Cryptocurrencies in Emerging Markets: A Stablecoin Solution?*

David Murakami† Ganesh Viswanath-Natraj‡

First version: 24 October 2021 (posted SSRN)
This version: 21 March 2023

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 cryptocurrencies in a workhorse small open economy model. We model a net positive welfare benefit relative to an economy with no cryptocurrency for the unbanked population when introducing low volatility currencies like stablecoins, and net welfare costs when introducing a high volatility currency like Bitcoin. Cryptocurrency adoption attenuates both domestic and foreign monetary policy transmission, and flexible exchange rates provide an effective buffer against cryptocurrency price shocks. Our findings motivate the increasing use of stablecoins in emerging markets as a hedge against macroeconomic uncertainty.

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

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

*The authors thank Dirk Baur, Toni Braun, Barry Eichengreen, Alex Ferreira, Andrea Ferrero, Jean Flemming, Jorge Herrada, Rich Lyons, Nicholas Sander, Ivan Shchapov, Linda Schilling, Eva Schliephake, Lauren Swinkels, Mauricio Ulate, Michael Wulfsohn, seminar participants at the Federal Reserve Board, the University of Oxford, the University of São Paulo, the University of Western Australia Blockchain conference, the 2022 Dynare conference, the 2022 Central Bank Research Association conference, and 2022 Money, Macro and Finance conference for their helpful comments and feedback.

†University of Milan and University of Pavia.
Email: david.murakami@unimi.it

‡University of Warwick, Warwick Business School.
Email: ganesh.viswanath-natraj@wbs.ac.uk

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 a cryptocurrency like Bitcoin from a macroeconomic and financial stability standpoint.[3] First and foremost is Bitcoin's volatility, with daily price changes an 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 stable cryptocurrency – referred to as a "stablecoin" – such as tether or USD Coin. 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.[6] Our model investigates 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; and whether digital currencies buffer or amplify an economy from foreign financial shocks. We generalize our findings to small open economies

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.
6. While we motivate our paper with El Salvador's Bitcoin experiment, our model is a general small open economy that has a central bank that can target the interest rate or the exchange rate. This generalization allows us to examine the effects of exchange rate regime on the effects of cryptocurrency adoption, and allow us to examine a richer set of shocks to the economy, in particular the effects of cryptocurrency adoption on domestic monetary policy transmission.

with both floating and fixed exchange rates, and test whether a flexible exchange rate regime can provide an insulation to digital currency movements.

Our baseline SOE model features two types of households: those that hold both domestic [fiat] currency and cryptocurrencies, and those that only hold cryptocurrencies.[7] 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.[8] Within this framework, we form a simple process for the adjustment of cryptocurrency deposits due to their valuation effects. The intuition is as follows. Households need to convert cryptocurrency to domestic currency at the time of consumption.[9] Valuation effects in the cryptocurrency lead to a change in the purchasing power of household cryptocurrency deposits, which affects consumption, labor, and bank lending. A baseline calibration predicts that a 1 percent decline in cryptocurrency prices will cause a peak decline in aggregate consumption of approximately 0.2%.

Using our model we make the following contributions. First, we compute the relative welfare of an economy with cryptocurrencies to an economy with no cryptocurrency deposits, which we denote as "cryptocurrency autarky". When the volatility of the cryptocurrency price shock is sufficiently high, the general equilibrium effects of volatile cryptocurrency 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 cryptocurrency autarky economy. Our welfare analysis sheds light on the proposed stablecoin solution: For a sufficiently low volatility of the cryptocurrency price shock, we obtain net benefits relative to autarky. Thus, we conjecture that stablecoins can provide an effective mechanism for consumption smoothing. By replacing a volatile cryptocurrency such as 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 cryptocurrency 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 households adopt cryptocurrencies, 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 of cryptocurrency autarky, we find the transmission of

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

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

9. For example, 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.

monetary policy is less effective in the case where cryptocurrency deposits are prevalent. The intuition is as follows. An increase in cryptocurrency 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 bank balance sheets are in cryptocurrencies.

Third, we contribute to the discussion of global financial cycles and the validity of the "Impossible Trinity" (trilemma) in which a SOE with perfect capital mobility has to choose between a fixed exchange rate or independent monetary policy, but cannot have both.[10] 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 (Miranda-Agrippino and Rey 2020).[11] We show that relative to cryptocurrency autarky and a managed float exchange rate regime, the adoption of cryptocurrencies dampens the effects of the global financial cycle.

Fourth, we assess whether the type of exchange rate regime matters for the transmission of the cryptocurrency 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. With respect to a unit standard deviation shock in cryptocurrency prices, we observe a peak decline in aggregate consumption of 0.2% for a rigid fixed exchange rate, and approximately 0.1% 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.

Finally, we compute the relative welfare of an economy with a cryptocurrency with respect to different macroeconomic shocks. This includes domestic monetary policy, foreign risk premia and the choice of exchange rate regime. Our results suggest that the introduction of a cryptocurrency provide welfare benefits to the unbanked households, and these benefits are increasing in the volatility of macroeconomic shocks. In an economy with cryptocurrency deposits, the unbanked households can hedge interest rate risk by smoothing consumption using cryptocurrency. We also show that adopting a cryptocurrency provides higher welfare gains in a fixed exchange rate regime. The findings suggest cryptocurrencies can help diversify macroeconomic risk, and supports the rationale for emerging markets with economic instability to increase their adoption of cryptocurrencies.[12]

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

11. 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.

12. Recent examples include the increased adoption of stablecoins by Turkey in response to high inflation and increased policy uncertainty, see

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 cryptocurrencies 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 cryptocurrency price shock, and conducts additional tests on differences between fixed and flexible exchange rate regimes and a welfare analysis. Section 6 concludes the paper.

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 ("unbanked households") that do not have access to domestic or international banking channels. Critically, the unbanked households only have access to cryptocurrencies as a medium of exchange and savings vehicle. Cryptocurrency prices are subject to a price shock similar to a terms of trade and commodity price shock studied in Drechsel and Tenreyro (2018) in that we assume an exogenous price process for cryptocurrencies. A crucial difference is that while the effects of commodity prices affect the allocation of commodity producing firms, in our model we motivate cryptocurrency price shocks as affecting the saving and consumption behavior of unbanked households. The costs of dollarization studied in Schmitt-Grohé and Uribe (2001) are the loss of monetary independence and ability to stabilize prices against asymmetric shocks. This is traded off 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 costs of dollarization ranging from 0.1% to 0.3% compared to alternative rules. In our paper, we also study welfare effects of cryptocurrency adoption relative to the standard of dollarization and flexible exchange rate regimes for different levels of volatility of the cryptocurrency price process.

Our work also relates to an emerging literature on the macroeconomic implications

https://www.ft.com/content/02194361-a5b9-4bf0-9147-f36ba7759cf1 for more details.

of global stablecoins and a Central Bank Digital Currency (CBDC) (Baughman and Flemming 2020; Benigno, Schilling, and Uhlig 2022; Benigno 2022; Ferrari Minesso, Mehl, and Stracca 2022; George, Xie, and Alba 2020; Skeie 2019; Ikeda 2020; Kumhof et al. 2021; Cong and Mayer 2021). Benigno, Schilling, and Uhlig (2022) model a two country framework in which a global stablecoin 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 cryptocurrency 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%. Skeie (2019) studies an equilibrium in which the cryptocurrency is susceptible to bank runs. Ferrari Minesso, Mehl, and Stracca (2022) setup a two country model with a CBDC issued by the home country. They find productivity spillovers are amplified in the presence of a CBDC, and that it reduces the effectiveness of the foreign country's monetary policy. Cong and Mayer (2021) model the political economy of currency competition with countries choosing between adopting a CBDC and a private cryptocurrency. They show that EMEs with weak fundamentals can derive net welfare benefits from cryptocurrency adoption as an alternative to adopting a CBDC or the US dollar.

Ikeda (2020) models a two-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 cryptocurrency deposits that are insulated from changes in the policy rate.

Finally, we contribute to a policy discussion on the cost and benefits of introducing a volatile cryptocurrency such as Bitcoin as legal tender. Alvarez, Argente, and Van Patten (2022) document survey evidence on the Bitcoin Chivo wallet, and analyze the determinants of Bitcoin adoption. They find that the unbanked population are not sufficiently incentivized to adopt the payment system. 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.[13] 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 Kenya can be used as a potential alternative to service the unbanked population.[14] Economists at the IMF (Adrian and Weeks-Brown

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

14. We expand on this argument in Section 3, where we discuss the costs and benefits of the cryptocur-

2021) have opposed El Salvador's 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 cryptocurrency, such as Bitcoin, as it is too volatile and unrelated to the real economy. If goods and services are priced in both a fiat currency and a cryptocurrency, 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 cryptocurrency, and as a result domestic prices could become highly unstable. In addition, Plassaras (2013) analyzes regulatory concerns with the IMF being unable to provide financial support through emergency loan provisions if the financial crisis is due to legal tender in cryptocurrencies.

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.[15] There are three potential benefits of adopting a cryptocurrency 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.[16] 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.[17] 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.[18]

A second potential benefit of a cryptocurrency 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.[19] 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.[20]

rency experiment in increasing financial inclusion.

15. https://www.npr.org/2021/09/07/1034838909/bitcoin-el-salvador-legal-tender-official-currency-cryptocurrency?t=1634944255426

16. https://datatopics.worldbank.org/g20fidata/country/el-salvador

17. See Appendix A.1 for a map of El Salvador's Bitcoin ATMs.

18. For more information on banking regulations, see https://coingeek.com/el-salvador-publishes-draft-regulations-for-banks-handling-btc/.

19. See https://data.worldbank.org/indicator/BX.TRF.PWKR.DT.GD.ZS?locations=SV.

20. See also https://www.bloomberg.com/news/articles/2021-08-23/el-salvador-readies-Bitcoin-rollout-with-200-atms-for-conversion.

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 encouraging foreign direct investment 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.[21]

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.[22] 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 cryptocurrency 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.[23] 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

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

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

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

quarterly returns of BTC/USD is 70 percent over the same period.[24] 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.

Another related benefit of stablecoins is providing an effective inflation hedge through digital dollarization. In January 2022, Turkish residents sold Lira for the Tether stablecoin in response to high inflation and domestic policy uncertainty.[25] Concerns about the devaluation of the Argentinan Peso after a government resignation led to a surge in demand for stablecoins.[26] Recent survey evidence conducted by Mastercard reveal that up to a third of households in Latin America have used stablecoins for retail payments.[27]

For stablecoins to become legal tender in emerging markets, stablecoins need to be appropriately regulated to be fully collateralized at all times.[28] 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.[29]

4 Model

We now introduce our baseline model with which we conduct our cryptocurrency experiments. We build a SOE 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 in-

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

25. Source: https://www.ft.com/content/02194361-a5b9-4bf0-9147-f36ba7759cf1

26. Source: https://www.coindesk.com/business/2022/07/04/argentines-take-refuge-in-stablecoins-after-economy-minister-resignation/

27. Source: https://www.prnewswire.com/news-releases/latin-america-s-crypto-conquest-is-driven-by-consumers-needs-819718066.html

28. 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

29. 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.

cluding SOE features from Galí and Monacelli (2005), ABK, and Akinci and Queraltó (2019).[30]

Our model features a banking sector which can hold cryptocurrency balances 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, and the influence of financial crises.[31]

4.1 Households and workers

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

The problem for the representative banked household is the following. They choose consumption, C_t^h, labor supply, L_t^h, equity holdings in firms, K_t^h, deposits held at the bank, D_t,[32] and cryptocurrency deposits, B_t^h,[33] to maximize the present value discounted

30. 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.

31. 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)).

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

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

33. Specifically, we define

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

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

sum of their expected utility,

$$\max_{C_t^h, L_t^h, K_t^h, D_t, B_t^h} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left[\ln \left(C_{t+s}^h - \zeta_0^h \frac{(L_{t+s}^h)^{1+\zeta^h}}{1+\zeta^h} \right) + \nu_0^h \frac{(B_{t+s}^h)^{1-\nu^h}}{1-\nu^h} \right],$$

subject to their period budget constraint,

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

where Q_t is the equity price in terms of final goods; $\chi^h(K_t, K_t^h)$ are BHH portfolio management costs; w_t^h are real wages of the BHH 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; z_t^k is the rental rate of capital; $R_t = 1 + i_t$ is the gross nominal interest rate; $\Pi_t = \frac{P_t}{P_{t-1}} = 1 + \pi_t$ is the gross domestic inflation rate, where P_t is the domestic price level; and R_t^c denotes a nominal return earned on cryptocurrency deposits held in digital wallets:

$$R_t^c = \frac{P_t^c}{P_{t-1}^c}. \quad (2)$$

Thus the nominal return earned is equal to the appreciation of cryptocurrency in domestic currency. The parameters β, ζ_0^i, ζ^i, ν_i, and λ are the household's discount factor, relative disutility from labor supply, the inverse-Frisch elasticity of labor supply, risk-aversion for cryptocurrency holdings, and one minus the depreciation rate of capital, respectively.[34]

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

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

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

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

$$1 = \mathbb{E}_t \left[\Lambda_{t,t+1}^h \frac{R_t^c}{\Pi_{t+1}} \right] + \nu_0^h \frac{\left(C_t^h - \zeta_0^h \frac{(L_t^h)^{1+\zeta_h}}{1+\zeta^h} \right)}{(B_t^h)^{\nu_h}}, \quad (6)$$

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

$$\Lambda_{t,t+1}^h = \beta \mathbb{E}_t \left[\frac{C_t^h - \frac{\zeta_0^h}{1+\zeta^h} (L_t^h)^{1+\zeta^h}}{C_{t+1}^h - \frac{\zeta_0^h}{1+\zeta^h} (L_{t+1}^h)^{1+\zeta^h}} \right]. \quad (7)$$

34. The households' preferences are of the Greenwood-Hercowitz-Huffman (GHH) form in order to shutoff the income effect to induce pro-cyclical labor supply.

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

$$\max_{\{C^u_{t+s},L^u_{t+s},B^u_{t+s}\}_{s=0}^{\infty}} \mathbb{E}_t \left[\sum_{s=0}^{\infty} \beta^s \left\{ \ln \left(C^u_{t+s} - \zeta^u_0 \frac{(L^u_{t+s})^{1+\zeta^u}}{1+\zeta^u} \right) + \nu^u_0 \frac{(B^h_{t+s})^{1-\nu_u}}{1-\nu_u} \right\} \right],$$

subject to the period budget constraint,

$$C^u_t + B^u_t = w^u_t L^u_t + \frac{R^c_{t-1}}{\Pi_t} B^u_{t-1}. \tag{8}$$

The FOCs that arise from the UHH problem are:

$$w^u_t = \zeta^u_0 (L^u_t)^{\zeta^u}, \tag{9}$$

$$1 = \mathbb{E}_t \left[\Lambda^u_{t,t+1} \frac{R^c_t}{\Pi_{t+1}} \right] + \nu^u_0 \frac{\left(C^u_t - \frac{\zeta^u_0}{1+\zeta^u} (L^u_t)^{1+\zeta_u} \right)}{(B^u_t)^{\nu_u}}, \tag{10}$$

where the stochastic discount factor of the UHH is defined as:

$$\Lambda^u_{t,t+1} = \beta \mathbb{E}_t \left[\frac{C^u_t - \frac{\zeta^u_0}{1+\zeta^u} (L^u_t)^{1+\zeta^u}}{C^u_{t+1} - \frac{\zeta^u_0}{1+\zeta^u} (L^u_{t+1})^{1+\zeta^u}} \right]. \tag{11}$$

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

$$\chi^h_t = \frac{\varkappa^h}{2} \left(\frac{K^h_t}{K_t} \right)^2 K_t, \tag{12}$$

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

Banked households 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.

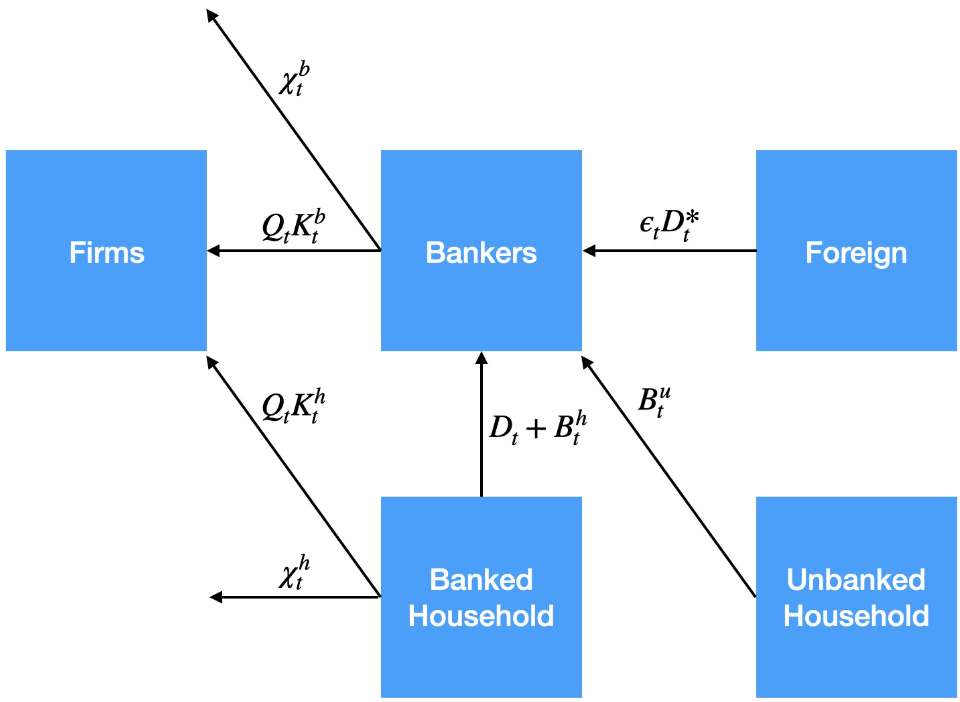


Figure 1: Graphical illustration of the model

4.2 Banks

A banker will finance her capital investments, of market value $Q_t k_t^b$, by receiving deposit funds from banked households in domestic currency, d_t, cryptocurrency deposits from unbanked households, b_t, and from foreign households in foreign currency converted to domestic currency units, $\epsilon_t d_t^*$. The banker faces exchange rate risk, and the real exchange rate is defined as

$$\epsilon_t = \frac{E_t P_t^*}{P_t}, \tag{13}$$

where E_t is the nominal exchange rate defined as the quantity of domestic currency units per one unit of foreign currency.[35] 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:

$$\chi_t^b = \frac{\varkappa^b}{2} x_t^2 Q_t k_t^b, \tag{14}$$

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

where $\varkappa^b > 0$ is a foreign borrowing cost parameter and $Q_t k_t^b$ is the asset holding of a banker.[36] x_t is the fraction of a banker's assets financed by foreign borrowing and is defined as:

$$x_t = \frac{\epsilon_t d_t^*}{Q_t k_t^b}. \tag{15}$$

Additionally, as the banker offers cryptocurrency wallet services to unbanked households,[37] we define x_t^c as a banker's cryptocurrency deposit leverage ratio:

$$x_t^c = \frac{b_t}{Q_t k_t^b}. \tag{16}$$

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.[38] 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:

$$\mathbb{V}_t^b = \mathbb{E}_t \left[\sum_{s=1}^{\infty} \Lambda_{t,t+s}^h \sigma^{s-1}(1-\sigma) n_{t+s} \right], \tag{17}$$

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 (17).[39]

A financial friction in line 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:

$$\Theta(x_t, x_t^c) = \frac{\theta_0}{\exp(\theta x_t + \theta^c x_t^c)}, \tag{18}$$

where we assume that $\{\theta_0, \theta, \theta^c\} > 0$. Thus, following Gertler and Kiyotaki (2010), we

36. 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).

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

38. 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.

