\ &\geq Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\eta} Y_t. \end{aligned}$$

The Lagrangian for intermediate firm i's problem is:

$$\begin{aligned} \mathcal{L} &= z_t^k K_{t-1}(i) + \epsilon_t M_t(i) + w_t^c L_t^h(i) + w_t^h L_t^h(i) \\ &- mc_t(i) \left\{ \begin{array}{c} A_t \left(\frac{K_{t-1}(i)}{\alpha_K}\right)^{\alpha_K} \left(\frac{M_t(i)}{\alpha_M}\right)^{\alpha_M} \left(\frac{L_t^c(i)}{\alpha_c}\right)^{\alpha_c} \left(\frac{L_t^h(i)}{1-\alpha_K-\alpha_M-\alpha_c}\right)^{1-\alpha_K-\alpha_M-\alpha_c} \\ - \left(\frac{P_t(i)}{P_t}\right)^{-\eta} Y_t \end{array} \right\}, \end{aligned}$$

where mc_t is the minimized unit cost of production or the real marginal cost. The FOCs to this problem are:

$$\begin{aligned} z_t^k &= mc_t(i) A_t \left(\frac{K_{t-1}(i)}{\alpha_K}\right)^{\alpha_K - 1} \left(\frac{M_t(i)}{\alpha_M}\right)^{\alpha_M} \left(\frac{L_t^c(i)}{\alpha_c}\right)^{\alpha_c} \left(\frac{L_t^h(i)}{1-\alpha_K-\alpha_M-\alpha_c}\right)^{1-\alpha_K-\alpha_M-\alpha_c}, \\ \epsilon_t &= mc_t(i) A_t \left(\frac{K_{t-1}(i)}{\alpha_K}\right)^{\alpha_K} \left(\frac{M_t(i)}{\alpha_M}\right)^{\alpha_M - 1} \left(\frac{L_t^c(i)}{\alpha_c}\right)^{\alpha_c} \left(\frac{L_t^h(i)}{1-\alpha_K-\alpha_M-\alpha_c}\right)^{1-\alpha_K-\alpha_M-\alpha_c}, \\ w_t^c &= mc_t(i) A_t \left(\frac{K_{t-1}(i)}{\alpha_K}\right)^{\alpha_K} \left(\frac{M_t(i)}{\alpha_M}\right)^{\alpha_M} \left(\frac{L_t^c(i)}{\alpha_c}\right)^{\alpha_c - 1} \left(\frac{L_t^h(i)}{1-\alpha_K-\alpha_M-\alpha_c}\right)^{1-\alpha_K-\alpha_M-\alpha_c}, \\ w_t^h &= mc_t(i) A_t \left(\frac{K_{t-1}(i)}{\alpha_K}\right)^{\alpha_K} \left(\frac{M_t(i)}{\alpha_M}\right)^{\alpha_M} \left(\frac{L_t^c(i)}{\alpha_c}\right)^{\alpha_c} \left(\frac{L_t^h(i)}{1-\alpha_K-\alpha_M-\alpha_c}\right)^{-\alpha_K-\alpha_M-\alpha_c}, \end{aligned}$$

which yields:

$$mc_t = \frac{1}{A_t} (z_t^k)^{\alpha_K} \epsilon_t^{\alpha_M} (w_t^c)^{\alpha_c} (w_t^h)^{1-\alpha_K-\alpha_M-\alpha_c}, \tag{37}$$

and where we also find that

$$Y_t = A_t \left(\frac{K_{t-1}}{\alpha_K}\right)^{\alpha_K} \left(\frac{M_t}{\alpha_M}\right)^{\alpha_M} \left(\frac{L_t^c}{\alpha_c}\right)^{\alpha_c} \left(\frac{L_t^h}{1-\alpha_K-\alpha_M-\alpha_c}\right)^{1-\alpha_K-\alpha_M-\alpha_c}, \tag{38}$$

where

$$K_{t-1} = \int_0^1 K_{t-1}(i)di,$$
$$M_t = \int_0^1 M_t(i)di,$$
$$L_t^h = \int_0^1 L_t^h(i)di,$$
$$L_t^c = \int_0^1 L_t^c(i)di,$$

is aggregate capital, imports, regular worker labor, and Bitcoin worker labor inputs used in production during period t, respectively. From the FOCs, we also yield the following expenditure shares:

$$\frac{\epsilon_t M_t}{z_t^k K_{t-1}} = \frac{\alpha_M}{\alpha_K}, \tag{39}$$
$$\frac{w_t^c L_t^c}{z_t^k K_{t-1}} = \frac{\alpha_c}{\alpha_K}, \tag{40}$$
$$\frac{w_t^h L_t^h}{z_t^k K_{t-1}} = \frac{1-\alpha_K-\alpha_M-\alpha_c}{\alpha_K}. \tag{41}$$

Inherent to each intermediate firm i's problem – in addition to selecting input quantities to minimize costs – is the choice of $P_t(i)$. Under Rotemberg (1982) pricing, firm i maximizes the net present value of profits,

$$\mathbb{V}_t(i) = \mathbb{E}_t\left\{\sum_{s=0}^{\infty}\Lambda_{t,t+s}\left[\left(\frac{P_{t+s}(i)}{P_{t+s}} - mc_{t+s}\right)Y_{t+s}(i) - \frac{\kappa}{2}\left(\frac{P_{t+s}(i)}{P_{t-1+s}(i)}-1\right)^2 Y_{t+s}\right]\right\},$$

by optimally choosing $P_t(i)$. Differentiating $\mathbb{V}_t(i)$ with respect to $P_t(i)$ yields the following FOC:

$$\begin{aligned}\frac{\mathbb{V}_t(i)}{\partial P_t(i)} : \kappa\left(\frac{P_t(i)}{P_{t-1}(i)}-1\right)\frac{Y_t}{P_{t-1}(i)} &= \frac{1}{P_t}\left(\frac{P_t(i)}{P_t}\right)^{-\eta} - \eta\left(\frac{P_t(i)}{P_t} - mc_t\right)\left(\frac{P_t(i)}{P_t}\right)^{-\eta-1}\frac{Y_t}{P_t}\\ &+ \kappa\mathbb{E}_t\left[\Lambda_{t,t+1}\left(\frac{P_{t+1}(i)}{P_t(i)}-1\right)Y_{t+1}\frac{P_{t+1}(i)}{P_t(i)^2}\right].\end{aligned}$$

Evaluating at the symmetric equilibrium where intermediate firms optimally price their output at $P_t(i) = P_t, \forall i$, allows us to write:[36]

$$(\Pi_t - 1)\Pi_t = \frac{1}{\kappa}(\eta mc_t + 1 - \eta) + \mathbb{E}_t\left[\Lambda_{t,t+1}\frac{Y_{t+1}}{Y_t}(\Pi_{t+1} - 1)\Pi_{t+1}\right]. \tag{42}$$

4.3.3 Investment good firms

We assume that investment goods are produced by perfectly competitive firms, and that the aggregate capital stock grows according to the following law of motion:

$$K_t = \lambda K_{t-1} + I_t \xi_t^K, \tag{43}$$

and recall that $\lambda = 1 - \delta$, where $\delta \in (0, 1)$ is the depreciation rate, and ξ_t^K is akin to a marginal efficiency of investment shock that affects how investment is transformed into capital, as in Justiniano, Primiceri, and Tambalotti (2011). Total investment costs are given by:

$$I_t\left[1 + \Phi\left(\frac{I_t}{\overline{I}}\right)\right],$$

where $\Phi(\cdot)$ are investment adjustment costs as in Christiano, Eichenbaum, and Evans (2005), and are defined as:

$$\Phi\left(\frac{I_t}{\overline{I}}\right) = \frac{\kappa_I}{2}\left(\frac{I_t}{\overline{I}} - 1\right)^2,$$

with $\Phi(1) = \Phi'(1) = 0$ and $\Phi''\left(\frac{I_t}{\overline{I}}\right) > 0$. The investment adjustment cost parameter $\kappa_I = \Phi''(1)$ is chosen so that the price elasticity of investment is consistent with instrumental variable estimates in Eberly (1997).

Thus, the representative investment good firm wishes to maximize its profits:

$$\max_{I_t} Q_t I_t - I_t - \Phi\left(\frac{I_t}{\overline{I}}\right) I_t.$$

Differentiating with respect to I_t gives the following FOC:

$$Q_t = 1 + \Phi\left(\frac{I_t}{\overline{I}}\right) + \left(\frac{I_t}{\overline{I}}\right)\Phi'\left(\frac{I_t}{\overline{I}}\right). \tag{44}$$

4.4 Foreign exchange

In this subsection we describe the role of foreign output, inflation, and interest rates. In what follows, starred variables denote the corresponding foreign version of

36. A standard expression for the New Keynesian Phillips Curve (NKPC) can be written by log linearising (42) about the non-inflationary steady state.

a variable.

We assume that exports are a function of foreign output, and are given as:

$$EX_t = \left(\frac{P_t}{E_t P_t^*}\right)^{-\varphi} Y_t^* = \epsilon_t^{\varphi} Y_t^*, \tag{45}$$

where φ is the price elasticity of foreign demand.

To pin down the nominal exchange rate, we first take logarithms of the definition for the real exchange rate, and then take first-differences:

$$\ln \epsilon_t - \ln \epsilon_{t-1} = \ln E_t - \ln E_{t-1} + \ln P_t^* - \ln P_{t-1}^* - (\ln P_t - \ln P_{t-1}).$$

This is simplified as:

$$\Delta \ln \epsilon_t = \Delta \ln E_t + \hat{\pi}_t^* - \hat{\pi}_t. \tag{46}$$

To simplify the analysis, we impose that foreign variables are given by a series of stationary AR(1) processes:

$$\ln\left(\frac{R_t^*}{\bar{R}^*}\right) = \rho_{R^*} \ln\left(\frac{R_{t-1}^*}{\bar{R}^*}\right) + \varepsilon_t^{R^*}, \tag{47}$$

$$\ln\left(\frac{Y_t^*}{\bar{Y}^*}\right) = \rho_{Y^*} \ln\left(\frac{Y_{t-1}^*}{\bar{Y}^*}\right) + \varepsilon_t^{Y^*}, \tag{48}$$

$$\ln\left(\frac{\Pi_t^*}{\bar{\Pi}^*}\right) = \rho_{\Pi^*} \ln\left(\frac{\Pi_{t-1}^*}{\bar{\Pi}^*}\right) + \varepsilon_t^{\Pi^*}. \tag{49}$$

4.5 Government

We follow ABK's assumption that the government operates macroprudential policy by taxing risky capital holdings, foreign borrowing, and Bitcoin deposits of bankers, and by offering a subsidy on banker net worth. Let τ_t^K,$\tau_t^{D^*}$, and τ_t^c be the tax rates on capital holdings, foreign debt, and Bitcoin deposits, respectively, and let τ_t^N be the subsidy rate offered on bankers' net worth. In aggregate, these macroprudential taxes and subsidies are balanced in the government's budget:

$$\tau_t^N N_t = \tau_t^K Q_t K_t^b + \tau_t^{D^*} \epsilon_t D_t^* + \tau_t^c B_t, \tag{50}$$

where N_t, K_t^b, D_t^*, and B_t denote aggregate net worth, capital holdings, foreign debt holdings, and Bitcoin deposits of the entire banking sector.

