Master thesis in Economics and Finance
Erasmus Mundus Joint Master Degree (EMJMD) QEM

Exchange rates and Bayesian Paradigm

Colloquy on international finance and education of economics

Chengzhang Kan

Supervisor: Roberto Casarin
Co-Supervisor: Stefano Colonnello

July 2022

Università
Ca'Foscari
Venezia

With the support of the
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Contents

Dedication

To our parents, and our teachers.

—*Everything is related.*[1]

To my beloved Venice and **Earth**: will we be able to come back and stay?

[1]Waldo Tobler's first law of geography put it as "everything is related to everything else" but I don't. Not only for simplification but also by removing "everything else" there forms a pace of conceptualization and breaking up the **duality** behind. Waldo Tobler is completely right on his second lawl: "The phenomenon external to an area of interest affects what goes on inside."[255] "History": the right way to perceive it is to realize (feel) forever and now you're history; "Nature": the only way to embrace it is to feel (realize) now and forever you're nature; and you cannot divide history from nature, nor nature from history.

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for their spoken or silent inspirations and elenctics, refutations and encouragements during the brewing of this work.

[2]One evening when we had a beer together, Prof. Michele Boldrin asked me: "you love economics, why don't go to U.S.?" Out of respect, I replied that I love Europe more and stopped with a smile as a reply. I thought I would write him something later as a formal answer. And here it is.

Abstract

This thesis first reviews the disciplinary origination of exchange rate and advantages of Bayesian methods to study it. Within the Bayesian inference framework, I apply Markov switching model to time series with Gibbs estimation to study the volatility of lagged return and relationship of exchange rates. The recent extreme volatility of RUB, EUR and RMB then drive me step from the stochastic model and further analyse the economic mechanisms accounting for such "unprecedented" phenomenon. I try to enrich this subject through discussion of popular statistical methods within the still-developing Bayesian paradigm via reflecting on the conceptualization of uncertainty. The logic of Bayesian paradigm combined with requirement of green financing and sustainability lead the discussion towards reflecting facts of macro-finance and the foundation of exchange rates, which bring along insights of global asset pricing and conceptual modeling of a future global currency.

Keywords: Exchange Rates, Bayesian Paradigm, Markov Switching Model, Gibbs Sampling, Macro Economics, International Finance, Asset Pricing, Commodity market, Uncertainty, Complexity, Belief formation, Green finance, Carbon pricing, CBDC

Chapter 1

Preliminaries

"To be sure, observation is superior to theories, and one must sometimes know how to bow before a fact, however inexplicable, however paradoxical, it might seem to us."[1]

Exchange rate is (one of) the most intriguing research object as a real entity rather than merely artificial concept subject to theories in finance and economics. Representing the relative value of a currency established by monetary authorities[2] with regards to any other currency once the economy encounter each other[227], the link-wise inter-subjectivity of exchange rate embodies the essential significance of money more than the point-wise concept of coins itself does. Directly approaching the central policies, the exchange rate is a piece of dark cloud lingering over the classic economics: unlike commonly agreed ideology such as trading where freedom is optimally preferred, there is no agreement in literature on whether free floating currency policy is absolutely optimal[38]. It is such a phenomena that gathers and devolves information across all levels of the global economic hierarchy, influentially more profound and pervasive than any other index. The debate of exchange rate regimes involves all aspects of finance while naturally going beyond economics per se, reflecting geopoliticultural conditions, thus always a right start point to investigate into global issues: it could also be a silver lining[52], especially in a broader context of emerging new currencies.

This thesis unfolds around the following questions: 1) what is the deeper mechanics behind the fluctuations of exchange rate, its relationship with asset pricing and what could be the future of currencies? 2) what does econometrics tell us about exchange rates? 3) how could we better model and illustrate the volatility of exchange rates? We digest these questions not subject to any theoretical frameworks but rather use the historical facts, observations and emerging events of exchange rates and currencies a mirror to reflect the discipline of finance and the discourse of economics.

[1] Pierre Paul Broca, 1865a. pp. 380381

[2] mostly national currencies, but may also be sub-national as in Hong Kong or supra-national as in the case of Euro.

This attempt becomes even more intriguing when combined with the research and upcoming launching of Central Bank Digital Currencies (CBDC).

1.1 The economics of exchange rates

Under the common assumptive conditions, the econometrics methods and stochastic modeling are powerful in analysing a free market[3], while we need to first depict a general background where such assumptions too simple and ideal to contrast to real world situations in terms of global economics facts of exchange rates, before we apply the econometric weapons.

As the world economy is increasingly integrating, the exchange rates are the top concern of any given country's economy due to its vitality on trade balance, and from this point of view we could say almost all currencies are managed since governments(central banks) endeavour to influence their currencies towards an expected direction[53]. Actually, if we take a careful reflection back in the history of global monetary policy, the Bretton Woods transition from fixed to flexible arrangements is overstated and regimes with limited flexibility remain in the majority[152]: as of 2014, 82 countries and regions used a managed float according to International Monetary Fund.

Adding with this background of managed exchange rates, to understand the object confronted, we must consider the main factors believed by economists that account for the dynamics of exchange rates:

- International balance of payments and trades.
- Interest rates causing capital flow hence the demand for domestic currency.
- Fiscal revenue and expenditures.
- Venture capital speculation and government intervened currency trading. A slope factor accounts for cross section of currency risk premia orthogonal to the high-minus-low carry trade factor together account for 18% to 80% of the monthly exchange rate movements[257].

The four factors listed above summarized from major literature range from top macro international level to micro corporate, institution and consumer level, again proved the omnipotence of our choice of interest of research object. In essence, "real exchange rate" is proposed to reveal the purchasing power of a currency and in the long run reflects the economic strength of a country. The most naturally accepted cogent theory for RER is Purchasing Power Parity (PPP)[79], which originally appeared from the sixteenth-century scholars in Salamanca and revived in the interwar period concerning the right level to reestablish international exchange parities, and in the early 1970s PPP was once favoured as a short-run equilibrium in the first

[3]in terms of FX, floating regimes

few years after the breakdown of the Bretton Woods system, while followed by increasingly challenge on both empirical and theoretical bases till the mid 1990s[240]. Since the mid 1990s, huge datasets have joined and improved this task of estimation as deviations narrowed between real exchange rates and PPP[251].

Following the study of PPP, there are empirical results advising countries, particularly if they are exporters of agricultural raw materials and products, to adopt a more flexible exchange rate system[4]. However, this conclusion is challenged in the observed facts of gas and oil market referring to the recent Russian ruble. We will pay a decent revisit to a (reversed) commodity supported logic of exchange rate in the discussion section.

Noticeably, the key approach to resolve the PPP puzzles is allowing for nonlinear dynamics in real exchange rate adjustment. PPP involving a currency pair imposes bilateral exchange rate, and generally weighted averages of bilateral exchange rates adjusted by relative consumer prices of the basket of foreign currencies is called the effective exchange rate (EER), which can be viewed as an overall measure of the country's external competitiveness and effectiveness of a country's Current Account (CA) in terms of its products regarding to the rest of the world[82]. There are several advanced version of EER: nominal effective exchange rate (NEER) is weighted with the inverse of the asymptotic trade weights; real effective exchange rate (REER) adjusts NEER by appropriate foreign price level and deflates by the home country price level, for example in FRED. And compared to NEER, a GDP weighted effective exchange rate might be more appropriate considering the global investment phenomenon.

Here the currency basket is a portfolio of currencies selected with varied weightings commonly used by investors to minimize currency fluctuations (high currency volatility) and also governments when setting the market value of a country's currency. The common measure used by FX traders is the U.S. dollar index consists of five major currencies: Euro, Japanese Yen, British Pound, Canadian Dollar, Swiss Fr. and Swedish Kr. The most important example of currency basket is the Special Drawing Rights (SDR) of the IMF (International Monetary Fund)[4] as a multilateral instrument of liquidity provision and storage of value[59]. Recently, on May 11, 2022, the Executive Board of the International Monetary Fund announced that the weight of the Chinese RMB will be raised to 12.28%, the weight of the US dollar will be raised from 41.73% to 43.38%, and the weight of the Euro, Yen and Br. Pound will be raised from 30.93%. , 8.33% and 8.09% were reduced to 29.31%, 7.59% and 7.44%. The weight reviewed in year T of currency i in the basket $w_{i,T}$ is ratio of an average over the sum of two key variables of the sum of the basket: 1) exports of goods and services (including current-income credit) of the currency area i; 2) world official reserves denominated in currencies[66].

The use of SDR is considerably general, such as pricing goods and services traded across borders (e.g. freighter tolls on the Suez Canal); as a unit of account or One

[4]International Monetary Fund. Review of the method of valuation of the SDR. Washington, DC: Finance Department; 2010.

of the accounting units in international financial institutions including the International Monetary Fund, the United Nations Common Fund for Commodities, the Bank for International Settlements, and the International Fund for Agricultural Development, regional financial institutions including Asian Development Bank, East African Development Bank, Arab Monetary Fund, African Development Bank, Islamic Development Bank and NGOs including Japan External Trade Organization, Economic Community of West African States, International Centre for Settlement of Investment Disputes; in international agreements and inter-state tax treaties such as the Convention on Limitation of Liability for Maritime Claims, the Montreal Protocol, etc.; though not recommended, still SDR serves as a currency peg in practice in countries such as Syria.

In the framework of general equilibrium, REER is believed to evolve with a dynamic equilibrium in the long-term[5]. Any substantial deviation from its equilibrium is called the misalignment of Real Exchange Rate. Any overvalued or undervalued REER is shown to have negative effects on a country's balance account[160]. Specifically, a protracted overvaluation is considered to be a sign of upcoming crisis due to vulnerability to speculative attacks and currency crisis, whereas a prolonged REER undervaluation entails pressure on domestic prices and consumption incentives hence mis-allocating resources between non-tradable and tradable sectors[159].

Given these facts on the significance of the equilibrium REER, however, this variable cannot be directly attained. The normative measure of the REER is the Fundamental Equilibrium Exchange Rate developed by Williamson[260], which focuses on long-term determinants of the REER consistent with macro balance regardless of cyclical and speculative fluctuations. This balance is characterized by internal and external balances. The former is reached when output level corresponds with both full employment of all production factors and a stable low rate of inflation. The latter holds when actual future CA balances are sustained with prolonged net capital flows. These "ideal" economic conditions of internal and external balances are never actually met. Key question also lies on the sustainable CA position defined as exogenous. Consequently, Clark and MacDonald proposed an econometric analysis of the REER behaviour called Behavioural Equilibrium Exchange Rate[58], considering substantial REER deviations from its PPP equilibrium level as a result of changes in economic situations defined by economic fundamentals rooting from home-produced goods proxy for a country's international competitiveness[84]. In this sense, the term behavior refers to macro economy movements such as the widely discussed "growth". Thus REER reaches Behavioural Equilibrium Exchange Rate when all the economic fundamentals are at their equilibrium values and the total REER misalignment is given by the extent to which economic fundamentals deviate from their long-run sustainable levels in cyclical movements, which is proven to be irresistible.

The most recent literature concerning on real exchange rates' behavioural equilibrium and misalignment[22] focuses on large emerging markets[239] which have long posed a challenge for finance[28], whose international reserve assets had hugely increased since the 2000s[220] and rising surpluses are considered to be based on

growing trade deficits with advanced economies[191]. The improved approach of Behavioural Equilibrium Exchange Rate estimation[210] is applied over 1995–2017 for a panel of Brazil, China, India, Indonesia, Mexico, Russia, Thailand and Turkey. Such a pipeline of estimation are also followed by the conceptualization of Fundamental Equilibrium Exchange Rate[61] with the long-run relationship estimated through panel co-integrating methods like fully modified and dynamic OLS[196] may escalated with advanced computational framework such as Actively Learned and Informed Equilibrium Nets for continuous time endogenous state variables and highly non-linear policy functions[128], however, never applied logically to real situation as in managed exchange rate regimes[262]. The obstacle should be overcome is we move beyond the stereotype of free market mechanism with de-conceptualization of equilibrium and re-conceptualization of uncertainty. New models shall unfold around the new observations and transform of paradigm of theories. We would consider the case of dynamic system with supervision and control like Central Bank Digital Currency (CBDC) as the future of National Account. As a matter of fact paralleling to this necessity of paradigm transform, China and European Union is advocating CBDC while U.S. is conservatively against it for CBDC is right in its role of completing global de-dollarization.

By choosing exchange rate as a phenomenal object and Bayesian Paradigm as an epistemological subject, we try to encompass the division of micro-meso-macro[77] to review the concept of **currency**. In a touchable layer, the retail market of currency exchange is paralleling to the complexity of the whole banking system[179]. Again, it well involves political, technical and cultural factors that entail the margin, where behavioral granules may have huge effects as rates quoted may vary from cash, a documentary transaction to electronic transfers. In this sense we include in discussion the huge potential for emerging digital currencies[15] not only those to be launched by central banks. The exchange rate is an eclectic collection of financial research objects from central bank monetary policies to international firms and household consumption and product market, which also drive us to go beyond Western-centrism (in our disciplined, the modern economics and finance, more precisely, a U.S.-centered narrative and academic vocabulary), as is already confessed in the disciplines such as anthropology and STSS(Science, Technology and Society Studies) to study the characterization of emerging economies such as alternative ways of corporation[29] and development[136]. Simply list few more facts that indicates such a tendency. China reaps a growing share of the SDR according to the traditional weighting scheme without its currency becoming a key currency of the international monetary system. FX turnover documented by BIS only limitedly captures the degree of use and liquidity of each currency, while official reserves would capture revealed preferences of central bank managing[31][5]. Under basic as-

[5]The way the international use of a currency is measured is questionable. In fact, a country may reap a large share of global trade while still invoicing exports and imports in foreign currencies. Although trade invoiced in RMB has developed rapidly in recent years, there is still a large gap between the share of China in global trade and the share of the RMB in trade invoicing (ECB, 2013). Likewise, measuring the international use of a currency in financial transactions through its share in allocated official reserves may be misleading for two reasons. Firstly, unallocated reserves are a growing proportion of official reserves (from 25% in 1995 to 44% in 2012, source IMF). Secondly,

sumptions concerning the future evolution of global trade and the distribution of foreign-exchange reserves, the RMB could become the first or second currency of the basket by 2040[89]. In her opening speech at the Brussels Economic Forum, U.S. Treasury Secretary Yellen pointed out that China has a large market share in new energy fields such as lithium refining, lithium-ion battery production and solar panel production. In this regard, Yellen said, "We have accepted the heavy dependence on China for rare earth supply. These minerals and materials constitute important inputs for aviation, automobile production, battery manufacturing, renewable energy systems and technology manufacturing. China has global 60% rare earth mining and nearly 40% reserves give China a geostrategic advantage." In fact, the American globalization policy has been considered hypocritical as the fundamental goals of the U.S. and China are different: China is willing to achieve an equal relationship between major powers, but the United States seeks that China(or any other emerging economics, and even developed economy like EU and Japan) will always be attached to the United States, and firmly opposes China's independence in science and technology. In fact, European Union and Japan are also not at ease with the U.S., with the EU-Japan summit held in Tokyo on May 12, 2022, they both agree that relying on the U.S. alone is no longer a viable option. In the future, Europe and Japan may announce digital partnerships. Senior EU officials pointed Russia as already posing the "most immediate threat" to the world order and urged China to take a more constructive role on the international stage.

Despite the transaction benefits of having a single world anchor currency, an equilibrium with two or three major currencies might still be preferable[241] because it provides a critical check on the center country's incentives to misbehave[100], like inflating away debt as U.S. is conducting through the Federal Reserve's main tool, the federal-funds rate, to affect not only borrowing costs for consumers but also shaping broader decisions by companies like how many people to hire. Driven by the 2022 attack entailed supply shock driven by present and future sanction occasions, Russian commodities are collapsing in price on the one hand and non-Russian commodities are in convocation on the other hand, resulting in a buyer's strike. Western central banks cannot close the gaping and have to deal with the inflationary impacts of "commodities basis" driven by the sanctions raised from their respective sovereigns. In any case, there is a growing concern on understanding emerging economies' internationalization strategy, especially through currency, such as how China selectively opening up its domestic bond and RMB market and presenting a dynamic reputation model[60] will be extremely interesting. Hence we also include the **RMB/CNY(Chinese Yuan)-US$; RUB(Russian)-RMB** exchange rates into our research object. The recent extreme volatility of RUB, EUR and RMB then drive us step from the stochastic model and further analyse the economic mechanisms accounting for such "unprecedented" phenomenon.

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the evolution of official reserve allocation may differ from that of private portfolios. For instance, the euro has developed in international bonds market while its share in official reserves has hardly increased since the launch of monetary union (ECB, 2013). Unfortunately, comprehensive data on private portfolio (encompassing bonds markets, stock markets and bank lending) is missing, which may explain continued reliance on official reserves.

The dollar hegemony is just an ephemeral illusion. Across the history and once again, we are navigating back to a Multi-polar Currency System. Reflecting upon the 2008 financial crisis, it is generally believed that the international monetary system had an major indirect contribution through extensive appetite for U.S. assets and subsequent low interest rates in the States prior to the crisis[8][87][90]. This source of liquidity provision in crisis is discretionary and its power is declining in line with the declining share of the U.S. in global economy[31]. Multilateral and regional facilities were developed during the crisis. Ever since then, the international monetary regime is again moving towards 'multipolar' system, with the U.S. dollar, the Chinese RMB and the Euro as its likely key pillars, corresponding to the long-term evolution of the balance of economic weight in the world economy[30]. This shift is exacerbating, as we are witnessing now, short-run exchange rate volatility and even the scope for "currency wars" and capital flows global liquidity provision. Which alternatives is materialising depends on the terms of cooperation within a multilateral framework as we are going to further analyse in discussion chapter.

Through out history, the authorities operate their politics and economics with promotions, controls and propaganda to impose strong or weak currency, categorizing the exchange rate to be floating or fixed(pegged/managed). In floating regimes, exchange rates are determined on the foreign exchange market open to various buyers and sellers through continuous 24 hours a day trading except weekends(from 20:15 GMT Sunday to 22:00 GMT Friday)[18]. The current exchange rate determined in such a mechanism is called spot exchange rate, with forward exchange rate as quoted and traded today but for payment and delivery on a specific term. Most trades on currency retail market are carried with the local currency, which requires the concept of buying and selling rate. Foreign exchange market is no less complicated or interesting than the stock market, and they are strongly mutual related, see for example, "living with the fear of floating"[175], concerning asset returns. Baseline financial econometric models are suitbale to apply to test the characteristics such as non-normality and volatility thus the absolute returns of freely floating currency pairs, especially Japanese Yen - U.S. dollar which is considered a preferred pair given the unique performance of Yen[219] while holding the efficiency of the market free from commodity market[218] (as we will come back to this concern later). Therefore we choose **Euro-US$; Yen-US$** as currency of interest in our first part of study focusing on the analysis of time series.

1.2 Econometrics of exchange rates

In fact, regarding the observations of exchange rate time series, literature has proclaimed sets of perplexing facts:

1. It is formidable to factor economic variables that significantly co-trend with the exchange rates, a phenomenon codified in abundant literature as "exchange rate disconnect".

2. The volatility of Exchange rates **cannot** be forecast with fundamentals at less

than one year scope[203] and the era of easy profits in major foreign currencies from simple trend-following strategies is over[233].

3. Inclination-tracing techniques[6] would have been profitable on exchange rates over extended periods of time if the technical rules have been divergences of filter rules or moving average that provide decisions of buy–selling rather than deriving rules from time series models, despite the latter potentially contain far more information with a full density forecast[81].