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

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

assume that as the banker raises a greater proportion of her funds from international financial markets and cryptocurrency 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 shut down 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.[40] In other words, the bankers face the following incentive constraint:

$$\mathbb{V}_t^b \geq \Theta(x_t, x_t^c) Q_t k_t^b, \tag{19}$$

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:

$$\left(1 + \tau_t^K + \frac{\varkappa^b}{2} x_t^2\right) Q_t k_t^b = d_t + (1 - \tau_t^{D^*}) \epsilon_t d_t^* + (1 + \tau_t^N) n_t + (1 - \tau_t^c) b_t. \tag{20}$$

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

$$n_t = (z_t^k + \lambda Q_t) k_{t-1}^b - \frac{R_{t-1}}{\Pi_t} d_{t-1} - \frac{R_{t-1}^*}{\Pi_t^*} \epsilon_t d_{t-1}^* - \frac{R_{t-1}^c}{\Pi_t} b_{t-1}, \tag{21}$$

40. 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 signaled 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	Cryptocurrency deposits b_t
	Foreign debt $\epsilon_t d_t^*$
	Net worth n_t

Table 1: Bank balance sheet

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 Banker's problem and financial market wedges

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:

$$\psi_t \equiv \frac{\mathbb{V}_t^b}{n_t}. \tag{22}$$

Additionally, defining ϕ_t as the leverage ratio of a bank,

$$\phi_t = \frac{Q_t k_t^b}{n_t}, \tag{23}$$

we can write the banker's problem as the following:

$$\psi_t = \max_{\phi_t, x_t} \left[\mu_t \phi_t + \left(1 + \tau_t^N - \frac{\varkappa^b}{2} x_t^2 \phi_t \right) \upsilon_t + \mu_t^* \phi_t x_t + \mu_t^c x_t^c \phi_t \right], \tag{24}$$

subject to

$$\psi_t = \Theta(x_t, x_t^c) \phi_t, \tag{25}$$

where $\Omega_{t,t+1}$ is the stochastic discount factor of the banker;[41] μ_t is the excess return on capital over home deposits; μ_t^c is the cost advantage of cryptocurrency holdings over home deposits; μ_t^* is the cost advantage of foreign currency debt over home deposits or the deviation from real uncovered interest parity (UIP); and υ_t is the marginal cost of deposits:

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

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

41. Note that we assume that the stochastic discount factor of the banker is a function of the stochastic discount factor of the banked households. This is because we assume that unbanked households do not hold domestic currency denominated deposits.

$$\mu_t^* = \mathbb{E}_t \left[\Omega_{t,t+1} \left\{ (1 - \tau_t^{D^*}) \frac{R_t}{\Pi_{t+1}} - \frac{\epsilon_{t+1}}{\epsilon_t} \frac{R_t^*}{\Pi_{t+1}^*} \right\} \right], \tag{28}$$

$$\upsilon_t = \mathbb{E}_t \left[\Omega_{t,t+1} \frac{R_t}{\Pi_{t+1}} \right], \tag{29}$$

$$\Omega_{t,t+1} = \Lambda_{t,t+1}^h (1 - \sigma + \sigma \psi_{t+1}). \tag{30}$$

Solving the banker's problem yields an optimal leverage ratio and share of foreign deposits:

$$\phi_t = \frac{(1 + \tau_t^N)\upsilon_t}{\Theta(x_t, x_t^c) - \mu_t - \mu_t^* x_t - \mu_t^c x_t^c + \frac{\varkappa^b}{2} x_t^2 \upsilon_t}, \tag{31}$$

$$x_t = \frac{\theta \mu_t^* - \varkappa^b \upsilon_t}{\theta \varkappa^b \upsilon_t} + \sqrt{\left(\frac{\mu_t^*}{\varkappa^b \upsilon_t}\right)^2 + 2\frac{\mu_t^c}{\varkappa^b \upsilon_t} x_t^c + \left(\frac{1}{\theta}\right)^2 + 2\frac{\mu_t}{\varkappa^b \upsilon_t}}. \tag{32}$$

For a complete description of the solution to the banker's problem, please refer to Appendix A.2.1.

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:

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

where $K_t(i)$, $M_t(i)$, $L_t^h(i)$, and $L_t^u(i)$ are capital, imports, banked household labor, and UHH 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, α_h, and α_u are input shares for capital, imports, banked households, and unbanked households, respectively, and are each assumed to be bound between 0 and 1 such that the share of inputs sum to unity giving a constant returns to scale production technology.

The cost minimization problem for each intermediate good producer is:

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

subject to:

$$A_t \left(\frac{K_{t-1}(i)}{\alpha_K}\right)^{\alpha_K} \left(\frac{M_t(i)}{\alpha_M}\right)^{\alpha_M} \left(\frac{L_t^h(i)}{\alpha_h}\right)^{\alpha_h} \left(\frac{L_t^u(i)}{\alpha_u}\right)^{\alpha_u} \geq Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\eta} Y_t.$$

The Lagrangian for intermediate firm i's problem is:

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

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

$$z_t^k = mc_t(i) A_t \left(\frac{K_{t-1}(i)}{\alpha_K}\right)^{\alpha_K - 1} \left(\frac{M_t(i)}{\alpha_M}\right)^{\alpha_M} \left(\frac{L_t^h(i)}{\alpha_h}\right)^{\alpha_h} \left(\frac{L_t^u(i)}{\alpha_u}\right)^{\alpha_u},$$

$$\epsilon_t = mc_t(i) A_t \left(\frac{K_{t-1}(i)}{\alpha_K}\right)^{\alpha_K} \left(\frac{M_t(i)}{\alpha_M}\right)^{\alpha_M - 1} \left(\frac{L_t^h(i)}{\alpha_h}\right)^{\alpha_h} \left(\frac{L_t^u(i)}{\alpha_u}\right)^{\alpha_u},$$

$$w_t^h = mc_t(i) A_t \left(\frac{K_{t-1}(i)}{\alpha_K}\right)^{\alpha_K} \left(\frac{M_t(i)}{\alpha_M}\right)^{\alpha_M} \left(\frac{L_t^h(i)}{\alpha_h}\right)^{\alpha_h - 1} \left(\frac{L_t^u(i)}{\alpha_u}\right)^{\alpha_u},$$

$$w_t^u = mc_t(i)A_t\left(\frac{K_{t-1}(i)}{\alpha_K}\right)^{\alpha_K}\left(\frac{M_t(i)}{\alpha_M}\right)^{\alpha_M}\left(\frac{L_t^h(i)}{\alpha_h}\right)^{\alpha_h}\left(\frac{L_t^u(i)}{\alpha_u}\right)^{\alpha_u-1},$$

which yields:

$$mc_t = \frac{1}{A_t}(z_t^k)^{\alpha_K}\epsilon_t^{\alpha_M}(w_t^h)^{\alpha_h}(w_t^u)^{\alpha_u}, \tag{33}$$

and where we also find that

$$Y_t = A_t\left(\frac{K_{t-1}}{\alpha_K}\right)^{\alpha_K}\left(\frac{M_t}{\alpha_M}\right)^{\alpha_M}\left(\frac{L_t^h}{\alpha_h}\right)^{\alpha_h}\left(\frac{L_t^u}{\alpha_u}\right)^{\alpha_u}, \tag{34}$$

where

$$\begin{aligned}
K_{t-1} &= \int_0^1 K_{t-1}(i)di,\\
M_t &= \int_0^1 M_t(i)di,\\
L_t^h &= \int_0^1 L_t^h(i)di,\\
L_t^u &= \int_0^1 L_t^u(i)di,
\end{aligned}$$

are aggregate capital, imports, BHH labor, and UHH labor inputs used in production during period t, respectively. From the FOCs, we also yield the following expenditure shares:

$$\frac{\epsilon_t M_t}{z_t^k K_{t-1}} = \frac{\alpha_M}{\alpha_K}, \tag{35}$$

$$\frac{w_t^h L_t^h}{z_t^k K_{t-1}} = \frac{\alpha_h}{\alpha_K}, \tag{36}$$

$$\frac{w_t^u L_t^u}{z_t^k K_{t-1}} = \frac{\alpha_u}{\alpha_K}. \tag{37}$$

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,

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

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

$$\kappa\left(\frac{P_t(i)}{P_{t-1}(i)} - 1\right)\frac{Y_t}{P_{t-1}(i)} = \frac{1}{P_t}\left(\frac{P_t(i)}{P_t}\right)^{-\eta}Y_t - \eta\left(\frac{P_t(i)}{P_t} - mc_t\right)\left(\frac{P_t(i)}{P_t}\right)^{-\eta-1}\frac{Y_t}{P_t}$$

$$+ \kappa \mathbb{E}_t \left[\Lambda^h_{t,t+1} \left(\frac{P_{t+1}(i)}{P_t(i)} - 1 \right) Y_{t+1} \frac{P_{t+1}(i)}{P_t(i)^2} \right].$$

Evaluating at the symmetric equilibrium where intermediate firms optimally price their output at $P_t(i) = P_t, \forall i$, allows us to write:[42]

$$(\Pi_t - 1)\Pi_t = \frac{1}{\kappa}(\eta mc_t + 1 - \eta) + \mathbb{E}_t \left[\Lambda^h_{t,t+1} \frac{Y_{t+1}}{Y_t} (\Pi_{t+1} - 1)\Pi_{t+1} \right]. \tag{38}$$

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:

$$K_t = \lambda K_{t-1} + I_t, \tag{39}$$

and recall that $\lambda = 1 - \delta$, where $\delta \in (0, 1)$ is the depreciation rate. Total investment costs are given by:

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

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

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

with $\Phi(1) = \Phi'(1) = 0$ and $\Phi'' \left(\frac{I_t}{\bar{I}} \right) > 0$. 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:

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

Differentiating with respect to I_t gives the following FOC:

$$Q_t = 1 + \Phi \left(\frac{I_t}{\bar{I}} \right) + \left(\frac{I_t}{\bar{I}} \right) \Phi' \left(\frac{I_t}{\bar{I}} \right). \tag{40}$$

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 a variable.

42. A standard expression for the New Keynesian Phillips Curve (NKPC) can be written by log linearising (38) about the non-inflationary steady state.

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

$$EX_t = \left(\frac{P_t}{E_t P_t^*}\right)^{-\varphi} Y_t^* = \epsilon_t^{\varphi} Y_t^*, \tag{41}$$

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:

$$\Delta \ln \epsilon_t = \Delta \ln E_t + \hat{\pi}_t^* - \hat{\pi}_t. \tag{42}$$

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

$$\ln\left(\frac{R_t^*}{\bar{R}^*}\right) = \rho_{R^*} \ln\left(\frac{R_{t-1}^*}{\bar{R}^*}\right) + \varepsilon_t^{R^*}, \tag{43}$$

$$\ln\left(\frac{Y_t^*}{\bar{Y}^*}\right) = \rho_{Y^*} \ln\left(\frac{Y_{t-1}^*}{\bar{Y}^*}\right) + \varepsilon_t^{Y^*}, \tag{44}$$

$$\ln\left(\frac{\Pi_t^*}{\bar{\Pi}^*}\right) = \rho_{\Pi^*} \ln\left(\frac{\Pi_{t-1}^*}{\bar{\Pi}^*}\right) + \varepsilon_t^{\Pi^*}. \tag{45}$$

4.5 Central bank and monetary policy

The domestic central bank is assumed to operate an inertial Taylor Rule:

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R} \left[\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\frac{1-\omega_E}{\omega_E}} \left(\frac{E_t}{\bar{E}}\right)^{\frac{\omega_E}{1-\omega_E}}\right]^{1-\rho_R} \exp(\varepsilon_t^R), \tag{46}$$

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 (46) 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 banked households and bankers:

$$K_t = K_t^h + K_t^b. \tag{47}$$

Likewise, aggregate consumption and labor supply by regular and unbanked households are given as:

$$C_t = C_t^h + C_t^u, \tag{48}$$
$$L_t = L_t^h + L_t^u. \tag{49}$$

The aggregate resource constraint of the domestic economy is

$$Y_t = C_t + \left[1 + \Phi\left(\frac{I_t}{\overline{I}}\right)\right] I_t + EX_t + \frac{\kappa}{2}(\Pi_t - 1)^2 Y_t + \chi_t^h + \chi_t^b, \tag{50}$$

which states that output must be consumed, invested, exported, and used to pay for adjustments.[43]

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

$$D_t^* = \frac{R_{t-1}^*}{\Pi_t^*} D_{t-1}^* + M_t - \frac{1}{\epsilon_t} EX_t, \tag{51}$$

the aggregate net worth of the bankers is:

$$\begin{aligned} N_t = \sigma &\left[(z_t^k + \lambda Q_t) K_{t-1}^b - \frac{R_{t-1}}{\Pi_t} D_{t-1} - \epsilon_t \frac{R_{t-1}^*}{\Pi_t^*} D_{t-1}^* - \frac{R_{t-1}^c}{\Pi_t} B_{t-1}\right] \\ &+ \gamma (z_t^k + \lambda Q_t) K_{t-1}, \end{aligned} \tag{52}$$

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

$$Q_t K_t^b \left(1 + \tau_t^K + \frac{\varkappa^b}{2} x_t^2\right) = \left(1 + \tau_t^K + \frac{\varkappa^b}{2} x_t^2\right) \phi_t N_t, \tag{53}$$

$$Q_t K_t^b \left(1 + \tau_t^K + \frac{\varkappa^b}{2} x_t^2\right) = (1 + \tau_t^N) N_t + D_t + (1 - \tau_t^{D*}) \epsilon_t D_t^* + (1 - \tau_t^c) B_t, \tag{54}$$

$$x_t = \frac{\epsilon_t D_t^*}{Q_t K_t^b}, \tag{55}$$

43. We note that GDP is given as:

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

and that net output is given as:

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

$$x_t^c = \frac{B_t}{Q_t K_t^b}. \tag{56}$$

We can see that (53) is an identity based on (23), and (54) is an aggregate version of the balance sheet identity, (20). Meanwhile, as all banks are identical, (55) and (56) are the corresponding aggregate versions of (15) and (16), respectively. When unbanked and banked households both use cryptocurrency deposits, their aggregate balance is held by the banker:

$$B_t = B_t^u + B_t^h. \tag{57}$$

Finally, the stationary AR(1) processes for TFP and cryptocurrency prices are given as:

$$\ln\left(\frac{A_t}{\bar{A}}\right) = \rho_A \ln\left(\frac{A_{t-1}}{\bar{A}}\right) + \varepsilon_t^A, \tag{58}$$

$$\ln\left(\frac{P_t^c}{\bar{P}^c}\right) = \rho_c \ln\left(\frac{P_{t-1}^c}{\bar{P}^c}\right) + \varepsilon_t^{Pc}. \tag{59}$$

A competitive equilibrium is a set of 11 prices, $\{\, E_t,\ mc_t,\ Q_t,\ R_t,\ R_t^c,\ w_t^h,\ w_t^u,\ z_t^k,\ \epsilon_t,\ \Pi_t,\ \tau^N \,\}$; 19 quantity variables, $\{\, B_t,\ B_t^h,\ B_t^u,\ C_t,\ C_t^h,\ C_t^u,\ D_t,\ D_t^*,\ EX_t,\ I_t,\ K_t,\ K_t^b,\ K_t^h,\ L_t,\ L_t^h,\ L_t^u,\ M_t,\ N_t,\ Y_t \,\}$; 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, $\{\, A_t,\ P_t^c \,\}$, which satisfy 43 equations: (3)-(6), (8)-(10), (25)-(29), and (31)-(59).

4.7 Calibration

We calibrate the parameters in our model using relatively standard values found in the New Keynesian 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% annualized, based on an average of interest rates from 2000 to 2020 in El Salvador from the IMF's *International Financial Statistics*.

The foreign interest rate is calibrated to an annualized rate of 2 percent, based on US historical data. 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 cryptocurrency deposits and the foreign deposits as symmetric with respect to the fraction of funds a banker can abscond with. Therefore, the elasticity of cryptocurrency 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 to be symmetric, $\theta_0 = \theta_0^c = 0.401$. The cryptocurrency sub-utility parameters for the banked and unbanked households, ν_u,ν_0^u,ν_h,ν_0^h is calibrated to yield a steady state cryptocurrency deposits that is equal to 20% of labor income in the steady state, and this matches data from the World Bank which has an aggregate savings rate of 20 percent for El Salvador.[44] 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 unbanked households, α_u, to match the labor share of the unbanked population in El Salvador. The total labor share is equal to $\alpha_h + \alpha_u = 0.52$. Based on data from the World Bank, the share of the unbanked population in 2020 is two thirds, giving $\alpha_u = \frac{2}{3} \times (0.52) = 0.3466$ and $\alpha_h = 0.1734$.[45] In the baseline specification we choose $\omega_E = 0.5$, which is in between a perfect fix ($\omega_E \to 1$) and a perfect float ($\omega_E \to 0$), and can be thought of as a managed float. We relax this assumption in subsequent results when we compare different exchange rate regimes in Section 5.5.

Turning to the calibration of macroeconomic shocks, productivity and foreign output shocks are assumed to have quarterly standard deviations of 1.3% and 2%, respectively. Meanwhile, innovations to foreign inflation, foreign and domestic interest rates have a standard deviation of 0.25% quarterly. We calibrate cryptocurrency price innovations to a quarterly standard deviation of a 1%, which is much lower than volatility estimates for Bitcoin. Using data from *Cryptocompare* between January 2017 to September 2021 we observe that the average quarterly volatility for Bitcoin was 70% throughout the sample period. In contrast, our calibration is a higher volatility than stablecoins like USDC and Tether which have an average quarterly volatility of between 0.1 and 0.2 percent (quarterly) volatility, respectively. We assume cryptocurrency price shocks are independent to other shocks, consistent with an empirical literature documenting a disconnect between bitcoin returns and macroeconomic fundamentals (Benigno and Rosa 2023; Umar et al. 2021; Pyo and Lee 2020; Marmora 2022). We assume a serial correlation coefficient of 0.85 (quarterly) for all our exogenous shock processes except for the cryptocurrency price process which we assume to be a transitory shock.

We provide steady state values and a variance decomposition for our baseline model and an economy without cryptocurrencies in Appendix A.4. The cryptocurrency economy has higher output and consumption for the unbanked households but lower for the banked

44. Data reference: https://data.worldbank.org/indicator/NY.GNS.ICTR.ZS?locations=SV.

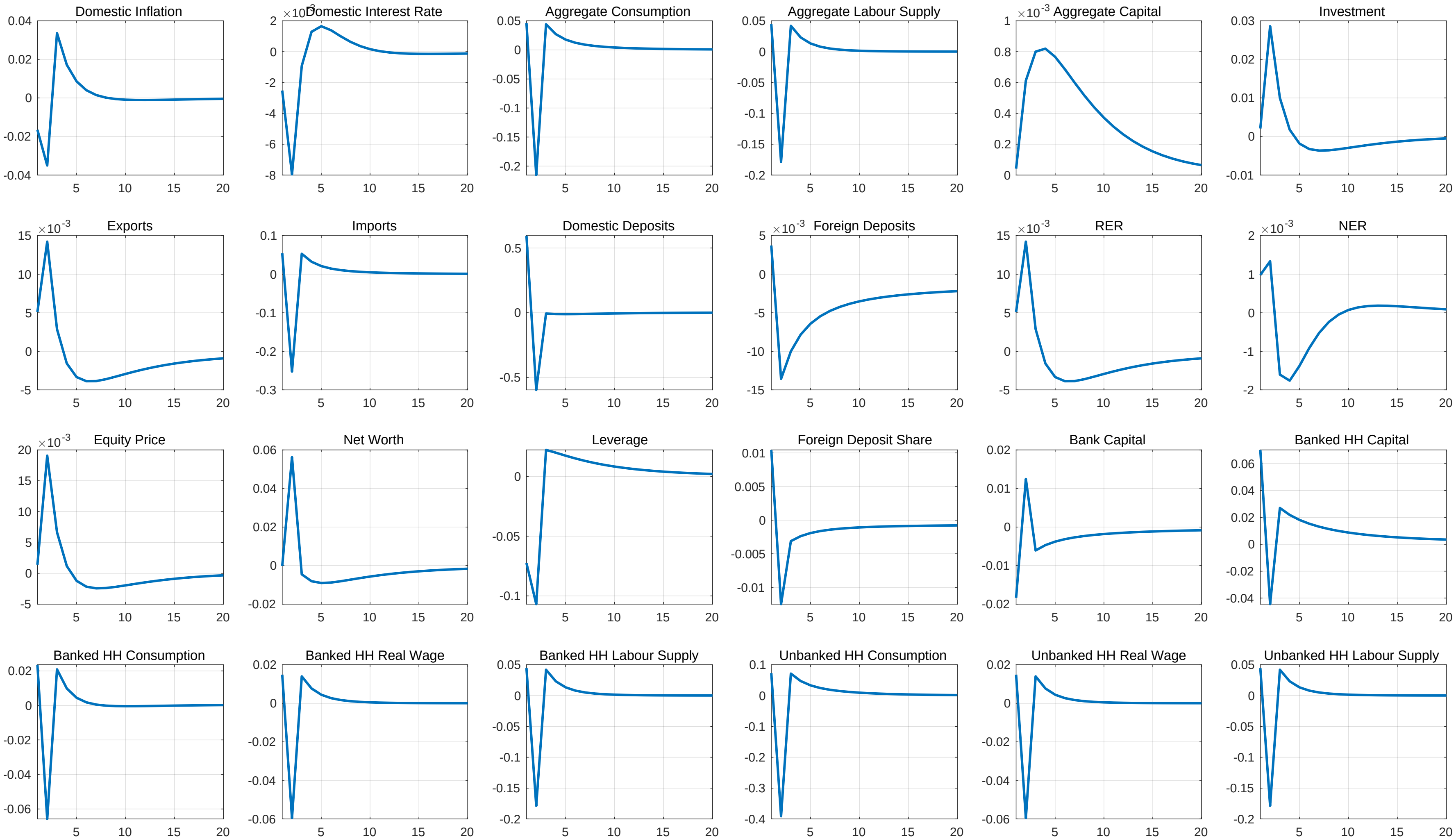
45. https://datatopics.worldbank.org/g20fidata/country/el-salvador

households. We also conduct a variance decomposition, and report that productivity, foreign inflation, and interest rate shocks are the primary sources of shocks to the domestic economy, jointly accounting for approximately 90 percent of output and consumption.