Meanwhile, the domestic central bank is assumed to operate an inertial Taylor

Rule:

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left[\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\frac{1-\omega_E}{\omega_E}} \left(\frac{E_t}{\bar{E}}\right)^{\frac{\omega_E}{1-\omega_E}}\right]^{1-\rho_R} \exp(\varepsilon_t^R), \tag{51}$$

where the central bank responds to inflation and fluctuations in the nominal exchange rate away from steady state target $\bar{E}$, and ε_t^R is a monetary policy shock. This particular formulation of the Taylor Rule in (51) is based on Galí and Monacelli (2016) and Akinci and Queraltó (2019), where $\omega_E \in [0, 1]$ is a sensitivity parameter depicting how strongly the central bank reacts to exchange rate fluctuations and the inflation rate. The Taylor Rule represents a strict inflation targeting regime as $\omega_E \to 0$, and an exchange rate peg as $\omega_E \to 1$. It allows hybrid regimes of managed exchange rates for values of $\omega_E \in (0, 1)$.

4.6 Market equilibrium

Aggregate capital is the sum of capital (equity) owned by regular workers and bankers:

$$K_t = K_t^h + K_t^b. \tag{52}$$

The aggregate resource constraint of the domestic economy is

$$Y_t = C_t + \left[1 + \Phi\left(\frac{I_t}{\bar{I}}\right)\right] I_t + EX_t + \frac{\kappa}{2}(\Pi_t - 1)^2 Y_t + \chi_t^h + \chi_t^b, \tag{53}$$

which states that output must be consumed, invested, exported, and used to pay for adjustments.[37]

The law of motion of aggregate net foreign debt is given as:

$$D_t^* = \frac{R_{t-1}^*}{\Pi_t^*} D_{t-1}^* + M_t - \frac{1}{\epsilon_t} EX_t, \tag{54}$$

the aggregate net worth of the bankers is:

$$N_t = \sigma \left[(z_t^k + \lambda Q_t) K_{t-1}^b - \frac{R_{t-1}}{\Pi_t} D_{t-1} - \epsilon_t \frac{R_{t-1}^*}{\Pi_t^*} D_{t-1}^* - \frac{R_{t-1}^c}{\Pi_t} B_{t-1}\right] + \gamma (z_t^k + \lambda Q_t) K_{t-1}, \tag{55}$$

37. We note that GDP is given as:

$$Y_t^{GDP} = Y_t - \epsilon_t M_t,$$

and that net output is given as:

$$Y_t^N = Y_t - \epsilon_t M_t - \frac{\kappa}{2}(\Pi_t - 1)^2 Y_t - \chi_t^h - \chi_t^b.$$

and the aggregate balance sheet of the banking sector is given by:

$$Q_tK_t^b\left(1+\frac{\varkappa^b}{2}x_t^2\right)=\left(1+\frac{\varkappa^b}{2}x_t^2\right)\phi_tN_t, \tag{56}$$

$$Q_tK_t^b\left(1+\frac{\varkappa^b}{2}x_t^2\right)=N_t+D_t+\epsilon_tD_t^*+B_t, \tag{57}$$

$$x_t=\frac{\epsilon_tD_t^*}{Q_tK_t^b}, \tag{58}$$

$$x_t^c=\frac{B_t}{Q_tK_t^b}. \tag{59}$$

We can see that (56) is an identity based on (24), and (57) is an aggregate version of the balance sheet identity, (21). Meanwhile, as all banks are identical, (58) and (59) are the corresponding aggregate versions of (16) and (17), respectively.

Finally, the stationary AR(1) processes for TFP, marginal efficiency of investment, and Bitcoin prices are given as:

$$\ln\left(\frac{A_t}{\bar{A}}\right)=\rho_A\ln\left(\frac{A_{t-1}}{\bar{A}}\right)+\varepsilon_t^A, \tag{60}$$

$$\ln\left(\frac{\xi_t^K}{\bar{\xi}^K}\right)=\rho_K\ln\left(\frac{\xi_{t-1}^K}{\bar{\xi}^K}\right)+\varepsilon_t^K, \tag{61}$$

$$\ln\left(\frac{\Pi_t^c}{\bar{\Pi}^c}\right)=\rho_{\Pi^c}\ln\left(\frac{\Pi_{t-1}^c}{\bar{\Pi}^c}\right)+\varepsilon_t^{\Pi^c}. \tag{62}$$

A competitive equilibrium is a set of 12 prices, $\{E_t, mc_t, Q_t, R_t, R_t^c, w_t^c, w_t^h, z_t^k, \epsilon_t, \Pi_t, \Pi_t^c, \tau_N\}$; 15 quantity variables, $\{B_t, C_t^c, C_t^h, D_t, D_t^*, EX_t, I_t, K_t, K_t^b, K_t^h, L_t^c, L_t^h, M_t, N_t, Y_t\}$; eight bank variables, $\{x_t, x_t^c, \psi_t, \phi_t, \upsilon_t, \mu_t, \mu_t^c, \mu_t^*\}$; three foreign variables, $\{R_t^*, Y_t^*, \Pi_t^*\}$; and two exogenous variables, $\{A_t, \xi_t^K\}$, which satisfy 40 equations: (3)-(5), (8)-(11), (25)-(28), (34)-(62).

4.7 Calibration

We calibrate the parameters in our model using relatively standard values found in the macroeconomics literature. The model frequency is quarterly. The baseline calibration of the domestic household block, banking, and firm sector is based on ABK (Table 2). Interest rates of the domestic country are calibrated to be 5 percent annualized, based on an average of interest rates from 2000 to 2020 in El Salvador from the IMF's *International Financial Statistics*.

The annualized US interest rate is 2 percent. For the banking parameters, the severity of the banker's moral hazard, management costs of foreign borrowing, and the fraction of household assets brought on by new bankers – θ_0, χ_b, and γ, respectively – are selected so that: i) the bank leverage multiple, ϕ, is roughly equal to 4 in steady state; ii) the spread between the rate of return on bank assets and deposits is 2 percent; and, iii) the fraction of foreign borrowing by bankers, x, is approximately 17.5 percent in steady state. The banker's continuation probability, σ, is set so that the annualized dividend payout of the banker is equal to $4(1-\sigma) = 24$ percent of the bank's net worth. The cost of foreign borrowing parameter, χ_b, is set so that the fraction of capital financed by banks is 0.75, which implies that the remaining share financed by domestic households is 0.25.

We assume bankers treat Bitcoin deposits and the foreign deposits as symmetric with respect to the fraction of funds a banker can abscond with. Therefore, the elasticity of Bitcoin financed leverage, θ^c, is set at 0.1, which is equivalent to the elasticity of foreign deposits to leverage. The moral hazard parameters are also assumed symmetric, $\theta_0 = \theta_0^c = 0.401$. The steady state Bitcoin deposits B_{ss} is calibrated to equal to 20% of labor income in the steady state, $\frac{B_{ss}}{w^c L^c} = 0.2$ and this matches data from the World Bank which has an aggregate savings rate of 20 percent for El Salvador.[38] The firm's capital share is one third and the import share is 0.18 following standard values in the literature. We calibrate the share of Bitcoin workers, α_c, to match the labor share of the unbanked population in El Salvador. The total labor share is equal to $1 - \alpha_K - \alpha_M = 0.52$. Based on data from the World Bank, the share of the unbanked population in 2020 is two thirds, giving $\alpha_c = \frac{2}{3} \times (1 - \alpha_K - \alpha_M) = 0.34666$ [39]

38. Data reference: https://data.worldbank.org/indicator/NY.GNS.ICTR.ZS?locations=SV.
39. https://datatopics.worldbank.org/g20fidata/country/el-salvador

Table 2: Baseline calibration

Parameter	Value	Description
β	0.9876	Household discount factor
ζ	1/3	Frisch elasticity of labor supply
ζ_0	7.883	Inverse labor supply capacity
$\varkappa^h$	0.0197	Regular worker direct finance cost
θ	0.1	Elasticity of foreign financed leverage
θ^c	0.1	Elasticity of Bitcoin financed leverage
θ_0	0.401	Bank moral hazard severity
θ_0^c	0.401	Bank moral hazard severity (Bitcoin)
σ	0.94	Banker survival probability
γ	0.0045	Fraction of total assets brough by new banks
$\varkappa^b$	0.0197	Bank management cost of foreign borrowing
α_K	0.3	Production share of capital
α_M	0.18	Production share of imports
α_c	0.3466	Production share of Bitcoin workers
λ	0.98	One minus the depreciation rate ($\delta = 0.02$)
ω_E	0.5	Monetary policy exchange rate sensitivity parameter
ρ_A	0.85	TFP AR(1) coefficient
ρ_R	0.8	Monetary policy inertia
ρ_{R^*}	0.85	Foreign interest rate AR(1) coefficient
ρ_{Y^*}	0.85	Foreign output AR(1) coefficient
ρ_{Π^*}	0.85	Foreign inflation AR(1) coefficient
ρ_{Π^c}	0.85	Bitcoin price AR(1) coefficient
ρ_{ξ^K}	0.85	Investment shock AR(1) coefficient