4. Standard exchange rate models cannot outperform a random walk forecast and that the forward rate is not an optimal predictor of the spot rate. Meanwhile, the term structure of forward premia contains valuable information for forecasting future spot exchange rates and exchange rate dynamics is certainly nonlinear[57].

5. There is significant variation in liquidity among currencies, substantial non-liquidity[7] costs, and strong commonality in liquidity across exchange rates, as well as with equity and bond markets[192] and liquidity spirals[23].

6. After removing periods in which the Federal Reserve is active, exchange rate predictability is dramatically reduced[177].

7. Trading in foreign exchange (FX) swaps exceeds that of spot FX with strong co-movement in spot and swap market liquidity conditions and a robust link between FX funding and market liquidity[170].

Among these econom rtric features, we especially care about the volatility of exchange rates. Classical view of financial econometrics assumed efficient market hypothesis with constant volatility of returns and mainly concerned with rationalizing the fat tails in the unconditional return distribution[95]. Such hypothesis of constant volatility is clearly rejected by the data showing volatility tends to cluster in time[96]. We lay a crucial importance of volatility in Finance since it is a proxy for risk and forecasting return and asset allocation. Given that volatility is not directly observable from returns and it is not constant through time, literature employ squared daily return or absolute return to proxy conditional volatility, and a widely used measure of historical volatility is moving average, especially exponentially weighted moving average concerning ghost features[225]. To study time series, the very start of the literature dating back to the first year of 20th century assume the dynamic of the time series (typically, asset prices) to be a Gaussian stochastic process[8][16]. Later in history courses this normality hypothesis is rejected due to the realization that such Gaussian models are unsatisfactory when applied to real

[6] to employ historical data to make future decisions, see through bootstrap approach by Levich and Thomas[181][50][177], genetic programming approach by Neely[221], Momentum-Based Strategies by Okunev and White[226].

[7] a currency pair's ability to be bought and sold without creating a major impact on its exchange rate.

[8] To guarantee the positiveness of the series, similar to what we will do with the exchange rates, successive studies modified this hypothesis by treating a logarithm to the series.

data by successive literature evidencing that asset returns are asymmetric, excessing kurtosis and multi-modality, see for example[96][97][193] [194]. One may reasonably consider whether ARIMA (autoregressive integrated moving average) and other race-horses of uni-variate time series analysis, could be applied to exchange rate analysis. Literature found out that ARIMA models entail suboptimal generators of shifting signals[221] and ARIMA estimation on data generated by typical Markov models leads to an ARIMA (1, 0, 2) in which the autoregressive (AR) and moving average (MA) coefficients nearly cancel, resulting in inevitably loss of information[73] and divisive conclusions.

Given the above facts, among the nonlinear models for time series with conditional mean (NLAR, AR with random coefficients, threshold models, dnamical system approach[256] and artificial neural networks[131]...) or with conditional variance (ARCH, GARCH and their variants), Markov switching models (of conditional mean[140]) and conditional heteroskedasticity[141]; of conditional variance[43][133]), expressively gauges time-varying moments rendering a legitimate estimation of foreign exchange market returns, as well as business-cycle[187] analysis[127], while is rid of particular limitations of other nonlinear models such as not easy to implement (numerical search, local minimum) or too specific for certain nonlinear patterns (level shift, asymmetry, volatility clustering). The forecasts of the Markov model are superior at predicting the direction of change of the exchange rate[91]. The work on employing Markov switching model to develop economically beneficial exchange currency trading strategies, turning out with the Markovian models' high return excess regardless of ambivalent performance on accuracy of forecasting under statistical tests. Still, there is no clear clue for the trends of exchange rate dynamic, but Markov regime-switching models by depending the mean on higher moments of the targeted distribution moderately heighten returns[81]. Through multiple structural equations for conditional mean and conditional variance and switching mechanism governed by Markovian state variables, the markov switching models characterize distinct (mean or variance) patterns over time and is more flexible than models with structural changes while allowing for regime persistence (random switching).

1.3 Bayesian Paradigm

Classical maximum likelihood approach[212] struggles in inferencing models with non-Gaussian dynamics features and with latent variables in data collected with higher frequencies (i.e. weekly, daily or even hourly), which is getting more and more outrageous nowadays and especially is the case for exchange rates. To analyze exchange rates, among the inference tools for nonlinear and non-Gaussian financial models, Bayesian paradigm remains a competitive choice for its strong probabilistic basis. The essence of Bayesian methodologies lies in the operation of a hierarchy of probabilistic models, touching a far broader ground stepping from the Gaussian. In order to comprehensively apply the paradigm, we first draw attentions to the emergence and initial development phase of the Bayesian approaches.

Bayes is actually a eponym. Bayes' Theorem[74] was not written by Thomas Bayes [68][139] but firstly precipitated by Laplace in his memoir on inverse probability

in limited form[247] and then by Keynes[163][165] in complete form: probability ratio × evidence ratio = posterior probability ratio. Bayes wrote an 'Essay toward solving a problem in the doctrine of chances', introducing 'a tandem probability set-up'[138]. But it was until 1774 Laplace taking up the same problem, that of combining the measurements of a star, to l'Académie Royal des Sciences, that his theorem of inverse probability is firstly stated clearly in modern form[247]. In 1921 comes the revisit of Keynes to the same problem that Bayes and Laplace dealt with, and again he tried to combine measurements into the most probable value of a quantity[164]. Keynes developed an expression for the probability of the data and notion of evidence ratio conditioning on circumstance, marking the starting point for priorist[124] applications[9] and evidentialist inference based on likelihood[258].

The prevailing popularity of Bayesian paradigm is in essence paralleling to the search for certainty[237], which evolves to the tremendously growing field of "learning". Human is probably the only animal that born to feel uncertain and lack of safety. In replace of reflecting such a problem in [149] the author polled with "What is the right measure of uncertainty?" Still, this question jumped too fast into a framework of "measurement", silently bypassed the crux of the problem. Instead, this canonical question might better be presented as: "What is the right conceptualization of uncertainty?" Reasoning the conceptualization of uncertainty entails enduring a transformation in frame of reference, similar to reflecting the development of non-standard logics, some of which today collate in formality and omnipotence to "mathematical logic" as incarnated by Barwise[24] and epitomised by Keisler[162].

By appraising induction and deduction in Bayesian data analysis as distinct from Bayesian theory, Bayesian methods legitimize dual inter-dependent criterion of individuum rationalitas, i.e. (+) probability theory is the logic of science[156] as degrees of belief represented as probabilities and (-) decision making is a process to maximise the subjective expected utility function[120]. I put (-) as infiltrating and omnipotent as economic theories has been endeavouring to unifying decision-making methodologies with uncertainty in presence of every field; while (+) stands for a penetrating spirit, an approach so obvious and persevering that it is the bullseye of criticism , which goes back to Keynes's treatise and Knight's pamphlet, where together Knight and Keynes held fundamentally different assumptions and consequently, derived divisive theories of uncertainty, much further apart than previously supposed[228]. Far from a liberal, Keynes was actually a political socialist who believed that economic futures could be predicted rationally via abstractly deduced probabilities and therefore expert economists could and should engage in economic planning, while Knight was more of a radical liberal, viewing uncertainty and paradox to be the infiltrating fact of human existence. Thus the political and economic complexities is far beyond any planner. The adjectivitive locution "Bayesian" was picked up by Fisher in 1956 when referring Bayesian prediction as "the probability, in the light of the previous experience, of obtaining c success in (c+d) further trials". The first use of 'Bayesian inference' comes from reading notes by L.J. Savage, as a response to the 'frequentist', which was first coined by Nagel[215][216] in order to differentiate

[9]Including Turing's cracking the Enigma code.[206]

his frequency-based definition from Keynes' logic-based definition, not only from the belief-based definitions of probability dating back to Laplace and right in the counter-place reacting to Keynes' elucidation of probability as the logical relation between two propositions[104].

It was actually the economist Keynes' interpretation of uncertainty alongside his economic theories that had veritably triggered the creation of appellations of Bayesian methods in econometrics that we are all now accustomed to. This understanding of the born of Bayesian paradigm paralleling to the economical thoughts of Keynes as the context of ideological "priors" provide us a valuable sense of how the mechanics of economies was formed in these classical theories. Noticably in Keynes' main concern was domestic macro economics and Knight died right in the year upon the collapse of Bretton Woods system. They haven't got a dual opportunity to witness the contemporary unprecedented complexity of international financial market. The probability attached to an uncertain event does not reflect the heuristic amount of information that led to the assignment of that probability[246], nor the relection on Triffin dilemma (the obstacle of dollar as a reserve currency under the Bretton Woods system, or more generally the use of any country's currency as an international reserve currency)[34]. The exponentially bursting chaotic phenomena is pushing the discipline to care about cornered certain models while a general thought like Keynes and Knight had contributed seems impossible to recur. What a pity. So we try to devote a discussion devoted to this direction. Carrying on the advantageous heirloom of Bayesian paradigm that it is initially born with, we unfold an interpretative economic elucidation and naturally reveals the indivisibility of fundamentally understanding, employing and improving this twin amid the modernity of our world, "Bayesian paradigms" and "economic and finance theories".

Still let's first talk statistically. The premier advantage of the Bayesian framework is its approachable flexibility, as compared to the maximum likelihood approach, embodied in the way in which prior distribution as an omnipotent contrivance to confine the parameterization of financial econometric model. Moreover, speculatively, presence of multiple local solutions in choosing an estimator entail a failure of applying standard asymptotic and test theory to maximum likelihood estimation, whereas Bayesian approach is refrained from these shortages: with prior and posterior distributions constructed on the parameter random variable space, and all the information are retained in the simulated posterior distributions.

Furthermore, Bayesian approach also make inference on the scaling of the model and well solve the variable dimension problems using simulation techniques such as Reversible Jump Markov Chain Monte Carlo(RJMCMC)[134] to flexibly construct reversible Markov chain samplers that jump between parameter sub-spaces of differing dimensionality, plus the inexpensive, high-speed computing boosted simulation techniques allowing a joint estimation of hidden states and latent parameters and provides a general state space representation for nonlinear, non-Gaussian models[47], as we are going to see in the second chapter. One of the most useful algorithms among the Bayesian simulation techniques is the Gibbs sampler. In essence, Gibbs sampling is based on elementary properties of Markov chains[49], while as

a computer-intensive statistical method successive to EM algorithm[70] and resampling techniques like bootstrap algorithm[85], and tracing back to Metropolis and Hastings Estimator[207][144]. The Gibbs sampler algorithm was born with an escalation of popularity initialized by the work of Geman[121] for image processing problems[71][135], and then Gelfand and Smith revealed its tremendous potentials by comparing the the Gibbs sampler to Stochastic substitution and the sample-weighing-resample algorithm to the calculation of Bayesian posterior densities for a variety of structured models.

As an alternative sampling- (or Monte Carlo-) based approaches among the a Markov Chain Monte Carlo(also known as MCMC) simulation method family, it is also closely related to the idea of data augmentation of Tanner and Wong[250] enabling demarginalization, systematic and random-scan. Gibbs sampling is a particular version of block Metropolis Hastings algorithm where the proposal distribution for $\mathbf{X}_i$ is exactly the conditional distribution $\pi_i(\mathbf{X}_i|\mathbf{X}_{-1})$ so that the acceptance probability is always equal to 1[238]. In general, this algorithm will be efficient if the high posterior density point is chosen to have sufficiently high mass. The disadvantage of the algorithm is the extra execution time needed to run the Gibbs sampler various times. Chib and Jeliazkov provided extensions of this algorithm to more complex Markov chain Monte Carlo samplers[55][56]. When assuming a hierarchical structure to estimate the heteroscedastic disturbances, Gibbs sampling algorithm can be applied to generate samples from the the posterior distribution that does not correspond to any know ones, which is usually and again the case in the research questions of this thesis.

Following these trends of researches, the main part of the methodology chapter of this thesis is devoted to apply Markov switching models to the analysis of exchange rates with an extension to the form of Bayesian switching volatility model and then the parameters of the model is estimated by Gibbs sampling with the conditional posterior distributions derived. This thesis further apply Bayesian inference to study the causal relationship between currency pair to reveal the exchange rate dynamics in floating regimes.

Chapter 2

Methods

This chapter provides a Bayesian econometric analysis of the exchange rates through the lens of a Markov Switching model.

2.1 Descriptive statistics

To first describe exchange rate data, besides sample mean and standard deviation, I also compute the sample skewness, S, as an attempt to quantify the asymmetry of the probability distribution, and the sample kurtosis, K, a measurement for the shape(tailedness) of the probability distribution. Distributions with negative excess kurtosis are called platykurtic, and with a positive excess kurtosis called leptokurtic.

We apply the definition as below:

$$S = \frac{\hat{\mu}_3}{\hat{\sigma}^3} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^3}{\left(\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2\right)^{3/2}}, \tag{2.1}$$

$$K = \frac{\hat{\mu}_4}{\hat{\sigma}^4} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^4}{\left(\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2\right)^{2}}, \tag{2.2}$$

I also apply Jarque–Bera test as a goodness-of-fit test of whether sample data have skewness and kurtosis matching the ones of a normal distribution, based on the fact that skewness and excess kurtosis are jointly equal to zero under normality[1]. The p-value of Jarque-Bera test is defined as below.

$$JB = \frac{S^2}{6/n} + \frac{(K-3)^2}{24/n} \tag{2.3}$$

[1]If the data comes from a normal distribution, the JB statistic asymptotically has a chi-squared distribution with two degrees of freedom, so the statistic can be used to test the hypothesis that the data are from a normal distribution.

I first transform the exchange rates data to log-returns. The absolute log-returns are then used as a proxy for the instantaneous volatility and can be used for detecting the presence of volatility clustering.

I apply a rolling-window estimation of the volatility and assess its stability over time by plotting each estimate and point-wise confidence intervals(i.e., $\hat{\theta} \pm 2[\hat{SE}(\hat{\theta})]$) over the rolling window[12].

The persistence in the absolute log-return values and the rolling windows estimates of the volatility of the considered most relevant currency pair **Yen-US$, Euro-$, RMB-$, Rub-$**[109] suggest even with normality there still exist **volatility clustering effects**, that is the volatility of the time series changes over time (heteroschedastic effects) and periods of high volatility are followed by high volatility (volatility persistence), which we define as Volatility Regimes.

2.2 Bayesian Switching Volatility Model

I introduce a Bayesian Markov Switching model to study volatility regimes. Assume the following latent variable model for the time series $X_t, t = 1, 2, .., T$:

$$X_t = \alpha(t) + \sigma(t)\varepsilon_t, \quad \varepsilon_t \sim \mathcal{N}(0,1) \ i.i.d., \ t = 1, \ldots, T \tag{2.4}$$

with time-varying parameters

$$\alpha(t) = \alpha_0 \mathbb{I}(U_t = 0) + \alpha_1 \mathbb{I}(U_t = 1) \tag{2.5}$$
$$\sigma(t) = \sigma_0 \mathbb{I}(U_t = 0) + \sigma_1 \mathbb{I}(U_t = 1) \tag{2.6}$$

where the latent variables U_t, $t = 1, \ldots, T$ indicate the high/low volatility regimes and share the common distribution

$$U_t \sim \mathcal{B}ern(\theta) \quad i.i.d., \ t = 1, \ldots, T \tag{2.7}$$

In the Bayesian frame note, I set the parameters (vector) of this model as

$$\Theta = (\alpha_0, \alpha_1, \sigma_0, \sigma_1, \theta) \tag{2.8}$$

and denote with $\hat{\Theta} = \mathbb{E}(\Theta|\mathcal{F})$ the Bayesian estimator of Θ, where $\mathcal{F} = \sigma(\{Y_t\}_{t=1,\ldots,T})$ is the information set at time T.

I assume the prior distribution of the key parameter of volatility to be inverse-gamma distribution which has the property of conditionally conjugacy: if $\sigma_i^2 \sim \mathcal{IG}(a_i, b_i), i = 0, 1$, then the conditional posterior distribution is also inverse-gamma[65]. Its probability density function is defined over the support $x > 0$; $\alpha, \beta > 0$,

$$f(x; \alpha, \beta) = \frac{\beta^\alpha}{\Gamma(\alpha)} (1/x)^{\alpha+1} \exp(-\beta/x)$$

The inverse-gamma $\mathcal{IG}(a, b)$ model can also be expressed as an inverse-χ^2 distribution with scale $s_a = \frac{b}{a}$ and degrees of freedom $\mu_a = 2a$, the parameterization of which can be helpful in understanding the information underlying various choices of proper prior distributions[119]. The prior contains $\sigma_0^2 < \sigma_1^2$ is assumed to identify the two regimes as low and high volatility respectively.

Together I assume the following prior distributions for the other parameters:

$$\alpha_0 \sim \mathcal{N}(m_0, \gamma_0^2), \quad \alpha_1 \sim \mathcal{N}(m_1, \gamma_1^2) \tag{2.9}$$
$$\theta \sim \mathcal{B}e(c, d) \tag{2.10}$$

Denote $\mathcal{F}_T = \sigma(\{X_u\}_{u \leq T-1})$ and $\mathcal{F}_t^U = \sigma(\{X_u\}_{u \leq T-1} \cup U_T)$ for two types of information sets available at time t. The first one includes past observations, the second includes also the current hidden state U_T.

Before implementing the Gibbs sampler, we establish our Bayesian posterior analysis on the likelihood function and write out $\mathbb{E}(X_t|\mathcal{F}_t^U)$ and $\mathbb{E}(X_t|\mathcal{F}_t)$.

$$\mathbb{E}(X_t) = \mathbb{E}(\alpha_1 U_t + \alpha_0(1 - U_t) + (\sigma_1 U_t + \sigma_0(1 - U_t))\varepsilon_t)$$

$$= \mathbb{E}(\alpha_1 U_t + \alpha_0(1 - U_t)) + \mathbb{E}(\sigma_1 U_t + \sigma_0(1 - U_t))\varepsilon_t$$

$$= \mathbb{E}(\alpha_1)\mathbb{E}(U_t) + \mathbb{E}(\alpha_0)(1 - \mathbb{E}(U_t)) + (\mathbb{E}(\sigma_1)U_t + \mathbb{E}(\sigma_0)(1 - U_t))\varepsilon_t$$

- For $\mathcal{F}_T = \sigma(\{X_u\}_{u \leq T-1})$.

$$\mathbb{E}(X_t|\mathcal{F}_t) = \hat{\alpha}_0\hat{\theta} + \hat{\alpha}_1(1 - \hat{\theta}) + \hat{\sigma_0}\hat{\theta} + (1 - \hat{\theta})\sigma_1\varepsilon_t$$

- For $\mathcal{F}_t^U = \sigma(\{X_u\}_{u \leq t-1} \cup U_t)$
  - If $U_t = 0$
  $$\mathbb{E}(X_t|\mathcal{F}_t^U) = \hat{\alpha}_0 + \hat{\sigma_0}\varepsilon_t$$
  - If $U_t = 1$
  $$\mathbb{E}(X_t|\mathcal{F}_t^U) = \hat{\alpha}_1 + \hat{\sigma_1}\varepsilon_t$$

2.3 Gibbs Sampler

In the Bayesian Switching Volatility Model, I estimate the parameters by following the **data augmentation** framework, where the likelihood is a function of the parameter vector and of the latent variables:

$$\mathcal{L}(X_1,\ldots,X_T,U_1,\ldots,U_T|\alpha_0,\alpha_1,\sigma_0^2,\sigma_1^2,\theta) =$$
$$= \prod_{t=1}^{T} \frac{1}{\sqrt{2\pi\sigma^2(t)}} \exp\left\{-\frac{1}{2}\left(X_t-\alpha(t)\right)^2\right\} \theta^{U_t}(1-\theta)^{1-U_t}$$

We set $\mathcal{T}_j = \{t|U_t = j\}$ and $T_j = \text{Card}(\mathcal{T}_j)$, $j = 0, 1$ where $\text{Card}(A)$ denotes the cardinality of the set A, that is the number of elements of A.