Table 2: Baseline calibration

Parameter	Value	Description
β	0.9876	Household discount factor
$\zeta^h = \zeta^u$	1/3	Inverse-Frisch elasticity of labor supply
$\zeta_0^h = \zeta_0^u$	7.883	Labor supply capacity
$\varkappa^h$	0.0197	BHH direct finance cost
$\nu_h = \nu_u$	2	Cryptocurrency sub-utility parameter
ν_0^u	0.0011	Cryptocurrency sub-utility parameter of UHH
ν_0^h	0.0008	Cryptocurrency sub-utility parameter of BHH
θ	0.1	Elasticity of foreign financed leverage
θ^c	0.1	Elasticity of cryptocurrency financed leverage
θ_0	0.401	Bank moral hazard severity
σ	0.94	Banker survival probability
γ	0.0045	Fraction of total assets brought 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_h	0.1734	Production share of BHH
α_c	0.3466	Production share of UHH
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_c	0	Cryptocurrency price AR(1) coefficient

Figure 2: Cryptocurrency price shock (baseline specification)



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

5 Results

5.1 Baseline specification

We trace the effects of a negative 1 per cent standard deviation shock to cryptocurrency prices over 20 periods in Figure 2. A cryptocurrency disinflationary shock reduces holdings of cryptocurrency and a decline in the savings of unbanked households. This causes unbanked households to cut down their consumption. Through GHH preferences, the decline in consumption reduces labor supply by unbanked households and a decline in the real wage. The general level of prices declines, and is accompanied with a peak decline in aggregate consumption of approximately 0.2%. Banked households also experience an initial decline in consumption. Their effects are muted relative to unbanked households as they do not hold cryptocurrency directly. Instead, their consumption losses are 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 the value of their cryptocurrency liabilities causes an increase in net worth of bankers. There is a reallocation toward holding more domestic and foreign 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.

5.2 Welfare analysis and stablecoin solution

To assess the potential costs and benefits of introducing cryptocurrency, we explore its effect on welfare of the banked and unbanked households. First, we setup a simple comparison of the household utility in the deterministic steady state with the cryptocurrency economy and crypto-autarky economy. To avoid any spurious welfare effects of holding cryptocurrency balances, we omit cryptocurrencies from the utility function of households in the following calculations. The welfare gains of adopting cryptocurrencies in the deterministic steady state are:

$$\begin{aligned}
\text{BHH:}\ & \ln\left(C^h - \zeta_0^h \frac{(L^h)^{1+\zeta^h}}{1+\zeta^h}\right)\Bigg|_{\text{crypto}} - \ln\left(C^h - \zeta_0^h \frac{(L^h)^{1+\zeta^h}}{1+\zeta^h}\right)\Bigg|_{\text{no crypto}} \\
& = 1.3750 - 1.3770 = -0.2\%, \\
\text{UHH:}\ & \ln\left(C^u - \zeta_0^u \frac{(L^u)^{1+\zeta^u}}{1+\zeta^u}\right)\Bigg|_{\text{crypto}} - \ln\left(C^u - \zeta_0^u \frac{(L^u)^{1+\zeta^u}}{1+\zeta^u}\right)\Bigg|_{\text{no crypto}} \\
& = 0.2109 - 0.2096 = 0.13\%.
\end{aligned}$$

Absent of shocks, this simple comparison indicates that the unbanked are made better off at the expense of banked households due to the introduction of cryptocurrencies.

We next repeat this exercise but we subject the economies to shocks, following the calibration strategy outlined in Section 4.7. To see how welfare scales with respect to volatility of cryptocurrency prices, Figure 3 plots the welfare gain for each household type over the no-cryptocurrency autarky economy for different levels of cryptocurrency price volatility. Welfare for the unbanked household is declining in cryptocurrency price volatility but relatively stable for the banked. Thus, the synthetic aggregate household welfare is decreasing in cryptocurrency price volatility. Based on the estimates in Figure 3, the gains for the banked household are -0.0335% and 0.3081% for the unbanked. Increasing the volatility of cryptocurrency prices to 5% implies welfare gains of -0.0151% and -0.0390% for the banked and unbanked household, respectively. Introducing cryptocurrencies to the economy with higher price volatility leads to slightly lower welfare losses for the banked households, at the expense of higher welfare losses for the unbanked.

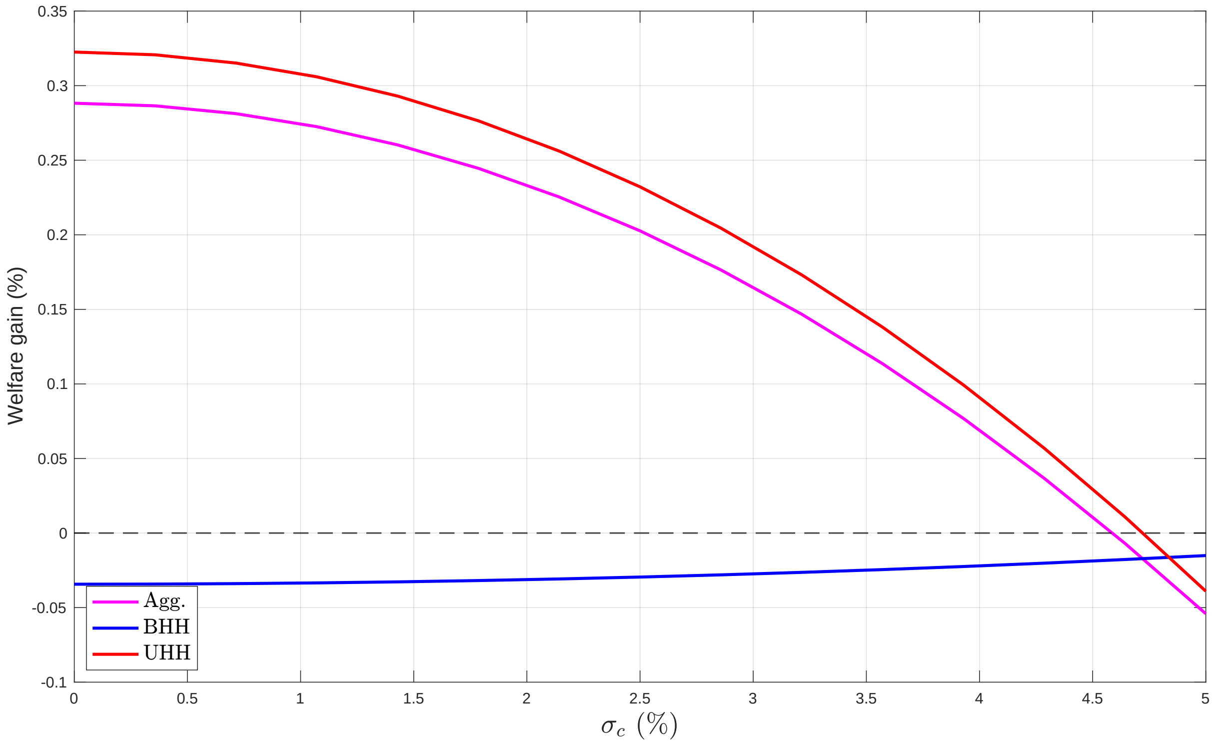
For unbanked households, we numerically determine a cutoff level of volatility σ_c of approximately 4.75% (quarterly), above which unbanked households experience net welfare losses relative to an economy with no cryptocurrency. Our analysis suggests for small levels of volatility of the cryptocurrency, the household benefits from holding a fraction of their income as savings, which helps stabilize consumption in the event of adverse shocks. For banked households, we find that the welfare in the baseline equilibrium is always lower than welfare in autarky. This is due to the general equilibrium effects of the cryptocurrency price shock, in which banks face exposure via balance sheet effects that affect lending.

At a high level of volatility – for example, Bitcoin's average quarterly volatility of 70% between January 2017 to September 2021 – 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. 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. Through the lens of our model, the benefits of consumption smoothing through savings in a stablecoin offset the costs of cryptocurrency volatility.

5.3 Monetary policy implications

Adrian and Weeks-Brown (2021) have opposed the El Salvador 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 (2022) show theoretically that when a cryptocurrency is freely circulating with domestic currencies in a two country economy,

Figure 3: Welfare gains and cryptocurrency price volatility



Note: Figure plots welfare gains for three different types of households: unbanked, banked and a representative household that aggregates consumption of unbanked and banked households. Welfare gains are calculated for varying levels of cryptocurrency price volatility. Welfare gains are with respect to an economy with no cryptocurrency deposits. The first moment of welfare is calculated using a second order log-linear approximation to the steady state.

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 cryptocurrency autarky economy. Our simulation for a unit standard deviation domestic monetary policy shock are presented in Figure 4.

In response to a positive orthogonalized shock to the domestic interest rate, 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; Bernanke, Gertler, and Gilchrist 1999; Gertler and Kiyotaki 2015): There is a reduction in net worth and asset prices through an increase in 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 find that the emergence of cryptocurrencies attenuates the direct impact of monetary policy on bank balance sheets. In Figure 4, we observe that in the baseline cryptocurrency economy, there is a smaller peak decline in consumption. The economic intuition is that in the cryptocurrency economy, the share of domestic deposits on the bank balance sheet is lower. Therefore, there are smaller effects of the contraction in domestic deposits on investment, output, and consumption. The results broadly support Adrian and Weeks-Brown (2021) by showing that the adoption of a cryptocurrency can lead to reduced effectiveness of interest rates to stabilize inflation and output. Our findings of an introduction of digital currency attenuating monetary policy transmission support Ikeda (2020) too.[46]

5.4 Global financial cycle considerations

In this section we repeat the exercise in Section 5.3 but with a foreign interest rate shock, akin to a global financial shock as documented in Rey (2015, 2016), in which international capital markets degrade the country's credit ratings, leading to capital outflows and higher yields on foreign debt. In our setup, the foreign interest rate shock is equivalent to an increase in the risk premium on foreign currency debt.

In Figure 5, a foreign interest rate increase causes investors to pursue higher yields overseas, leading to a capital outflow and exchange rate depreciation. 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. However, here the foreign interest rate increase affects the nominal exchange rate, leading to an increase in the liabilities of the banking sector to foreign creditors. Thus, a decline in the cost advantage of foreign currency debt over home deposits causes a reduction in the bank net worth and leverage ratio, and increases the ratio of the bank's share of foreign debt to equity. 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. The fall in lending and thus productive capacity of the domestic economy outweighs the increase in exports arising from the exchange rate depreciation. The domestic economy can no longer export their way to growth due to exogenous global financial conditions, and thus the classic Mundell-Fleming-Dornbusch story breaks (Dedola, Rivolta, and Stracca 2017; Miranda-Agrippino and Rey 2020).[47]

Similar to our results on domestic monetary policy transmission, we observe that in the baseline cryptocurrency economy, there is a smaller peak decline in consumption in response to a foreign monetary shock. The economic intuition is that in the cryp-

46. 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.

47. In our baseline calibration, we set $\omega_E = 0.5$, and so the domestic central bank weighs both domestic inflation and exchange rate fluctuations in setting the interest rate. But other studies such as by ABK and Akinci and Queraltó (2019) show similar qualitative results for other exchange rate regimes. Those studies find that fixed exchange rate regimes generally perform worse than floating exchange rate regimes, in line with the argument of Obstfeld (2015) that the "Impossible Trinity" still holds, albeit with more complex considerations. We avoid assessing the arguments for or against the monetary policy trilemma in this paper.

tocurrency economy, the share of foreign deposits on the bank balance sheet is lower. Therefore, there are smaller effects of the contraction in foreign deposits on investment, output, and consumption. The implication here is that for an EME, such as El Salvador, the circulation of cryptocurrencies as legal tender helps to buffer the effect of global financial shocks.

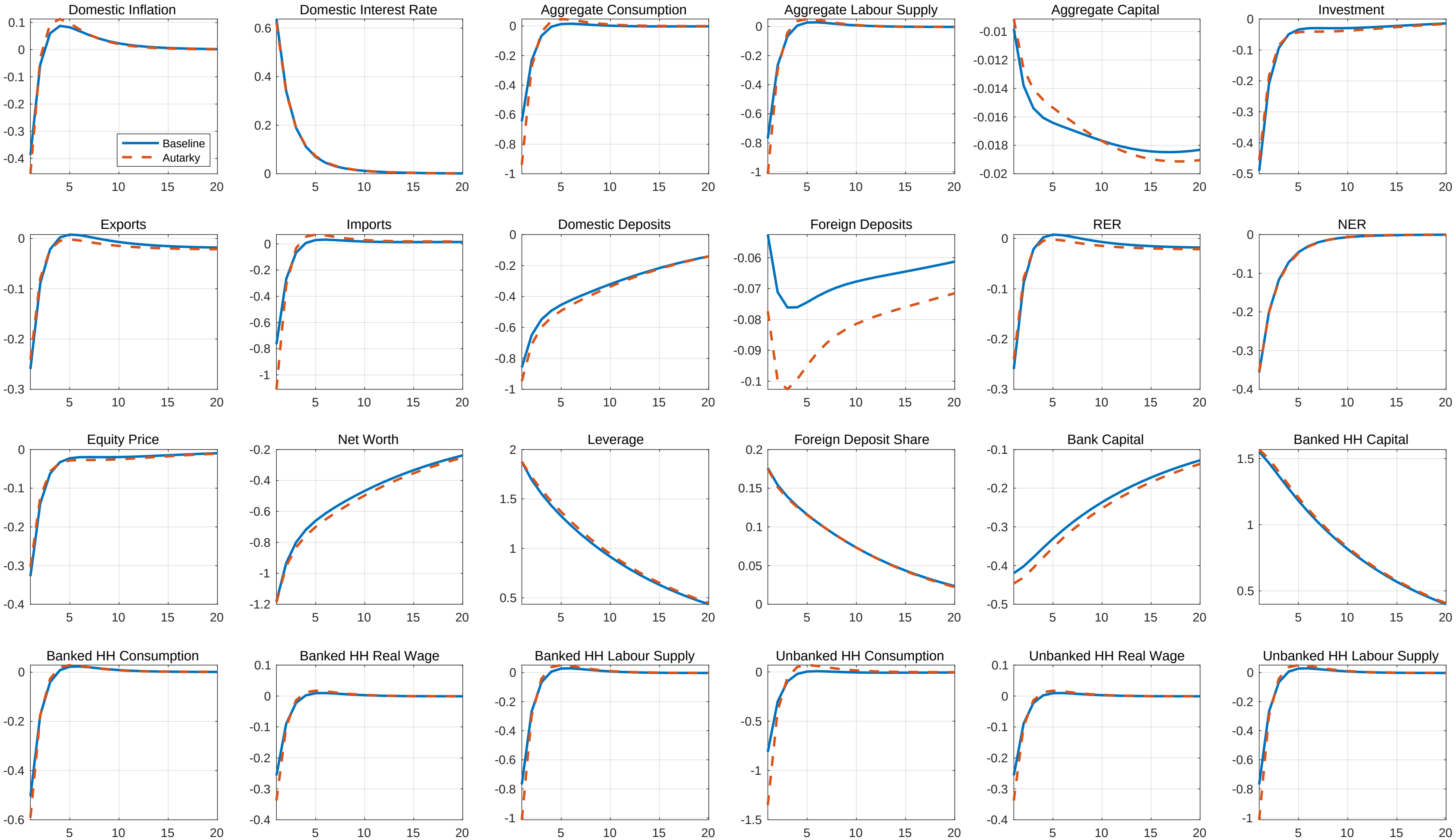
We can also test if shocks to productivity, foreign output, and foreign inflation are different in an economy with foreign digital currency deposits. Our results are provided in Appendix A.5 for consideration. Quantitatively, we find no evidence that the presence of cryptocurrency deposits significantly affects the response of real economic variables to the aforementioned shocks. Bank balance sheets are unaffected in response to productivity and foreign output shocks. Only nominal shocks, like a foreign inflation shock, affect bank balance sheets through a net worth channel.

5.5 Fixed versus floating exchange rates

The response of domestic interest rates to a cryptocurrency price shock depends on the exchange rate regime. Equation (46) 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 $\omega_E = 0.01$, in which the central bank uses interest rates to target the price level.

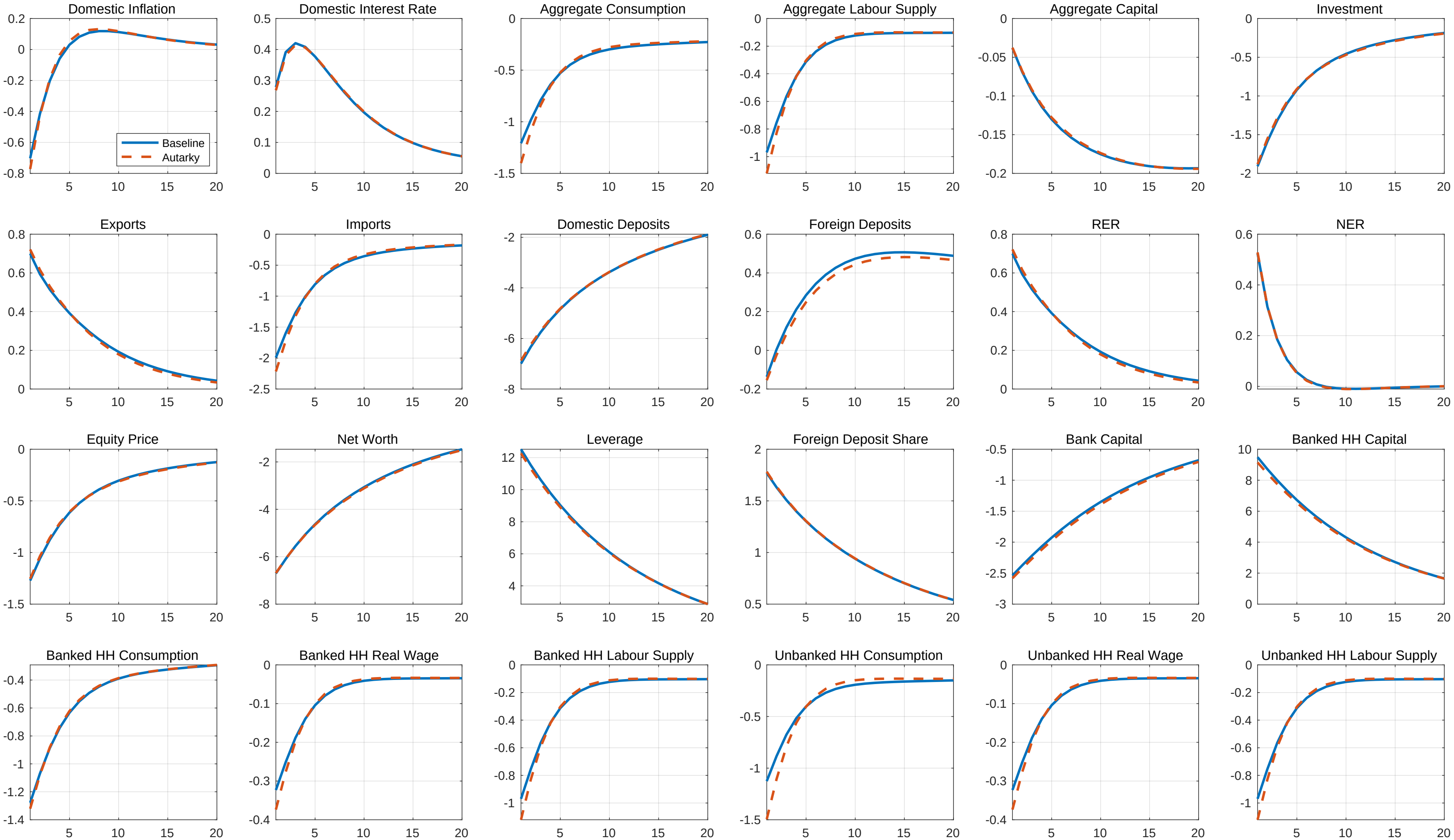
Figure 6 shows the results of the simulations in response to a standardized cryptocurrency price shock. In response to the contraction in output and consumption, prices decline. Comparing the two regimes, we find flexible exchange rates provide a buffer through a nominal exchange rate depreciation. By 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 aggregate consumption of 0.2% and 0.1% for the fixed and flexible exchange rate regimes, respectively. The decline in output, consumption, and investment in response to a cryptocurrency price shock is therefore dampened with a flexible exchange rate regime. The policy takeaway for an EME is that conditional on mandating a cryptocurrency as legal tender, a floating exchange rate softens the effects of cryptocurrency asset price shocks.