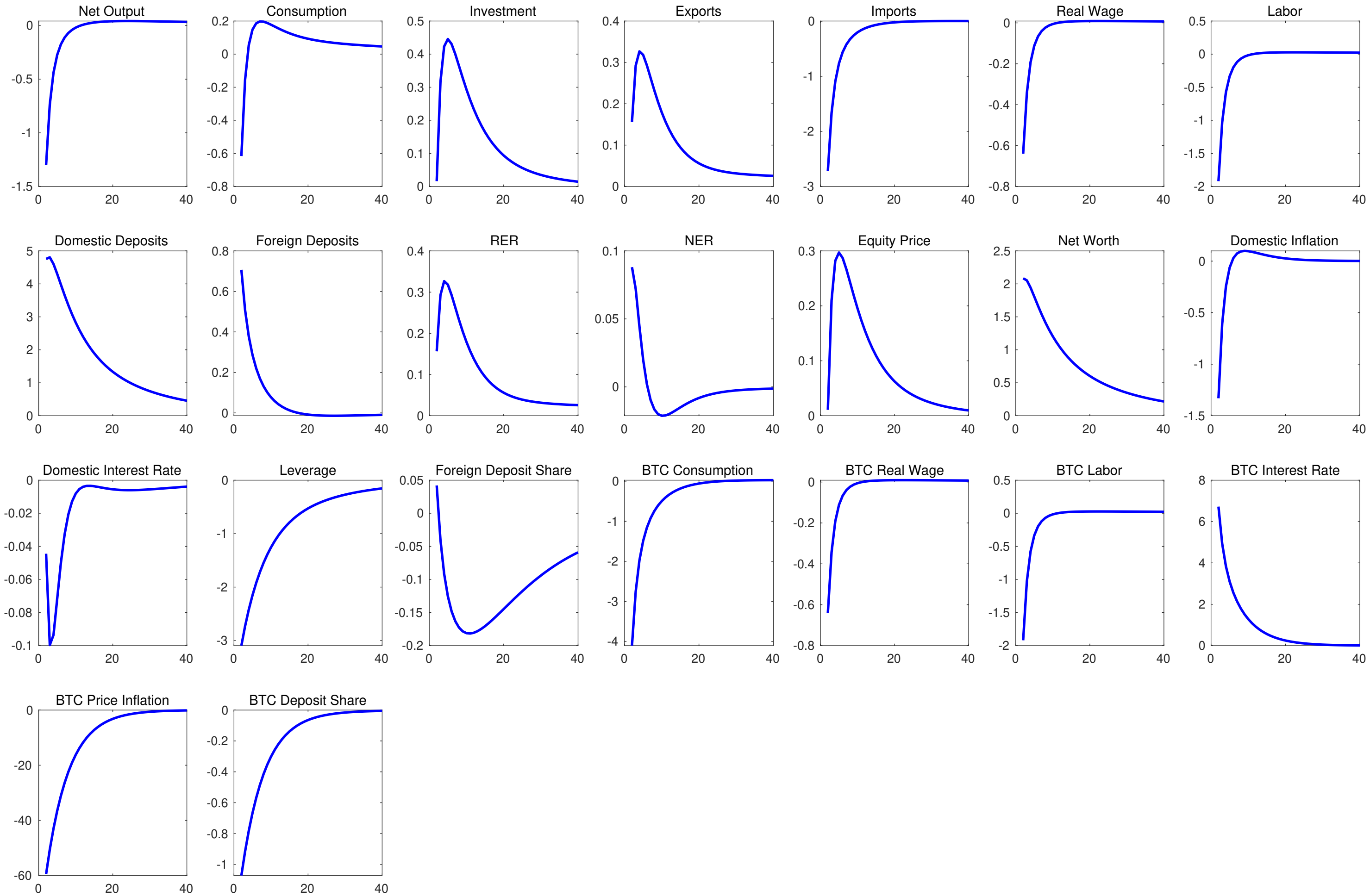
In the baseline specification we choose $\omega_E = 0.5$, which is in between a perfect fix ($\omega_E \rightarrow 1$) and a perfect float ($\omega_E \rightarrow 0$), and can be thought of as a managed float. We relax this in subsequent results when we compare different exchange rate regimes in Section 5.6. We assume a serial correlation coefficient of 0.85 (quarterly) for all our exogenous shock processes. Innovations to the foreign interest rate and domestic interest rate are 100 basis points annualized. Productivity and output shocks are assumed to have a innovation of 1 percent and 3 percent quarterly. We calibrate Bitcoin innovations to 70 percent quarterly return, based on Bitcoin price data from *Cryptocompare* from January 2017 to September 2021.

5 Results

5.1 Baseline specification

We trace the effects of a 1 standard deviation innovation to Bitcoin prices over 40 periods in Figure 2. A Bitcoin disinflationary shock reduces holdings of Bitcoin and a decline in the savings of Bitcoin households. This causes Bitcoin workers to cut down their consumption. Through Greenwood–Hercowitz–Huffman preferences, the decline in consumption reduces labor supply by Bitcoin workers and a decline in the real wage. The general level of prices declines, and a peak decline in net output of approximately 1 percent. Domestic currency households also experience an initial decline in consumption. This is due to the general equilibrium effects of a decline in wages, labor supply, and income that both sets of households experience. Turning to the banking sector, the decline in Bitcoin deposits causes a net decline in leverage and an increase in net worth of bankers. There is a reallocation toward holding more domestic and foreign currency deposits. The positive effect of net worth causes a rise in asset prices and investment, but this is not enough to offset the decline in consumption, wages and output due to the valuation of household savings. The central bank responds to the decline in prices by lowering interest rates. This triggers a nominal and real exchange rate depreciation, which increases net exports.

Figure 2: Bitcoin price shock (baseline specification)



Note: Figure plots impulse responses of model variables with respect to a 1 standard deviation innovation to Bitcoin prices. Time periods are measured in quarters, and responses are measured as a percent deviation from steady state. Domestic Inflation, Domestic Interest Rate, BTC Interest Rate, and BTC Price Inflation are annualized.

5.2 Bitcoin autarky

Next, we simulate the calibrated economy with all shocks, and compare it to an economy with zero Bitcoin deposits, which we denoted as Bitcoin autarky. Table 3 presents results of the variance decomposition of shocks for the economic variables of output, consumption of domestic currency and Bitcoin households, and the nominal exchange rate. A first order log-linear approximation around the steady state is used in the analysis. In the Bitcoin autarky economy, the variance decomposition shows that the primary shocks to the domestic economy are foreign interest rate and inflation shocks, which jointly account for approximately 70 percent of output, consumption and nominal exchange rate movements. The importance of foreign monetary shocks for emerging markets broadly supports empirical findings in Miranda-Agrippino and Rey (2020) and Dedola, Rivolta, and Stracca (2017). Turning to the economy with Bitcoin deposits, the baseline calibration of shock variances shows that Bitcoin price shocks are the most important source of fluctuations for aggregate output and consumption of Bitcoin households, explaining 75.7 and 94.6 percent of the variance, respectively. Through general equilibrium effects, it still explains the variance of the consumption of domestic currency households with 38 percent.

Table 3: Variance decomposition of Bitcoin economy versus Bitcoin autarky

	Bitcoin Autarky				Bitcoin Economy			
	Y	C	C^c	E	Y	C	C^c	E
A	23.50	16.71	17.81	3.16	5.70	10.36	0.96	3.07
K	0.19	0.27	0.12	0.01	0.05	0.17	0.01	0.01
R	4.44	2.67	9.86	26.88	1.08	1.66	0.53	26.17
Y^*	1.21	0.36	1.58	0.11	0.29	0.22	0.09	0.10
Π^*	42.41	42.87	47.81	22.47	10.29	26.58	2.58	21.88
R^*	28.25	37.12	22.82	47.38	6.85	23.02	1.23	46.13
Π^c	0	0	0	0	75.74	38.00	94.60	2.63

5.3 Welfare analysis and stablecoin solution

We compute welfare for regular domestic currency, Bitcoin, and aggregate households for different levels of volatility. Welfare is calculated based on maximizing the value function for each type of household:

$$V_t^i = U(C_t^i, L_t^i) + \beta V_{t+1}^i, i \in [h, b]. \tag{63}$$

In addition to computing welfare for domestic and Bitcoin households, we compute a synthetic welfare for an aggregate household. The utility function $U^{Agg} = U(C_t^h + C_t^b, L_t^h + L_t^b)$ is based on evaluating the utility function,

$$U(C_t^i, L_t^i) = \ln\left(C_{t+s}^i - \frac{\zeta_0}{1+\zeta}(L_{t+s}^i)^{1+\zeta}\right), i \in [h, b], \tag{64}$$

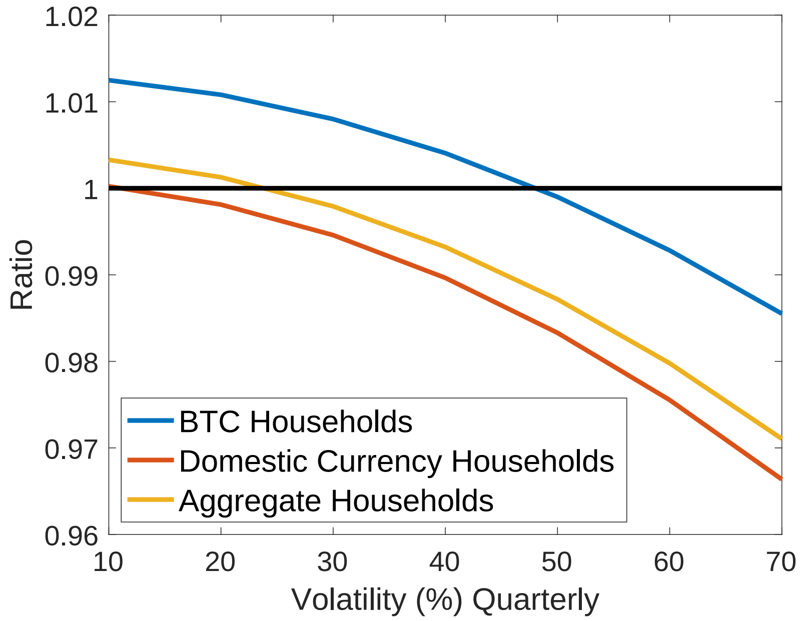
where consumption and labor inputs are the sum of each household consumption and labor inputs, respectively. We compute the first moment of welfare of each type of household based on a second order log-linear approximation to the steady state, as in Woodford (2003), Schmitt-Grohé and Uribe (2004), and Galí and Monacelli (2005). We normalize welfare to a Bitcoin autarky economy in which Bitcoin households hold zero deposits. Figure 3 plots the welfare for each household type normalized by the autarky level for different levels of Bitcoin volatility.

We note the welfare for all three types of households is declining in Bitcoin volatility. For Bitcoin households, we numerically determine a cutoff level of volatility σ_B^* of 50 percent (quarterly). For a volatility less than this threshold level, the Bitcoin household receives net welfare gains relative to autarky. For small levels of volatility of the digital currency, the household benefits from holding a fraction of their income as savings, which helps stabilize consumption in the event of adverse shocks. For domestic currency households, we find that the welfare in the Bitcoin equilibrium is always lower than welfare in autarky. This is due to the general equilibrium effects of the Bitcoin price shock, in which banks face exposure via balance sheet effects that affect lending. Firms face increased volatility in firm wages and labor demand. This induces higher variance in consumption and labor supply relative to the autarky equilibrium. For the representative household, results in Figure 3 show a threshold for volatility is now 25 percent (quarterly).

In the baseline specification, Bitcoin's volatility of 70 percent (quarterly) is above the cut-off threshold volatility for the representative household. There are net welfare losses as costs of a volatile store of value exceed the benefits of financial inclusion and consumption smoothing benefits. Stablecoins have a much lower volatility than Bitcoin[40] Through the lens of our model, the benefits of consumption smoothing through savings in a stablecoin offset the costs of increased volatility of consumption, firm wages, and bank balance sheets.