We combine the same terms and get:

$$\mathcal{L}(X_1,\ldots,X_T,U_1,\ldots,U_T|\alpha_0,\alpha_1,\sigma_0^2,\sigma_1^2,\theta) =$$
$$= (2\pi\sigma_0^2)^{-T_0/2} \exp\left\{-\frac{1}{2}\sum_{t\in\mathcal{T}_0}\left(X_t-\alpha_0\right)^2\right\}(1-\theta)^{T_0}$$
$$\cdot(2\pi\sigma_1^2)^{-T_1/2} \exp\left\{-\frac{1}{2}\sum_{t\in\mathcal{T}_1}\left(X_t-\alpha_1\right)^2\right\}\theta^{T_1} \tag{2.11}$$

The joint parameter and latent variable posterior distribution is not tractable, thus the analytical derivation of the posterior mean is not easy. I choose an alternative approach to estimate the Markov switching model: the method of **Gibbs sampler**, also see e.g., Albert and Chib[6] and McCulloch, Tsay and Tiao[201][202][254], as the evolution and literature of which is introduced in the first chapter.

The general Gibbs sampling process is summarized in the following:

Let $\mathbf{X}$ be a multidimensional random variable with probability density function π on a space$(\mathcal{X}, \mathcal{B}(\mathcal{X})$.

Let $\mathbf{X}$ be partitioned in p sub-groups, that is w.l.o.g. $\mathbf{X} = (\mathbf{X}_1, ..., \mathbf{X}_p)$ and denote with π_i the density of $\mathbf{X}_i$ conditional on $\mathbf{X}_1, ..., \mathbf{X}_{i-1}, \mathbf{X}_{i+1}, ..., \mathbf{X}_p$.

The conditional densities $\{\pi_i\} = 1, ...p$ can be multivariate and are called full conditional densities. In the Gibbs sampling algorithm the transition from a random number $\mathbf{X}^{(t)}$, generated at the $\mathbf{t}$-th iteration, to the next one $\mathbf{X}^{(t+1)}$ is

Given $\mathbf{X}^{(t)} = \mathbf{x}^{(t)}$

1. $\mathbf{X}_1^{(t+1)} \sim \pi_1(x_1|\mathbf{x}_2^{(t)}, ..., \mathbf{x}_p^{(t)})$

2. $\mathbf{X}_2^{(t+1)} \sim \pi_2(x_2|\mathbf{x}_1^{(t+1)}, \mathbf{x}_3^{(t)}, ..., \mathbf{x}_p^{(t)})$

3. $\vdots$

p. $\mathbf{X}_p^{(t+1)} \sim \pi_p(x_p|\mathbf{x}_2^{(t+1)}, \mathbf{x}_3^{(t+1)}, ..., \mathbf{x}_{p-1}^{(t+1)})$

In our Bayesian Switching Volatility Model, the above algorithm iterates the following steps

$$\begin{aligned}(\alpha_0, \alpha_1) &\sim p(\alpha_0, \alpha_1|\sigma_0^2, \sigma_1^2, \theta, \underline{U}, \underline{X}) \\ (\sigma_0^2, \sigma_1^2) &\sim p(\sigma_0, \sigma_1|\alpha_0, \alpha_1, \theta, \underline{U}, \underline{X}) \\ \theta &\sim p(\theta|\alpha_0, \alpha_1, \sigma_0, \sigma_1, \underline{U}, \underline{X}) \\ \underline{U} &\sim p(\underline{U}|\alpha_0, \alpha_1, \sigma_0^2, \sigma_1^2, \theta, \underline{X})\end{aligned}$$

where $\underline{X} = (X_1, \ldots, X_T)$ and $\underline{U} = (U_1, \ldots, U_T)$.

Now I discuss the full conditional distributions, which can also be derived by using the result in Eq. 2.11.

Full Conditional Distribution of $\underline{U}$

The Gibbs sampler generate U_t at each iteration from the full conditional distribution

$$\begin{aligned}&p(U_t|\alpha_0, \alpha_1, \sigma_0^2, \sigma_1^2, \theta, U_1, \ldots, U_{t-1}, U_{t+1}, \ldots, U_T) \propto \\ &\propto \mathcal{B}in(1, \bar{\xi}_t)\end{aligned} \tag{2.12}$$

where

$$\bar{\xi}_t = \frac{\theta \exp\left\{-\frac{1}{2\sigma_1^2}(X_t - \alpha_1)^2\right\}}{\theta \exp\left\{-\frac{1}{2\sigma_1^2}(X_t - \alpha_1)^2\right\} + (1-\theta)\exp\left\{-\frac{1}{2\sigma_0^2}(X_t - \alpha_0)^2\right\}}$$

Full Conditional Distribution of α_j

The intercept parameters $\alpha_j, j = 0, 1$ are generated from:

$$p(\alpha_j|\sigma_j^2, \theta, \underline{U}, \underline{X}) \propto \mathcal{N}(\bar{m}_j, \bar{\gamma}_j^2) \tag{2.13}$$

with

$$\bar{m}_j = \bar{\gamma}_j^2 \left(\frac{1}{\sigma_j^2}\sum_{t \in \mathcal{T}_j} X_t + \frac{m_j}{\gamma_j^2}\right), \quad \bar{\gamma}_j^2 = \left(\frac{T_j}{\sigma_j^2} + \frac{1}{\gamma_j^2}\right)^{-1}$$

where $\mathcal{T}_j = \{t|U_t = j\}$ and $T_j = \text{Card}(\mathcal{T}_j)$, $j = 0, 1$ where $\text{Card}(A)$ denotes the cardinality of A, that is the number of elements of the set A.

Full Conditional Distribution of σ_j^2

The variance parameters $\sigma_j^2, j = 0, 1$ are generated from:

$$p(\sigma_0^2, \sigma_1^2 | \alpha_0, \alpha_1, \theta, \underline{U}, \underline{X}) \propto \mathcal{IG}(\bar{a}_0, \bar{b}_0)\mathcal{IG}(\bar{a}_1, \bar{b}_1)\mathbb{I}(\sigma_0^2 < \sigma_1^2)$$

where

$$\bar{a}_j = a_j + \frac{T_j}{2}, \quad \bar{b}_j = b_j + \frac{1}{2}\sum_{t \in \mathcal{T}_j} (X_t - \alpha_j)^2 \tag{2.14}$$

Full Conditional Distribution of θ

The regime possibility θ is generated from:

$$p(\theta | \alpha_0, \alpha_1, \sigma_0^2, \sigma_1^2, \theta, \underline{U}, \underline{X}) \propto \mathcal{B}e(\bar{c}, \bar{d}) \tag{2.15}$$

with

$$\bar{c} = c + \sum_{t=1}^{T} U_t, \quad \bar{d} = d + T - \sum_{t=1}^{T} U_t$$

Now we look for $\mathbb{E}(X_t | \mathcal{F}_t^U)$ and $\mathbb{E}(X_t | \mathcal{F}_t)$.

$$\begin{aligned}
\mathbb{E}(X_t) &= \mathbb{E}(\alpha_1 U_t + \alpha_0(1 - U_t) + (\sigma_1 U_t + \sigma_0(1 - U_t))\varepsilon_t) \\
&= \mathbb{E}(\alpha_1 U_t + \alpha_0(1 - U_t)) + \mathbb{E}(\sigma_1 U_t + \sigma_0(1 - U_t))\varepsilon_t \\
&= \mathbb{E}(\alpha_1)\mathbb{E}(U_t) + \mathbb{E}(\alpha_0)(1 - \mathbb{E}(U_t)) + (\mathbb{E}(\sigma_1)U_t + \mathbb{E}(\sigma_0)(1 - U_t))\varepsilon_t
\end{aligned}$$

Together we have:

$$\mathbb{E}(X_t | \mathcal{F}_t) = \mathbb{E}(\mathbb{E}(X_t | \mathcal{F}_t^U) | \mathcal{F}_t)$$

$$= \mathbb{E}(\alpha_0 U_T + \alpha_1(1 - U_T) | \mathcal{F}_t)$$

In the above results, define the moments of the model, e.g. $\mu(X_t | \mathcal{F}_t) = \alpha_0\theta + \alpha_1(1 - \theta)$, and we have:

$$\hat{\alpha_j} = \mathbb{E}(\mathcal{N}(\bar{m}_j, \bar{\gamma}_j^2) | \mathcal{F}_t) = \bar{m}_j = \bar{\gamma}_j^2 \left(\frac{1}{\sigma_j^2} \sum_{t \in \mathcal{T}_j} X_t + \frac{m_j}{\gamma_j^2} \right), \quad \bar{\gamma}_j^2 = \left(\frac{T_j}{\sigma_j^2} + \frac{1}{\gamma_j^2} \right)^{-1}$$

$$\hat{\sigma_j} = \mathbb{E}(\mathcal{IG}(\bar{a}_i, \bar{b}_i)) = \frac{\bar{b}_j}{\bar{a}_j - 1}, \quad \bar{a}_j = a_j + \frac{T_j}{2}, \quad \bar{b}_j = b_j + \frac{1}{2}\sum_{t \in \mathcal{T}_j} (X_t - \alpha_j)^2$$

$$\hat{\theta} = \mathbb{E}(\mathcal{B}e(\bar{c}, \bar{d})|\mathcal{F}_t) = \frac{\bar{c}}{\bar{c} + \bar{d}}, \quad \bar{c} = c + \sum_{t=1}^{T} U_t, \quad \bar{d} = d + T - \sum_{t=1}^{T} U_t$$

where $\mathcal{T}_j = \{t|U_t = j\}$ and $T_j = \text{Card}(\mathcal{T}_j)$, $j = 0, 1$ where $\text{Card}(A)$ denotes the cardinality of A, that is the number of elements of the set A. $\hat{\mu} = \hat{\alpha_0}\hat{\theta} + \hat{\alpha_1}(1 - \hat{\theta})$ is the plug-in estimator.

2.4 Relationship between Exchange Rates

Now we further consider to apply the two regime switching intercept model to investigate the time series relationship between exchange rates. The lagged Markov switching model can be interpreted as the short term causality between exchange rates. Similar application of Markov switching model to time series relationship also see e.g. on causal relationship between energy consumption and GDP[1], money–output relationship[232] and recent work on renewable-energy and economic growth[51].

Establish the following model

$$X_t = \alpha(t) + \beta(t)Z_{t-1} + \sigma(t)\varepsilon_t, \quad \varepsilon_t \sim \mathcal{N}(0, 1) \tag{2.16}$$

with time-varying parameters

$$\alpha(t) = \alpha_0\mathbb{I}(U_t = 0) + \alpha_1\mathbb{I}(U_t = 1) \tag{2.17}$$
$$\beta(t) = \beta_0\mathbb{I}(U_t = 0) + \beta_1\mathbb{I}(U_t = 1) \tag{2.18}$$
$$\sigma(t) = \sigma_0\mathbb{I}(U_t = 0) + \sigma_1\mathbb{I}(U_t = 1) \tag{2.19}$$

where the latent indicator variables U_t $t = 1, \ldots, T$ have common distribution

$$U_t \sim \mathcal{B}ern(\theta) \quad i.i.d.\, t = 1, \ldots, T \tag{2.20}$$

Assume for α_j, σ_j and θ the same prior distributions as in Section 2.2, whereas for β_j assume two independent normal prior distribution $\mathcal{N}(0, s_j^2)$.

For this model the likelihood is written as:

$$\mathcal{L}(X_1, \ldots, X_T, U_1, \ldots, U_T|\alpha_0, \alpha_1, \beta_0, \beta_1, \sigma_0^2, \sigma_1^2, \theta) =$$
$$= \prod_{t=1}^{T} \frac{1}{\sqrt{2\pi\sigma^2(t)}} \exp\left\{-\frac{1}{2}\left((X_t - \alpha(t) - \beta(t)Z_{t-1})\right)^2\right\} \theta^{U_t}(1 - \theta)^{1-U_t}$$

The joint parameter and latent variable posterior distribution is not proportional to any known distribution, thus we apply **Gibbs sampler** again to estimate the above model.

The full conditionals of the Gibbs sampler are:

Full conditional of α_j

$$p(\alpha_j|\beta_j, \sigma_j^2, \theta, \underline{U}, \underline{X})$$

$$\propto \mathcal{N}(\bar{m}_j, \bar{\gamma}_j^2) \tag{2.21}$$

with

$$\bar{m}_j = \bar{\gamma}_j^2 \left(\frac{1}{\sigma_j^2} \sum_{t \in \mathcal{T}_j} (X_t - \beta_j Z_{t-1}) + \frac{m_j}{\gamma_j^2} \right), \quad \bar{\gamma}_j^2 = \left(\frac{T_j}{\sigma_j^2} + \frac{1}{\gamma_j^2} \right)^{-1}$$

where $\mathcal{T}_j = \{t | U_t = j\}$ and $T_j = \text{Card}(\mathcal{T}_j)$, $j = 0, 1$, where $\text{Card}(A)$ denotes the cardinality of A, that is the number of elements of the set A.

Full conditional of β_j

$$p(\beta_j|\alpha_j, \sigma_j^2, \theta, \underline{U}, \underline{X})$$

$$\propto \mathcal{N}(\bar{v}_j, \bar{s}_j^2)$$

with

$$\bar{v}_j = \bar{s}_j^2 \left(\frac{1}{\sigma_j^2} \sum_{t \in \mathcal{T}_j} (X_t - \alpha_j) Z_{t-1} \right), \quad \bar{s}_j^2 = \left(\frac{1}{\sigma_j^2} \sum_{t \in \mathcal{T}_j} Z_{t-1}^2 + \frac{1}{s_j^2} \right)^{-1} \tag{2.22}$$

(2.23)

Full conditional of σ_j^{-2}

$$p(\sigma_0^2, \sigma_1^2 | \alpha_0, \alpha_1, \beta_0, \beta_1, \theta, \underline{U}, \underline{X})$$

$$\propto \mathcal{IG}a(\bar{a}_0, \bar{b}_0) \cdot \mathcal{IG}a(\bar{a}_1, \bar{b}_1) \quad \mathbb{I}(\sigma_0^2 < \sigma_1^2) \tag{2.24}$$

where

$$\bar{a}_j = a_j + \frac{T_j}{2}, \quad \bar{b}_j = b_j + \frac{1}{2} \sum_{t \in \mathcal{T}_j} (X_t - \alpha_j - \beta_j Z_{t-1})^2 \tag{2.25}$$

Full conditional of θ

$$p(\theta|\alpha_0, \alpha_1, \beta_0, \beta_1, \sigma_0^2, \sigma_1^2, \theta, \underline{U}, \underline{X})$$

$$\propto \mathcal{B}e(\bar{c}, \bar{d}) \tag{2.26}$$

with

$$\bar{c} = c + \sum_{t=1}^{T} U_t, \quad \bar{d} = d + T - \sum_{t=1}^{T} U_t \tag{2.27}$$

Full conditional of $\underline{U}$

We apply the same iterative procedure to the elements of U. The resulting algorithm is called single-move Gibbs sampler. At each iteration U_t is simulated from its full conditional distribution:

$$p(U_t|\alpha_0, \alpha_1, \sigma_0^2, \sigma_1^2, \theta, U_1, \ldots, U_{t-1}, U_{t+1}, \ldots, U_T$$

$$\propto \mathcal{B}in(1, \bar{\xi}_t) \tag{2.28}$$

where

$$\bar{\xi}_t = \frac{\theta \exp\left\{-\frac{1}{2\sigma_1^2}(X_t - \alpha_1 - \beta_1 Z_{t-1})^2\right\}}{\theta \exp\left\{-\frac{1}{2\sigma_1^2}(X_t - \alpha_1 - \beta_1 Z_{t-1})^2\right\} + (1-\theta)\exp\left\{-\frac{1}{2\sigma_0^2}(X_t - \alpha_0 - \beta_0 Z_{t-1})^2\right\}}$$

It worth to be pointed out that this part of methodology in this thesis is a simplified modification of recent works on Bayesian analysis of exchange rate volatility correlations, see most frontier work of Markov-switching vector auto-regressive (VAR) model on the stochastic correlation for contagion between major and Asian-Pacific currencies[48]. The log-volatility dynamics and the correlation of currencies could be illustrated by two independent Markov chains to allow for various effects such as spill-overs and shifts with various degrees of intensity. The Gibbs sampler with data augmentation in this thesis is more comlicated and effective than that based on classical MCMC algorithms.

Chapter 3

Results

"You see, I have the advantages of having found out how hard it is to get to know something. I know what it means to know something. And therefore I see how they get their information and I can't believe that they know it."[1]

3.1 Descriptive statistics

We obtain the dataset `Exchange.xls` containing CCY-CCY Delayed Price from Federal Reserve Economic Data and Yahoo Finance, including six *exchange rates* series **CNY(Chinese Yuan)-US$; RUB(Russian)-US$; US$-EU; CNY-EU; RUB-CNY; Yen(Japanese)-US$**.[2]

From the histogram and the best normal distribution we can tell normality holds for most relevant currency pair **Yen-US$**. However, such normality is no longer the case when we look at the other five most recent exchange rate series. As summarized in the following table 1 the kurtosis and skewness, the p-value of Jarque-Bera test are all less than the smallest tabulated value. The extreme volatility especially occurs in the exchange rate concerning Russian Ruble for the reason of the recent war, as shown in 23.

3.2 Bayesian inference and Gibbs estimation

We first apply Bayesian inference to Yen-dollar time series. Remind the prior distributions we set for the Markov switch model are

[1] Richard Phillips Feynman's comment on social sciences

[2] The first five series are sampled at the daily frequency in the recent five year(2017/04/21-2022/04/21) and **Yen-US$ rate** from 1st January 1999 to 3rd November 2011. Such a database is designed based on the importance of currencies, the typical rule of Yen as floating regime to show the stylized fact that how volatility of exchange rates are getting abnormal recently.

Table 1: Abnormalities

currency	**kurtosis**	**skewness**
CNY(Chinese Yuan)-US$	7.3648	0.1232
RUB(Russian)-US$	111.7671	4.3250
US$-EU	5.4579	-0.2296
CNY-EU	5.6746	0.0951
RUB-CNY	111.3749	4.2880

$$\alpha_0 \sim \mathcal{N}(m_0, \gamma_0^2), \quad \alpha_1 \sim \mathcal{N}(m_1, \gamma_1^2) \tag{3.1}$$
$$\sigma_0^2 \sim \mathcal{IG}(a_0, b_0), \quad \sigma_1^2 \sim \mathcal{IG}(a_1, b_1)\mathbb{I}(\sigma_0^2 < \sigma_1^2) \tag{3.2}$$
$$\theta \sim \mathcal{B}e(c, d) \tag{3.3}$$

In this Bayesian frame, we set the parameter family

$\Theta = \alpha_0, \alpha_1, \sigma_0, \sigma_1, \theta$ and $\hat{\Theta} = \mathbb{E}(\Theta|\mathcal{F})$

with prior parameterization $m_0 = -0.05$, $\gamma_0 = 0.05$, $m_1 = 0.05$, $\gamma_1 = 0.05$, $a_1 = 10$, $b_1 = 4$, $a_0 = 10$, $b_0 = 4$, $c = 10$, $d = 30$.