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



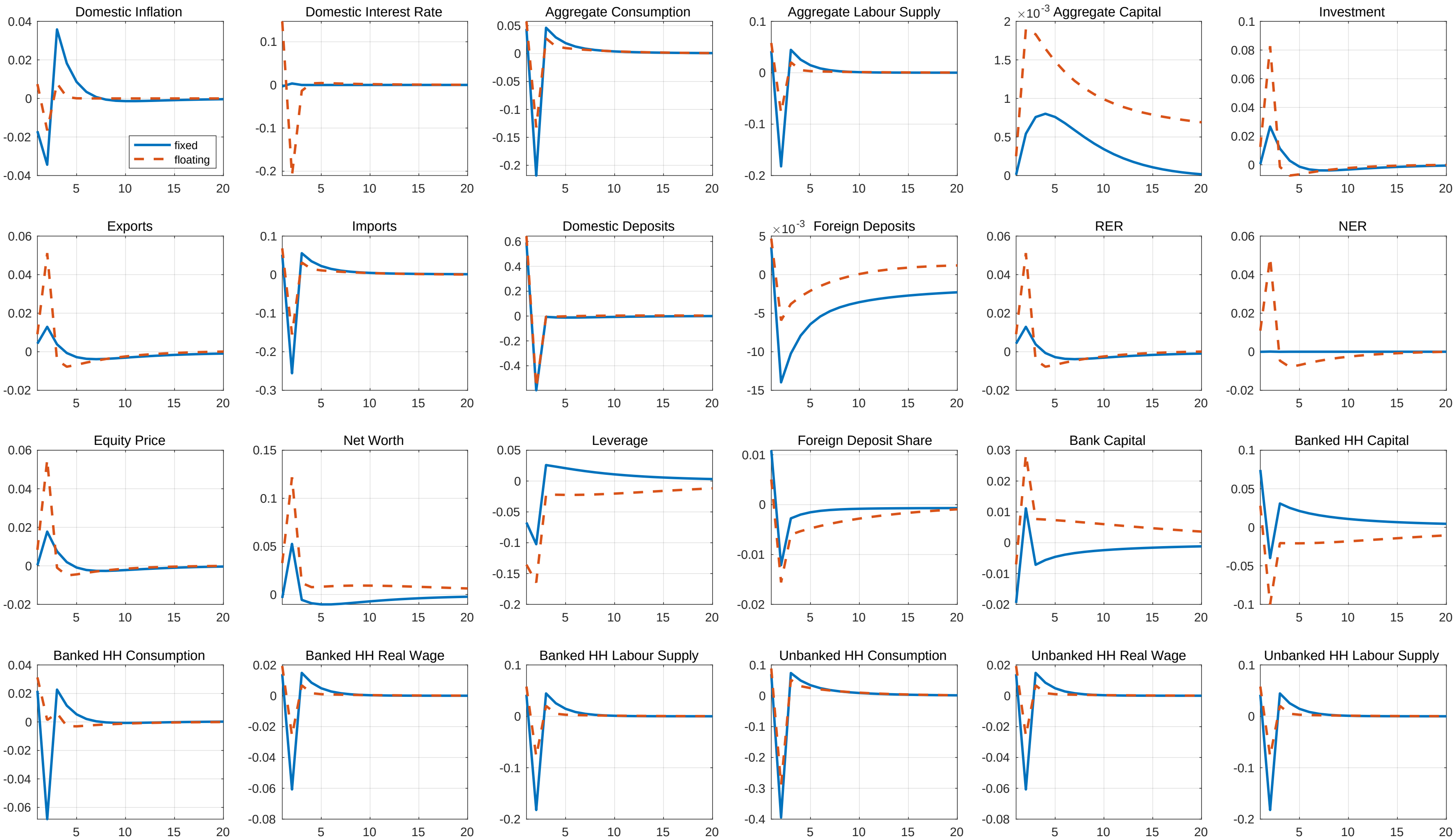
Note: Figure plots impulse responses of model variables with respect to a 1 standard deviation domestic interest rate shock. Time periods are measured in quarters, and responses are measured as a percent deviation from steady state. Domestic Inflation and Domestic Interest Rate are annualized. Solid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

Figure 5: Foreign interest rate shock: Baseline vs cryptocurrency 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 cryptocurrency deposits. Dashed line indicates an economy with zero cryptocurrency deposits (cryptocurrency autarky).

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



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

5.6 Welfare effects of monetary policy, risk premia and exchange rate regime

In Figure 7, we plot welfare level for different household types, compared to the autarky level, under varying levels of volatility of a domestic or foreign interest rate shock, and for different exchange rate regimes. Solid lines indicate a cryptocurrency volatility of 0 per cent, and dotted lines indicate a volatility of 3 per cent (quarterly). We measured welfare while also considering the impact of shocks to the domestic interest rate, foreign output, productivity, and foreign inflation. The welfare level for all three household types in the cryptocurrency economy are increasing in the volatility of domestic monetary policy and foreign risk premia shocks. Monetary policy shocks can increase the volatility of consumption for both types of households. However, in an economy with cryptocurrency deposits, the unbanked households can hedge interest rate risk by smoothing consumption. In the third panel of the Figure, we measure the welfare level for banked and unbanked households with respect to the exchange rate regime. The results show that adopting a cryptocurrency provides higher gains in a fixed exchange rate regime.

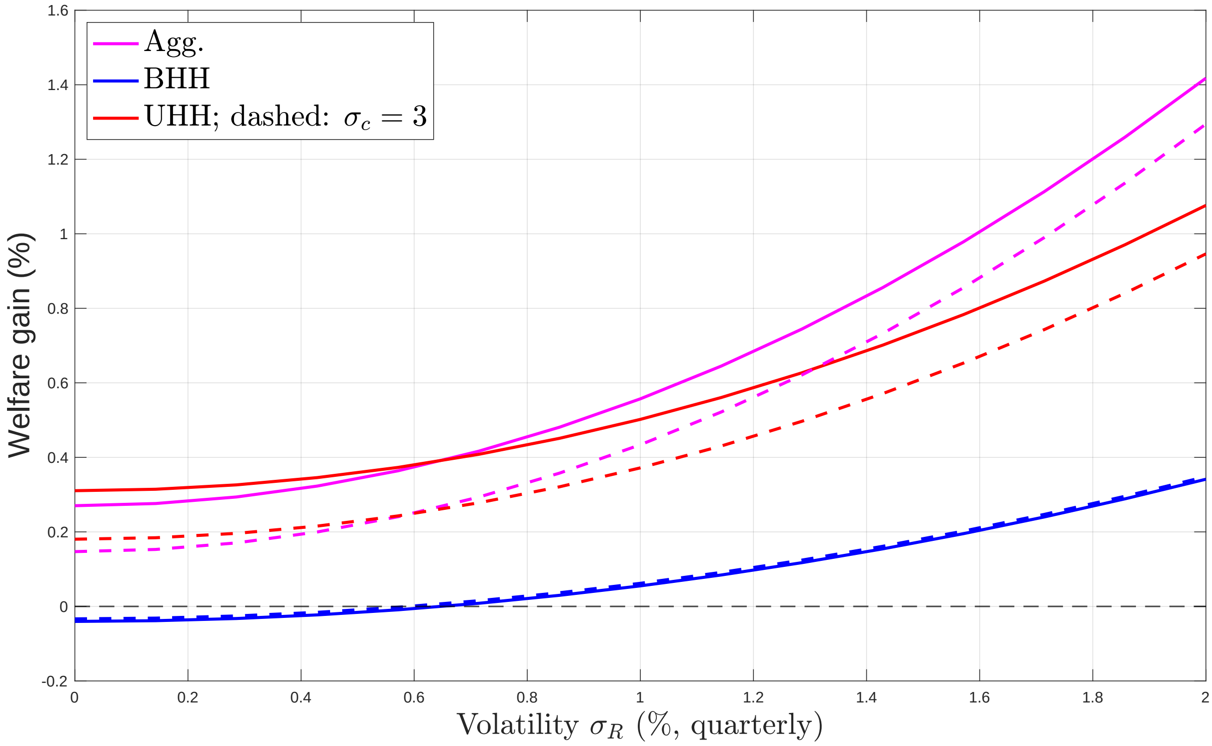
In sum, the welfare effects we observe in a cryptocurrency economy suggest cryptocurrencies help diversify macroeconomic risk. This is consistent with a recent empirical literature documenting the disconnect of Bitcoin returns from macroeconomic fundamentals (Benigno and Rosa 2023; Umar et al. 2021; Pyo and Lee 2020; Marmora 2022). Authors find that Bitcoin returns are unresponsive to FOMC and macroeconomic announcement releases, and are considered a potential hedge against macroeconomic uncertainty and inflation risk in emerging markets. Comparing the different sets of macroeconomic shocks, we find that the greatest welfare gains of using cryptocurrency are with respect to foreign risk premia shocks.

We provide additional results on our welfare analysis for consideration in Appendix A.6. Welfare gains are realized for a cryptocurrency economy with respect to shocks to foreign inflation, output and domestic productivity. This further supports the empirical observation that countries typically use cryptocurrencies as a hedge against macroeconomic risk and high inflation.[48] We also show that our welfare analysis is robust to different combinations of cryptocurrency volatility and the macroeconomic shock. In all cases, the aggregate and unbanked household welfare is increasing in the variance of macroeconomic shocks, however the welfare gains of diversification attenuate with higher levels of the cryptocurrency volatility.

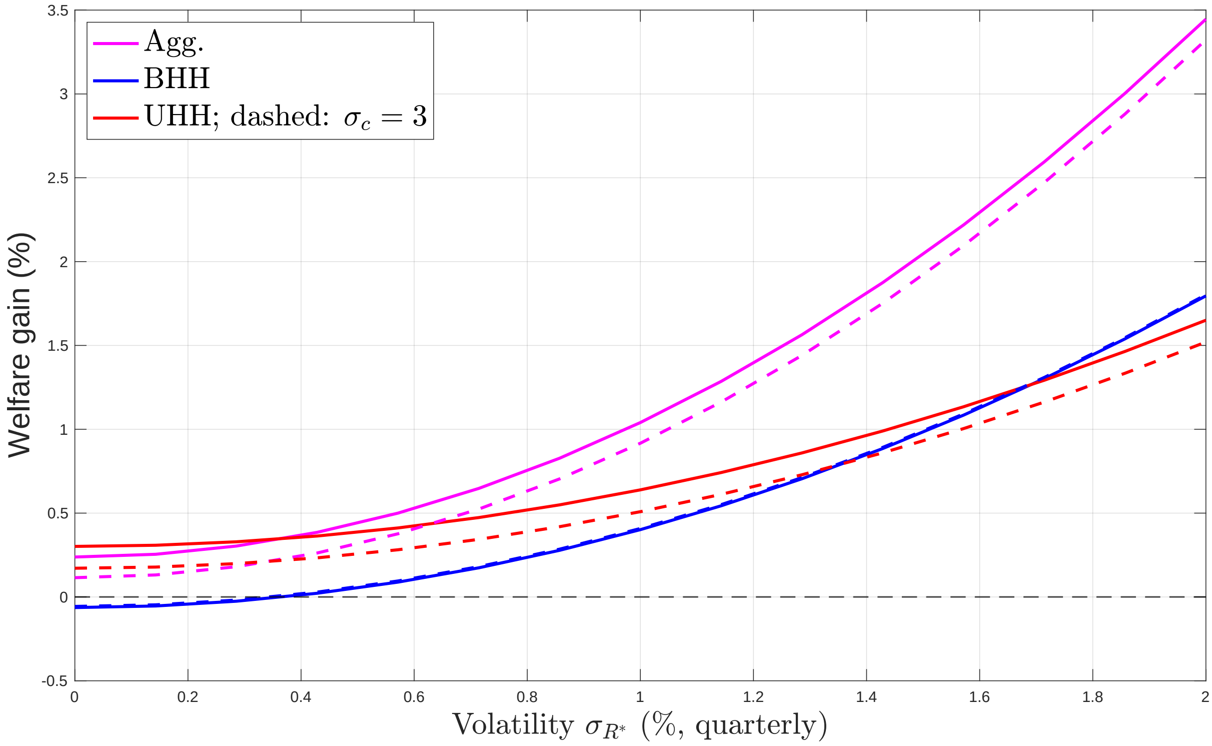
48. For a discussion of the benefits of stablecoin adoption in emerging markets, we refer readers to section 3.2

Figure 7: Welfare gains and domestic monetary policy, foreign risk premia and exchange rate regime

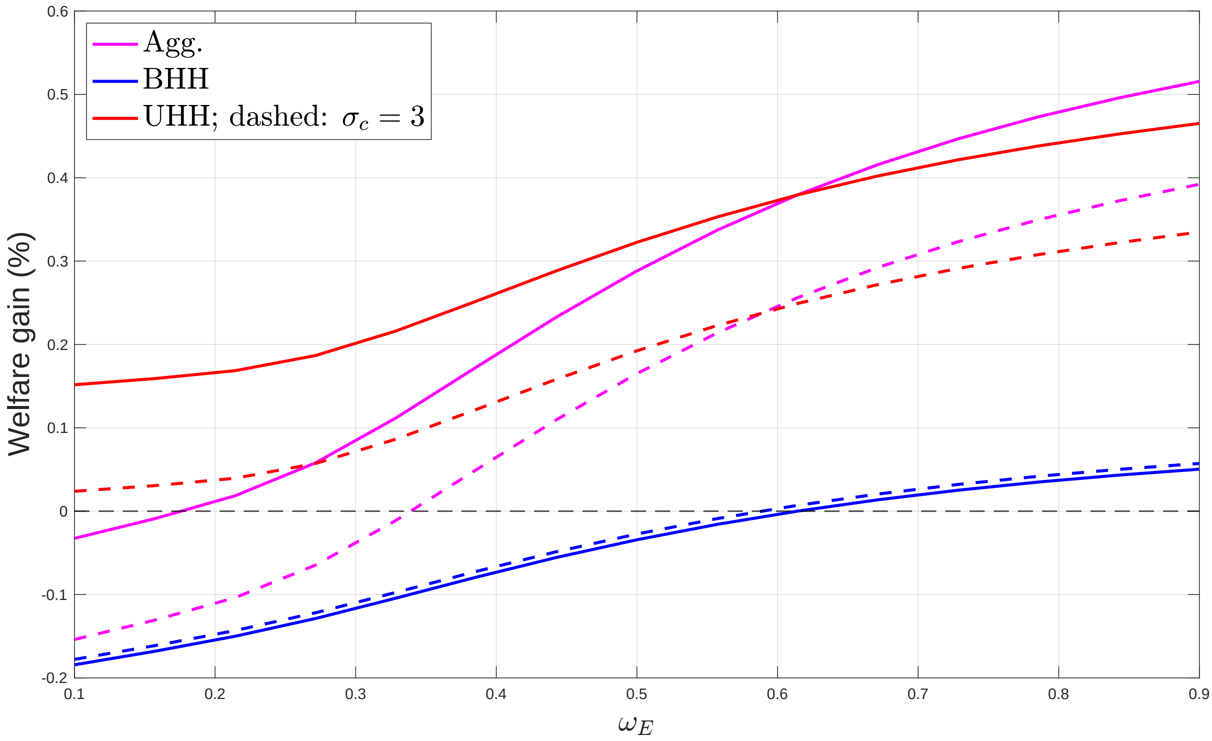
(a) Domestic monetary policy



(b) Foreign risk premia



(c) Exchange rate regime



Note: Figure plots welfare gains for three different types of households: unbanked, banked and a representative household that aggregates consumption of unbanked and banked households. In Figure 7a we compute welfare gains for different levels of volatility of domestic interest rates. In Figure 7b we compute welfare gains for different levels of volatility of foreign risk premia. In Figure 7c we compute welfare gains about the deterministic steady state for different FX regimes (where $\omega_E \to 1$ is a fixed exchange rate and $\omega_E \to 0$ is a floating exchange rate). Welfare gains are with respect to an economy with no cryptocurrency deposits. Solid lines indicate welfare gains are computed for a level of zero cryptocurrency price volatility. Dashed lines indicate welfare gains are computed for a positive level of cryptocurrency price volatility, $\sigma_c = 3$ percent (quarterly). The first moment of welfare is calculated using a second order log-linear approximation to the steady state.

6 Conclusion

In this paper we study the macroeconomic costs and benefits of El Salvador's monetary experiment to make a cryptocurrency, such as Bitcoin, legal tender by introducing a SOE model that features two types of households: those that hold domestic currency deposits and those that strictly hold cryptocurrency. Within this framework, we form a simple process for the adjustment of cryptocurrency deposits due to valuation effects. Valuation effects in cryptocurrencies lead to a change in the purchasing power of household cryptocurrency deposits, affecting consumption and labor decisions, and bank balance sheets. The model's baseline calibration predicts a 1 percent decline in cryptocurrency prices will cause a peak decline in aggregate consumption of approximately 0.2%.

In our analysis, we make the following 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 a cryptocurrency such as 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 that 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 cryptocurrencies attenuates 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 (2022) 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 the case in which households hold no cryptocurrency deposits, cryptocurrency 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. Defining a risk premium as an exogenous markup on foreign currency debt, we compute the relative welfare of an economy with the digital currency to an autarky economy for different levels of risk premia. Our results suggest large welfare benefits for the unbanked. These households can use cryptocurrency to smooth consumption and dampen the negative effects of an increase in risk premia.

Fourth, we test if the effects of introducing cryptocurrency as legal tender 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 cryptocurrency price shocks. This supports the Obstfeld (2015) view that monetary independence plays a key role in insulation from foreign shocks to the economy.

Finally, we conduct a welfare analysis with respect to macroeconomic shocks to domestic monetary policy, foreign risk premia and the choice of exchange rate regime. The welfare gains of unbanked households in an economy with cryptocurrencies are increasing in the volatility of macroeconomic shocks and for a fixed exchange rate regime. Taken together, our findings motivate why emerging markets use stablecoins as a hedge against macroeconomic instability and high inflation.

References

Adrian, Tobias, and Rhoda Weeks-Brown. 2021. *Cryptoassets as National Currency? A Step Too Far.* Edited by IMF Blog. [Online; posted 26-July-2021]. %5Curl%7Bhttps://blogs.imf.org/2021/07/26/cryptoassets-as-national-currency-a-step-too-far/%7D.

Ahmed, Shaghil, Ozge Akinci, and Albert Queralto. 2021. "US Monetary Policy Spillovers to Emerging Markets: Both Shocks and Vulnerabilities Matter." *FRB of New York Staff Report,* no. 972.

Akinci, Ozge, and Albert Queraltó. 2019. "Exchange Rate Dynamics and Monetary Spillovers with Imperfect Financial Markets." *International Finance Discussion Papers (Board of Governors of the Federal Reserve System),* no. 1254.

Alvarez, Fernando E, David Argente, and Diana Van Patten. 2022. *Are Cryptocurrencies Currencies? Bitcoin as Legal Tender in El Salvador.* Technical report. National Bureau of Economic Research.

Aoki, Kosuke, Gianluca Benigno, and Nobuhiro Kiyotaki. 2016. "Monetary and Financial Policies in Emerging Markets." *working paper.*

Aycinena, Diego, CA Martinez, and Dean Yang. 2010. "The impact of transaction fees on migrant remittances: Evidence from a field experiment among migrants from el salvador." *University of Michigan.*

Baughman, Garth, and Jean Flemming. 2020. "Global Demand for Basket-Backed Stablecoins."

Benigno, Gianluca, and Carlo Rosa. 2023. "The Bitcoin–Macro Disconnect." *FRB of New York Staff Report,* no. 1052.

Benigno, Pierpaolo. 2022. "Monetary Policy in a World of Cryptocurrencies." *Journal of the European Economic Association,* https://doi.org/10.1093/jeea/jvac066.

Benigno, Pierpaolo, Linda M Schilling, and Harald Uhlig. 2022. "Cryptocurrencies, currency competition, and the impossible trinity." *Journal of international economics* 136:103601.

Bernanke, Ben S., Mark Gertler, and Simon Gilchrist. 1999. "The Financial Accelerator in a Quantitative Business Cycle Framework." *Handbook of Macroeconomics* 1 (C): 1341–1393.

Blanchard, Olivier J., and Nobuhiro Kiyotaki. 1987. "Monopolistic Compeitition and the Effects of Aggregate Demand." *American Economic Review* 77 (4): 647–666.

Calvo, Guillermo A. 1998. "Capital Flows and Capital-Market Crises: The Simple Economics of Sudden Stops." *Journal of Applied Economics* 1:35–54.

Christiano, Lawrence J., Martin S. Eichenbaum, and Charles L. Evans. 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy* 113 (1): 1–45.

Clarida, Richard, Jordi Galí, and Mark Gertler. 1999. "The Science of Monetary Policy: A New Keynesian Perspective." *Journal of Economic Literature* 37 (4): 1661–1707.

Cong, Lin William, and Simon Mayer. 2021. "The Coming Battle of Digital Currencies." *Available at SSRN 3992815.*

Dedola, Luca, Giulia Rivolta, and Livio Stracca. 2017. "If the Fed Sneezes, Who Catches a Cold?" *Journal of International Economics* 108:S23–S41.

Drechsel, Thomas, and Silvana Tenreyro. 2018. "Commodity booms and busts in emerging economies." *Journal of International Economics* 112:200–218.

Eberly, Janice C. 1997. "International Evidence on Investment and Fundamentals." *European Economic Review* 41 (6): 1055–1078.