40. For example, stablecoins such as Tether and USDC, two of the largest stablecoins by market cap, are between 0.1 and 0.2 percent (quarterly) volatility, respectively.

Figure 3: Welfare analysis for different levels of Bitcoin volatility

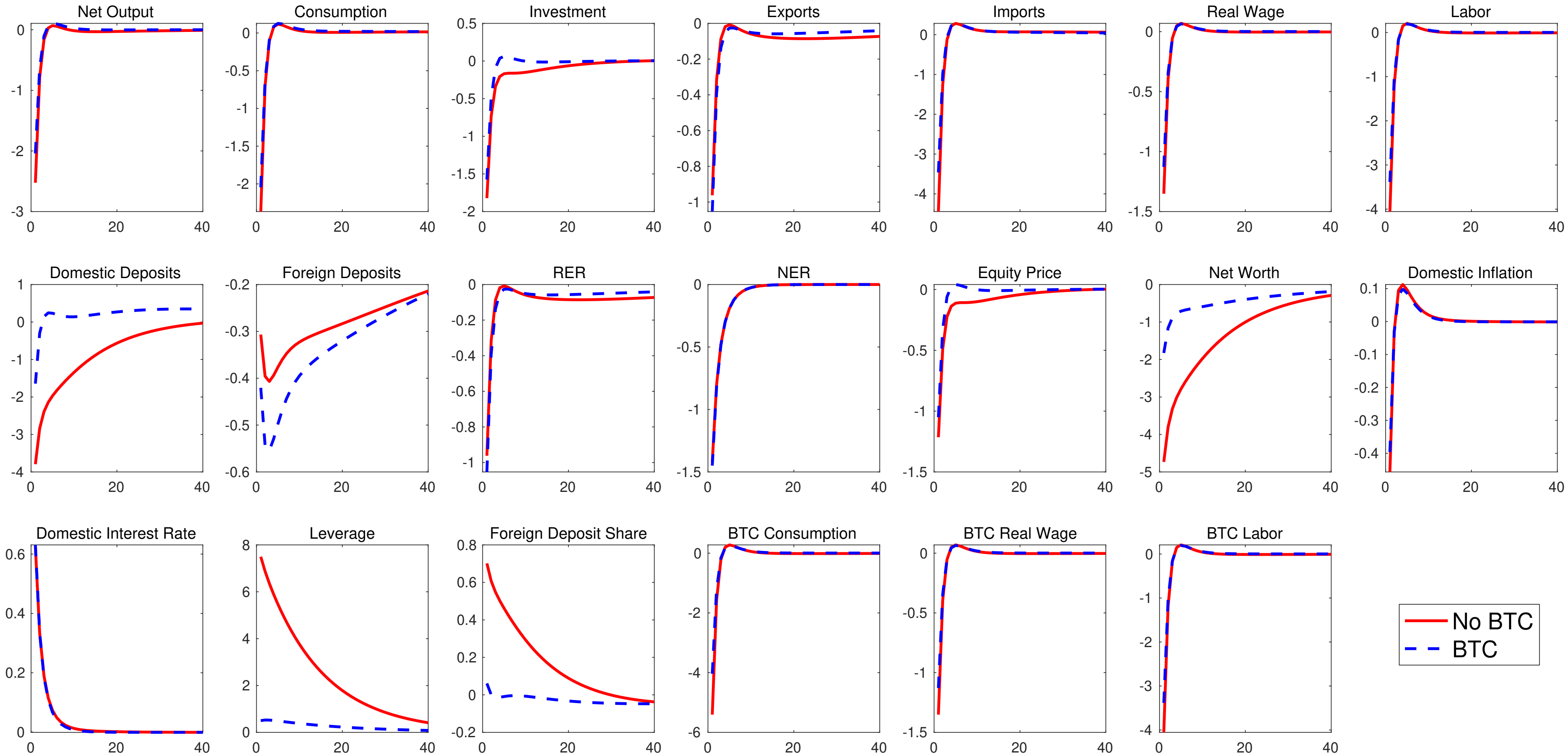


Note: Figure plots welfare of three different types of households: households using Bitcoin as legal tender, domestic currency as legal tender, and a representative household that aggregates consumption of Bitcoin and domestic currency households. Welfare for the baseline calibration is normalized by the welfare for a Bitcoin autarky economy in which Bitcoin households hold zero deposits. The first moment of welfare is calculated using a second order log-linear approximation to the steady state.

5.4 Monetary policy implications

Adrian and Weeks-Brown (2021) have opposed the Bitcoin law on the grounds that central banks cannot set interest rates on a foreign currency, potentially leading to unstable prices and a reducing the effectiveness of monetary policy to stabilize inflation. In a similar argument, Benigno, Schilling, and Uhlig (2019) show theoretically that when a digital currency is freely circulating with domestic currencies in a two country economy, interest rates are equalized across countries and the sovereign central bank therefore loses control to set interest rates. We test these arguments through the lens of our model. Specifically, we compare the baseline specification to a Bitcoin autarky economy. Our simulation for a unit standard deviation domestic monetary policy shock are presented in Figures 4.

Figure 4: Domestic interest rate shock: Baseline vs Bitcoin autarky



Note: Figure plots impulse responses of model variables with respect to a 1 standard deviation domestic interest rate shock. Time periods are measured in quarters, and responses are measured as a percent deviation from steady state. Domestic Inflation and Domestic Interest Rate are annualized. Solid line indicates baseline specification with Bitcoin deposits. Dashed line indicates an economy with zero Bitcoin deposits (Bitcoin autarky).

In response to a hike in domestic interest rates, we observe a systematic transmission to bank balance sheets. The mechanism through which the domestic interest rate affects asset prices is based on the financial accelerator models (Kiyotaki and Moore 1997; Gertler and Kiyotaki 2015). A rise in domestic interest rates reduces net worth and asset prices through increasing the cost of raising domestic deposits. A decline in net worth causes the bank to scale back loans causing a decline in investment. Through general equilibrium effects, monetary policy then causes a decline in output, and consumption. We compare the responses of a baseline *Bitcoin autarky* economy to one which has introduced Bitcoin deposits. We find the existence of a foreign digital currency attenuates the direct impact of monetary policy on bank balance sheets. In Figure 4, we observe that in the Bitcoin economy, there is a smaller decline in net worth of 2 percent as opposed to 5 percent for the Bitcoin autarky economy. The economic intuition is that in the Bitcoin economy, the share of domestic deposits on the bank balance sheet is lower. Therefore, there are smaller effects of the contraction in domestic deposits, investment, output, and consumption. While differences in output and consumption between the baseline specification and Bitcoin autarky are small, there are noticeable differences in bank balance sheets, lending and investment. The results broadly support Adrian and Weeks-Brown (2021) by showing that the adoption of a digital currency like Bitcoin can lead to a reduced effectiveness of interest rates to stabilize inflation output. Our findings of an introduction of digital currency attenuating monetary policy transmission support Ikeda (2020).[41]

In addition to domestic monetary policy transmission channels, we can also test if shocks to productivity, capital, foreign output, and foreign inflation, are different in an economy with foreign digital currency deposits.[42] Our results are provided in Appendix A.3 for consideration. Quantitatively, we find no evidence that the presence of Bitcoin deposits significantly affects the response of real economic variables to the aforementioned shocks. Bank balance sheets are unaffected in response to foreign output, domestic capital, and productivity shocks. Only nominal shocks, like a foreign inflation shock, affect bank balance sheets through a net worth channel.

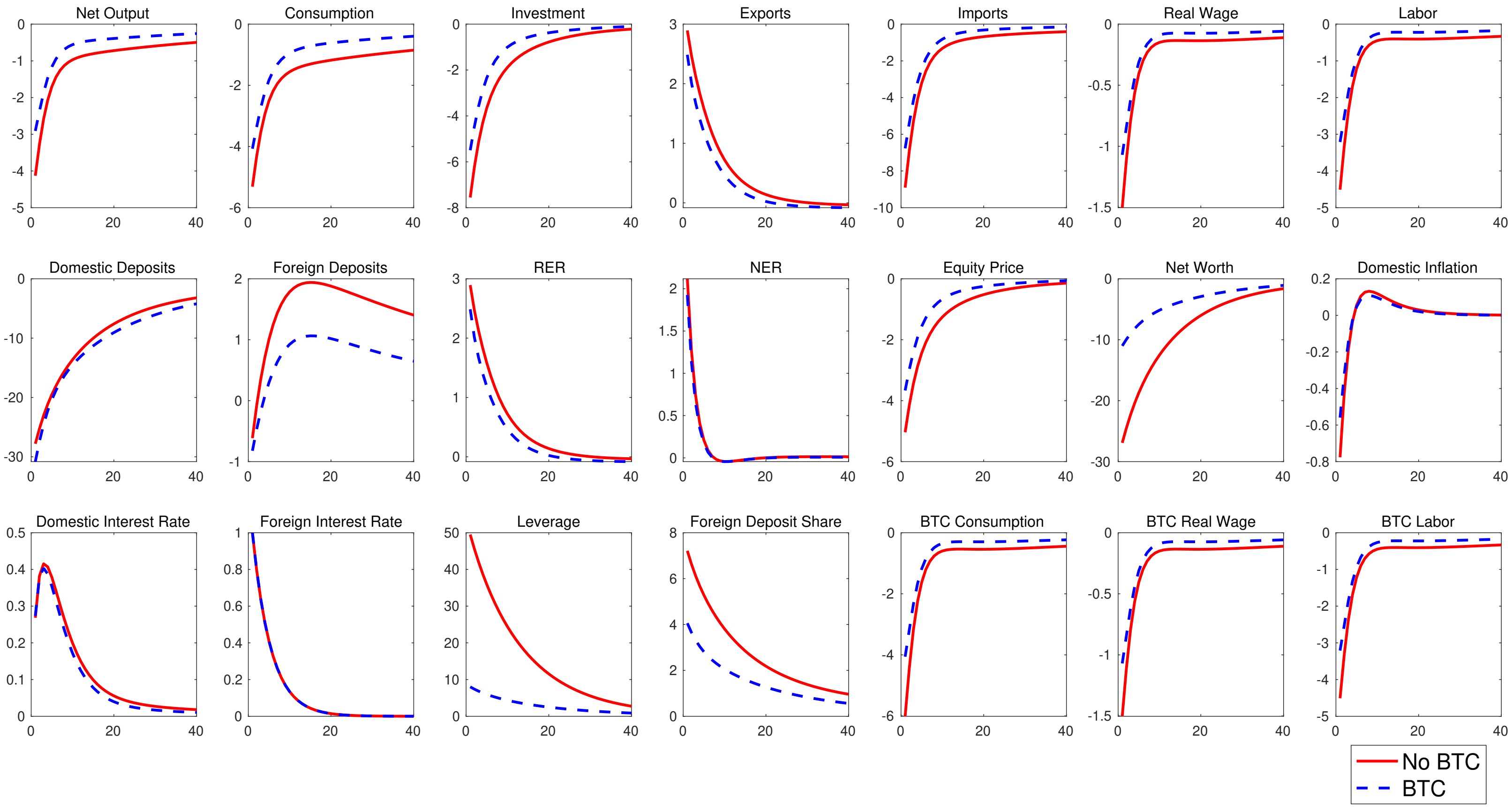
41. In Ikeda (2020), monetary policy attenuation is achieved through pricing in a foreign digital currency. This can attenuate output and consumption effects through an expenditure switching channel, in contrast to the bank deposit channel we put forward in our paper.