Apply the code `Exchange.m` given in Appendix and get the following parameter estimates: $\hat{\alpha}_0 = -0.0115$, $\hat{\alpha}_1 = 0.0580$, $\sigma_0^2 = 0.0723$, $\sigma_1^2 = 0.2491$, $\theta = 0.0928$.

Compare the posterior distributions with the priors we can tell that the observations are informative about the parameter values. The prior and posterior distributions of the parameters are given in Figures 1-4.

Figure 4 shows the posterior probability of the regimes (gray area) and the estimates of the allocation variables U_t. Remind that $\sigma_0^2 < \sigma_1^2$, so σ_1^2 stands for the high volatility, and accordingly the regime $U_t = 1$ is labelling high volatility clustering.

Figure 9 shows the log-returns, the histogram and the best normal distribution of **Yen-US$ rate**.

Figure22 shows the sequential estimates of the volatility with a rolling window of 60 days (blue) and 180 days (red), as well as absolute returns, which are a proxy for the instantaneous volatility and can be used for detecting the presence of volatility clustering. The main descriptive statistics for the Yen-US$ are:

- mean: -0.011307; standard deviation: 0.67323
- kurtosis: 6.3826; skewness: -0.24644

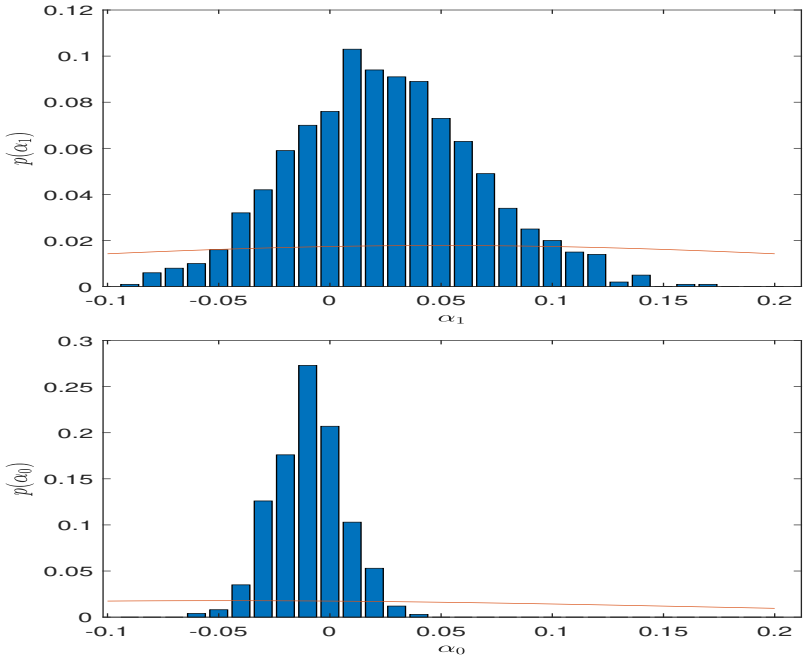

Figure 1: Prior density and posterior histogram for α_1 and α_0

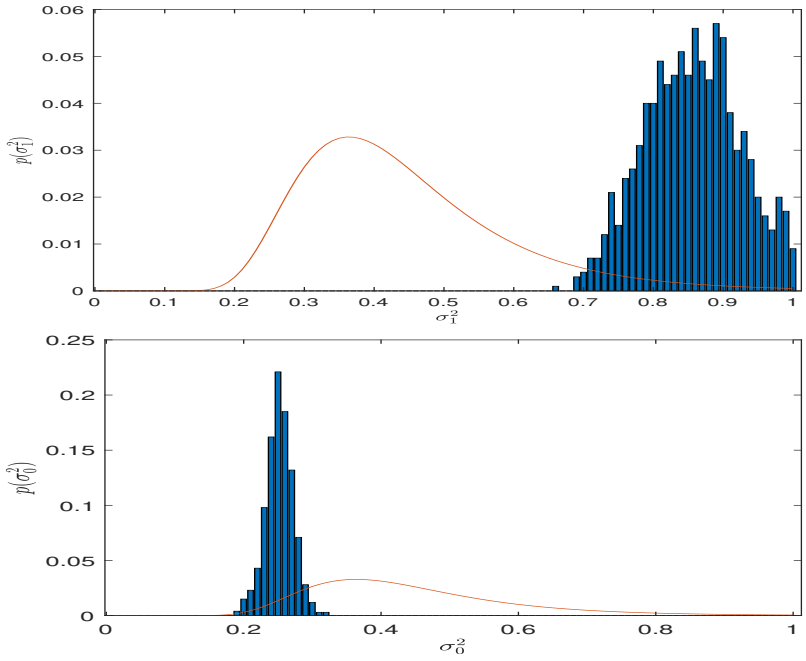

Figure 2: Prior density and posterior histogram for σ_1^2 and σ_0^2

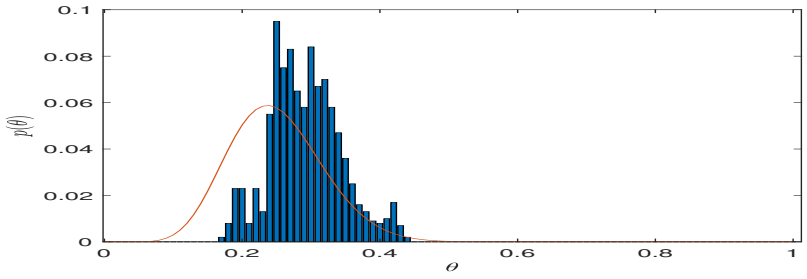

Figure 3: Prior density and posterior histogram for θ.

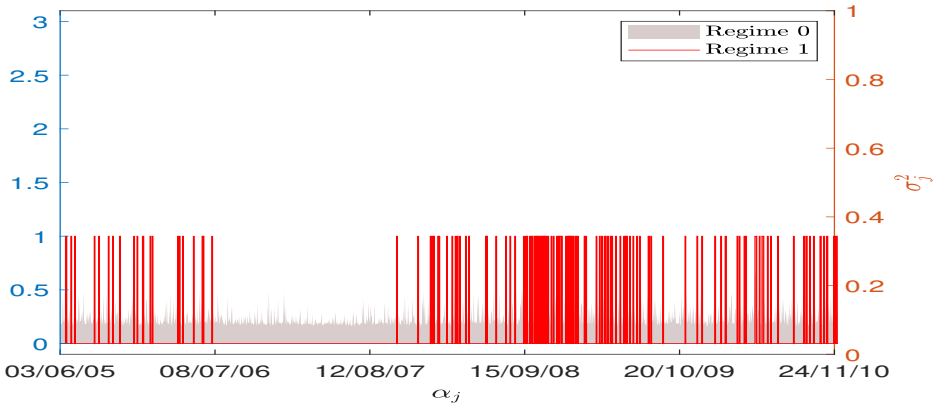

Figure 4: Scatter plots of the MCMC samples of the pairs (α_0, σ_0^2) and (α_1, σ_1^2) from the posterior distribution with Bayesian estimates. Regime 1 indicates high volatility.

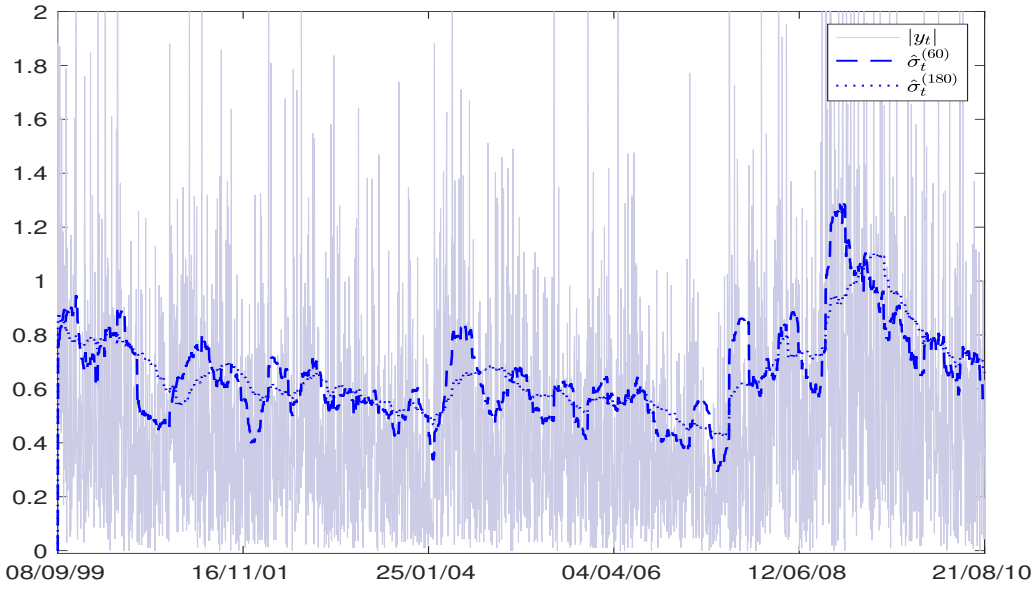

Figure 5: Estimated volatility.

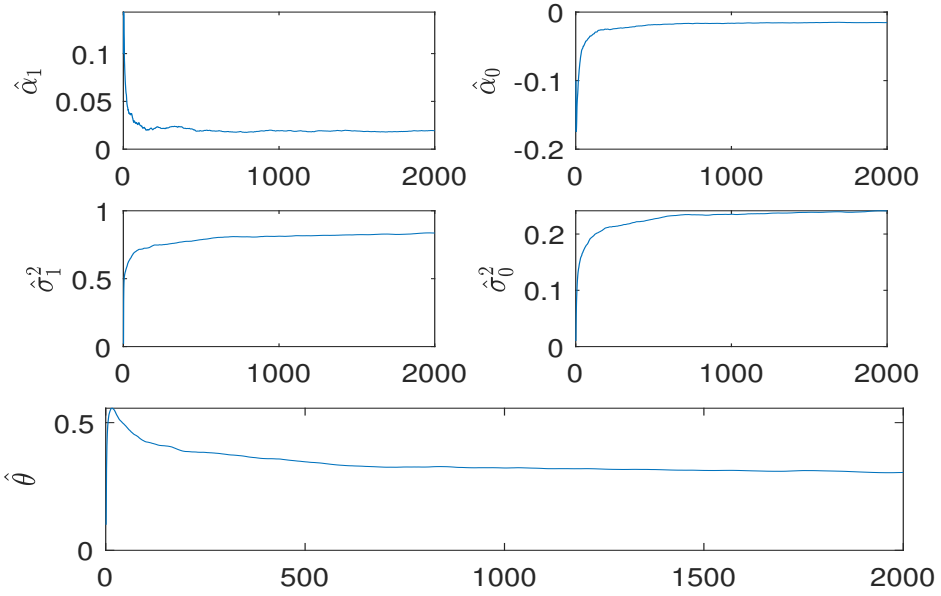

Figure 6: MCMC progressive averages increasing the number of MCMC simulations.

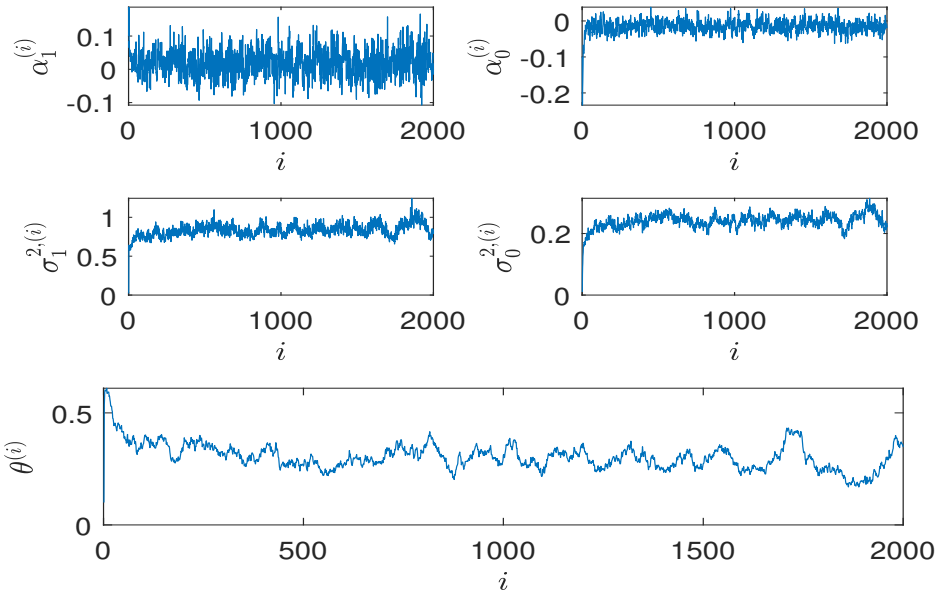

Figure 7: MCMC simulated samples.

There is **excess of kurtosis**($6.3826 > 3$), that is tails are thicker than the normal tails, and there is a **longer tail to the left** since the skewness is negative. But still it the Jarque-Bera test result indicated that it meaningfully fit the normal distribution.

For each parameter, I use the MCMC samples to find the 2.5% and the 97.25% quantiles of the posterior distribution to get the 95% HPD region as table 2

In Bayesian inference, if zero belongs to the HPD region, (also called credible interval), then the coefficient is not significant. Seeing form the HPD, the expected returns are significant in the two regimes.

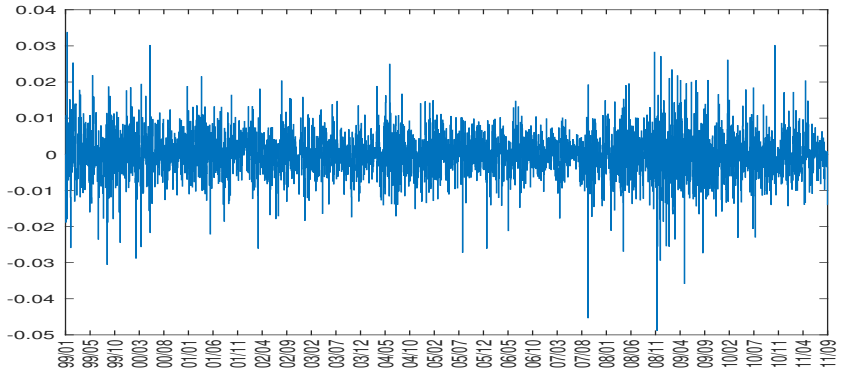

Figure 8: Log-return on exchange rates of **Yen-US$ rate**.

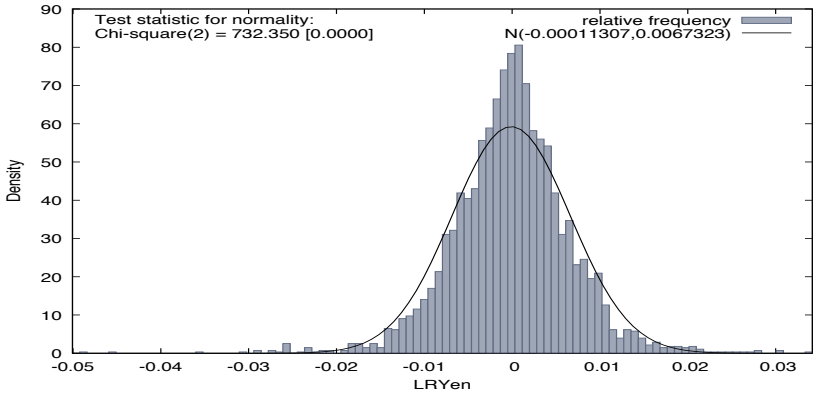

Figure 9: Histogram and fitted normal density of **Yen-US$ rate**.

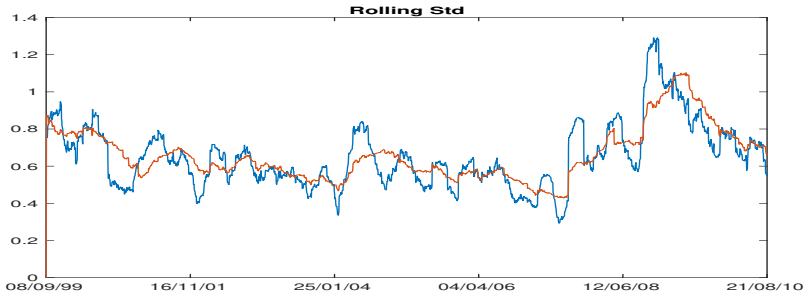

Figure 10: Sequential estimates of the volatility with a rolling window of 60 days (blue) and 180 days (red) of **Yen-US$ rate**

In Bayesian inference, if the credible intervals of two parameters do not overlap, than the parameters differ in their value. Use the credible intervals, we see among regime-specific volatilities, $\alpha_1, \sigma_0^2, \theta$ are different, and α_0, σ_1^2 are overlapped.

```
%% 95% confidence intervals
%alpha1_hat
q0025_alpha1=icdf('normal',0.025,m1_bar,gam1_bar)
q09725_alpha1=icdf('normal',0.9725,m1_bar,gam1_bar)
```

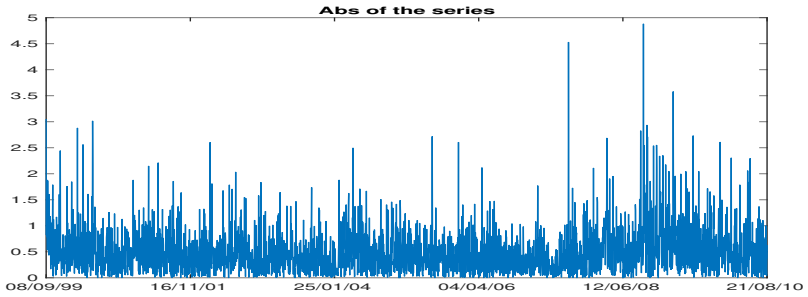

Figure 11: Absolute returns are a proxy for the instantaneous volatility and can be used for detecting the presence of volatility clustering of **Yen-US$ rate**

Θ	0.25% quantile	97.25% quantile
α_0	-0.0010	-6.4867e-04
α_1	-0.0737	-0.0618
σ_0^2	5.5761e+05	6.1746e+05
σ_1^2	7.8766e+04	1.0085e+05
θ	0.1314	0.1547

Table 2: 95% HPD region

```
%sigma20_hat
q0025_sigma20=gaminv(0.025,a0_bar,b0_bar)
q09725_sigma20=gaminv(0.9725,a0_bar,b0_bar)
%sigma21_hat
q0025_sigma21=gaminv(0.025,a1_bar,b1_bar)
q09725_sigma21=gaminv(0.9725,a1_bar,b1_bar)
%theta_hat
q0025_theta=icdf('beta',0.025,c_bar, d_bar)
q009725_theta=icdf('beta', 0.9725, c_bar, d_bar)
%% downsampleMCMC
downsample_alf0_hat=downsample(alf0_hat,4)
autocorr(downsample_alf0_hat)
autocorr(alf0_hat,'NumLags',3)
%THINNING
thinnig=downsample(downsample_alf0_hat,4)
autocorr(thinnig)
```

For α_0 generated by the Gibbs sampler is not independent. I run the code above to check the randomness of the sub-sample: 1) Build a sub-sample keeping 1 sample every 4, it is not random as they still hold auto-correlation; 2) build a sub-sample of the Gibbs sample by discarding 3 samples every 4 samples. It is a random sample.