Ferrari Minesso, Massimo, Arnaud Mehl, and Livio Stracca. 2022. "Central Bank Digital Currency in an Open Economy." *Journal of Monetary Economics* 127:54–68.

Galí, Jordi, and Tommaso Monacelli. 2005. "Monetary Policy and Exchange Rate Volatility in a Small Open Economy." *Review of Economic Studies* 72 (3): 707–734.

———. 2016. "Understanding the Gains from Wage Flexibility: The Exchange Rate Connection." *American Economic Review* 106 (12): 3829–3968.

George, Ammu, Taojun Xie, and Joseph D Alba. 2020. "Central bank digital currency with adjustable interest rate in small open economies." *Available at SSRN 3605918.*

Gertler, Mark, Simon Gilchrist, and Fabio M. Natalucci. 2007. "External Constraints on Monetary Policy and the Financial Accelerator." *Journal of Money, Credit and Banking* 39 (2-3): 295–330.

Gertler, Mark, and Peter Karadi. 2011. "QE 1 vs 2 vs 3... A Framework for Analyzing Large Scale Asset Purchase Programs as a Monetary Policy Tool." *International Journal of Central Banking* 9 (S1): 5–53.

Gertler, Mark, and Nobuhiro Kiyotaki. 2010. "Financial Intermediation and Credit Policy in Business Cycle Analysis." *Handbook of Monetary Economics* 3:547–599.

———. 2015. "Banking, Liquidity, and Bank Runs in an Infinite Horizon Economy." *American Economic Review* 105 (7): 2011–2043.

Gopinath, Gita, Emine Boz, Camila Casas, Federico J Dıíez, Pierre-Olivier Gourinchas, and Mikkel Plagborg-Møller. 2020. "Dominant currency paradigm." *American Economic Review* 110 (3): 677–719.

Gourinchas, Pierre-Olivier. 2018. "Monetary Policy Transmission in Emerging Markets: An Application to Chile." Edited by Enrique G. Mendoza, Ernesto Pastén, and Diego Saravia, Central Banking, Analysis, and Economic Policies Book Series, 25:279–324.

Hanke, Steve, Nicholas Hanlon, Mihir Chakravarthi, et al. 2021. "Bukele's Bitcoin Blunder."

Ikeda, Daisuke. 2020. "Digital Money as a Unit of Account and Monetary Policy in Open Economies" (December).

Kiyotaki, Nobuhiro, and John Moore. 1997. "Credit Cycles." *Journal of Political Economy* 105 (2): 211–248.

Kulish, Mariano, and Daniel M Rees. 2017. "Unprecedented changes in the terms of trade." *Journal of International Economics* 108:351–367.

Kumhof, Michael, Marco Pinchetti, Phurichai Rungcharoenkitkul, and Andrej Sokol. 2021. "Central bank digital currencies, exchange rates and gross capital flows." *Paper presented at ECB International aspects of digital currencies and fintech.*

Marmora, Paul. 2022. "Does monetary policy fuel bitcoin demand? Event-study evidence from emerging markets." *Journal of International Financial Markets, Institutions and Money* 77:101489.

Mendoza, Enrique G. 2010. "Sudden Stops, Financial Crises, and Leverage." *American Economic Review* 100 (5): 1941–1966.

Miranda-Agrippino, Silvia, and Hélène Rey. 2020. "U.S. Monetary Policy and the Global Financial Cycle." *The Review of Economic Studies* 87 (6): 2754–2776.

Obstfeld, Maurice. 2015. "Trilemmas and Tradeoffs: Living with Financial Globalization." *Global Liquidity, Spillovers to Emerging Markets and Policy Responses (Central Banking, Analysis, and Economic Policies Book Series)* 20 (1): 13–78.

Obstfeld, Maurice, Jay C. Shambaugh, and Alan M. Taylor. 2005. "The Trilemma in History: Tradeoffs Among Exchange Rates, Monetary Policies, and Capital Mobility." *The Review of Economics and Statistics* 87 (3): 423–438.

Plassaras, Nicholas A. 2013. "Regulating digital currencies: bringing Bitcoin within the reach of IMF." *Chi. J. Int'l L.* 14:377.

Prasad, Eswar S. 2021. *The Future of Money: How the Digital Revolution is Transforming Currencies and Finance.* Harvard University Press.

Pyo, Sujin, and Jaewook Lee. 2020. "Do FOMC and macroeconomic announcements affect Bitcoin prices?" *Finance Research Letters* 37:101386.

Rey, Hélène. 2015. "Dilemma not Trilemma: The Global Financial Cycle and Monetary Policy Independence." *CEPR Discussion Papers* 10591.

———. 2016. "International Channels of Transmission of Monetary Policy and the Mundellian Trilemma." *IMF Economic Review* 64 (1): 6–35.

Rotemberg, Julio J. 1982. "Sticky Prices in the United States." *Journal of Political Economy* 90 (6): 1187–1211.

Routledge, Bryan, and Ariel Zetlin-Jones. 2021. "Currency stability using blockchain technology." *Journal of Economic Dynamics and Control,* 104155.

Schmitt-Grohé, Stephanie, and Martín Uribe. 2003. "Closing Small Open Economy Models." *Journal of International Economics* 61:163–185.

———. 2004. "Solving Dynamic General Equilibrium Models using a Second-Order Approximation to the Policy Function." *Journal of Economic Dynamics and Control* 28 (4): 755–775.

Schmitt-Grohé, Stephanie, and Martin Uribe. 2001. "Stabilization policy and the costs of dollarization." *Journal of money, credit and banking,* 482–509.

Skeie, David R. 2019. "Digital currency runs." *Available at SSRN 3294313.*

Smets, Frank, and Rafael Wouters. 2007. "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review* 97 (3): 586–606.

Subacci, Paola. 2021. *In Bitcoin we Trust.* Edited by Project Syndicate. [Online; posted 24-June-2021]. %5Curl%7Bhttps://www.project-syndicate.org/commentary/risks-of-el-salvador-adopting-bitcoin-by-paola-subacchi-2021-06%7D.

Suri, Tavneet, and William Jack. 2016. "The long-run poverty and gender impacts of mobile money." *Science* 354 (6317): 1288–1292.

Taylor, John B. 1996. "How Should Monetary Policy Respond to Shocks While Maintaining Long-Run Price Stability? Conceptual Issues." *Achieving Price Stability (Federal Reserve Bank of Kansas City),* 181–195.

———. 2007. "Housing and Monetary Policy." *NBER Working Paper* 13682.

Umar, Muhammad, Chi-Wei Su, Syed Kumail Abbas Rizvi, and Xue-Feng Shao. 2021. "Bitcoin: A safe haven asset and a winner amid political and economic uncertainties in the US?" *Technological Forecasting and Social Change* 167:120680.

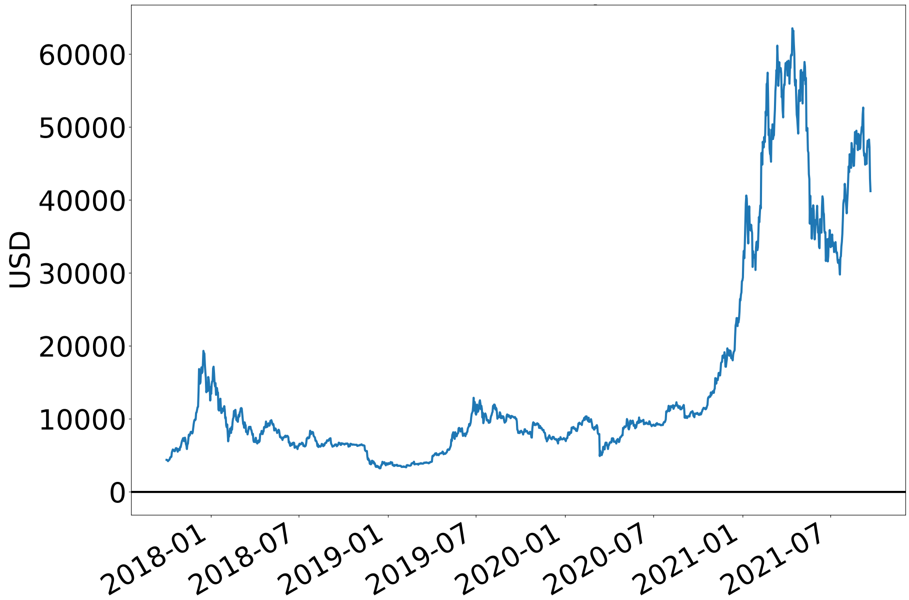
Woodford, Michael. 2003. *Interest and Prices.* Princeton University Press.

A Appendix

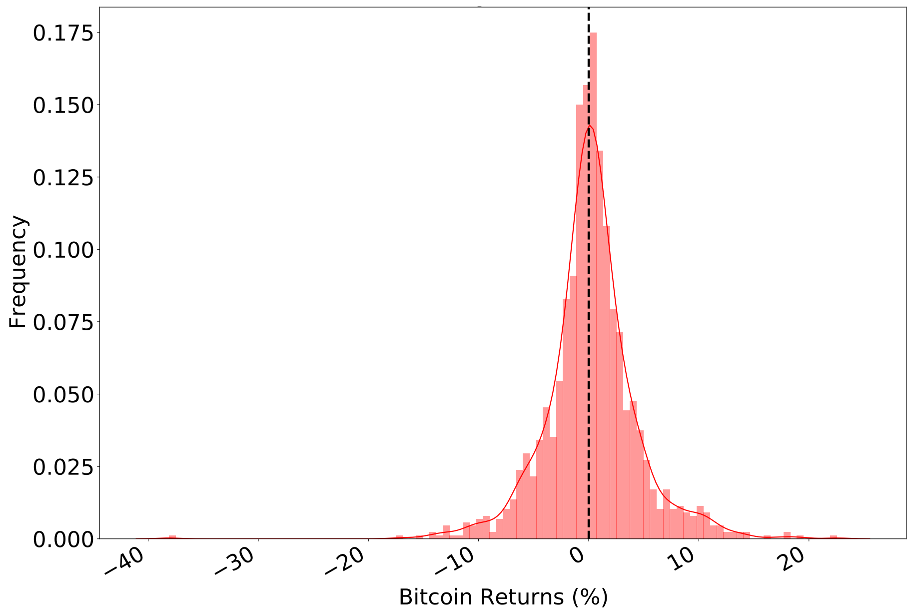
A.1 Figures

Figure 8: Bitcoin prices and returns

(a) Bitcoin prices



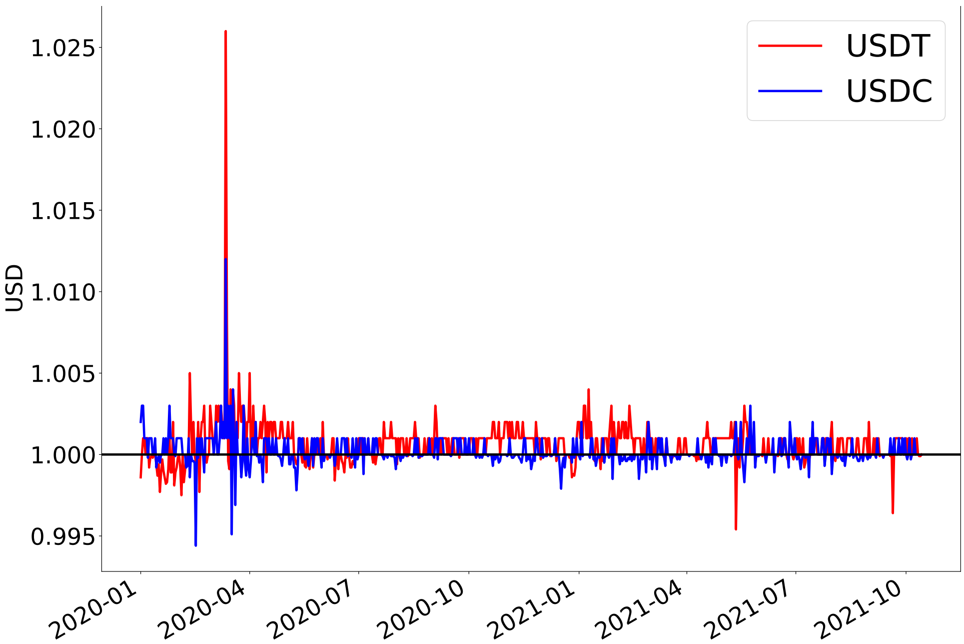
(b) Bitcoin returns (daily)



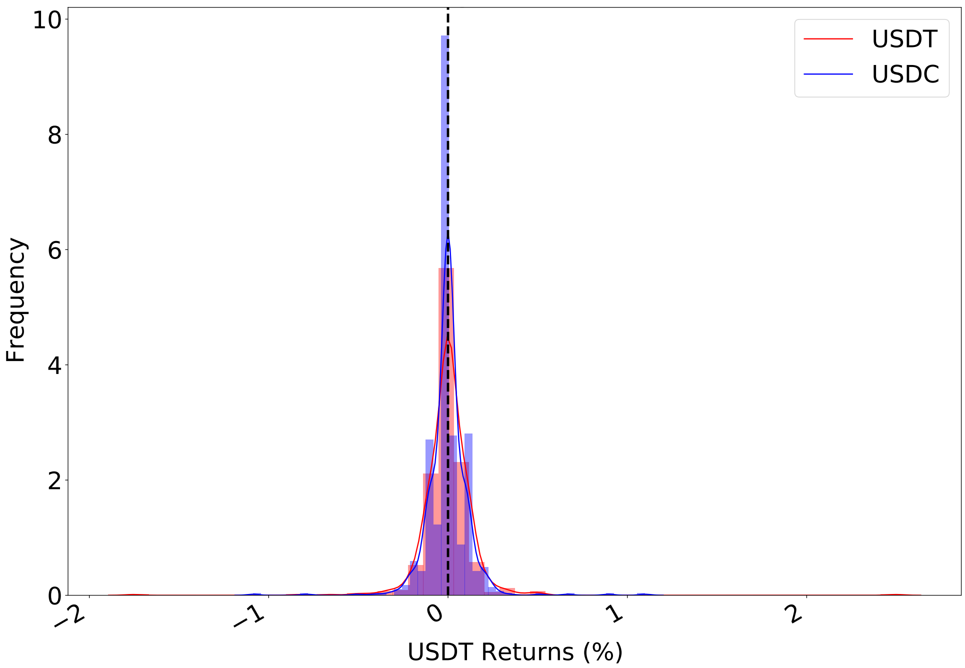
Note: Figure 8a: Bitcoin prices from January 2018 to September 2019. Figure 8b: Histogram of daily returns. Source: Cryptocompare.

Figure 9: Stablecoin prices and returns

(a) Stablecoin prices

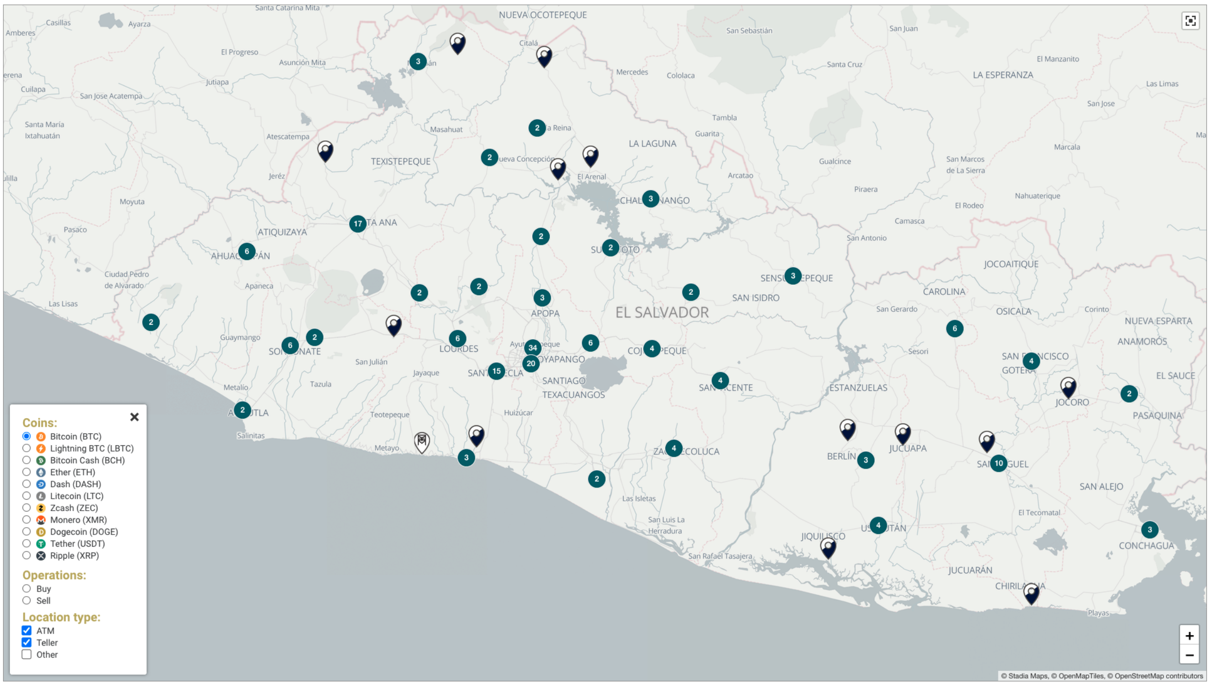


(b) Stablecoin returns (daily)



Note: Figure 9a: Stablecoins Tether, USDC, and DAI prices from January 2020 to September 2021. Figure 9b: Histogram of daily returns. Source: Cryptocompare.

Figure 10: 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 extended solutions

A.2.1 Rewriting and solving the banker's problem

With the constraints of the banker established in Section 4.2.1, we can proceed to write the banker's problem as:

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

subject to the incentive constraint (19) and the balance sheet constraint (20).

As discussed in Section 4.2.2, dividing $\mathbb{V}_t^b$ by n_t yields a Tobin Q expression of the form:

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

where the evolution of net worth, n_{t+1}/n_t, is attained by simply iterating banker's flow of funds constraint (21) forward by one period, and then divide through by n_t:

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

Rearrange the balance sheet constraint (20) 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 (22), yields the following:

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

with μ_t, μ_t, μ_t^*, μ_t^c, υ_t, and $\Omega_{t,t+1}$ as defined in Section 4.2.2.

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 are:

$$(1+\lambda_t)\left[\mu_t + \mu_t^* x_t + \mu_t^c x_t^c - \frac{\varkappa^b}{2}x_t^2\upsilon_t\right] = \lambda_t\Theta(x_t, x_t^c), \tag{60}$$

$$(1+\lambda_t)\left[\varkappa^b x_t\upsilon_t - \mu_t^*\right] = \theta\lambda_t\Theta(x_t, x_t^c), \tag{61}$$

$$\psi_t = \phi_t\Theta(x_t, x_t^c). \tag{62}$$

Use (62) and substitute into the banker's objective function to yield:

$$\phi_t = \frac{(1+\tau_t^N)\upsilon_t}{\Theta(x_t, x_t^c) - \mu_t - \mu_t^* x_t - \mu_t^c x_t^c + \frac{\varkappa^b}{2}x_t^2\upsilon_t}. \tag{63}$$

Then, combine (60) and (61) 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

$$x_t = \frac{\theta\mu_t^* - \varkappa^b\upsilon_t}{\theta\varkappa^b\upsilon_t} + \sqrt{\left(\frac{\mu_t^*}{\varkappa^b\upsilon_t}\right)^2 + 2\frac{\mu_t^c}{\varkappa^b\upsilon_t}x_t^c + \left(\frac{1}{\theta}\right)^2 + 2\frac{\mu_t}{\varkappa^b\upsilon_t}}. \tag{64}$$

These expressions are (31) and (32) in the main body of the text. This concludes the problem and optimal choices of the banker.

A.3 Model overview

A competitive equilibrium is a set of 11 prices, $\{E_t, mc_t, Q_t, R_t, R_t^c, w_t^h, w_t^u, z_t^k, \epsilon_t, \Pi_t, \tau^N\}$; 19 quantity variables, $\{B_t, B_t^h, B_t^u, C_t, C_t^h, C_t^u, D_t, D_t^*, EX_t, I_t, K_t, K_t^b, K_t^h, L_t, L_t^h, L_t^u, M_t, N_t, Y_t\}$; 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, $\{A_t, P_t^c\}$, which satisfy 43 equations. In addition to the baseline economy, we solve for the cryptocurrency autarky economy by setting cryptocurrency deposits to zero ($B = 0$), which in turn makes the share of the bank balance sheet in cryptocurrencies zero ($x^c = 0$). The first order condition with respect to cryptocurrency deposits is no longer needed, and so R^c and P^c are no longer required.