42. The capital shock can be thought of as a marginal efficiency of investment shock as in Justiniano, Primiceri, and Tambalotti (2011).

5.5 Global financial cycle considerations

In Figure 5, we repeat the exercise in Section 5.4, but with a foreign interest rate shock. A foreign interest rate increase causes investors to pursue higher yields overseas, leading to a capital outflow and a contraction of bank balance sheets. keeping up aggregate demand and preventing a domestic recession. A decline in the cost advantage of foreign currency debt over home deposits causes a reduction in the banker's net worth and leverage ratio, and increases the ratio of banker's share of foreign debt to total loans made. A decline in bank net worth and leverage leads to a fall in capital prices through a financial accelerator mechanism. The deterioration of domestic financial conditions then spills over to the real economy, as the decline in net worth reduces loans made to firms for investment. This sees output and consumption consequently fall by up to 4 percent in the baseline specification. Similar to the effects of domestic monetary policy shocks, the channel through which foreign interest rate shocks affect the economy is through bank balance sheet effects. Bank net worth and leverage are less sensitive to a foreign interest rate shock in the Bitcoin economy. For example, while net worth declines by up to 25 percent following the foreign interest rate hike in the Bitcoin autarky economy, net worth declines by only 10 percent in the baseline specification.

Figure 5: Foreign interest rate shock: Baseline vs Bitcoin autarky



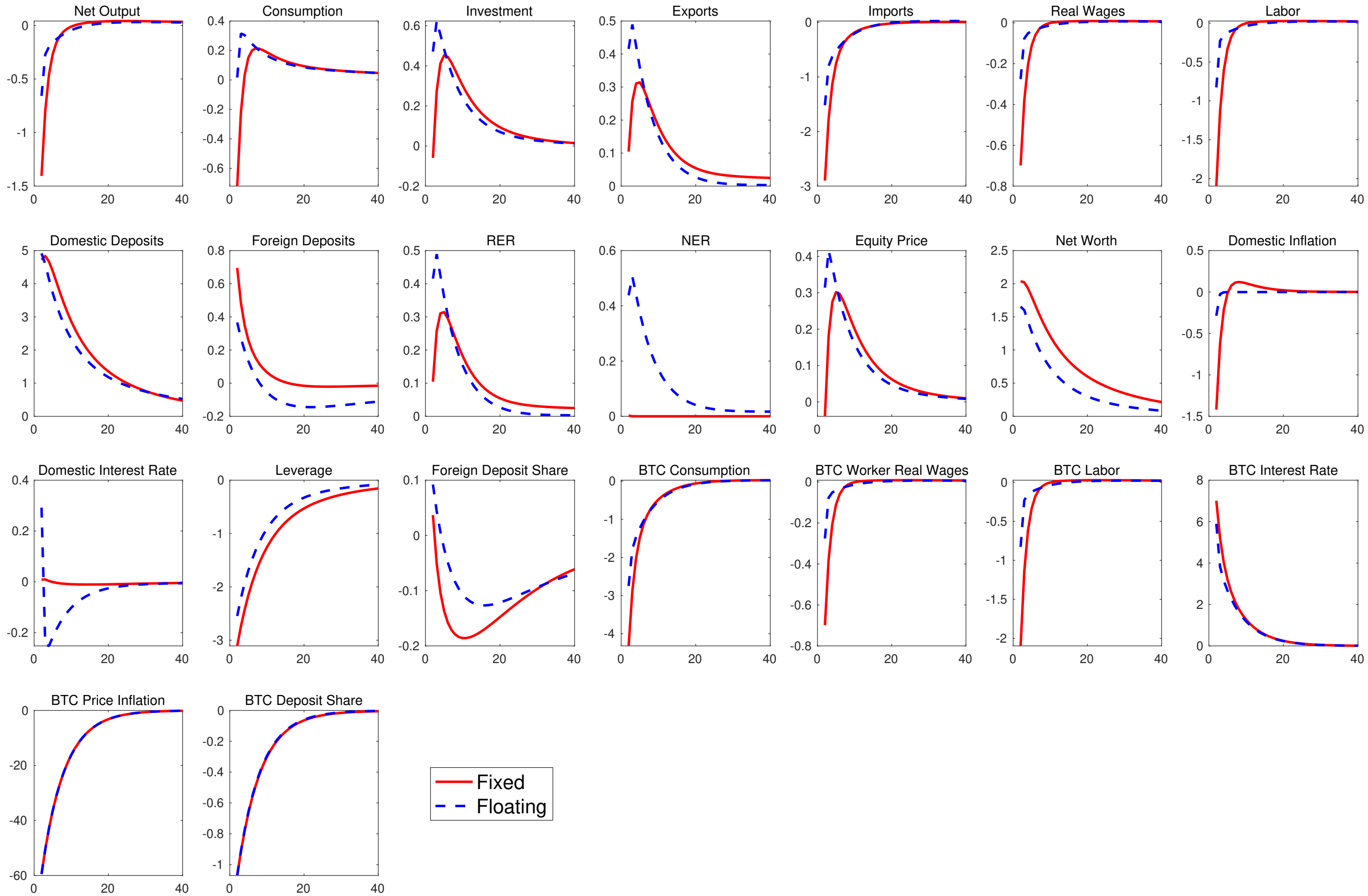
Note: Figure plots impulse responses of model variables with respect to a 1 standard deviation foreign interest rate shock. Time periods are measured in quarters, and responses are measured as a percent deviation from steady state. Domestic Inflation, Domestic Interest Rate, and Foreign Interest Rate are annualized. Solid line indicates baseline specification with Bitcoin deposits. Dashed line indicates an economy with zero Bitcoin deposits (Bitcoin autarky).

5.6 Fixed versus floating exchange rates

The response of domestic interest rates to a Bitcoin price shock depends on the exchange rate regime. Equation (51) specifies the path of domestic interest rates. We compare two extreme cases of the Taylor rule: a fixed exchange rate peg is approximated by $\omega_E = 0.99$ in which the central bank uses interest rates to target the nominal exchange rate. A free floating exchange rate regime is approximated by $\omega_E \to 0.01$, in which the central bank uses interest rates to target the price level.

Figure 6 shows the results of the simulations in response to a standardized bitcoin inflation shock. In response to the contraction in output and consumption, prices decline. Comparing the two regimes, we find flexible exchange rates provide a buffer through a nominal exchange rate depreciation. By allowing the interest rate to target the price level, exchange rates depreciate in the floating exchange rate regime. This helps stabilize prices through increasing import costs and the pass-through of inflation due to the assumption of producer currency pricing. A larger real exchange rate depreciation then causes a recovery through net exports. We observe a peak decline in output of 1.5 percent and 0.5 percent for the fixed and flexible exchange rate regime respectively. The decline in output and consumption, and investment is therefore dampened with a flexible exchange rate regime. Our results support the arguments made in Obstfeld (2015) that flexible exchange rate regimes provide greater insulation against foreign shocks.

Figure 6: Bitcoin price shock: Fixed versus flexible exchange rate regimes



Note: Figure plots impulse responses of model variables with respect to a 1 standard deviation Bitcoin price shock. Time periods are measured in quarters, and responses are measured as a percent deviation from steady state. Domestic Inflation, Domestic Interest Rate, BTC Interest Rate, and BTC Price Inflation are annualized. Solid line indicates a fixed exchange rate regime ($\omega_E = 0.99$), and dashed line indicates a flexible exchange rate regime ($\omega_E = 0.01$).

6 Conclusion

In this paper we study the macroeconomic costs and benefits of El Salvador's monetary experiment to make Bitcoin as legal tender. Introducing a small open economy model that features two types of households that hold domestic currency and Bitcoin respectively. Within this framework, we form a simple process for adjustment of Bitcoin deposits due to valuation effects in Bitcoin. Valuation effects in Bitcoin lead to a change in the purchasing power of household Bitcoin deposits, affecting consumption and labor decisions, and bank balance sheets. The model's baseline calibration predicts a 1 standard deviation decline in Bitcoin prices will cause a peak decline in output of approximately 1 percent.

In our analysis, we make four contributions to the policy debate on digital currencies. First, we evaluate the welfare of households for different levels of volatility of the digital currency. We compute the relative welfare of an economy with the digital currency to an autarky economy where the majority of households are unbanked and have no access to a savings vehicle. Our results suggest that Bitcoin brings net welfare losses through the general equilibrium effects of more volatile consumption, bank lending and firm labor demand. In contrast, a digital currency with sufficiently low volatility, such as a stablecoin, can result in net welfare benefits. Households that were initially unbanked and can now use a stablecoin receive benefits through a savings vehicle that they can use to smooth consumption. These consumption smoothing benefits can offset the loss of volatility of the stablecoin vis-a-vis the dollar. Our work provides a rationale for El Salvador to change its policy of Bitcoin as legal tender to stablecoins.

Second, we test whether monetary policy transmission is more or less effective in the presence of a digital currency. We find that monetary policy becomes a less effective stabilizer when households increase use of a foreign currency. The intuition is that holding deposits in Bitcoin attenuate the effect of domestic monetary policy on bank balance sheets. An attenuation in the bank lending channel leads to smaller output and consumption effects. This supports arguments in Adrian and Weeks-Brown (2021) and Benigno, Schilling, and Uhlig (2019) that the introduction of a digital currency can render sovereign monetary policy obsolete.

Third, we contribute to the discussion of global financial cycles. Based on a shock to the foreign interest rate, we find that relative to a baseline calibration in which households hold no cryptocurrency deposits, Bitcoin adoption dampens the effects of the global financial cycle. Similar to the effects of domestic monetary policy, the channel is through attenuating the effect on bank balance sheets, which in turn leads to smaller output and consumption effects. Finally, we test if the effects of introducing a digital currency is dependent on the exchange rate regime. Comparing a fixed exchange rate regime to an inflation targeting central bank with floating exchange rates, we find floating exchange rates provide a buffer against Bitcoin price shocks. This supports the Obstfeld (2015) view that monetary independence plays a key role in insulation from foreign shocks to the economy.