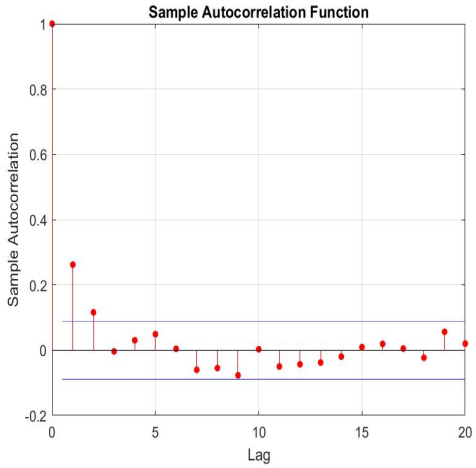

Figure 12: Sub-sample keeping 1 sample every 4.

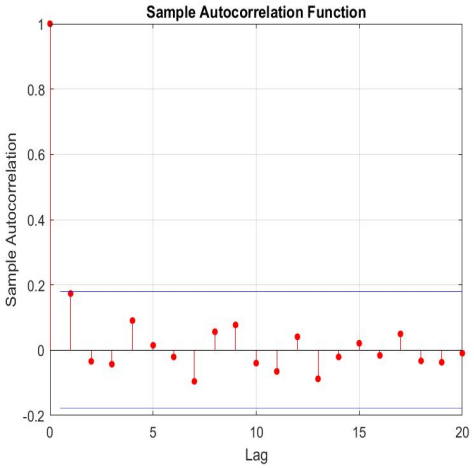

Figure 13: Thinning(discarding 3 samples every 4 samples).

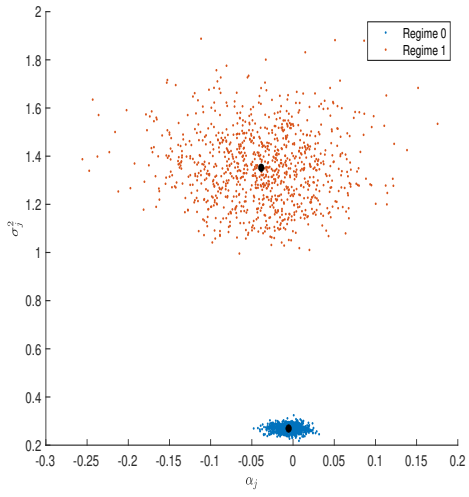

Figure 14: Regime clustering.

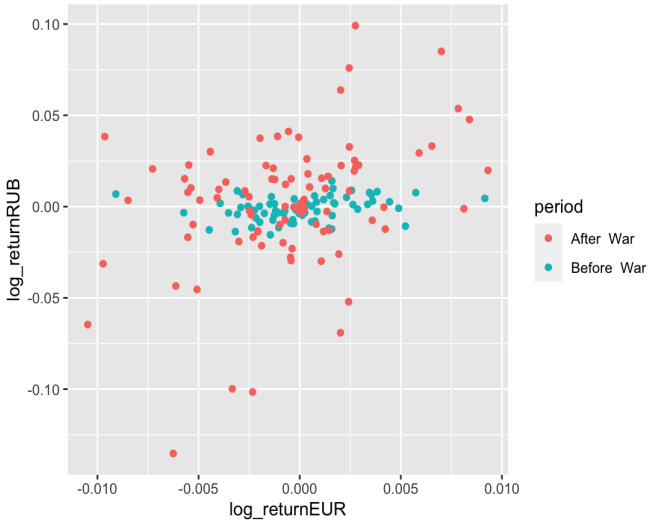

Figure 15: Turning after war of volatility of **RUB-USD** regards to **EUR-USD**

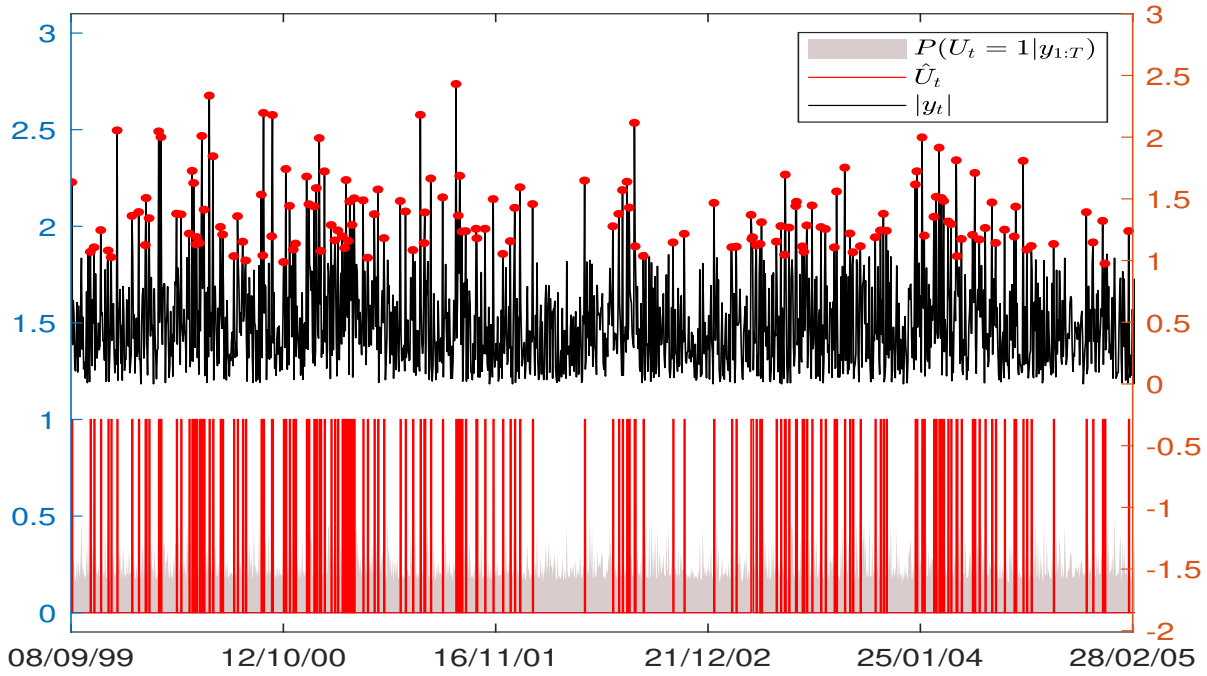

Figure 16: Posterior regimes (red line), probability of the regime 1 (gray area), absolute return (black line), and observations classified as high volatility observations (red dots).

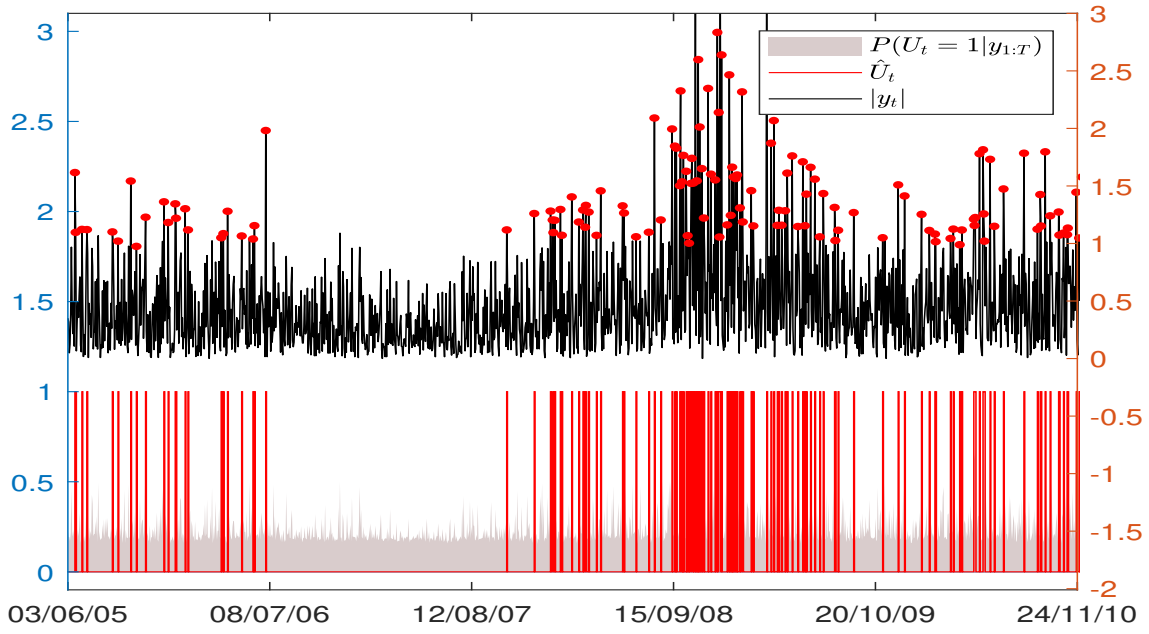

Figure 17: Posterior regimes (red line), probability of the regime 1 (gray area), absolute return (black line), and observations classified as high volatility observations (red dots).

3.3 Relationship between Exchange Rates

When X_t is the EU-US$ rate and Z_{t-1} is the lagged Yen-US$ rate, I try to implement the Gibbs sampler in Matlab and exhibit the code `Causality.m` given in Appendix B. Apparently the sample size is too big for a PC computation capacity and the computation is so time consuming that I cannot run it with the whole sample.

By cutting the first 40 sample and run the codes on this sub-sample[3], I acquire the plot of the posterior distribution of β_0 and β_1 indicating the causality from EU-US$ to Yen-US$, shown in Figure 20 and Figure 21. Their estimated values are $\beta_0 = -0.0644$; $\beta_1 = 0.2092$ and the Posterior Progressive MCMC are shown as Figure 19.

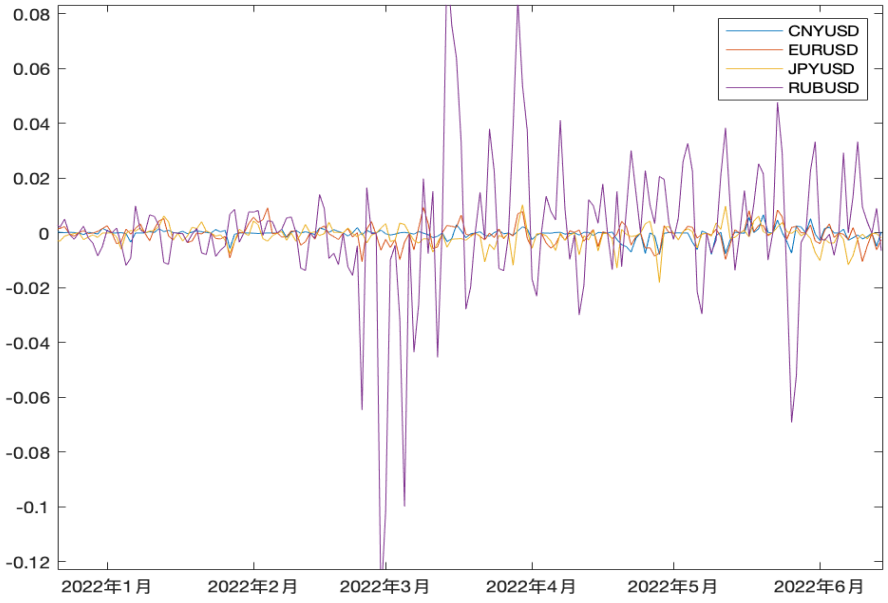

Figure 18: Volatility of **RUB-USD rate** regards to [EUR, Yen, RMB]

3.4 Extreme volatility

Key evidence of dynamics of exchange rates such as long swings in U.S. dollar exchange rates rejecting the random walk[92] with the extension of the sample period and data frequency adding robustness in favor of Markov regime-switching model[167] are again supported by this study applying Markov regime-switching model to study the volatility of exchange rates. The posterior distribution of the parameters could be distant from the prior and normal distribution and there are particular periods in which high volitility regimes cluster.

[3]The computational complexity seems grow exponentially. For 40 samples, getting the Gibbs results needs 20 minutes. For the original whole data, I cannot see the waitbar move.

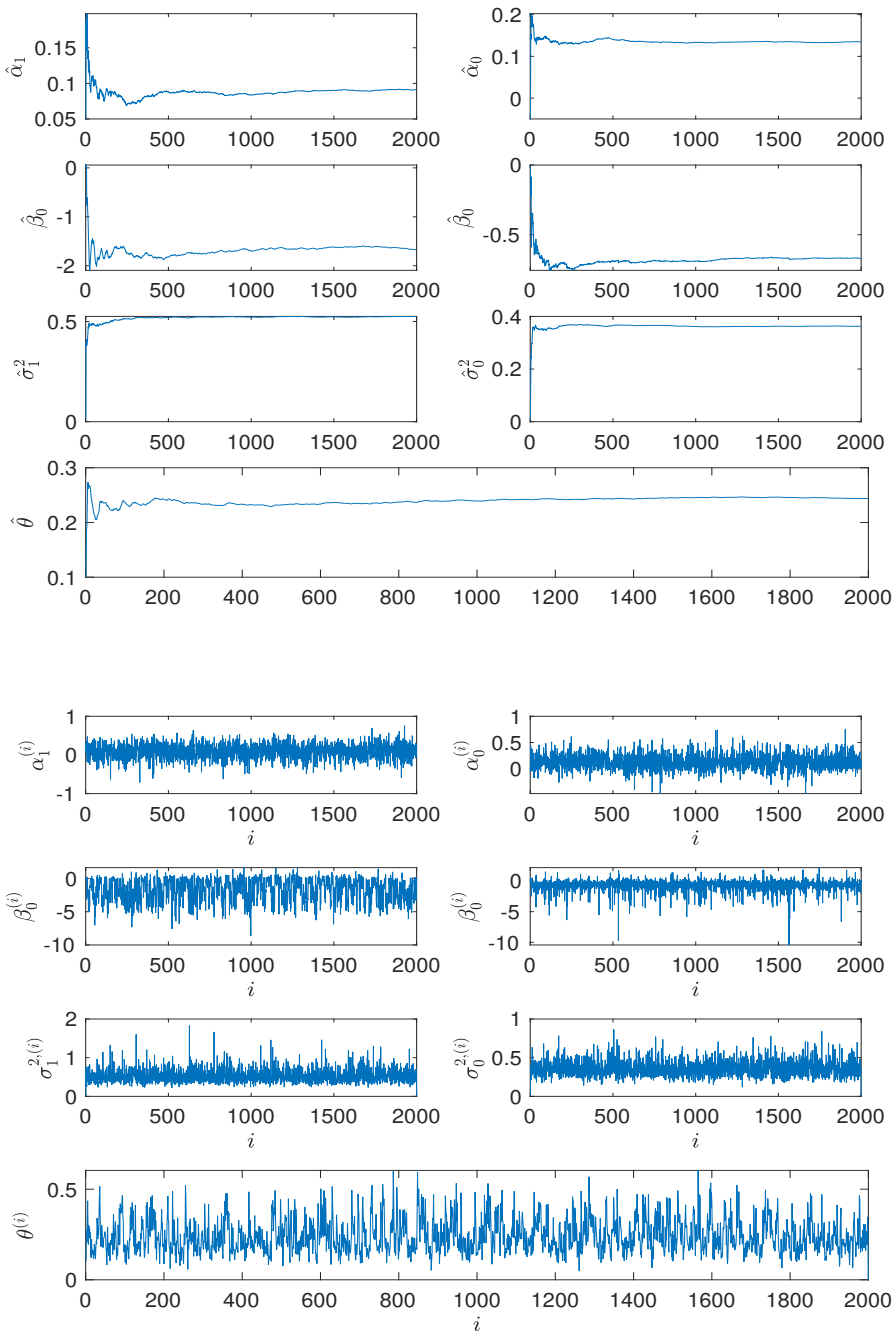

Figure 19: Posterior MCMC averages and trace plots.

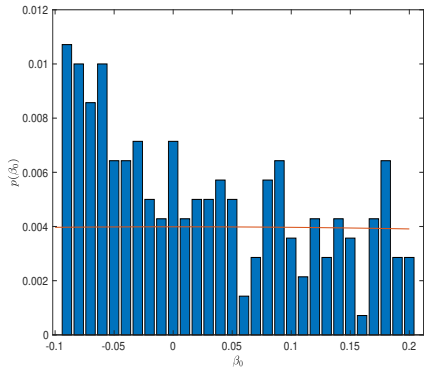

Figure 20: Prior density and posterior histogram for β_0.

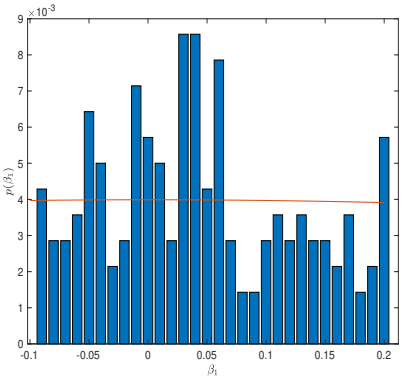

Figure 21: Prior density and posterior histogram for β_1.

Especially, when extending our analysis to updated emerging economy data, we illustrated extreme volatility. Using sequential estimates of the volatility and absolute returns as a proxy for the instantaneous volatility and for detecting the presence of volatility clustering of **RUB-USD rate** and **RUB-CNY rate**, we first look sequential estimates of the volatility and absolute returns with a rolling window of 10 days (blue) and 30 days (red) of **RUB-USD rate** as shown in Figure**??** (we could see the recent extreme volatility is overlapped in the latter thus we must consider a frequent window).

Then we apply a rolling window of 2 days (blue) absolute returns of **RUB-U.S.$ rate** as comparison as shown in Figure23. We could obviously observe an extreme volatility of absolute returns clustered on the tail. In general and an updated time scope, we compare the volatility of RUB with other currencies in Figure18 and we could easily tell this unusual volatility of **RUB-CNY rate** compared to other major currencies in our data set and the burst of war as a turning point of exchange rate volatility is clearly indicated in Figure15.

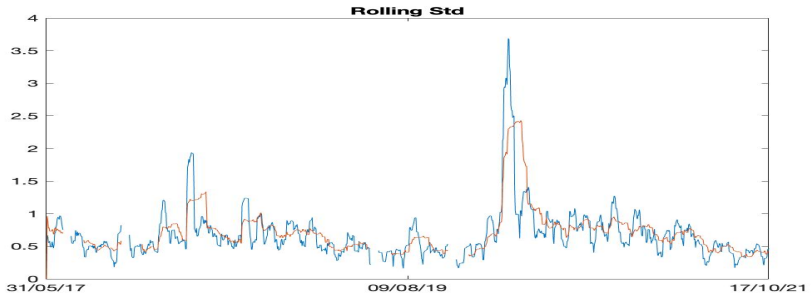

Figure 22: Sequential estimates of the volatility with a rolling window of 10 days (blue) and 30 days (red) of **RUB-U.S.$ rate**

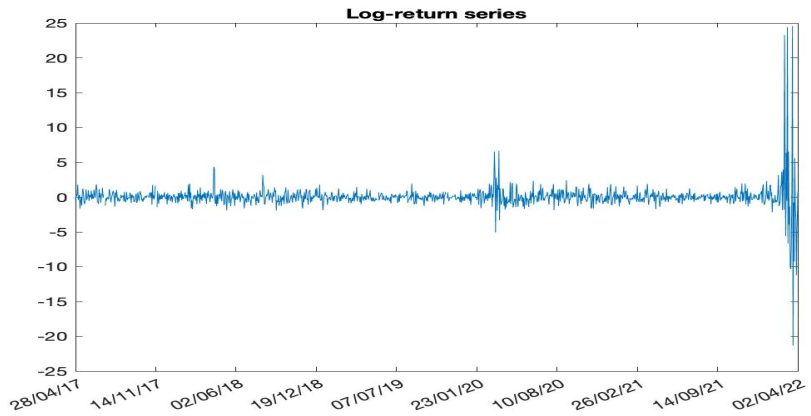

Figure 23: Log returns with a rolling window of 2 days of **RUB-U.S.$ rate**

Here is a bottom-line summary of the results:

- The dynamics of exchange rates indeed could not fit in with any normality/random walk assumptions with the extension of the sample period entailing varied volatility clustering features. This point corresponds to and extends to the previous seminal discussion of long swings.
- The shift between posterior and prior distribution of parameters indicate the model captures the information in the data and the key parameter of volatility is delightedly interpretative to mark volatility regimes. The methodology in which we applied Bayesian estimation with Markov switching model is proved to be favored in studying volatility.
- There is relationship between the main currencies and possibly corresponding to the effect of central bank interventions on the weekly returns and volatility investigated between same region and regimes before[27].
- In an constantly updated time scope, the recent volatility of RUB is unprecedentedly high compared to both itself and with other currencies. The burst of war is clearly detected as a turning point of exchange rate volatility, thus this unique volatility is not a spillover of merely financial crises and could not easily fit the story of shift-contagion[132]. Therefore we explore the possible interpretations and indications of the future trends the in the following discussion chapter.