Households.

$$
\begin{aligned}
w_t^h &= \zeta_0^h (L_t^h)^{\zeta^h} && (65)\\
1 &= \mathbb{E}_t \left[\Lambda_{t,t+1}^h \frac{z_{t+1}^k + \lambda Q_{t+1}}{Q_t + \varkappa^h \frac{K_t^h}{K_t}} \right] && (66)\\
1 &= \mathbb{E}_t \left[\Lambda_{t,t+1}^h \frac{R_t}{\Pi_{t+1}} \right] && (67)\\
1 &= \mathbb{E}_t \left[\Lambda_{t,t+1}^h \frac{R_t^c}{\Pi_{t+1}} \right] + \nu_0^h \frac{\left(C_t^h - \zeta_0^h \frac{(L_t^h)^{1+\zeta_h}}{1+\zeta_h} \right)}{(B_t^h)^{\nu_h}} && (68)\\
C_t^u + B_t^u &= w_t^u L_t^u + \frac{R_{t-1}^c}{\Pi_t} B_{t-1}^u && (69)\\
w_t^u &= \zeta_0^u (L_t^u)^{\zeta^u} && (70)\\
1 &= \mathbb{E}_t \left[\Lambda_{t,t+1}^u \frac{R_t^c}{\Pi_{t+1}} \right] + \nu_0^u \frac{\left(C_t^u - \zeta_0^u \frac{(L_t^u)^{1+\zeta_u}}{1+\zeta^u} \right)}{(B_t^u)^{\nu_0^u}} && (71)
\end{aligned}
$$

Banks.

$$
\begin{aligned}
\mu_t &= \mathbb{E}_t \left[\Omega_{t,t+1} \left\{ \frac{z_{t+1}^k + \lambda Q_{t+1}}{Q_t} - (1+\tau_t^K) \frac{R_t}{\Pi_{t+1}} \right\} \right] && (72)\\
\mu_t^c &= \mathbb{E}_t \left[\Omega_{t,t+1} \left\{ (1-\tau_t^c) \frac{R_t}{\Pi_{t+1}} - \frac{R_t^c}{\Pi_{t+1}} \right\} \right] && (73)\\
\mu_t^* &= \mathbb{E}_t \left[\Omega_{t,t+1} \left\{ (1-\tau_t^{D^*}) \frac{R_t}{\Pi_{t+1}} - \frac{\epsilon_{t+1}}{\epsilon_t} \frac{R_t^*}{\Pi_{t+1}^*} \right\} \right] && (74)\\
\upsilon_t &= \mathbb{E}_t \left[\Omega_{t,t+1} \frac{R_t}{\Pi_{t+1}} \right] && (75)\\
\psi_t &= \phi_t \Theta(x_t, x_t^c) && (76)\\
\phi_t &= \frac{(1+\tau_t^N)\upsilon_t}{\Theta(x_t, x_t^c) - \mu_t - \mu_t^* x_t - \mu_t^c x_t^c + \frac{\varkappa^b}{2} x_t^2 \upsilon_t} && (77)\\
x_t &= \frac{\theta \mu_t^* - \varkappa^b \upsilon_t}{\theta \varkappa^b \upsilon_t} + \sqrt{\left(\frac{\mu_t^*}{\varkappa^b \upsilon_t} \right)^2 + 2 \frac{\mu_t^c}{\varkappa^b \upsilon_t} x_t^c + \left(\frac{1}{\theta} \right)^2 + 2 \frac{\mu_t}{\varkappa^b \upsilon_t}} && (78)
\end{aligned}
$$

Firms.

$$
\begin{aligned}
mc_t &= \frac{1}{A_t} (z_t^k)^{\alpha_K} \epsilon_t^{\alpha_M} (w_t^h)^{\alpha_h} (w_t^u)^{\alpha_u} && (79)\\
Y_t &= A_t \left(\frac{K_{t-1}}{\alpha_K} \right)^{\alpha_K} \left(\frac{M_t}{\alpha_M} \right)^{\alpha_M} \left(\frac{L_t^h}{\alpha_h} \right)^{\alpha_h} \left(\frac{L_t^u}{\alpha_u} \right)^{\alpha_u} && (80)\\
\frac{\epsilon_t M_t}{z_t^k K_{t-1}} &= \frac{\alpha_M}{\alpha_K} && (81)\\
\frac{w_t^h L_t^h}{z_t^k K_{t-1}} &= \frac{\alpha_h}{\alpha_K} && (82)
\end{aligned}
$$

$$\frac{w_t^u L_t^u}{z_t^k K_{t-1}} = \frac{\alpha_u}{\alpha_K} \tag{83}$$

$$(\Pi_t - 1)\Pi_t = \frac{1}{\kappa}(\eta mc_t + 1 - \eta) + \mathbb{E}_t\left[\Lambda_{t,t+1}^h \frac{Y_{t+1}}{Y_t}(\Pi_{t+1} - 1)\Pi_{t+1}\right] \tag{84}$$

$$K_t = \lambda K_{t-1} + I_t \tag{85}$$

$$Q_t = 1 + \Phi\left(\frac{I_t}{\bar{I}}\right) + \left(\frac{I_t}{\bar{I}}\right)\Phi'\left(\frac{I_t}{\bar{I}}\right) \tag{86}$$

Foreign exchange.

$$\epsilon_t = \frac{E_t P_t^*}{P_t} \tag{87}$$

$$EX_t = \epsilon_t^{\varphi} Y_t^* \tag{88}$$

$$\Delta \ln \epsilon_t = \Delta \ln E_t + \hat{\pi}_t^* - \hat{\pi}_t \tag{89}$$

$$\ln\left(\frac{R_t^*}{\bar{R}^*}\right) = \rho_{R^*} \ln\left(\frac{R_{t-1}^*}{\bar{R}^*}\right) + \varepsilon_t^{R^*} \tag{90}$$

$$\ln\left(\frac{Y_t^*}{\bar{Y}^*}\right) = \rho_{Y^*} \ln\left(\frac{Y_{t-1}^*}{\bar{Y}^*}\right) + \varepsilon_t^{Y^*} \tag{91}$$

$$\ln\left(\frac{\Pi_t^*}{\bar{\Pi}^*}\right) = \rho_{\Pi^*} \ln\left(\frac{\Pi_{t-1}^*}{\bar{\Pi}^*}\right) + \varepsilon_t^{\Pi^*} \tag{92}$$

Central Bank

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_R}\left[\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\frac{1-\omega_E}{\omega_E}}\left(\frac{E_t}{\bar{E}}\right)^{\frac{\omega_E}{1-\omega_E}}\right]^{1-\rho_R}\exp(\varepsilon_t^R) \tag{93}$$

Market equilibrium.

$$K_t = K_t^h + K_t^b \tag{94}$$

$$C_t = C_t^h + C_t^u \tag{95}$$

$$L_t = L_t^h + L_t^u \tag{96}$$

$$Y_t = C_t + \left[1 + \Phi\left(\frac{I_t}{\bar{I}}\right)\right] I_t + EX_t + \frac{\kappa}{2}(\Pi_t - 1)^2 Y_t + \chi_t^h + \chi_t^b \tag{97}$$

$$D_t^* = \frac{R_{t-1}^*}{\Pi_t^*} D_{t-1}^* + M_t - \frac{1}{\epsilon_t} EX_t \tag{98}$$

$$N_t = \sigma\left[(z_t^k + \lambda Q_t)K_{t-1}^b - \frac{R_{t-1}}{\Pi_t}D_{t-1} - \epsilon_t \frac{R_{t-1}^*}{\Pi_t^*}D_{t-1}^* - \frac{R_{t-1}^c}{\Pi_t}B_{t-1}\right] + \gamma(z_t^k + \lambda Q_t)K_{t-1} \tag{99}$$

$$Q_t K_t^b\left(1 + \frac{\varkappa^b}{2}x_t^2\right) = \left(1 + \frac{\varkappa^b}{2}x_t^2\right)\phi_t N_t \tag{100}$$

$$Q_t K_t^b\left(1 + \frac{\varkappa^b}{2}x_t^2\right) = N_t + D_t + \epsilon_t D_t^* + B_t, \tag{101}$$

$$x_t = \frac{\epsilon_t D_t^*}{Q_t K_t^b} \tag{102}$$

$$x_t^c = \frac{B_t}{Q_t K_t^b} \tag{103}$$

$$B_t = B_t^h + B_t^u \tag{104}$$

$$R_t^c = \frac{P_t^c}{P_{t-1}^c} \tag{105}$$

Exogenous processes.

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

$$\ln\left(\frac{P_t^c}{\bar{P}^c}\right) = \rho_{P^c} \ln\left(\frac{P_{t-1}^c}{\bar{P}^c}\right) + \varepsilon_t^{P^c} \tag{107}$$

A.4 Model steady state and variance decomposition

Table 3 provides the deterministic steady state, unconditional mean, and standard deviations for a selection of key variables for both the baseline cryptocurrency economy and no-cryptocurrency economy. We observe the deterministic steady state of output and consumption of the unbanked population is higher in the economy with cryptocurrencies. In contrast, the deterministic steady state is lower for the banked population. In order to consider the welfare effects of uncertainty in the economy, the unconditional mean is calculated by simulating the model by taking a second-order log-linear approximation about the steady state as in Woodford (2003), Schmitt-Grohé and Uribe (2004), and Galí and Monacelli (2005).The economy is subject to shocks to productivity, domestic and foreign interest rates, foreign inflation and output and the cryptocurrency shock, based on calibration estimates in 4. Our results are preserved when comparing the unconditional mean of the variables across the two economies. In general, the variance of consumption and output is less in the economy with cryptocurrencies, which suggests cryptocurrency deposits can be used to smooth consumption and insures households against macroeconomic shocks.

Table 3: Key variables for welfare analysis

Variable	Deterministic steady state		Mean		Std. dev. (%)	
	crypto	no crypto	crypto	no crypto	crypto	no crypto
Y	16.0313	16.0115	15.9550	15.9262	4.3757	4.7004
C^h	5.8083	5.8140	5.7936	5.7916	5.8481	5.8898
C^u	4.9391	4.9330	4.9132	4.9008	5.1736	6.7349
L^h	0.4189	0.4185	0.4172	0.4165	4.3522	5.0437
L^u	0.7042	0.7036	0.7013	0.7001	4.3522	5.0437
ε	0.5467	0.5427	0.5398	0.5357	3.6332	3.6177
M	4.6917	4.7206	4.7251	4.7511	7.1685	8.1236
EX	2.7520	2.7455	2.7174	2.7102	4.4234	4.3965
Q	1.0000	1.0000	0.9957	0.9955	4.4107	4.4081
N	21.3855	21.1283	20.4887	20.2252	28.0239	28.1400
D^*	68.4181	67.7039	59.6444	59.0274	5.6354	5.5606
D	32.3872	33.0567	33.2256	34.1410	31.8836	31.0657
B^h	0.5062	-	0.7233	-	120.4543	-
B^u	0.8776	-	0.8962	-	13.3126	-

Next, we simulate the calibrated economy with all shocks, and compare it to an economy with zero cryptocurrency deposits. Table 4 presents results of the variance decomposition of shocks for the economic variables of output, consumption of regular and unbanked households, and the nominal exchange rate. A second order log-linear approximation around the steady state is used in the analysis. In the cryptocurrency autarky economy, the variance decomposition shows that the primary source of shocks to the domestic economy are productivity, foreign inflation and interest rate shocks, which jointly account for approximately 90 percent of output and consumption. For exchange rates and capital, the most important shock is foreign monetary shocks, which broadly supports empirical findings relating to the global financial cycle (Miranda-Agrippino and Rey 2020; Dedola, Rivolta, and Stracca 2017).

Table 4: Variance decomposition (quantities and prices)

(a) Baseline economy

Shock	mc	Π	z^k	w	R	ϵ	E	Q	Y	M	L	C^h	C^u	I	K^h	K^b	EX	N	D	D^*	B^h	B^u
ε^A	75.2	60.8	39.6	42.4	15.4	71.4	15.8	34.1	50.8	30.2	42.4	38.2	39.0	34.1	5.2	1.1	48.2	0.1	1.7	21.0	1.6	40.0
ε^R	3.2	1.2	4.8	3.7	26.0	0.7	18.8	0.7	1.8	1.4	3.7	0.9	3.0	0.7	1.3	1.2	0.5	1.0	0.4	0.7	1.7	6.6
ε^{Y^*}	4.7	3.7	11.1	9.0	1.0	5.5	1.2	0.3	6.4	11.3	9.0	2.0	8.4	0.3	2.2	1.8	36.2	1.9	2.6	11.4	0.1	17.9
ε^{Π^*}	12.6	29.1	30.1	29.3	2.7	7.7	22.4	35.2	24.6	31.8	29.3	31.1	32.4	35.2	53.4	55.9	5.2	55.7	52.9	28.6	0.3	6.8
ε^{R^*}	4.2	5.3	14.2	15.4	54.9	14.6	41.9	29.7	16.3	25.1	15.4	27.9	16.6	29.7	37.9	40.0	9.9	41.4	42.4	38.3	4.5	26.5
ε^{P^c}	0.1	0.0	0.3	0.2	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.1	0.0	91.7	2.2

(b) Cryptocurrency autarky economy

Shock	mc	Π	z^k	w	R	ϵ	E	Q	Y	M	L	C^h	C^u	I	K^h	K^b	EX	N	D	D^*
ε^A	74.7	61.3	44.5	46.4	17.0	70.7	15.7	35.4	50.0	36.3	46.4	38.9	46.4	35.4	5.6	1.2	47.9	0.1	1.8	26.4
ε^R	4.0	1.5	5.8	4.8	25.1	0.7	18.7	0.6	2.8	2.2	4.8	1.1	4.8	0.6	1.4	1.3	0.4	1.1	0.5	1.0
ε^{Y^*}	5.3	4.1	11.2	9.5	1.2	5.5	1.2	0.3	7.5	11.2	9.5	2.1	9.5	0.3	2.3	1.9	36.0	1.9	2.6	10.8
ε^{Π^*}	11.7	27.5	25.7	25.6	2.8	8.1	22.2	34.5	23.8	28.0	25.6	30.4	25.6	34.5	52.6	55.2	5.5	55.2	51.8	25.8
ε^{R^*}	4.3	5.6	12.8	13.7	54.0	15.1	42.1	29.2	15.9	22.2	13.7	27.4	13.7	29.2	38.2	40.4	10.2	41.7	43.3	36.0

Table 5: Variance decomposition (bank variables)

(a) Baseline economy

Shock	x	x^c	ψ	ϕ	υ	μ	μ^*	μ^c
ε^A	1.23	3.11	1.50	1.28	1.62	1.70	0.77	0.85
ε^R	0.28	1.89	0.96	0.89	0.95	1.16	0.41	1.79
ε^{Y^*}	4.12	0.72	2.70	2.74	2.75	2.04	3.76	0.08
ε^{Π^*}	50.83	12.00	54.54	54.54	54.54	55.23	52.31	0.61
ε^{R^*}	43.53	1.09	40.31	40.54	40.13	39.87	42.74	5.66
ε^{P^c}	0.00	81.20	0.00	0.00	0.00	0.00	0.01	91.01

(b) Cryptocurrency autarky economy

Shock	x	x^c	ψ	ϕ	υ	μ	μ^*	μ^c
ε^A	1.41	-	1.59	1.35	1.70	1.78	0.80	-
ε^R	0.29	-	1.03	0.97	1.03	1.27	0.42	-
ε^{Y^*}	4.00	-	2.79	2.84	2.84	2.10	3.70	-
ε^{Π^*}	50.53	-	54.24	54.18	54.20	54.61	51.99	-
ε^{R^*}	43.77	-	40.35	40.65	40.23	40.24	43.08	-

A.5 Additional results: productivity, foreign output and inflation shocks

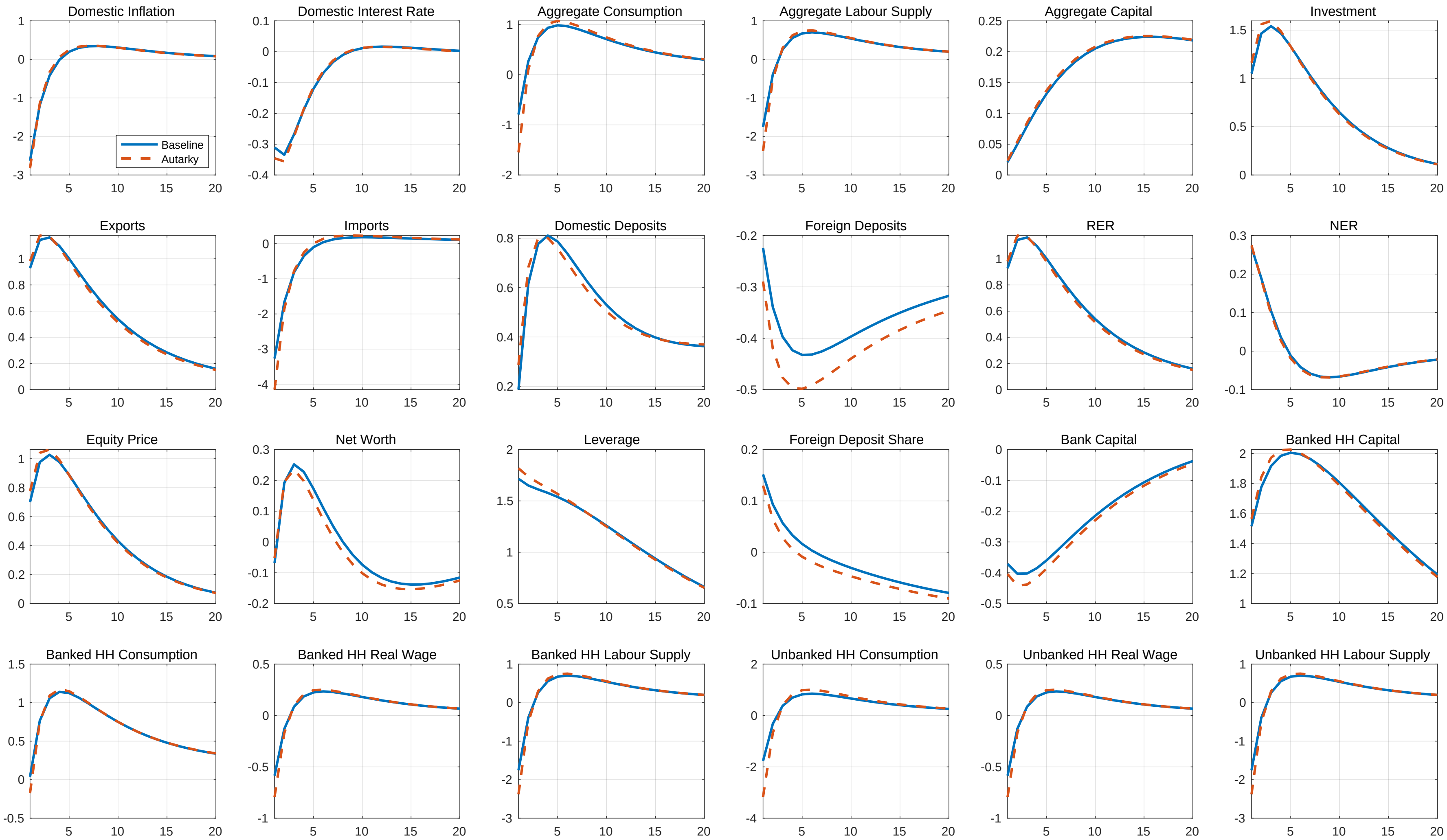
In Figures 11, 12, and 13 we test shocks to domestic productivity, foreign output, and foreign inflation in an economy with and without cryptocurrency. Quantitatively, we find no evidence of real economy shocks in the presence of cryptocurrency deposits. Bank balance sheets are unaffected in response to foreign output, domestic capital and productivity shocks. In contrast, a foreign inflation shock affect bank balance sheets through a net worth channel.

A.6 Additional results: Welfare plots

In Figure 14, we plot welfare level for different household types, compared to the autarky level, under varying levels of volatility of domestic productivity, foreign output and foreign inflation. Solid lines indicate a cryptocurrency volatility of 0 per cent, and dotted lines indicate a volatility of 3 per cent (quarterly). We measured welfare while also considering the impact of shocks to the foreign interest rate and domestic interest rate. The welfare level for all three household types in the cryptocurrency economy are increasing in the volatility of all three shocks. The strongest welfare gains are realized with respect to foreign inflation shocks. These shocks can increase the volatility of consumption for both types of households. However, in an economy with cryptocurrency deposits, the unbanked households can hedge inflation risk by smoothing consumption.