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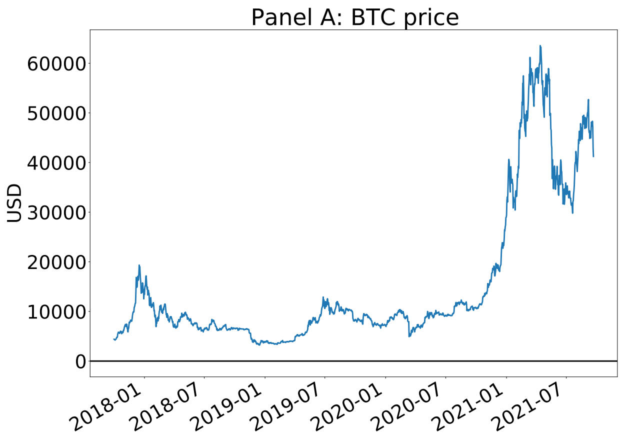
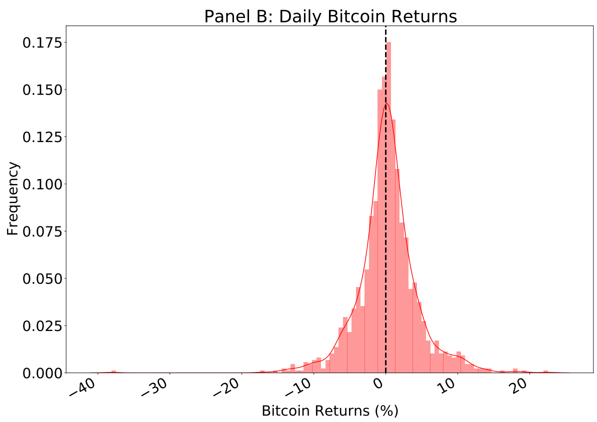
A Appendix

A.1 Figures

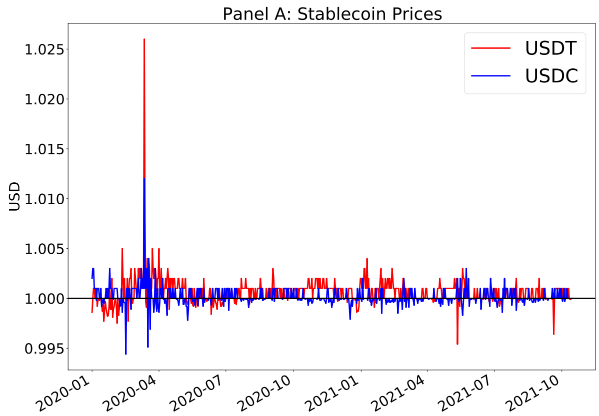
Figure 7: **Top**: Bitcoin prices. **Bottom**: Histogram of daily Bitcoin returns

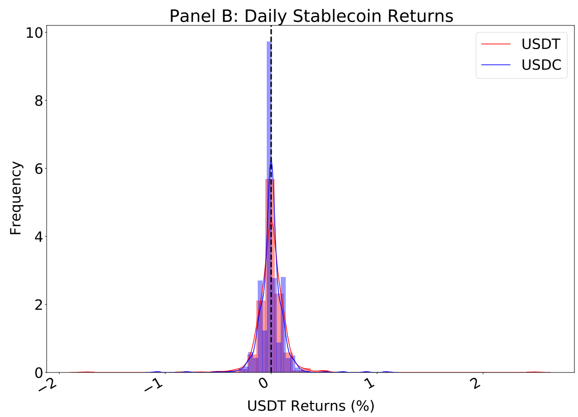




Note: Top panel: the Bitcoin price from January 2018 to September 2019. Bottom panel: Histogram of daily returns. Data source: cryptocompare

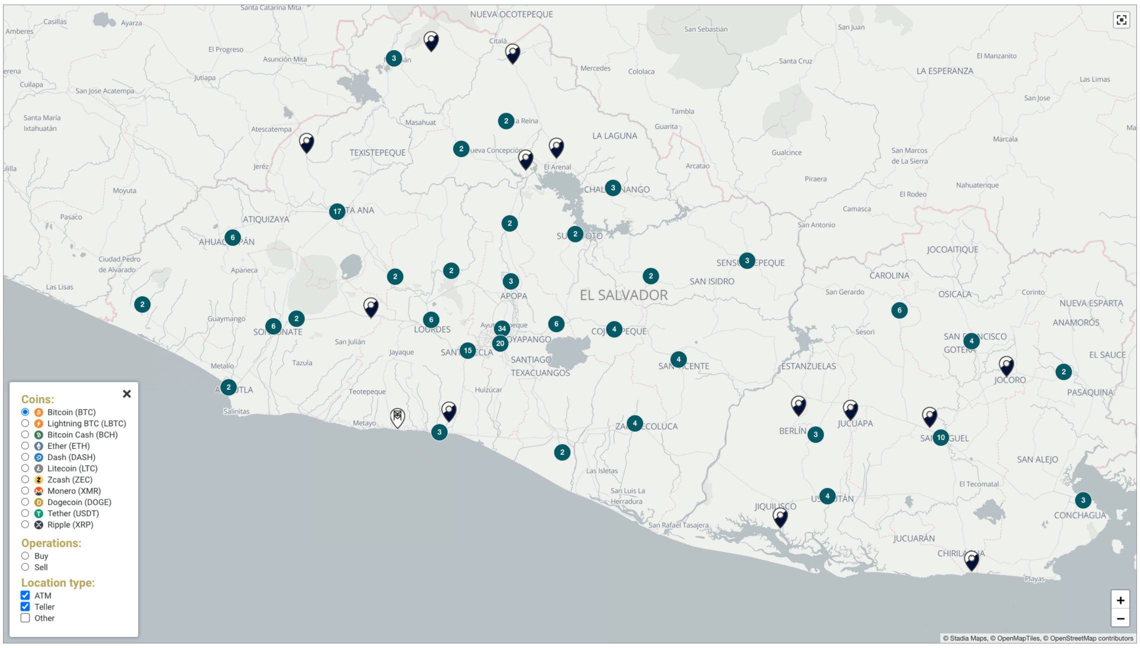
Figure 8: **Top**: Stablecoin prices. **Bottom**: Histogram of daily stablecoin returns





Note: Top panel: Stablecoins Tether, USDC and DAI prices from January 2020 to September 2021. Bottom panel: Histogram of daily returns. Data source: cryptocompare

Figure 9: Map of El Salvador Bitcoin-Dollar ATMs



Note: Figure plots all Bitcoin-Dollar ATMs in a map of El Salvador. Source: https://coinatmradar.com/

A.2 Model overview

A competitive equilibrium is a set of 12 prices, $\{ E_t,\ mc_t,\ Q_t,\ R_t,\ R_t^c,\ w_t^c,\ w_t^h,\ z_t^k,\ \epsilon_t,\ \Pi_t,\ \Pi_t^c,\ \tau_N \}$; 15 quantity variables, $\{ B_t,\ C_t^c,\ C_t^h,\ D_t,\ D_t^*,\ EX_t,\ I_t,\ K_t,\ K_t^b,\ K_t^h,\ L_t^c,\ L_t^h,\ M_t,\ N_t,\ Y_t \}$; eight bank variables, $\{ x_t,\ x_t^c,\ \psi_t,\ \phi_t,\ \upsilon_t,\ \mu_t,\ \mu_t^c,\ \mu_t^* \}$; three foreign variables, $\{ R_t^*,\ Y_t^*,\ \Pi_t^* \}$; and two exogenous variables, $\{ A_t,\ \xi_t^K \}$, which satisfy 40 equations. In addition to the Bitcoin economy, we solve for the Bitcoin autarky economy by setting Bitcoin deposits $B = 0$, which in turn makes the share of the bank balance sheet in bitcoin $x_t^c = 0$. The first order condition with respect to Bitcoin deposits is no longer needed, and so R_t^c and Bitcoin price shock Π_t^c is no longer required.

Household

$$C_t^c + B_t = w_t^c L_t^c + \frac{R_{t-1}^c}{\Pi_t} B_{t-1} \tag{65}$$

$$w_t^c = \zeta_0 L_t^{c\zeta}, \tag{66}$$

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1}^c \frac{R_t^c}{\Pi_{t+1}} \right], \tag{67}$$

$$\Lambda_{t,t+1}^c = \beta \mathbb{E}_t \left[\frac{C_t^c - \frac{\zeta_0}{1+\zeta} L_t^{c\,1+\zeta}}{C_{t+1}^c - \frac{\zeta_0}{1+\zeta} {L_{t+1}^c}^{1+\zeta}} \right]. \tag{68}$$

$$w_t = \zeta_0 L_t^{\zeta}, \tag{69}$$

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1}^c \frac{z_{t+1}^k + \lambda Q_{t+1}}{Q_t + \varkappa^h \frac{K_t^h}{K_t}} \right], \tag{70}$$

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1} \frac{R_t}{\Pi_{t+1}} \right], \tag{71}$$

$$\Lambda_{t,t+1} = \beta \mathbb{E}_t \left[\frac{C_t - \frac{\zeta_0}{1+\zeta} L_t^{1+\zeta}}{C_{t+1} - \frac{\zeta_0}{1+\zeta} L_{t+1}^{1+\zeta}} \right]. \tag{72}$$

Banks

$$\mu_t^c = \mathbb{E}_t \left[\Omega_{t,t+1} \left\{ (1 - \tau_t^c) \frac{R_t}{\Pi_{t+1}} - \frac{P_{t+1}^c}{P_t^c} \frac{R_t^c}{\Pi_{t+1}} \right\} \right] \tag{73}$$

$$x_t^c = \frac{b_t}{Q_t k_t^b}. \tag{74}$$

$$\chi_t^h = \frac{\varkappa^h}{2}\left(\frac{K_t^h}{K_t}\right)^2 K_t, \tag{75}$$

$$\chi_t^b = \frac{\varkappa^b}{2} x_t^2 Q_t k_t^b, \tag{76}$$

$$\Theta(x_t, x_t^c) = \frac{\theta_0 + \theta_0^c}{\exp(\theta x_t)\exp(\theta^c x_t^c)}, \tag{77}$$

$$\mu_t = \mathbb{E}_t\left[\Omega_{t,t+1}\left\{\frac{z_{t+1}^k + \lambda Q_{t+1}}{Q_t} - (1+\tau_t^K)\frac{R_t}{\Pi_{t+1}}\right\}\right], \tag{78}$$

$$\mu_t^* = \mathbb{E}_t\left[\Omega_{t,t+1}\left\{(1-\tau_t^{D^*})\frac{R_t}{\Pi_{t+1}} - \frac{\epsilon_{t+1}}{\epsilon_t}\frac{R_t^*}{\Pi_{t+1}^*}\right\}\right] \tag{79}$$

$$\upsilon_t = \mathbb{E}_t\left[\Omega_{t,t+1}\frac{R_t}{\Pi_{t+1}}\right] \tag{80}$$