Chapter 4

Discussion and Outlook

"One does not substitute oneself for the past, one just adds a new link."[1]

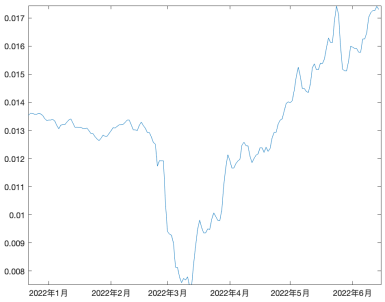

Figure 24: Ruble's plunge and recover.

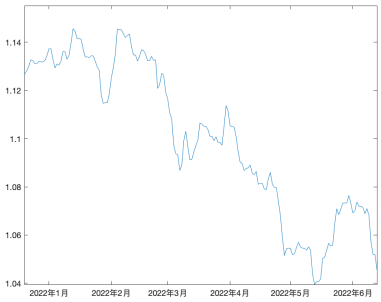

Figure 25: Euro's dive.

Insights into the dynamics of a complex system are often gained by focusing on large fluctuations[114]. With the burst out of Ukrainian war on Feb. 24, the official exchange rate of Russian Ruble suddenly plunged to a record-breaking all-time low in a few days and then rebounded and edgily recovering to the value higher than it held before the war, contrast to the trend of Euro-$, see in Figures below[2]. The huge volatility observed and illustrated contradicts to a series of researches, especially to the most recent systematic studies of global currency exchange rates concluding that over the 21st century, especially after the 2008 crisis since 2014, global exchange rate volatility has been heading downwards[3], particularly among the G3 countries (U.S.$, euro and Japanese Yen), or more completely, the G4 (including China)[154]. This trending towards stability of exchange rates ceased to hold true since the burst of Ukraine war, one of the story consisting our turbulent 2022[137].

[1] Paul Cezanne, 1904

[2] Data and plot obtained from Oanda and through R package "quantmod".

[3] especially the fact that exchange rate volatility antagonist the low levels reached in the zenith of Bretton Woods I, through the Covid-19 recession till last year, compared to measures of stock price volatility, which was at that time considered unusual, given exchange rate volatility generally rises in U.S. recessions.

Following this general background the first part we comment on relevant Macro-finance theories behind the observed crisis. Then we dedicate a few paragraphs to revisit the choice of models for asset pricing, as it's tightly paralleling to the theories of exchange rates and the essentials of currency. In the second section we discuss the quantified conceptualization of uncertainty involved in this issue of exchange rate, devoting a dialog to the mainstream developing tools. And in the last section we evolve a perspective on the future international monetary systems and digital currencies as renewing the definition of currency beyond exchange rates.

4.1 "Macro"-finance asset(commodity?) pricing

The Euro-zone debt monetization[174] and helicopter money drops[174] we are witnessing is actually an antique, as we draw attention to previous pandemic recession such as in Venice around the year of 1630 where the final outcomes of re-distributive policies financed by earmarking future tax revenues to the payment of debt interests were an extraordinary monetary expansion coupled with losses for the money issuer[118] and and currency devaluation [126]. A consequential wartime demands of currency in the Napoleonic Era resulted in the reorganization or dissolution of many early public banks[236] with the standing out of the Bank of England, whose adept management of a fiscally backed money entailed the development of central banks as they function today. The rise of global currency is always backed by the rise of global empires, from Dutch gulden to British Pound to the U.S. dollar we have today. Currency has always been related to war.

Central banks print money to buy debt, especially among the world's three major currencies, entailing in large-scale debt monetization. Currently, U.S. debt and debt monetization are the largest ever, wealth and income disparities are the largest since the 1930s, and political divides are the largest ever. Stimulate "economic development" or inequality of the world? It has been going too far from the real macro goal. How to repay the borrowed debt? Who to repay the overprinted money. This is the real imbalance behind the global currency, the real tension that made the war break out. Depth and the duration of the crisis depend on how great these imbalances are[214]. The cause of the crisis was the fact that there were accumulation of certain imbalances in the world - is concerned as the global system as a scrap, as well as individual countries.

Though given many ratifying evidences on dollar dominance besides the de facto exchange rate regime, including the importance of dollar funding for global banks and non-financial firms[41], the outsize influence of US Federal Reserve policy in global capital markets[235], the widespread prevalence of dollar pricing in trade in global markets[129], and monetary authorities of the world choosing U.S.$ as the anchor/reference currency underscoring the broad significance of the dollar across global markets[152], many researchers maintain to demonstrate that since the share of U.S. in global economy is dropping, the U.S.$'s role as the de facto world currency is also fading. The world is evolving towards a multi-polar system where the euro dominates in Europe, the US dollar is the anchor in the Americas while Chinese RMB becomes the main currency in Asia[88]. Hence, a refinement by re-

moving the dollar-centered narrative is that the dynamism in liquidity yields on government bonds and funds staked to smart contracts that control the liquidity pools across countries all contribute a significant impact on exchange rates[192]. A better rationalized theory would be on capital flows drive exchange rates in imperfect financial markets by altering the balance sheets of financiers that bear the risks resulting from international imbalances in the demand for financial assets and resulting in real consequences for output and risk sharing featuring non-tradables, production, sticky prices or wages, various forms of international pricing-to-market, and unemployment[115].

The rise of "shadow banking" explained by profiling the institutional cash pools draws a different illustration than the supply-side perspective as a view of banks' funding preferences and arbitrage reveals the Triffin dilemma of the US banking system[231]. Apart from the common safe assets story remarking that the role of the United States as the world's safe asset supplier has shaped the dynamics of the dollar exchange rate[158], the record accumulation of reserves since 2002 was also believed to explain why many countries are coveting to stabilize exchange rates in an environment of markedly reduced capital controls, which is an important addendum to the conventional depiction of the macroeconomic dilemma[152] and U.S. $ as international and safe-haven currency has surged since the global financial crisis[185]. If we look into the framing of J.P. Morgan as the "Bakken Shale" of global dollar funding markets, and as the system's Lender of Next-to-Last Resort: J.P. Morgan cannot print reserves like the Federal Reserve(FED), but it has the biggest amount of reserves at the FED relative to other banks and the bank that has the most reserves backstops the liquidity of the system during non-systemic episodes of liquidity shocks. Parallelingly, in the global commodity market, the equivalent counterpart of J.P.Morgan is the Russian Federation. Not only did Russia own as much in Foreign exchange reserves as J.P. Morgan owns in reserves at the FED, but most critically, Russia's exports of commodities(just as J.P. Morgan's "exports" of reserves) exceed the exports of every country in the world, leaving U.S. behind.

In our investigation of exchange rates, if we go back to the classical economic explanation of currencies exchange rates level based on the theory of purchasing-power parity (PPP)[251], remarking that asymptotically exchange rates should evolve towards the rate that would equalise the prices of an identical basket of goods and services in any two countries, this embodiment of exchange rates to an identical basket of goods and services could also be ideally expressed as the commodity market, which the energy supply consists an essential part of. We extend this part of discussion in Appendix.

4.2 The conceptualization of uncertainty

What we demonstrated in the methods and result chapter is a self-consistent codification of phenomenon and theory, due to the fact that in mathematics, statistics and therefore econometrics, there is no bother of the division macro-micro, whereas in economics, there always is. Nobel laureate, Paul Krugman, once pointed out that in the past 30 years of macroeconomic research is useless, to say it nicely, and even

harmful, to say it badly by arguing that economists turn a blind eye to catastrophic macroeconomic failures because they mistake the beauty and precision of theoretical models for reality[172]. In the "micro" scope, Nobel laureate Ronald H. Coase once complained that microeconomics is riddled with "black-box models" that fail to understand the actual contractual relationship between firms and markets. When transaction costs are low and property rights are clearly defined, innovative private contracts are likely to solve problems caused by collective behavioral failures such as environmental pollution; however, because economists are obsessed with oversimplified price theories , policymakers still largely rely on the use of fiscal tools[62].

Contemporary economists' fascination with simplified analysis and mathematical models seems to have transformed the profession from theoretical to ideological, thereby disconnecting it from the real economy. The macro-micro division is nothing more than a discourse, a legacy in literature again and again trying to rescue bubbles, liquidity, and the economy[40]. This discourse dominating the English education of economics discipline never holds given in the researches such as[113]. Macro- model explanation of business cycles arguing that individual firm shocks average out in the aggregate breaks down in front of empirical facts where the distribution of firm sizes is fat-tailed. Idiosyncratic firm-level fluctuations can explain an important part of aggregate shocks[4], and provide a micro-foundation for shocks of macro-aggregate productivity. Macroeconomic questions can be clarified by looking at the behavior of large firms. Actually, the fluctuations of most economic aggregates such as exports, trade balance[5] and exchange rate, may be also fitted into this logic line, regardless of macro-micro division. The actual starting point of such possibility and assumption base of any macro- or micro- model is always the perception of **uncertainty**, the form of which are mostly taken granted of.

Could we model this excess volatility of Rub following the idea of joint fluctuations in exchange rates, interest rates, options, and stock markets by Emmanuel Farhi and Xavier Gabaix[99], which claims to be accounting for also other major puzzles in exchange rates disconnect, forward premium puzzle and co-movements between stocks and telltale signs of disaster risk in currency options? Unfortunately in this recent case of Rub volatility, the assumptions of this model: "A stochastic infinite horizon open economy model" where "at each date t, each country receives a random endowment of the tradable good", the probability of world disasters and country's exposure to these events is time-varying doesn't hold. Maybe we could form a model to test if this shock meet the sufficient conditions for a process on the real line to be persistent or transient as characterization of long-run outcomes[36]? The hypothesis that distribution of resources in a population evolves as driven both by chance (shocks) and necessity (interaction, e.g. competition) is too rough compared with

[4]The idiosyncratic movements of the largest 100 firms in the United States appear to explain about one-third of variations in output growth.

[5]See in export superstars: among 32 countries, the top firm on average accounts for 14% of a country's total (nonoil) exports, and the top five firms make up 30%. Variation in exports from the top firm in a country explains about one-third of the variation in sectoral exports relative to income across countries, with the variation in top five firms explains nearly half of exports. Revealed comparative advantage in a sector can even be created by a single firm[110].

the actual "macro" and financial facts we gathered in the first part of our discussion. Such questions could be made to almost every related literature following likely the same logic of Krugman's attack. The criticisms of this ad hominem "attack" on modern economist, saying that they are politicised[63] are themselves per se politicised ignorance of what economics and finance is fundamentally all about. Saying Krugman's attack is a striking emptiness of useful ideas is also a shortsighted understanding of true "usefulness". Admittedly, the simplicity and precision of micro- and macro- models make them useful in explaining price mechanisms and the balance of key aggregate economic variables, but neither model can describe or analyze the actual behavior of key market players or key phenomena, such as what here we care about, the exchange rate. These models fail to answer the key question of economics as defined by Paul Samuelson[244] — what should we produce? For whom are goods and services produced, shipped, and sold? - and rarely refers to the "location" and "time" of economic activity. To consist with the scope of this thesis, we further conclude this topics in Appendix.

4.3 Currency of the future

Bayesian paradigm's obvious and long (intentionally) ignored lemma is: the right economics must be based on a common-agreed understanding of history, recent recent efforts in this direction see "The dawn of everything"[130]. More specifically here, corresponding to and closing our discussion of exchange rates and currency, we propose an international digital currency framework (previous work see[186]) established on historical accountability[222] for greenhouse gas emissions based carbon pricing[168] and global energy budgeting, which requires a truly functioning United Nation (at least rotating presidency like EU), not one manipulated by any country, which requires huge effort on international spirit of legislation. This currency system is especially designed for international interactions, whereas domestically the functioning of currency could be as of variety as classical. The issue we concern lies in the key word of "exchange", if we look back into the history how human beings fight when cultures are confronted with each other. Could we finally in the name of culture make an end of the conflicts between communities? In fact, the basic unit of any society is family, which corresponds to the original etymology of "economics": "art of managing a household"[6]. Don't you see, paralleling to the world's "evolving" towards more and more complexity, the younger generations are more and more confused, lost, mentally unhealthy? Don't you realize, it is more and more difficult to fall in love with someone, in the sense of unwavering, pure, holding on to a lifelong and healthy thriving, child-bearing, love relationship, is going extinct? Yet saying so I am not fully pessimistic with human's future. We could view this contemporary time as simply an adolescence of human growth, where the financial and economic system has been developing and exploring itself tremendously as a teenager going crazy sometimes. We are just a bit eager for true maturity now, which may look like

[6]1580s, from French économique or directly from Latin oeconomicus "of domestic economy," from Greek oikonomikos "practiced in the management of a household or family" (also the name of a treatise by Xenophon on the duties of domestic life), hence, "frugal, thrifty," from oikonomia "household management". (https://www.etymonline.com/)

"Full of merit, yet poetically / Humans dwell upon the earth" (Hölderlin's Hymn "The Ister"). Therefore, with the completeness of world re-balancing accounting for history in terms of commodity(represented by carbon) based global budgeting and the establishment of the digital currency framework, the rest of the work would be focused on the true and real culture. The parity between local communities will not be based on purchasing power, but rather the spiritual wealth. The real culture is the set of techniques and arts of dwelling locally with all the beings. I was once deeply moved by Darwin, in terms of faith[166] and theology of evolution[146]. Later I realized this recognized or unrealized Darwinian intention among economists following him[108] is strongly questionable, more severe than the shadow of Max[147] for the obvious fact: in modern economics it is presumed that human beings are superior to the other species. Rather, it could be clearly proved that human beings are inferior to the other living beings, probably the worst, since human beings are the only species on this planet that not only kill each other but also invented enormous ways to torment each other and even enjoy and benefit from afflict some one else into suffering[7]. The ruthless mean on fellow citizens exponents when coming to animals. How shall we talk about animal welfare economics[189], more than economics of animal health and production[243]? How could we establish the subjectivity of all living beings in terms of environmental philosophy? And more closely, standing in the core of anthropology, how shall the local communities meritly communicate with each other? Certainly not the modern art that is everywhere (especially in Venice) now. Any commercialized art is naturally kicked out. The current art market and art finance: a way of washing money, avoiding tax: avoiding pay for the justice, the carbon price that they should pay. They should not exist in market based on such a currency that the consumption of which is based on the circulation of the life. Imagine the future of travelling: not everyone can travel, cause it would be very costly and demanding (in terms of our dwelling philosophy and global budgeting). Only the poets, the representatives of their culture are encouraged to bring their spirit to the others. So the future of education should cultivate everyone to become a poet (including those of insurmountable disabilities, since they could be spiritually healthy and strong). The spirit of poetry is: orderly innovation. So will be the spirit of all the forms of enjoyment (which now consists of our consumptive society) and cultural exploration.

As a summary of conceptualization of uncertainty and Bayesian paradigm guided rationality: the chaos we are witnessing comes per se evolves endogenously and lack of a strong systematic prior will entail a cognitive dynamic in which more we measure (methods see control graphs of actual Fortran programs[199], permutation entropy for time series for chaotic dynamical systems similar to Lyapunov exponents[21]), etc.) the more complexity we get. A decent prior view is that all agents adapts to the endogenous evolution of the complexity of their own situations. It sounds rational but actually impossible and mistaken to compare the complexity of varied systems, as there is no finite defined system in reality as captured by Leibniz's great chain of being[46] and revealed in Cantor's continuum problem[123]. Ignorant of these endo-

[7] I was first enlightened of this idea by my friend Fangxiong Sheng when we were on Mountain Qingcheng

genieties of complexity, would the claimed contributions of economics theory itself based on hallucinate ideals and correlations be convincing? The economics discipline claim itself to be theoretical[8]. Then let us carry this spirit of theoretical reflections into the core problems economics confronts us: the economics of inequality[14] lies in information asymmetry which lies in the architecture of power structure[161][9]. This endogenous deviltry is claiming that the market is **hypercritically** "free", as the necessary conditions of "truly free" at least includes one: the market should be free from any centred currency. In our current situation, the global market is struggling its way on de-dollarization due to this systematic trend. There is a certainty of uncertainty of the change of the rule of the game. A near achievable goal is with forward-looking perspective on digital currencies lies in Central Bank Digital Currencies (CBDCs). The rise of cryptos hurts stronger fiat currencies (e.g., USD), but can benefit weaker fiat currencies. Countries with strong but non-dominant currencies (e.g., China and India) have the highest incentives to launch CBDCs to gain technological first-mover advantage[64]. How about the future of Euro? I expect a more influential and independent Europe through the reformation of future currency hand in hand with emerging economies for an integrated Euro-Asia and organized world, also in the sense of cultural parity future previously illustrated. These subjects are raised within such a motif of currency due to a perspective that in the web of lives[234], the actual "currency" accounting for the real calculation going on could be considered as (the carefully treated concept) karma, which is then far too much away from economics. There is the essence of life here, but it is beyond my words.

[8]Theory of mathematical modelling carries a heavy load of notation, and economic papers are, if not the worst, probably not the best container for it: if L is the first-order language of signature K, then Tarski's model-theoretic truth definition tells us when a sentence of L is true in A, and when an assignment of elements of A to variables satisfies a formula of L in A. How many economists know of this?

[9]But how many economists understand and discusses Foucault in their researches?

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[1] Causal relationship between energy consumption (EC) and GDP: a Markov-switching (MS) causality, author=Fallahi, Firouz, journal=Energy, volume=36, number=7, pages=4165–4170, year=2011, publisher=Elsevier.

[2] Wafa Fahmi Abdelati. International experience of de-dollarization. In *Cambodia*. International Monetary Fund.

[3] Lada A Adamic. Zipf, power-laws, and pareto-a ranking tutorial. *Xerox Palo Alto Research Center, Palo Alto, CA, http://ginger. hpl. hp. com/shl/papers/ranking/ranking. html*, 2000.

[4] Bismark Addai, Adjei Gyamfi Gyimah, and Kwadwo Poku-Agyemang. Exchange rate regimes and global cocoa trade: to float or to peg? *Cogent Economics & Finance*, 8(1):1719593, 2020.

[5] Q Farooq Akram. Real equilibrium exchange rates for Norway. *Explaining movements in the Norwegian exchange rate*, 32:53–86, 2003.

[6] James H Albert and Siddhartha Chib. Bayesian analysis of binary and polychotomous response data. *Journal of the American Statistical Association*, 88(422):669–679, 1993.