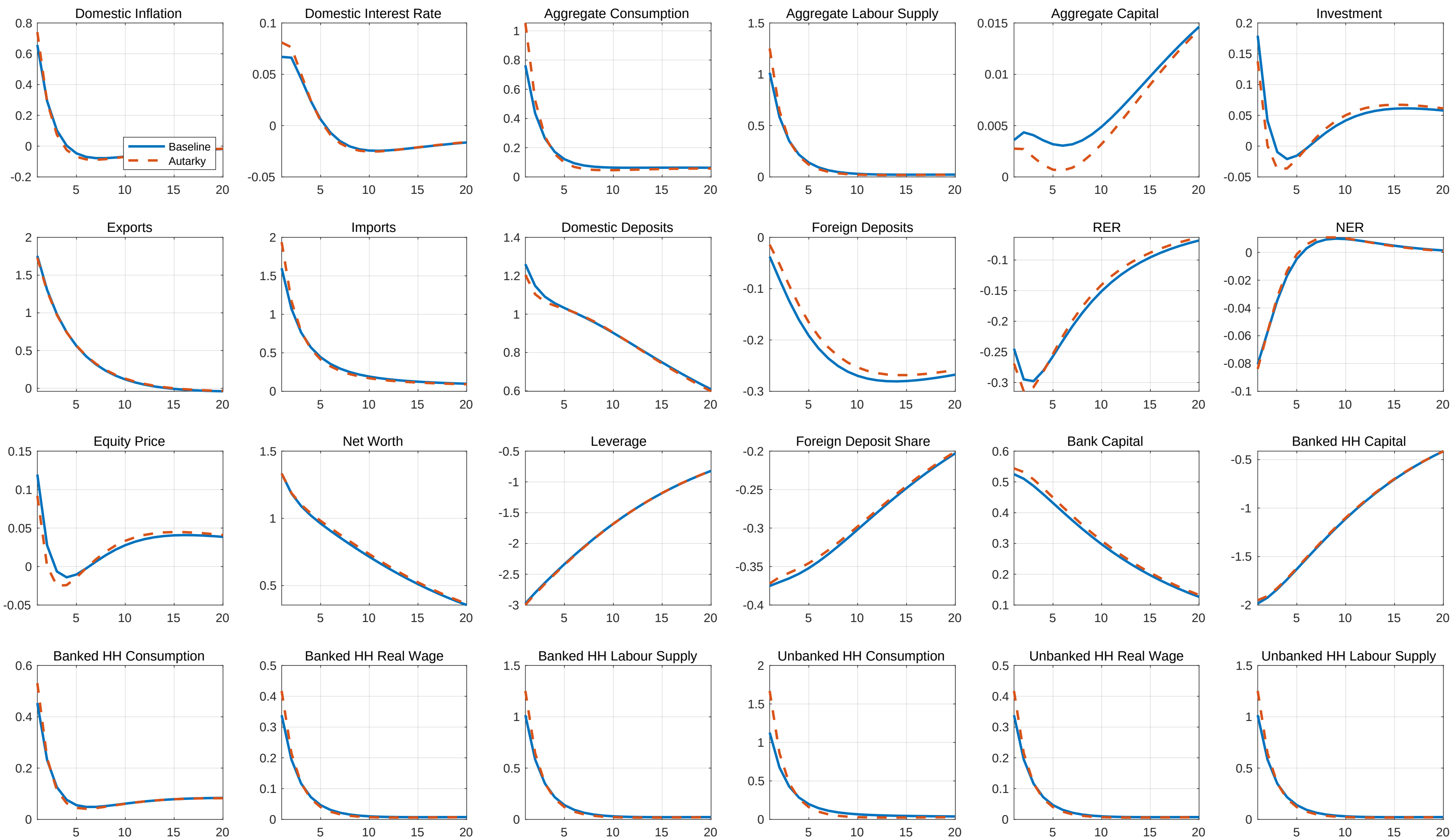
We plot welfare of each household type for varying levels of cryptocurrency price volatility and each of our macroeconomic shocks and exchange rate regime in Figures 15 to 20. For each of these plots, we show that our welfare analysis is robust to different combinations of cryptocurrency volatility and the macroeconomic shock. In all cases, the aggregate and unbanked household welfare is increasing in the variance of macroeconomic shocks, and for a fixed exchange rate regime. However the welfare gains of diversification attenuate with higher levels of the cryptocurrency volatility.

Figure 11: Domestic productivity shock: Baseline vs cryptocurrency autarky



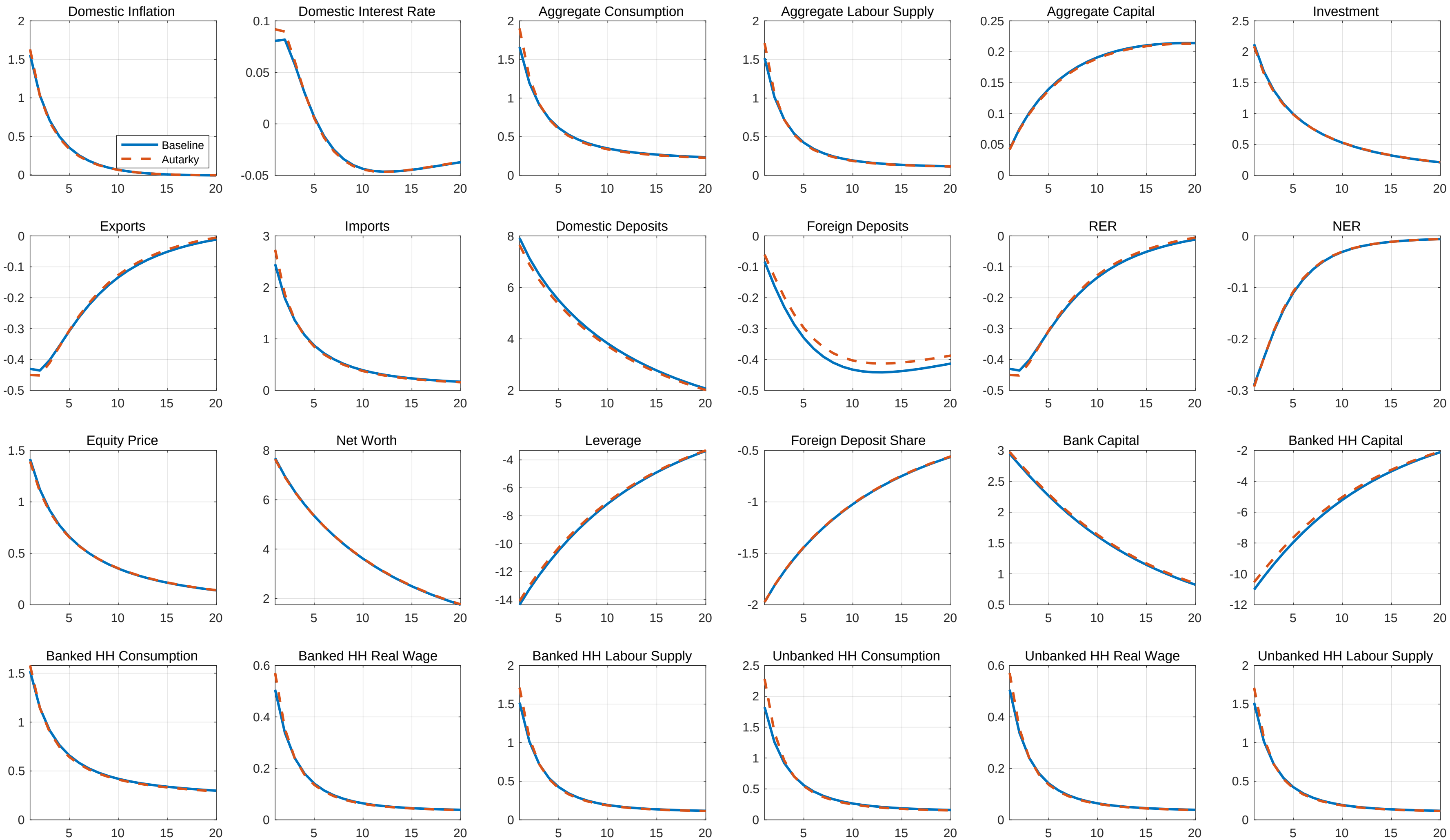
Note: Figure plots impulse responses of model variables with respect to a 1 standard deviation domestic productivity shock. Time periods are measured in quarters, and responses are measured as a percent deviation from steady state. Domestic Inflation and Domestic Inflation Rate are annualized. Solid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

Figure 12: Foreign output shock: Baseline vs cryptocurrency 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 cryptocurrency deposits. Dashed line indicates an economy with zero cryptocurrency deposits (cryptocurrency autarky).

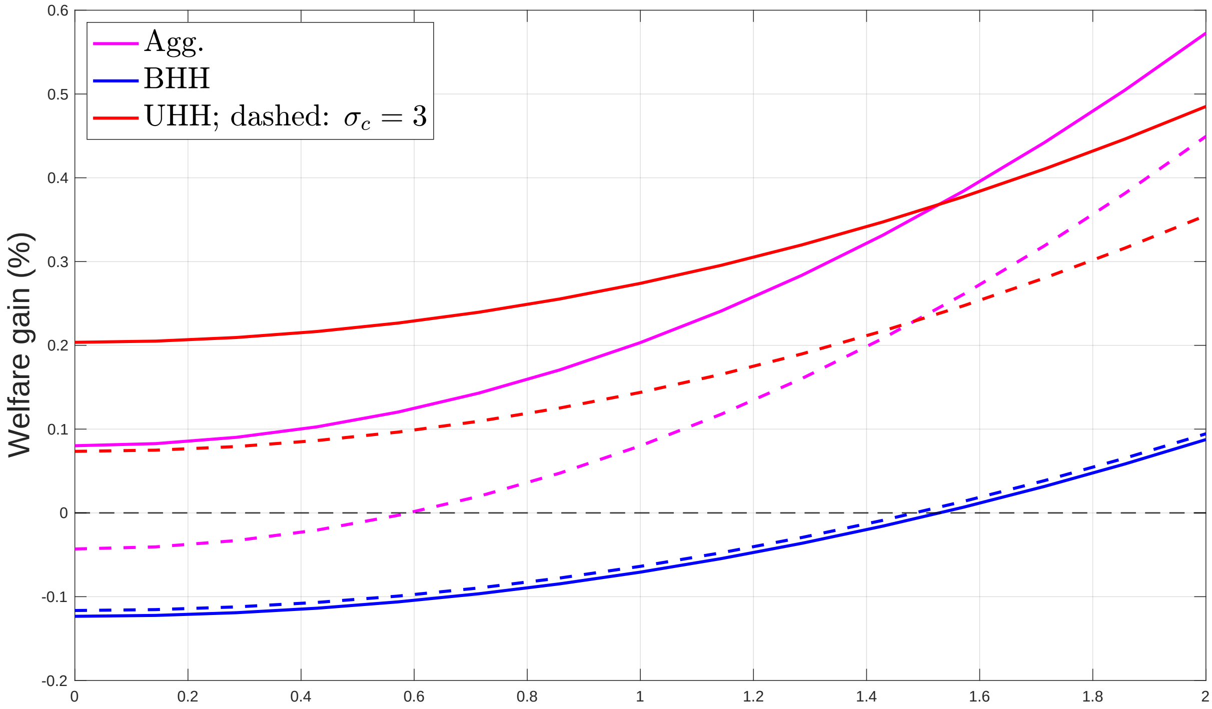
Figure 13: Foreign inflation shock: Baseline vs cryptocurrency autarky



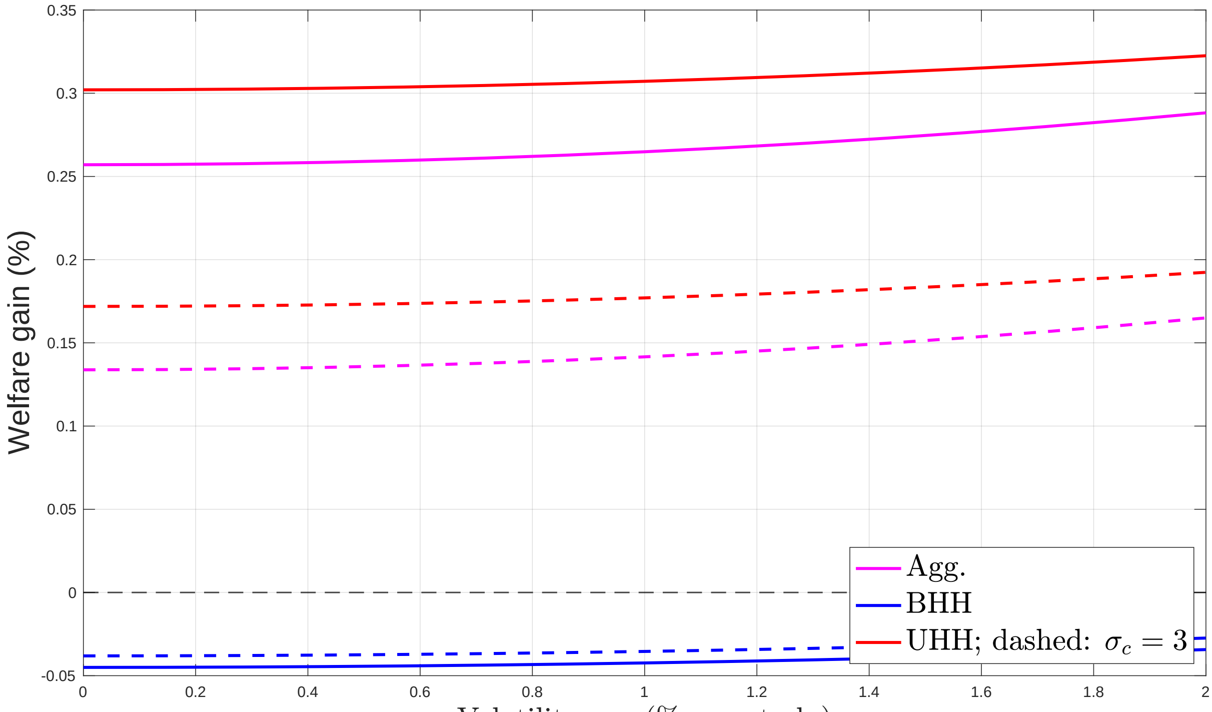
Note: Figure plots impulse responses of model variables with respect to a 1 standard deviation foreign inflation shock. Time periods are measured in quarters, and responses are measured as a percent deviation from steady state. Domestic Inflation and Domestic Interest Rate are annualized. Solid line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

Figure 14: Welfare gains and domestic productivity, foreign output and foreign inflation

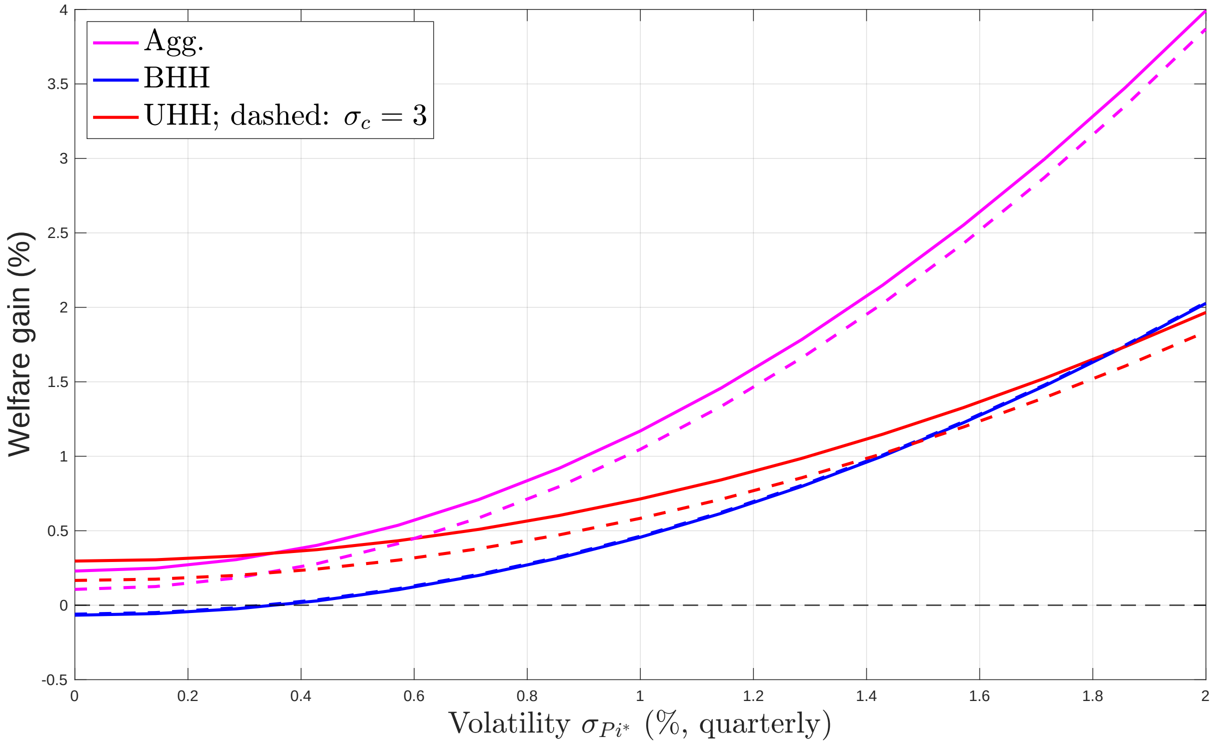
(a) Domestic productivity



(b) Foreign output



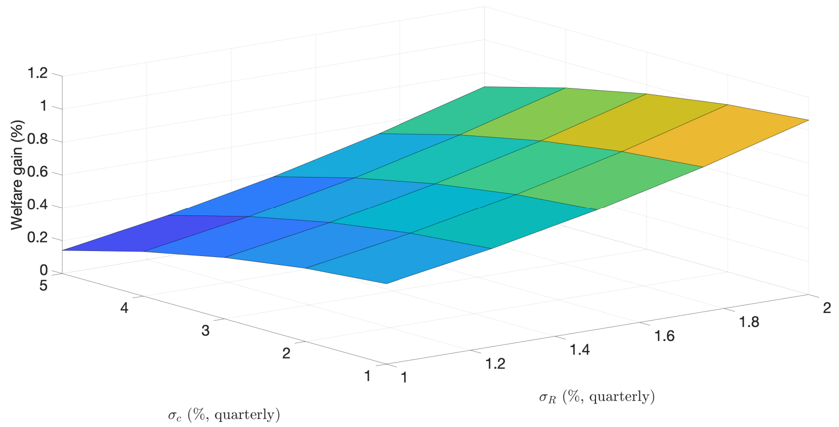
(c) Foreign inflation



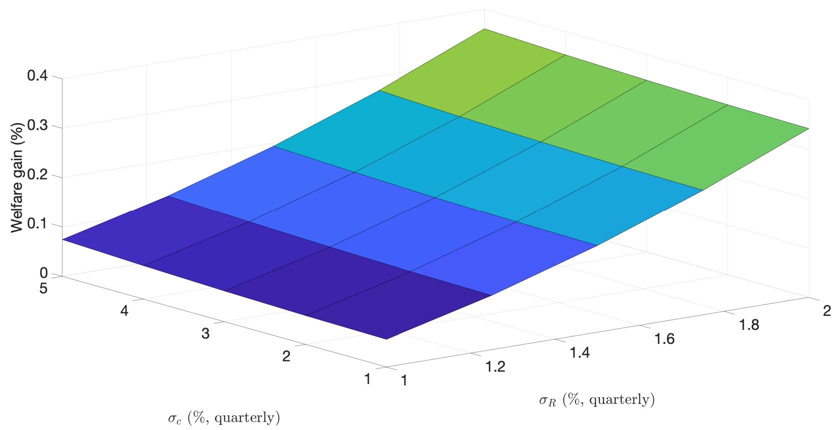
Note: Figure plots welfare gains for three different types of households: unbanked, banked and a representative household that aggregates consumption of unbanked and banked households. In Figure 14a we compute welfare gains for different levels of volatility of domestic interest rates. In Figure 14b we compute welfare gains for different levels of volatility of foreign output. In Figure 14c we compute welfare gains for different levels of volatility of foreign inflation. Welfare gains are with respect to an economy with no cryptocurrency deposits. Solid lines indicate welfare gains are computed for a level of zero cryptocurrency price volatility. Dashed lines indicate welfare gains are computed for a positive level of cryptocurrency price volatility, $\sigma_c = 3$. The first moment of welfare is calculated using a second order log-linear approximation to the steady state.