$$\Omega_{t,t+1} = \Lambda_{t,t+1}(1-\sigma+\sigma\psi_{t+1}). \tag{81}$$

$$\psi_t = \Theta(x_t, x_t^c)\phi_t. \tag{82}$$

$$\phi_t = \frac{(1+\tau_t^N)\upsilon_t}{\Theta(x_t, x_t^c) - \mu_t - \mu_t^* x_t - \mu_t^c x_t^c + \frac{\varkappa^b}{2}x_t^2\upsilon_t}. \tag{83}$$

$$x_t = \frac{\theta\mu_t^* - \varkappa^b\upsilon_t}{\theta\varkappa^b\upsilon_t} + \sqrt{\left(\frac{\mu_t^*}{\upsilon_t\varkappa^b}\right)^2 + 2\frac{\mu_t^c x_t^c}{\upsilon_t\varkappa^b} + \left(\frac{1}{\theta}\right)^2 + 2\frac{\mu_t}{\upsilon_t\varkappa^b}}. \tag{84}$$

$$N_t = \sigma\left[(z_t^k + \lambda Q_t)K_{t-1}^b - \frac{R_{t-1}}{\Pi_t}D_{t-1} - \epsilon_t\frac{R_{t-1}^*}{\Pi_t^*}D_{t-1}^* - \Pi_t^c\frac{R_{t-1}^c}{\Pi_t}B_{t-1}\right] + \gamma(z_t^k + \lambda Q_t)K_{t-1}, \tag{85}$$

$$Q_t K_t^b \left(1 + \frac{\varkappa^b}{2} x_t^2\right) = \left(1 + \frac{\varkappa^b}{2} x_t^2\right) \phi_t N_t, \tag{86}$$

$$Q_t K_t^b \left(1 + \frac{\varkappa^b}{2} x_t^2\right) = N_t + D_t + \epsilon_t D_t^* + B_t, \tag{87}$$

$$x_t = \frac{\epsilon_t D_t^*}{Q_t K_t^b}. \tag{88}$$

$$\tau_t^N N_t = \tau_t^K Q_t K_t^b + \tau_t^{D^*} \epsilon_t D_t^* + \tau_t^c B_t, \tag{89}$$

Firms

$$mc_t = \frac{1}{A_t} (z_t^k)^{\alpha_K} \epsilon_t^{\alpha_M} (w_t^c)^{\alpha^c} (w_t^h)^{1-\alpha_K-\alpha_M-\alpha_B}, \tag{90}$$

$$Y_t = A_t \left(\frac{K_{t-1}}{\alpha_K}\right)^{\alpha_K} \left(\frac{M_t}{\alpha_M}\right)^{\alpha_M} \left(\frac{L_t}{1-\alpha_K-\alpha_M-\alpha_B}\right)^{1-\alpha_K-\alpha_M-\alpha_B} \left(\frac{L_t^c}{\alpha_B}\right)^{\alpha_B}, \tag{91}$$

$$\frac{w_t^c L_t^c}{z_t^K K_{t-1}} = \frac{\alpha_B}{\alpha_K} \frac{\epsilon_t M_t}{z_t^k K_{t-1}} \qquad = \frac{\alpha_M}{\alpha_K}, \tag{92}$$

$$\frac{w_t^h L_t^h}{z_t^k K_{t-1}} = \frac{1-\alpha_K-\alpha_M-\alpha_B}{\alpha_K}. \tag{93}$$

$$(\Pi_t - 1)\Pi_t = \frac{1}{\kappa}(\eta m c_t + 1 - \eta) + \mathbb{E}_t \left[\Lambda_{t,t+1} \frac{Y_{t+1}}{Y_t} (\Pi_{t+1} - 1)\Pi_{t+1}\right]. \tag{94}$$

$$K_t = \lambda K_{t-1} + I_t \xi_t^K, \tag{95}$$

$$Q_t = 1 + \Phi\left(\frac{I_t}{\bar{I}}\right) + \left(\frac{I_t}{\bar{I}}\right) \Phi'\left(\frac{I_t}{\bar{I}}\right). \tag{96}$$

$$K_t = K_t^h + K_t^b. \tag{97}$$

Market clearing

$$EX_t = \left(\frac{P_t}{E_t P_t^*}\right)^{-\varphi} Y_t^* = \epsilon_t^{\varphi} Y_t^*, \tag{98}$$

$$\Delta \ln \epsilon_t = \Delta \ln E_t + \hat{\pi}_t^* - \hat{\pi}_t. \tag{99}$$

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_i} \left[\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\frac{1-\omega_E}{\omega_E}} \left(\frac{E_t}{\bar{E}}\right)^{\frac{\omega_E}{1-\omega_E}}\right]^{1-\rho_i} \exp(\varepsilon_t^R), \tag{100}$$

$$Y_t = C_t + C_t^c + \left[1 + \Phi\left(\frac{I_t}{\bar{I}}\right)\right] I_t + EX_t + \frac{\kappa}{2}(\Pi_t - 1)^2 Y_t + \chi_t^h + \chi_t^b, \tag{101}$$

$$D_t^* = \frac{R_{t-1}^*}{\Pi_t^*} D_{t-1}^* + M_t - \frac{1}{\epsilon_t} EX_t, \tag{102}$$

Shocks

$$\ln\left(\frac{R_t^*}{\bar{R}^*}\right) = \rho_{R^*} \ln\left(\frac{R_{t-1}^*}{\bar{R}^*}\right) + \varepsilon_t^{R^*}, \tag{103}$$

$$\ln\left(\frac{Y_t^*}{\bar{Y}^*}\right) = \rho_{Y^*} \ln\left(\frac{Y_{t-1}^*}{\bar{Y}^*}\right) + \varepsilon_t^{Y^*}, \tag{104}$$

$$\ln\left(\frac{\Pi_t^*}{\bar{\Pi}^*}\right) = \rho_{\Pi^*} \ln\left(\frac{\Pi_{t-1}^*}{\bar{\Pi}^*}\right) + \varepsilon_t^{\Pi^*} \tag{105}$$

$$\ln\left(\frac{A_t}{\bar{A}}\right) = \rho_A \ln\left(\frac{A_{t-1}}{\bar{A}}\right) + \varepsilon_t^A, \tag{106}$$

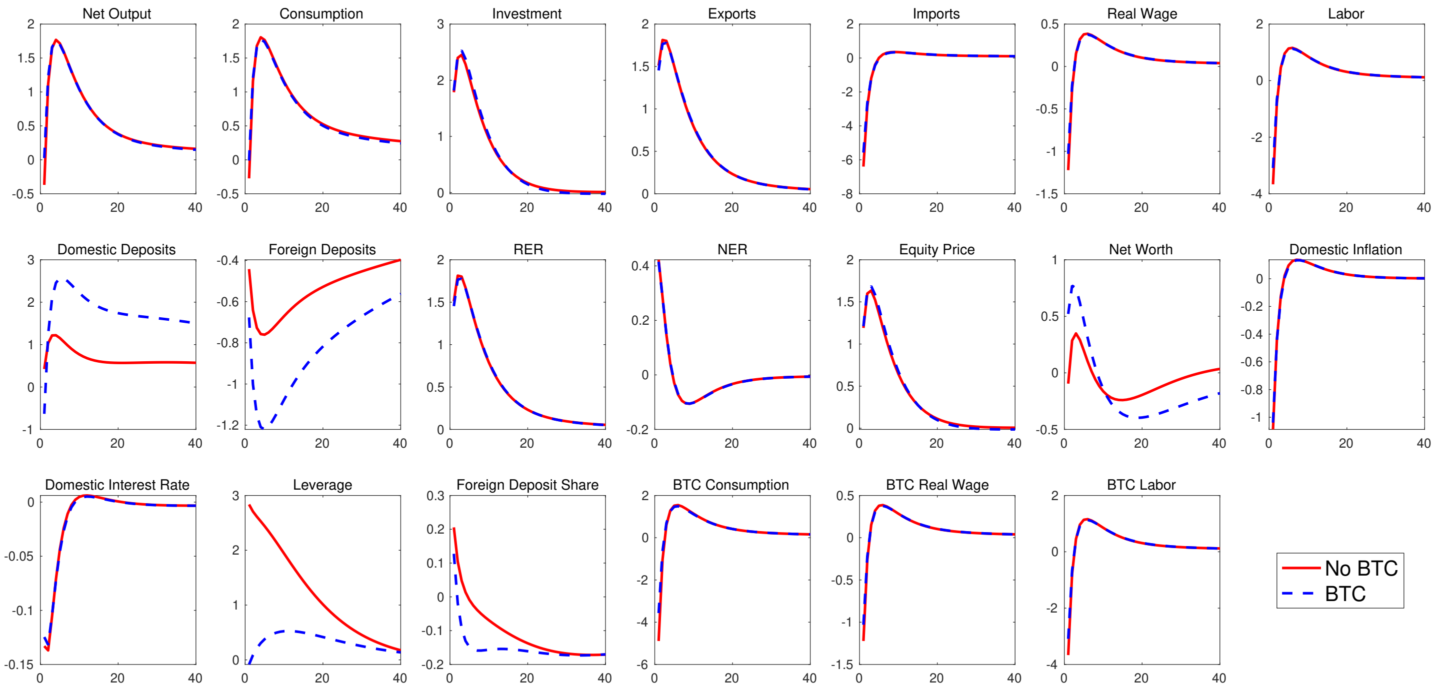
$$\ln\left(\frac{\xi_t^K}{\bar{\xi}^K}\right) = \rho_K \ln\left(\frac{\xi_{t-1}^K}{\bar{\xi}^K}\right) + \varepsilon_t^K, \tag{107}$$

$$\ln\left(\frac{\Pi_t^c}{\bar{\Pi}^c}\right) = \rho_{\Pi^c} \ln\left(\frac{\Pi_{t-1}^c}{\bar{\Pi}^c}\right) + \varepsilon_t^{\Pi^c}. \tag{108}$$