[7] Laura Alfaro, Ester Faia, Nora Lamersdorf, and Farzad Saidi. Health externalities and policy: The role of social preferences. Technical report, ECONtribute Discussion Paper, 2021.

[8] Miguel Almunia, Agustin Benetrix, Barry Eichengreen, Kevin H O'Rourke, and Gisela Rua. From great depression to great credit crisis: Similarities, differences and lessons. *Economic Policy*, 25(62):219–265, 2010.

[9] João Amador and Sónia Cabral. Networks of value-added trade. *The World Economy*, 40(7):1291–1313, 2017.

[10] Roger T Ames and David L Hall. *Focusing the familiar: A translation and philosophical interpretation of the Zhongyong*. University of Hawaii Press, 2001.

[11] Daniel Andrei, Bruce Carlin, and Michael Hasler. Asset pricing with disagreement and uncertainty about the length of business cycles. *Management Science*, 65(6):2900–2923, 2019.

[12] Elena Andreou and Eric Ghysels. Rolling-sample volatility estimators: some new theoretical, simulation and empirical results. *Journal of Business & Economic Statistics*, 20(3):363–376, 2002.

[13] W Brian Arthur. Foundations of complexity economics. *Nature Reviews Physics*, 3(2):136–145, 2021.

[14] Anthony B. Atkinson. The economics of inequality, 1975.

[15] Raphael Auer and Rainer Böhme. The technology of retail central bank digital currency. *BIS Quarterly Review, March*, 2020.

[16] Louis Bachelier. Théorie de la spéculation. In *Annales Scientifiques de l'École Normale Supérieure*, volume 17, pages 21–86, 1900.

[17] Alain Badiou. *Mathematics of the Transcendental*. A&C Black, 2014.

[18] Richard T Baillie and Patrick C McMahon. *The foreign exchange market: Theory and econometric evidence*. Cambridge University Press, 1990.

[19] Mehmet Balcilar, Reneé Van Eyden, Josine Uwilingiye, and Rangan Gupta. The impact of oil price on south african gdp growth: A Bayesian Markov switching-VAR analysis. *African Development Review*, 29(2):319–336, 2017.

[20] Andrew Balmford, Tatsuya Amano, Harriet Bartlett, Dave Chadwick, Adrian Collins, David Edwards, Rob Field, Philip Garnsworthy, Rhys Green, Pete Smith, et al. The environmental costs and benefits of high-yield farming. *Nature Sustainability*, 1(9):477–485, 2018.

[21] Christoph Bandt and Bernd Pompe. Permutation entropy: A natural complexity measure for time series. *Physical Review Letters*, 88(17):174102, 2002.

[22] Krittika Banerjee and Ashima Goyal. Behavioural equilibrium real exchange rates and misalignments: Evidence from large emerging markets. *Economic Analysis and Policy*, 70:414–436, 2021.

[23] Erik Banks. Liquidity spirals and financial distress. In *Liquidity Risk*, pages 108–121. Springer, 2014.

[24] Jon Barwise. An introduction to first-order logic. In *Studies in Logic and the Foundations of Mathematics*, volume 90, pages 5–46. Elsevier, 1977.

[25] Leslie A Baxter and Barbara M Montgomery. *Relating: Dialogues and dialectics*. Guilford Press, 1996.

[26] Cary F Baynes and Hellmut Wilhelm. *The I Ching or book of changes*, volume 31. Princeton University Press, 2011.

[27] Michel Beine, Sébastien Laurent, and Christelle Lecourt. Official central bank interventions and exchange rate volatility: Evidence from a regime-switching analysis. *European Economic Review*, 47(5):891–911, 2003.

[28] Geert Bekaert and Campbell R Harvey. Emerging markets finance. *Journal of Empirical Finance*, 10(1-2):3–55, 2003.

[29] Frederico Belo, Dapeng Hao, Xiaoji Lin, Zhigang Qiu, and Jincheng Tong. A tale of two sectors: Implications of state ownership structure on corporate policies and asset prices in china. *Available at SSRN 3966723*, 2021.

[30] Agnès Bénassy-Quéré, Emmanuel Farhi, Pierre-Olivier Gourinchas, Jacques Mistral, Jean Pisani-Ferry, Hélène Rey, et al. Réformer le système monétaire international. *Conseil d'Analyse Économique (CAE)*, (99), 2011.

[31] Agnès Bénassy-Quéré and Jean Pisani-Ferry. What international monetary system for a fast-changing world economy. Technical report, Bruegel Working Paper, 2011.

[32] Ingolfur Blühdorn. Post-capitalism, post-growth, post-consumerism? eco-political hopes beyond sustainability. *Global Discourse*, 7(1):42–61, 2017.

[33] Michael D Bordo et al. The contribution of a monetary history of the united states, 1867-1960 to monetary history. *Money, history, and international finance: essays in honor of Anna J. Schwartz*, pages 15–78, 1989.

[34] Michael D Bordo and Robert N McCauley. Triffin: dilemma or myth? *IMF economic review*, 67(4):824–851, 2019.

[35] Claudio Borio. The covid-19 economic crisis: Dangerously unique. *Business Economics*, 55(4):181–190, 2020.

[36] Giulio Bottazzi and Pietro Dindo. Drift criteria for persistence of discrete stochastic processes on the line. *Journal of Mathematical Economics*, page 102696, 2022.

[37] Anna D Broido and Aaron Clauset. Scale-free networks are rare. *Nature Communications*, 10(1):1–10, 2019.

[38] J Lawrence Broz and Jeffry A Frieden. The political economy of international monetary relations. *Annual Review of Political Science*, 4(1):317–343, 2001.

[39] Markus Brunnermeier, Emmanuel Farhi, Ralph SJ Koijen, Arvind Krishnamurthy, Sydney C Ludvigson, Hanno Lustig, Stefan Nagel, Monika Piazzesi, et al. Perspectives on the future of asset pricing. *Review of Financial Studies*, 34(4):2126–2160, 2021.

[40] Markus K Brunnermeier. Bubbles, liquidity, and the macroeconomy. *NBER Reporter Online*, (2):10–12, 2010.

[41] Valentina Bruno and Hyun Song Shin. Cross-border banking and global liquidity. *The Review of Economic Studies*, 82(2):535–564, 2015.

[42] Andrea Buraschi and Paul Whelan. Term structure models with differences in beliefs. *Imperial College Business School Working Paper*, 2012.

[43] Jun Cai. A Markov model of switching-regime ARCH. *Journal of Business & Economic Statistics*, 12(3):309–316, 1994.

[44] John Y Campbell and Robert J Shiller. The dividend-price ratio and expectations of future dividends and discount factors. *The Review of Financial Studies*, 1(3):195–228, 1988.

[45] Alina Carare and Mark Stone. Inflation targeting regimes. 2003.

[46] Laurence Carlin. Leibniz's great chain of being. *Studia leibnitiana*, pages 131–150, 2000.

[47] Roberto Casarin. Simulation methods for nonlinear and non-Gaussian models in finance. *Premio SIE, Rivista Italiana degli Economisti*, 2:341–345, 2005.

[48] Roberto Casarin, Domenico Sartore, and Marco Tronzano. A bayesian markov-switching correlation model for contagion analysis on exchange rate markets. *Journal of Business & Economic Statistics*, 36(1):101–114, 2018.

[49] George Casella and Edward I George. Explaining the Gibbs sampler. *The American Statistician*, 46(3):167–174, 1992.

[50] PH Kevin Chang and Carol L Osler. Methodical madness: Technical analysis and the irrationality of exchange-rate forecasts. *The Economic Journal*, 109(458):636–661, 1999.

[51] Yiyang Chen, Rogemar Mamon, Fabio Spagnolo, and Nicola Spagnolo. Renewable-energy and economic growth: A Markov-switching approach. *Energy*, page 123089, 2022.

[52] Yu-Fu Chen, Michael Funke, and Nicole Glannemann. Dundee discussion papers in economics 258: Dark clouds or silver linings? Knightian uncertainty and climate change. 2011.

[53] Ka Ming Cheng. Currency devaluation and trade balance: Evidence from the us services trade. *Journal of Policy Modeling*, 42(1):20–37, 2020.

[54] Yong Cheng. Current research on gödel's incompleteness theorems. *Bulletin of Symbolic Logic*, pages 1–52, 2020.

[55] Siddhartha Chib and Ivan Jeliazkov. Marginal likelihood from the Metropolis–Hastings output. *Journal of the American Statistical Association*, 96(453):270–281, 2001.

[56] Siddhartha Chib and Ivan Jeliazkov. Accept–reject Metropolis–Hastings sampling and marginal likelihood estimation. *Statistica Neerlandica*, 59(1):30–44, 2005.

[57] Richard H Clarida, Lucio Sarno, Mark P Taylor, and Giorgio Valente. The out-of-sample success of term structure models as exchange rate predictors: a step beyond. *Journal of International Economics*, 60(1):61–83, 2003.

[58] Mr Peter B Clark and Mr Ronald MacDonald. *Exchange rates and economic fundamentals: a methodological comparison of BEERs and FEERs*. International Monetary Fund, 1998.

[59] Peter B Clark and Jacques Polak. International liquidity and the role of the SDR in the international monetary system. 2002.

[60] Christopher Clayton, Amanda Dos Santos, Matteo Maggiori, and Jesse Schreger. Internationalizing like china. *Available at SSRN*, 2022.

[61] William R Cline, John Williamson, et al. Estimates of fundamental equilibrium exchange rates, may 2010. Technical report, Peterson Institute for International Economics, 2010.

[62] Ronald Harry Coase. *Essays on economics and economists*. University of Chicago Press, 1994.

[63] John H Cochrane. How did paul krugman get it so wrong? 1. *Economic Affairs*, 31(2):36–40, 2011.

[64] Lin William Cong and Simon Mayer. The coming battle of digital currencies. *Available at SSRN 3992815*, 2021.

[65] John D Cook. Inverse gamma distribution. *online: http://www. johndcook. com/inverse gamma. pdf, Tech. Rep*, 2008.

[66] Mark S Copelovitch. *The International Monetary Fund in the global economy: Banks, bonds, and bailouts*. Cambridge University Press, 2010.

[67] Antonio Coppola, Matteo Maggiori, Brent Neiman, and Jesse Schreger. Redrawing the map of global capital flows: The role of cross-border financing and tax havens. *The Quarterly Journal of Economics*, 136(3):1499–1556, 2021.

[68] Andrew I Dale. Bayes or laplace? an examination of the origin and early applications of bayes' theorem. *Archive for History of Exact Sciences*, pages 23–47, 1982.

[69] Zsolt Darvas. Timely measurement of real effective exchange rates. Technical report, Bruegel, 2021.

[70] Arthur P Dempster, Nan M Laird, and Donald B Rubin. Maximum likelihood from incomplete data via the em algorithm. *Journal of the Royal Statistical Society: Series B (Methodological)*, 39(1):1–22, 1977.

[71] Haluk Derin, Howard Elliott, Roberto Cristi, and Donald Geman. Bayes smoothing algorithms for segmentation of binary images modeled by Markov random fields. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, (6):707–720, 1984.

[72] Neluka Devpura. Can oil prices predict japanese yen? *Asian Economics Letters*, 1(3):17964, 2020.

[73] Hans Dewachter. Can Markov switching models replicate chartist profits in the foreign exchange market? *Journal of International Money and Finance*, 20(1):25–41, 2001.

[74] Yadolah Dodge, David Cox, and Daniel Commenges. *The Oxford dictionary of statistical terms*. Oxford University Press on Demand, 2006.

[75] Matthias Doepke and Fabrizio Zilibotti. *Love, money, and parenting: How economics explains the way we raise our kids*. Princeton University Press, 2019.

[76] Michael Dooley, David Folkerts-Landau, and Peter Garber. Bretton woods ii still defines the international monetary system. *Pacific Economic Review*, 14(3):297–311, 2009.

[77] Kurt Dopfer, John Foster, and Jason Potts. Micro-meso-macro. *Journal of Evolutionary Economics*, 14(3):263–279, 2004.

[78] Rudiger Dornbusch. Expectations and exchange rate dynamics. *Journal of Political Economy*, 84(6):1161–1176, 1976.

[79] Rudiger Dornbusch. Purchasing power parity, 1985.

[80] Wenxin Du, Carolin E Pflueger, and Jesse Schreger. Sovereign debt portfolios, bond risks, and the credibility of monetary policy. *The Journal of Finance*, 75(6):3097–3138, 2020.

[81] Michael Dueker and Christopher J Neely. Can Markov switching models predict excess foreign exchange returns? *Journal of Banking & Finance*, 31(2):279–296, 2007.

[82] Gilles Dufrénot and Etienne B Yehoue. Real exchange rate misalignment: A panel co-integration and common factor analysis. 2005.

[83] Richard M Ebeling. Monetary central planning and the state. *Future of Freedom Foundation*, 2015.

[84] Sebastian Edwards. Real and monetary determinants of real exchange rate behavior: Theory and evidence from developing countries. *Journal of Development Economics*, 29(3):311–341, 1988.

[85] Bradley Efron. *The jackknife, the bootstrap and other resampling plans*. SIAM, 1982.

[86] Paul Ehling, Michael Gallmeyer, Christian Heyerdahl-Larsen, and Philipp Illeditsch. Disagreement about inflation and the yield curve. *Journal of Financial Economics*, 127(3):459–484, 2018.

[87] Barry Eichengreen. *Global imbalances and the lessons of Bretton Woods*. Mit Press, 2010.

[88] Barry Eichengreen. *Exorbitant Privilege: The rise and fall of the Dollar and the Future of the International Monetary System*. Oxford University Press, 2011.

[89] Barry Eichengreen et al. Managing a multiple reserve currency world. *The Future Global Reserve System: An Asian Perspective*, 2010.

[90] Barry Eichengreen and Ricardo Hausmann. *Other people's money: debt denomination and financial instability in emerging market economies*. University of Chicago Press, 2010.

[91] Charles Engel. Can the Markov switching model forecast exchange rates? *Journal of international economics*, 36(1-2):151–165, 1994.

[92] Charles Engel and James D Hamilton. Long swings in the exchange rate: are they in the data and do markets know it?, 1989.

[93] Charles Engel and Steve Pak Yeung Wu. Liquidity and exchange rates: An empirical investigation. Technical report, National Bureau of Economic Research, 2018.

[94] Friedrich Engels. *Dialectics of nature*. Wellred Books, 1960.

[95] Eugene F Fama. Mandelbrot and the stable paretian hypothesis. *The journal of "B"usiness*, 36(4):420–429, 1963.

[96] Eugene F Fama. The behavior of stock-market prices. *The journal of Business*, 38(1):34–105, 1965.

[97] Eugene F Fama and Richard Roll. Some properties of symmetric stable distributions. *Journal of the American Statistical Association*, 63(323):817–836, 1968.

[98] Tony Fan, Yucheng Liang, and Cameron Peng. Belief updating: Inference versus forecast revision. *Available at SSRN 3889069*, 2021.

[99] Emmanuel Farhi and Xavier Gabaix. Rare disasters and exchange rates. *The Quarterly Journal of Economics*, 131(1):1–52, 2016.

[100] Emmanuel Farhi and Matteo Maggiori. A model of the international monetary system. *The Quarterly Journal of Economics*, 133(1):295–355, 2018.

[101] Mitchell J Feigenbaum. Quantitative universality for a class of nonlinear transformations. *Journal of Statistical Physics*, 19(1):25–52, 1978.

[102] Guanhao Feng, Stefano Giglio, and Dacheng Xiu. Taming the factor zoo: A test of new factors. *The Journal of Finance*, 75(3):1327–1370, 2020.

[103] José Paulo Silva Ferreira. Resenha do livro "de-dollarization: The revolt against the dollar and the rise of a new financial world order".

[104] Stephen E Fienberg. When did bayesian inference become "Bayesian"? *Bayesian Analysis*, 1(1):1–40, 2006.

[105] Caroline Flammer. Corporate green bonds. *Journal of Financial Economics*, 142(2):499–516, 2021.

[106] Michel Foucault. *Les mots et les choses*. Gallimard Paris, 1990.

[107] Michel Foucault and Angèle Kremer-Marietti. *L'archéologie du savoir*, volume 1. Gallimard Paris, 1969.

[108] Robert H Frank. The darwin economy. In *The Darwin Economy*. Princeton University Press, 2012.

[109] Michael Frenkel, Christian Pierdzioch, and Georg Stadtmann. The effects of japanese foreign exchange market interventions on the yen/us dollar exchange rate volatility. *International Review of Economics & Finance*, 14(1):27–39, 2005.

[110] Caroline Freund and Martha Denisse Pierola. Export superstars. *Review of Economics and Statistics*, 97(5):1023–1032, 2015.

[111] Milton Friedman and Anna Jacobson Schwartz. *A monetary history of the United States, 1867-1960*, volume 14. Princeton University Press, 2008.

[112] Xavier Gabaix. Zipf's law for cities: an explanation. *The Quarterly Journal of economics*, 114(3):739–767, 1999.

[113] Xavier Gabaix. The granular origins of aggregate fluctuations. *Econometrica*, 79(3):733–772, 2011.

[114] Xavier Gabaix, Parameswaran Gopikrishnan, Vasiliki Plerou, and H Eugene Stanley. A theory of power-law distributions in financial market fluctuations. *Nature*, 423(6937):267–270, 2003.

[115] Xavier Gabaix and Matteo Maggiori. International liquidity and exchange rate dynamics. *The Quarterly Journal of Economics*, 130(3):1369–1420, 2015.

[116] Mirta Galesic, Henrik Olsson, Jonas Dalege, Tamara van der Does, and Daniel L Stein. Integrating social and cognitive aspects of belief dynamics: towards a unifying framework. *Journal of the Royal Society Interface*, 18(176):20200857, 2021.

[117] Mirta Galesic and Daniel L Stein. Statistical physics models of belief dynamics: Theory and empirical tests. *Physica A: Statistical Mechanics and its Applications*, 519:275–294, 2019.

[118] Jordi Galí. Helicopter money: The time is now. *Mitigating the COVID Economic Crisis: Act Fast and Do Whatever*, 31:31–39, 2020.

[119] Andrew Gelman. Prior distributions for variance parameters in hierarchical models (comment on article by browne and draper). *Bayesian Analysis*, 1(3):515–534, 2006.

[120] Andrew Gelman. Induction and deduction in Bayesian data analysis. 2011.

[121] Stuart Geman and Donald Geman. Stochastic relaxation, Gibbs distributions, and the Bayesian restoration of images. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, (6):721–741, 1984.

[122] Stefano Giglio, Matteo Maggiori, Johannes Stroebel, and Stephen Utkus. Five facts about beliefs and portfolios. *American Economic Review*, 111(5):1481–1522, 2021.

[123] Kurt Gödel. What is Cantor's continuum problem? *The American Mathematical Monthly*, 54(9):515–525, 1947.

[124] Irving John Good. 46656 varieties of Bayesians. *American Statistician*, 25(5):62, 1971.

[125] Marvin Goodfriend. Interest rate policy should not react directly to asset prices. *Asset Price Bubbles: The Implications for Monetary, Regulatory, and International Policies, MIT press, January*, pages 445–58, 2003.

[126] Charles Goodhart, Donato Masciandaro, and Stefano Ugolini. Helicopter money in another pandemic recession: Venice, 1630. *VoxEU*, 2021.

[127] Thomas H Goodwin. Business-cycle analysis with a Markov-switching model. *Journal of Business & Economic Statistics*, 11(3):331–339, 1993.

[128] Goutham Gopalakrishna. Aliens and continuous time economies. *Swiss Finance Institute Research Paper*, (21-34), 2021.