Figure 15: Relative welfare, domestic monetary policy, and cryptocurrency volatility

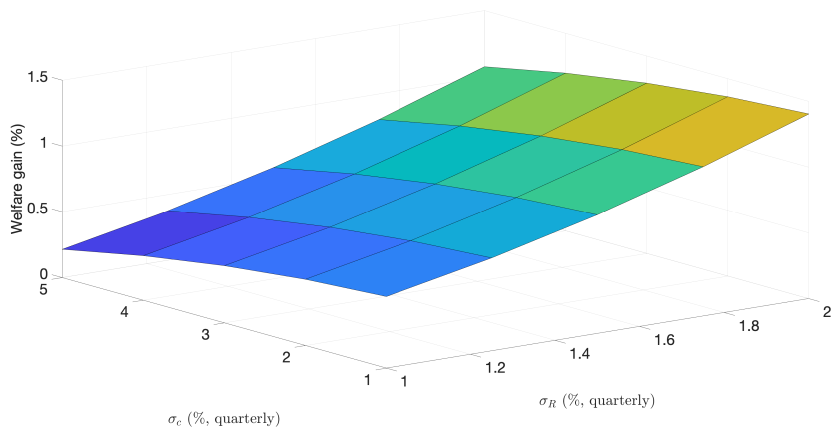
(a) Unbanked households



(b) Banked households



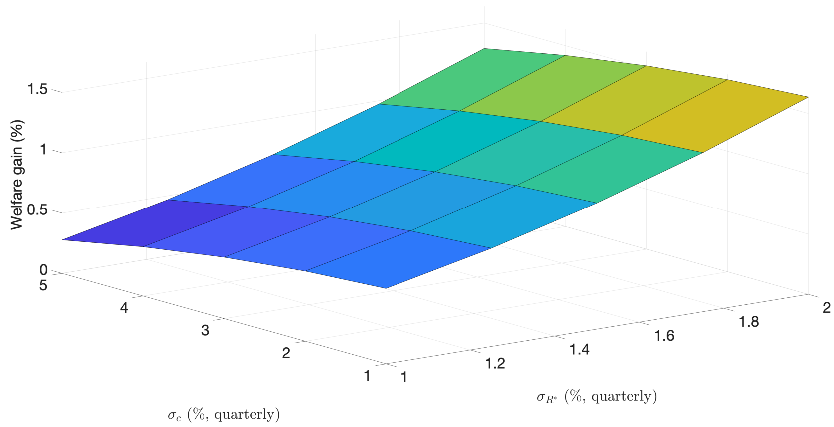
(c) Aggregate household



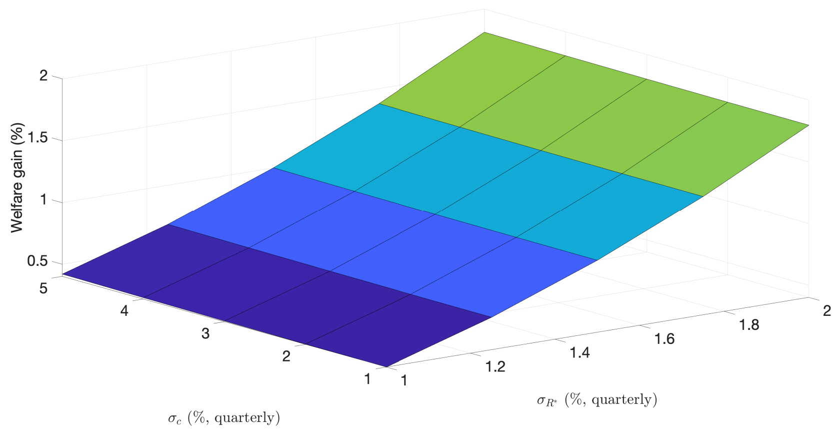
Note: Figure plots welfare of three different types of households: unbanked households (Figure 15a), banked households (Figure 15b), and a representative household that aggregates consumption of unbanked and banked households (Figure 15c). Welfare gains are with respect to an economy with no cryptocurrency deposits. The first moment of welfare is calculated using a second order log-linear approximation to the steady state for different levels of volatility of the domestic interest rate and volatility of the cryptocurrency.

Figure 16: Relative welfare, risk premium volatility, and cryptocurrency volatility

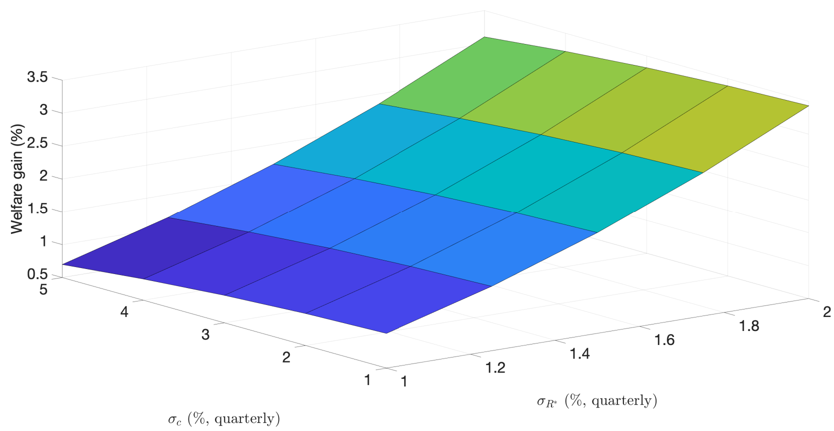
(a) Unbanked households



(b) Banked households



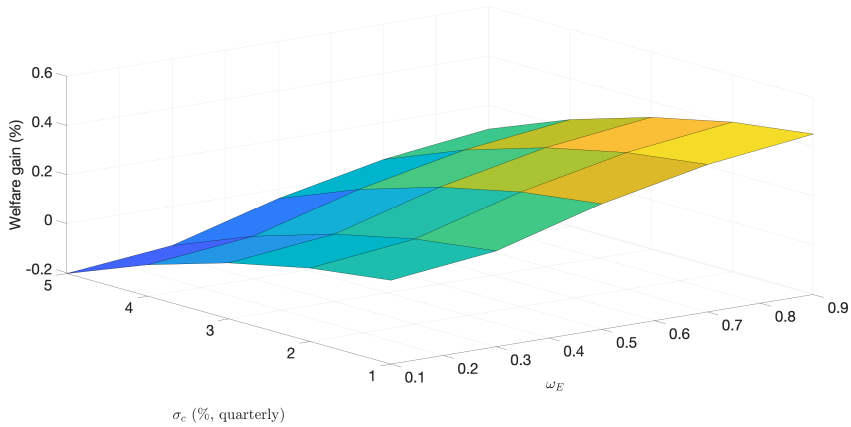
(c) Aggregate household



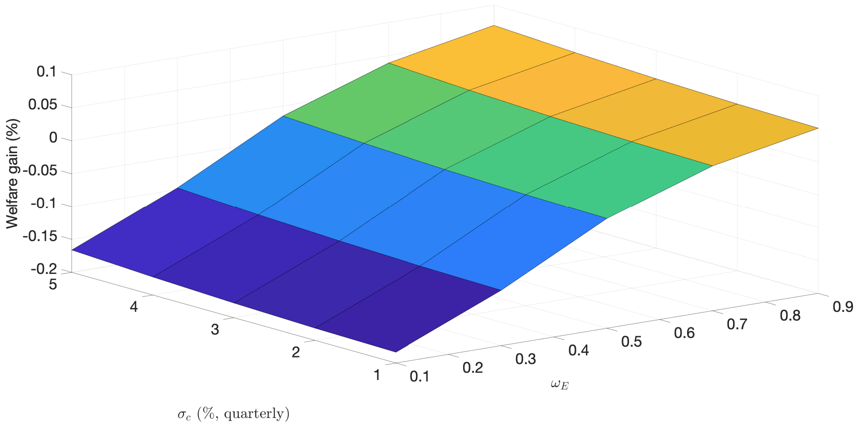
Note: Figure plots welfare of three different types of households: unbanked households (Figure 16a), banked households (Figure 16b), and a representative household that aggregates consumption of unbanked and banked households (Figure 16c). Welfare gains are with respect to an economy with no cryptocurrency deposits. The first moment of welfare is calculated using a second order log-linear approximation to the steady state for different levels of volatility of the risk premium on foreign debt and volatility of the cryptocurrency.

Figure 17: Relative welfare, exchange rate regime, and cryptocurrency volatility

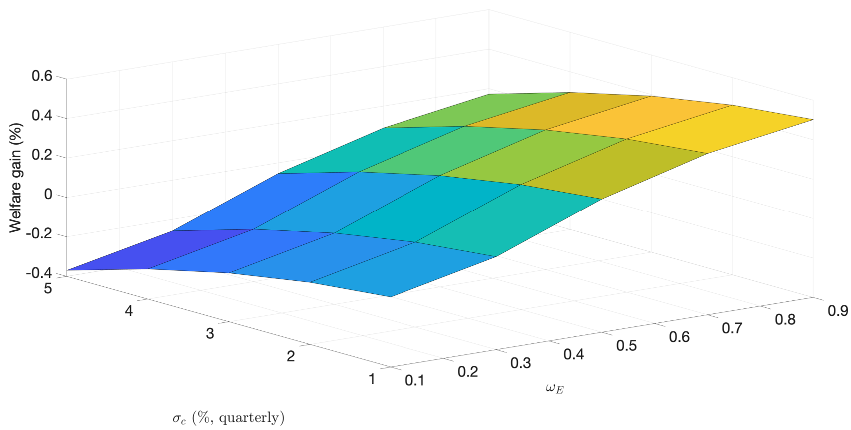
(a) Unbanked households



(b) Banked households



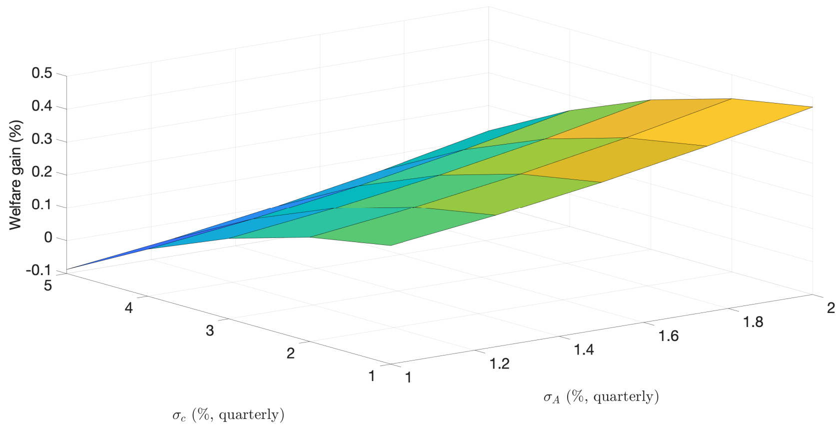
(c) Aggregate household



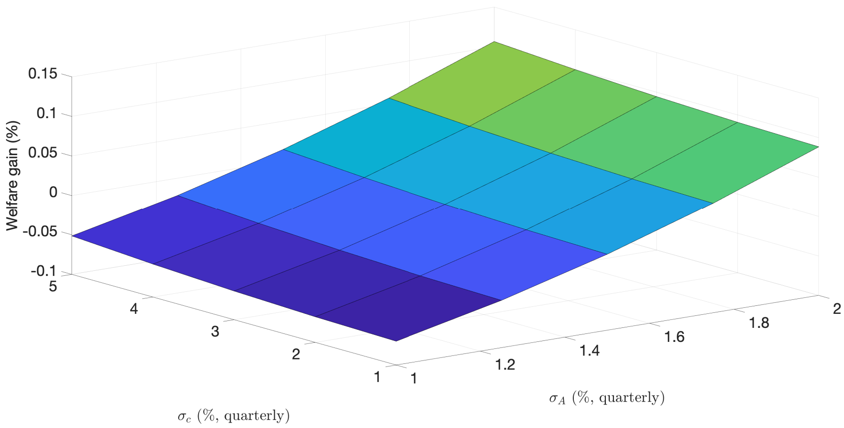
Note: Figure plots welfare of three different types of households: unbanked households (Figure 17a), banked households (Figure 17b), and a representative household that aggregates consumption of unbanked and banked households (Figure 17c). Welfare for the baseline calibration is normalized by the welfare for a cryptocurrency autarky economy in which unbanked households hold zero deposits. The first moment of welfare is calculated using a second order log-linear approximation to the steady state for different exchange rate regimes (where $\omega_E \to 1$ is a fixed exchange rate and $\omega_E \to 0$ is a floating exchange rate), and volatility of the cryptocurrency.

Figure 18: Relative welfare, productivity and cryptocurrency volatility

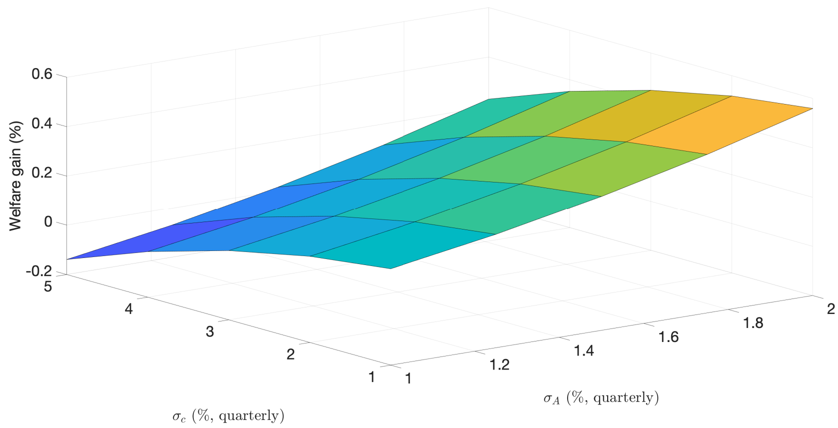
(a) Unbanked households



(b) Banked households



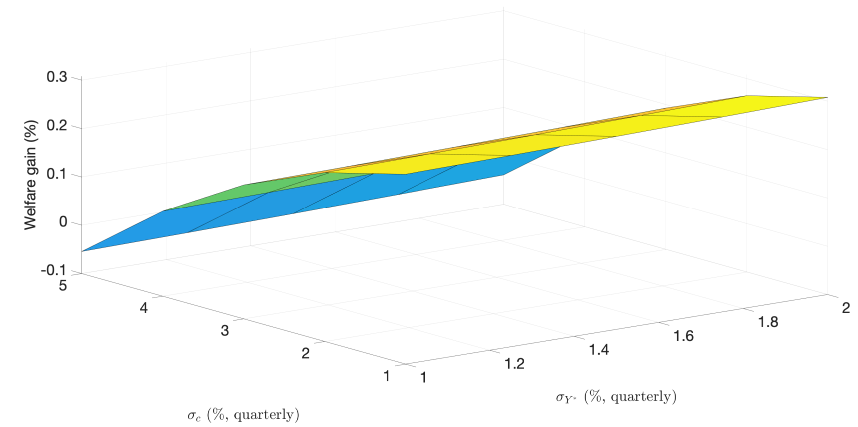
(c) Aggregate household



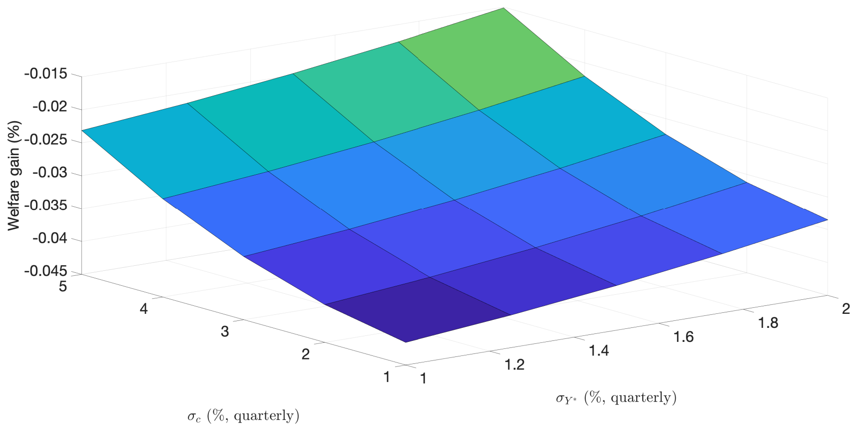
Note: Figure plots welfare of three different types of households: unbanked households (Figure 16a), banked households (Figure 16b), and a representative household that aggregates consumption of unbanked and banked households (Figure 16c). Welfare gains are with respect to an economy with no cryptocurrency deposits. The first moment of welfare is calculated using a second order log-linear approximation to the steady state for different levels of volatility of domestic productivity and volatility of the cryptocurrency.

Figure 19: Relative welfare, foreign output volatility, and cryptocurrency volatility

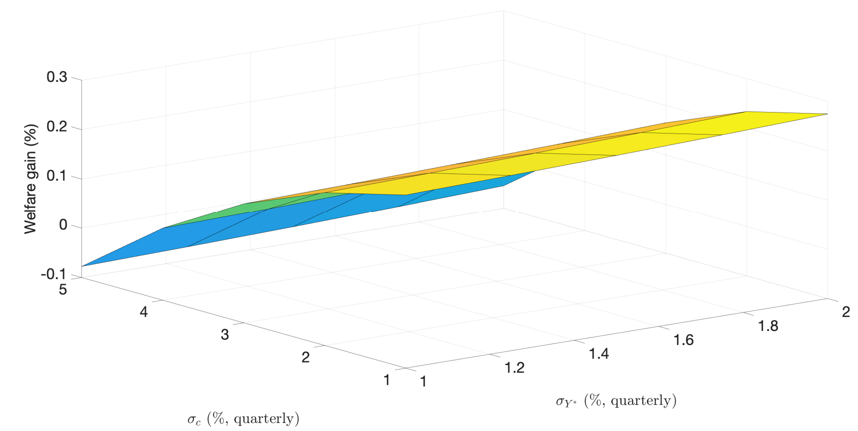
(a) Unbanked households



(b) Banked households



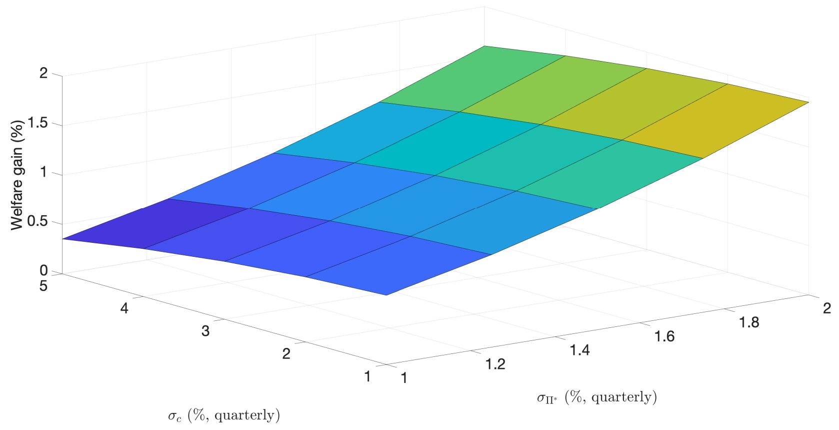
(c) Aggregate household



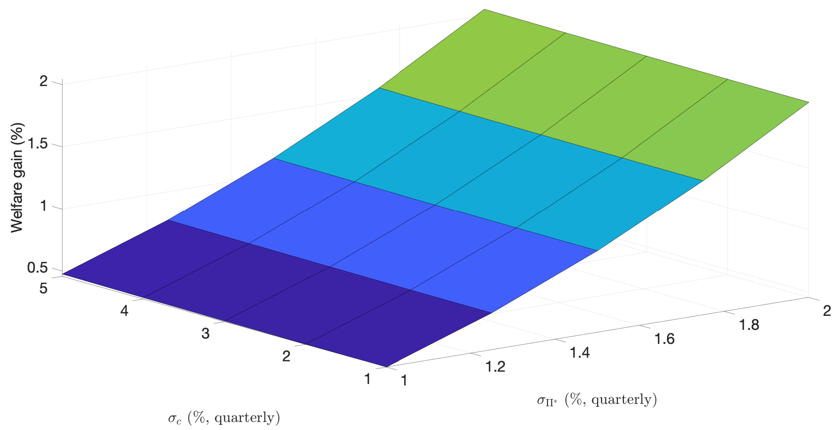
Note: Figure plots welfare of three different types of households: unbanked households (Figure 19a), banked households (Figure 19b), and a representative household that aggregates consumption of unbanked and banked households (Figure 19c). Welfare gains are with respect to an economy with no cryptocurrency deposits. The first moment of welfare is calculated using a second order log-linear approximation to the steady state for different levels of volatility of foreign output and volatility of the cryptocurrency.

Figure 20: Relative welfare, foreign inflation volatility, and cryptocurrency volatility

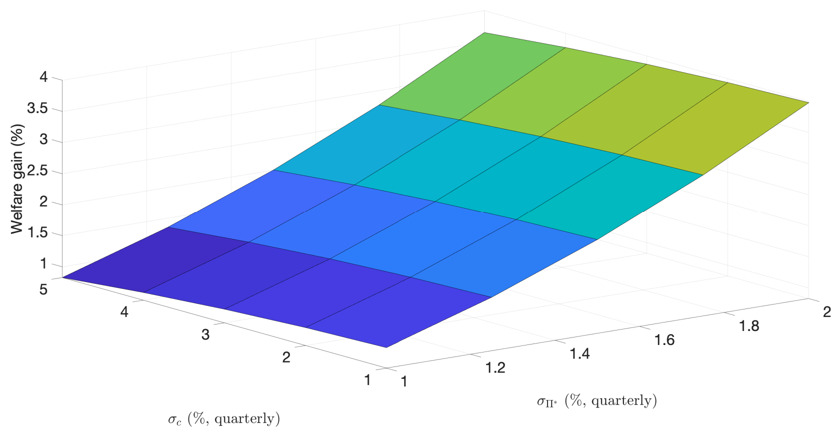
(a) Unbanked households



(b) Banked households



(c) Aggregate household



Note: Figure plots welfare of three different types of households: unbanked households (Figure 20a), banked households (Figure 20b), and a representative household that aggregates consumption of unbanked and banked households (Figure 20c). Welfare gains are with respect to an economy with no cryptocurrency deposits. The first moment of welfare is calculated using a second order log-linear approximation to the steady state for different levels of volatility of foreign inflation and volatility of the cryptocurrency.