A.3 Additional results

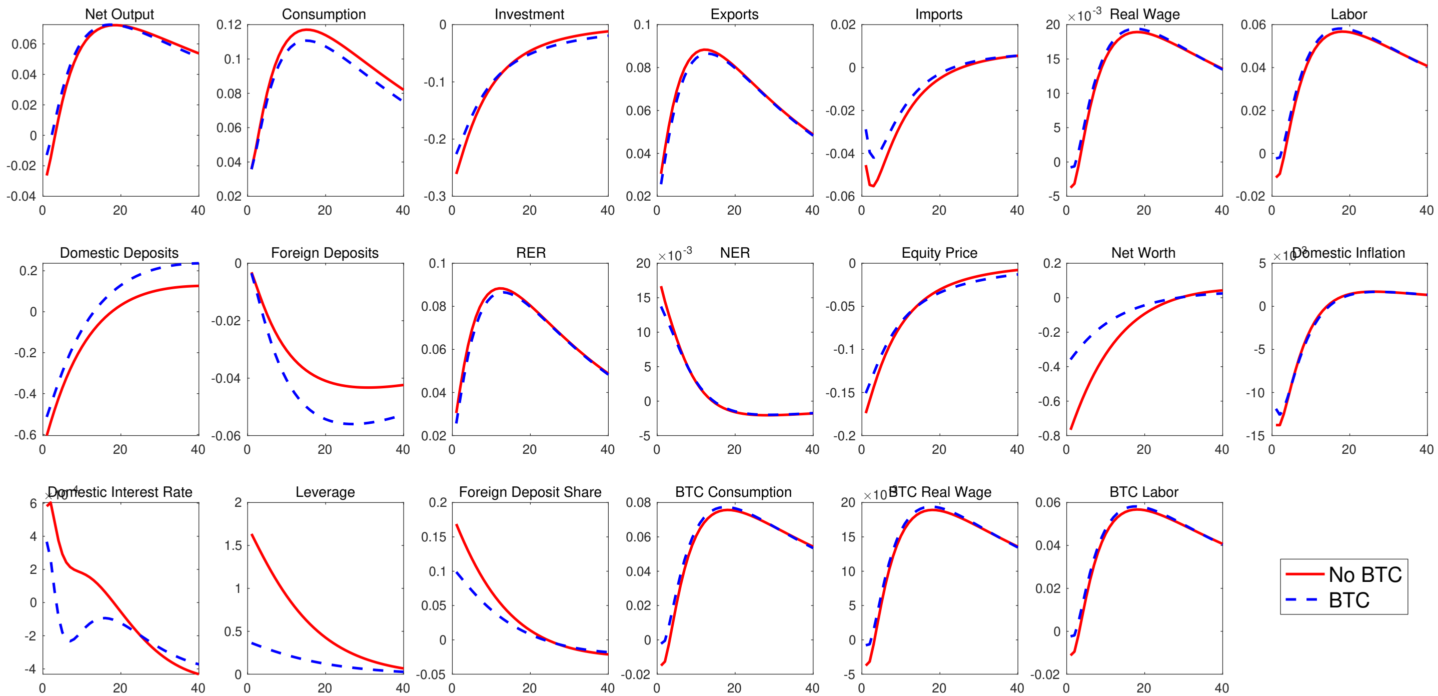
In Figures 10, 11, 12 and 13 we test if shocks to domestic productivity and capital, foreign output and inflation, are different in an economy with foreign digital currency deposits. Quantitatively, we find no evidence of real economy shocks in the presence of Bitcoin deposits. Bank balance sheets are unaffected in response to foreign output, domestic capital and productivity shocks. In contrast, a foreign inflation shock affect bank balance sheets through a net worth channel.

Figure 10: Domestic productivity shock: Baseline vs Bitcoin autarky



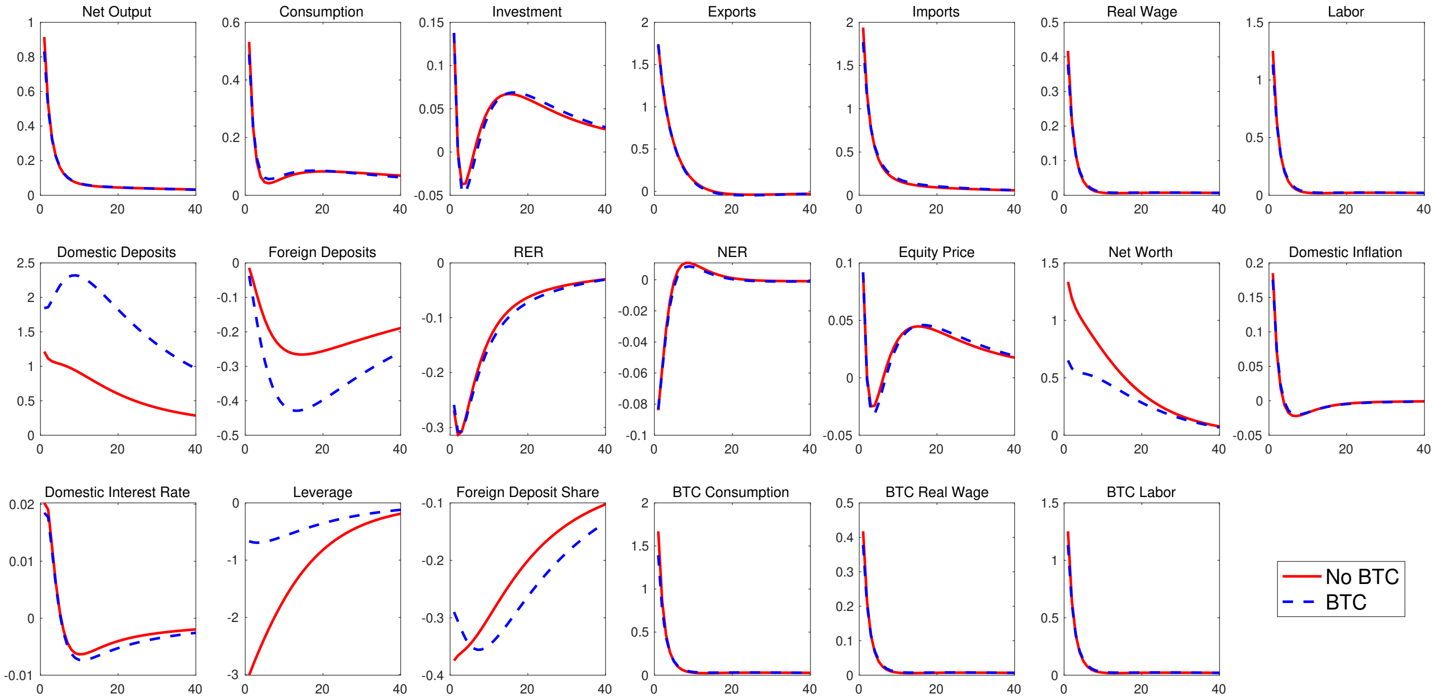
Note: Figure plots impulse responses of model variables with respect to a 1 standard deviation domestic productivity shock. Time periods are measured in quarters, and responses are measured as a percent deviation from steady state. Domestic Inflation and Domestic Inflation Rate are annualized. Solid line indicates baseline specification with Bitcoin deposits. Dashed line indicates an economy with zero Bitcoin deposits (Bitcoin autarky).

Figure 11: Domestic capital shock: Baseline vs Bitcoin autarky



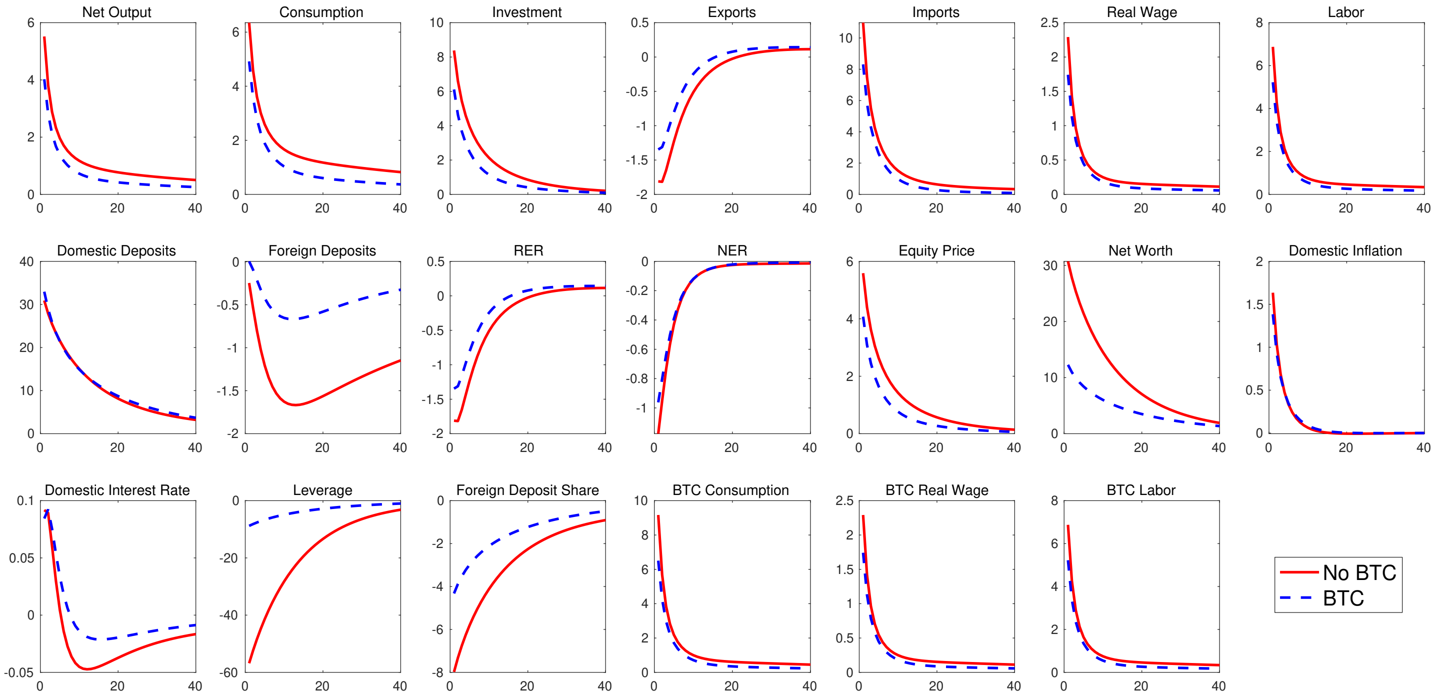
Note: Figure plots impulse responses of model variables with respect to a 1 standard deviation domestic capital shock. Time periods are measured in quarters, and responses are measured as a percent deviation from steady state. Domestic Inflation and Domestic Interest Rate are annualized. Solid line indicates baseline specification with Bitcoin deposits. Dashed line indicates an economy with zero Bitcoin deposits (Bitcoin autarky).

Figure 12: Foreign Output shock: Baseline vs Bitcoin autarky



Note: Figure plots impulse responses of model variables with respect to a 1 standard deviation foreign output shock. Time periods are measured in quarters, and responses are measured as a percent deviation from steady state. Domestic Inflation and Domestic Interest Rate are annualized. Solid line indicates baseline specification with Bitcoin deposits. Dashed line indicates an economy with zero Bitcoin deposits (Bitcoin autarky).

Figure 13: Foreign Inflation shock: Baseline vs Bitcoin autarky



Note: Figure plots impulse responses of model variables with respect to a 1 standard deviation foreign inflation shock. Time periods are measured in quarters, and responses are measured as a percent deviation from steady state. Domestic Inflation and Domestic Interest Rate are annualized. Solid line indicates baseline specification with Bitcoin deposits. Dashed line indicates an economy with zero Bitcoin deposits, (Bitcoin autarky).