[129] Gita Gopinath. The international price system. Technical report, National Bureau of Economic Research, 2015.

[130] David Graeber and David Wengrow. *The dawn of everything: A new history of humanity*. Penguin UK, 2021.

[131] Clive WJ Granger, Timo Terasvirta, et al. Modelling non-linear economic relationships. *OUP Catalogue*, 1993.

[132] Toni Gravelle, Maral Kichian, and James Morley. Detecting shift-contagion in currency and bond markets. *Journal of International Economics*, 68(2):409–423, 2006.

[133] Stephen F Gray. Modeling the conditional distribution of interest rates as a regime-switching process. *Journal of Financial Economics*, 42(1):27–62, 1996.

[134] Peter J Green. Reversible jump Markov chain Monte Carlo computation and Bayesian model determination. *Biometrika*, 82(4):711–732, 1995.

[135] Dorothy M Greig, Bruce T Porteous, and Allan H Seheult. Exact maximum a posteriori estimation for binary images. *Journal of the Royal Statistical Society: Series B (Methodological)*, 51(2):271–279, 1989.

[136] Francesco Grillo, Raffaella Y Nanetti, et al. *Democracy and Growth in the Twenty-first Century*. Springer, 2018.

[137] Veronica Guerrieri, Guido Lorenzoni, Ludwig Straub, and Iván Werning. Macroeconomic implications of covid-19: Can negative supply shocks cause demand shortages? Technical report, National Bureau of Economic Research, 2020.

[138] Ian Hacking. Slightly more realistic personal probability. *Philosophy of Science*, 34(4):311–325, 1967.

[139] Anders Hald. *A history of parametric statistical inference from Bernoulli to Fisher, 1713-1935*. Springer Science & Business Media, 2008.

[140] James D Hamilton. A new approach to the economic analysis of nonstationary time series and the business cycle. *Econometrica: Journal of the econometric society*, pages 357–384, 1989.

[141] James D Hamilton and Raul Susmel. Autoregressive conditional heteroskedasticity and changes in regime. *Journal of Econometrics*, 64(1-2):307–333, 1994.

[142] Graham Harman. Speculative realism. In *Critical Terms in Futures Studies*, pages 287–290. Springer, 2019.

[143] Joel Hasbrouck and Richard M Levich. Network structure and pricing in the fx market. *Journal of Financial Economics*, 141(2):705–729, 2021.

[144] W Keith Hastings. Monte Carlo sampling methods using Markov chains and their applications. 1970.

[145] Harald Hau and Helene Rey. Exchange rates, equity prices, and capital flows. *The Review of Financial Studies*, 19(1):273–317, 2006.

[146] John F Haught. *God after Darwin: A theology of evolution*. Routledge, 2018.

[147] Geoffrey Martin Hodgson. *Economics in the Shadows of Darwin and Marx*. Edward Elgar Publishing, 2014.

[148] Samuel Hollander. The economics of adam smith. In *The Economics of Adam Smith*. University of Toronto Press, 2019.

[149] Hykel Hosni. Towards a Bayesian theory of second-order uncertainty: Lessons from non-standard logics. In *David Makinson on classical methods for non-classical problems*, pages 195–221. Springer, 2014.

[150] Mitsuru Igami. Artificial intelligence as structural estimation: Deep blue, bonanza, and alphago. *The Econometrics Journal*, 23(3):S1–S24, 2020.

[151] Emirhan Ilhan, Zacharias Sautner, and Grigory Vilkov. Carbon tail risk. *The Review of Financial Studies*, 34(3):1540–1571, 2021.

[152] Ethan Ilzetzki, Carmen M Reinhart, and Kenneth S Rogoff. Exchange arrangements entering the twenty-first century: Which anchor will hold? *The Quarterly Journal of Economics*, 134(2):599–646, 2019.

[153] Ethan Ilzetzki, Carmen M Reinhart, and Kenneth S Rogoff. Will the secular decline in exchange rate and inflation volatility survive covid-19? Technical report, National Bureau of Economic Research, 2020.

[154] Ethan Ilzetzki, Carmen M Reinhart, and Kenneth S Rogoff. Rethinking exchange rate regimes. Technical report, National Bureau of Economic Research, 2021.

[155] Edward Allen Irons. *Tian Dao: The net of ideology in a Chinese religion*. Graduate Theological Union, 2000.

[156] Edwin T Jaynes. *Probability theory: The logic of science*. Cambridge University Press, 2003.

[157] Qiang Ji, Syed Jawad Hussain Shahzad, Elie Bouri, and Muhammad Tahir Suleman. Dynamic structural impacts of oil shocks on exchange rates: lessons to learn. *Journal of Economic Structures*, 9(1):1–19, 2020.

[158] Zhengyang Jiang, Arvind Krishnamurthy, and Hanno Lustig. Foreign safe asset demand and the dollar exchange rate. *The Journal of Finance*, 76(3):1049–1089, 2021.

[159] Juthathip Jongwanich. Real exchange rate overvaluation and currency crisis: evidence from thailand. *Applied Economics*, 40(3):373–382, 2008.

[160] Juthathip Jongwanich. Equilibrium real exchange rate, misalignment, and export performance in developing asia. *Asian Development Bank Economics Research Paper Series*, (151), 2009.

[161] Jonathan Joseph. Foucault and reality. *Capital & Class*, 28(1):143–165, 2004.

[162] H Jerome Keisler. Fundamentals of model theory. In *Studies in Logic and the Foundations of Mathematics*, volume 90, pages 47–103. Elsevier, 1977.

[163] John Maynard Keynes. A treatise on probability. *Diamond*, 3(2):12, 1909.

[164] John Maynard Keynes. The principal averages and the laws of error which lead to them. *Journal of the Royal Statistical Society*, 74(3):322–331, 1911.

[165] John Maynard Keynes. *A treatise on probability*. Macmillan and Company, limited, 1921.

[166] Philip Kitcher. *Living with Darwin: Evolution, design, and the future of faith*. Oxford University Press, 2009.

[167] Franc Klaassen. Long swings in exchange rates: are they really in the data? *Journal of Business & Economic Statistics*, 23(1):87–95, 2005.

[168] David Klenert, Linus Mattauch, Emmanuel Combet, Ottmar Edenhofer, Cameron Hepburn, Ryan Rafaty, and Nicholas Stern. Making carbon pricing work for citizens. *Nature Climate Change*, 8(8):669–677, 2018.

[169] John Knoblock et al. *Xunzi: A translation and study of the complete works*, volume 1. Stanford University Press, 1988.

[170] Ingomar Krohn and Vladyslav Sushko. Fx spot and swap market liquidity spillovers. *Journal of International Money and Finance*, 120:102476, 2022.

[171] Philipp Krueger, Zacharias Sautner, and Laura T Starks. The importance of climate risks for institutional investors. *The Review of Financial Studies*, 33(3):1067–1111, 2020.

[172] Paul Krugman. How did economists get it so wrong? *New York Times*, 2(9):2009, 2009.

[173] Leslie D Kwakye, Victoria Fisher, Margaret Jackson, and Oona Jung-Beeman. Bayesian causal inference modeling of attentional effects on the temporal binding window of multisensory integration. *Journal of Vision*, 19(10):19–19, 2019.

[174] Nikolaos A Kyriazis. Eurozone debt monetization and helicopter money drops: How viable can this be? *Journal of Central Banking Theory and Practice*, 6(3):5–15, 2017.

[175] Amartya Lahiri and Carlos A Végh. Living with the fear of floating. *Preventing Currency Crises in Emerging Markets*, page 663, 2001.

[176] Simone Landini, Mauro Gallegati, and J Barkley Rosser. Consistency and incompleteness in general equilibrium theory. *Journal of Evolutionary Economics*, 30(1):205–230, 2020.

[177] Blake LeBaron. Technical trading rule profitability and foreign exchange intervention. *Journal of International Economics*, 49(1):125–143, 1999.

[178] Chi-Chuan Lee, Chien-Chiang Lee, and Yong-Yi Li. Oil price shocks, geopolitical risks, and green bond market dynamics. *The North American Journal of Economics and Finance*, 55:101309, 2021.

[179] Csaba Lentner. The structural outline of the development and consolidation of retail foreign currency lending. *Public Finance Quarterly*, 60(3):297–311, 2015.

[180] Richard M Levich and Lee R Thomas. The merits of active currency risk management: evidence from international bond portfolios. *Financial Analysts Journal*, 49(5):63–70, 1993.

[181] Richard M Levich and Lee R Thomas III. The significance of technical trading-rule profits in the foreign exchange market: a bootstrap approach. *Journal of International Money and Finance*, 12(5):451–474, 1993.

[182] Karen K Lewis. Global asset pricing. *The Annual Review of Financial Economics is*, 3:435–66, 2011.

[183] Dan Li and Geng Li. Whose disagreement matters? household belief dispersion and stock trading volume. *Review of Finance*, 25(6):1859–1900, 2021.

[184] Tien-Yien Li and James A Yorke. Period three implies chaos. In *The theory of chaotic attractors*, pages 77–84. Springer, 2004.

[185] Andrew Lilley, Matteo Maggiori, Brent Neiman, and Jesse Schreger. Exchange rate reconnect. *The Review of Economics and Statistics*, pages 1–28.

[186] Qiao Liu, Zefeng Chen, and Sylvia Xiaolin Xiao. A theory of carbon currency. *Fundamental Research*, 2(3):375–383, 2022.

[187] Robert E Lucas Jr. Understanding business cycles. In *Carnegie-Rochester conference series on public policy*, volume 5, pages 7–29. North-Holland, 1977.

[188] Robert E Lucas Jr. Asset prices in an exchange economy. *Econometrica*, pages 1429–1445, 1978.

[189] Jayson L Lusk and F Bailey Norwood. Animal welfare economics. *Applied Economic Perspectives and Policy*, 33(4):463–483, 2011.

[190] Matteo Maggiori, Brent Neiman, and Jesse Schreger. International currencies and capital allocation. *Journal of Political Economy*, 128(6):2019–2066, 2020.

[191] Anthony J Makin. Lessons for macroeconomic policy from the global financial crisis. *Economic Analysis and Policy*, 64:13–25, 2019.

[192] Loriano Mancini, Angelo Ranaldo, and Jan Wrampelmeyer. Liquidity in the foreign exchange market: Measurement, commonality, and risk premiums. *The Journal of Finance*, 68(5):1805–1841, 2013.

[193] Benoit Mandelbrot. New methods in statistical economics. *Journal of Political Economy*, 71(5):421–440, 1963.

[194] Benoit B Mandelbrot. Negative fractal dimensions and multifractals. *Physica A: Statistical Mechanics and its Applications*, 163(1):306–315, 1990.

[195] N Gregory Mankiw and Ricardo Reis. Sticky information versus sticky prices: a proposal to replace the new Keynesian Phillips curve. *The Quarterly Journal of Economics*, 117(4):1295–1328, 2002.

[196] Rui Mano, Ms Carolina Osorio Buitron, Mr Luca A Ricci, and Mr Mauricio Vargas. *The Level REER model in the External Balance Assessment (EBA) Methodology*. International Monetary Fund, 2019.

[197] Miguel-Angel Martin-Delgado. Alan turing and the origins of complexity. *arbor*, page n6006, 2013.

[198] John A Mathews and Mark Selden. China: The emergence of the Petroyuan and the challenge to U.S. dollar hegemony. *The Asia-Pacific Journal*, 16(22/3):1–12, 2018.

[199] Thomas J McCabe. A complexity measure. *IEEE Transactions on Software Engineering*, (4):308–320, 1976.

[200] Ken McCormick. The tao of laissez-faire. *Eastern Economic Journal*, 25(3):331–341, 1999.

[201] Robert E McCulloch and Ruey S Tsay. Bayesian analysis of autoregressive time series via the Gibbs sampler. *Journal of Time Series Analysis*, 15(2):235–250, 1994.

[202] Robert E McCulloch and Ruey S Tsay. Statistical analysis of economic time series via Markov switching models. *Journal of Time Series Analysis*, 15(5):523–539, 1994.

[203] Richard A Meese and Kenneth Rogoff. Empirical exchange rate models of the seventies: Do they fit out of sample? *Journal of International Economics*, 14(1-2):3–24, 1983.

[204] Quentin Meillassoux. *After finitude: An essay on the necessity of contingency*. Bloomsbury Publishing, 2010.

[205] Alessandro Melone, Otto Randl, Leopold Sögner, and Josef Zechner. Stock-oil comovement: Fundamentals or financialization? *Available at SSRN 3668239*, 2021.

[206] Robert K Merton. *The sociology of science: Theoretical and empirical investigations*. University of Chicago press, 1973.

[207] Nicholas Metropolis, Arianna W Rosenbluth, Marshall N Rosenbluth, Augusta H Teller, and Edward Teller. Equation of state calculations by fast computing machines. *The journal of Chemical Physics*, 21(6):1087–1092, 1953.

[208] Fabio Milani and Ashish Rajbhandari. Expectation formation and monetary dsge models: Beyond the rational expectations paradigm. In *DSGE Models in Macroeconomics: Estimation, Evaluation, and New Developments*. Emerald Group Publishing Limited, 2012.

[209] Frederic S Mishkin. Global financial instability: framework, events, issues. *Journal of Economic Perspectives*, 13(4):3–20, 1999.

[210] Peter J Montiel. *Macroeconomics in emerging markets*. Cambridge University Press, 2011.

[211] Gregory Moore and Nathan Seiberg. Taming the conformal zoo. *Physics Letters B*, 220(3):422–430, 1989.

[212] In Jae Myung. Tutorial on maximum likelihood estimation. *Journal of Mathematical Psychology*, 47(1):90–100, 2003.

[213] Elvira Nabiullina. Central bank strategies to boost investor confidence in an era of volatility, rapid economic transformation, and uncertainty. *Women Shaping Global Economic Governance*, page 27, 2019.

[214] Elvira Nabiullina et al. Economic policy in times of crisis-analysis and outlook. *Economic Policy*, 3:73–85, 2009.

[215] Ernest Nagel. The meaning of probability. *Journal of the American Statistical Association*, 31(193):10–30, 1936.

[216] Ernest Nagel. Some theses in the philosophy of logic. *Philosophy of Science*, 5(1):46–51, 1938.

[217] Stefan Nagel and Zhengyang Xu. Dynamics of subjective risk premia. Technical report, National Bureau of Economic Research, 2022.

[218] Tadahiro Nakajima and Shigeyuki Hamori. Causality-in-mean and causality-in-variance among electricity prices, crude oil prices, and Yen–US dollar exchange rates in Japan. *Research in International Business and Finance*, 26(3):371–386, 2012.

[219] Paresh Kumar Narayan. Has covid-19 changed exchange rate resistance to shocks? *Asian Economics Letters*, 1(1):17389, 2020.

[220] Shibananda Nayak and Mirza Allim Baig. International reserves and domestic money market disequilibrium: empirics for india and china. *International Journal of Emerging Markets*, 2019.

[221] Christopher Neely, Paul Weller, and Rob Dittmar. Is technical analysis in the foreign exchange market profitable? a genetic programming approach. *Journal of financial and Quantitative Analysis*, 32(4):405–426, 1997.

[222] Eric Neumayer. In defence of historical accountability for greenhouse gas emissions. *Ecological Economics*, 33(2):185–192, 2000.

[223] Mark EJ Newman and Duncan J Watts. Renormalization group analysis of the small-world network model. *Physics Letters A*, 263(4-6):341–346, 1999.

[224] Maurice Obstfeld and Kenneth Rogoff. Exchange rate dynamics redux. *Journal of Political Economy*, 103(3):624–660, 1995.

[225] Takaaki Ohnishi, Takayuki Mizuno, Kazuyuki Aihara, Misako Takayasu, and Hideki Takayasu. Statistical properties of the moving average price in dollar–yen exchange rates. *Physica A: Statistical Mechanics and its Applications*, 344(1-2):207–210, 2004.

[226] John Okunev and Derek White. Do momentum-based strategies still work in foreign currency markets? *Journal of Financial and Quantitative Analysis*, 38(2):425–447, 2003.

[227] Arthur O'sullivan and Steven M Sheffrin. Economics: Principles in action. 2003.

[228] Mark D Packard, Per L Bylund, and Brent B Clark. Keynes and Knight on uncertainty: peas in a pod or chalk and cheese? *Cambridge Journal of Economics*, 45(5):1099–1125, 2021.

[229] Margherita Pagani and Renaud Champion. *Artificial Intelligence for Sustainable Value Creation*. Edward Elgar Publishing, 2021.

[230] Hélène Poirson. How do countries choose their exchange rate regime? *IMF working paper*, 2001.

[231] Zoltan Pozsar. Institutional cash pools and the triffin dilemma of the US banking system. *IMF Working Paper*, 2011.

[232] Zacharias Psaradakis, Morten O Ravn, and Martin Sola. Markov switching causality and the money–output relationship. *Journal of Applied Econometrics*, 20(5):665–683, 2005.

[233] Kuntara Pukthuanthong-Le, Richard M Levich, and Lee R Thomas. Do foreign exchange markets still trend? *The Journal of Portfolio Management*, 34(1):114–118, 2007.

[234] Aidan Rankin. *Jainism and environmental philosophy: Karma and the web of life*. Routledge, 2018.

[235] Hélène Rey. Dilemma not trilemma: the global financial cycle and monetary policy independence. Technical report, National Bureau of Economic Research, 2015.

[236] William Roberds and François R Velde. Early public banks. *Available at SSRN 2399046*, 2014.

[237] Christian P Robert. The search for certainty: a critical assessment. *Bayesian Analysis*, 5(2):213–222, 2010.

[238] Christian P Robert and George Casella. The Metropolis—Hastings algorithm. In *Monte Carlo statistical methods*, pages 267–320. Springer, 2004.

[239] Cynthia A Roberts, Leslie Elliott Armijo, and Saori N Katada. *The BRICS and collective financial statecraft*. Oxford University Press, 2018.

[240] Kenneth Rogoff. The purchasing power parity puzzle. *Journal of Economic literature*, 34(2):647–668, 1996.

[241] Kenneth Rogoff. Why not a global currency? *American Economic Review*, 91(2):243–247, 2001.

[242] Rudy Rucker. Infinity and the mind. In *Infinity and the Mind*. Princeton University Press, 2019.

[243] Jonathan Rushton. *The economics of animal health and production*. Cabi, 2009.

[244] Paul A Samuelson. The pure theory of public expenditure. *The review of economics and statistics*, pages 387–389, 1954.

[245] Mirela Sandulescu, Fabio Trojani, and Andrea Vedolin. Model-free international stochastic discount factors. *The Journal of Finance*, 76(2):935–976, 2021.

[246] David Schmeidler. Subjective probability and expected utility without additivity. *Econometrica: Journal of the Econometric Society*, pages 571–587, 1989.

[247] Stephen M Stigler. Laplace's 1774 memoir on inverse probability. *Statistical Science*, 1(3):359–363, 1986.

[248] Mr Mark R Stone. *Greater monetary policy transparency for the G3: Lessons from full-fledged inflation targeters*. International Monetary Fund, 2003.

[249] Georg Strasser. Exchange rate pass-through and credit constraints. *Journal of Monetary Economics*, 60(1):25–38, 2013.

[250] Martin A Tanner and Wing Hung Wong. The calculation of posterior distributions by data augmentation. *Journal of the American statistical Association*, 82(398):528–540, 1987.

[251] Alan M Taylor and Mark P Taylor. The purchasing power parity debate. *Journal of Economic Perspectives*, 18(4):135–158, 2004.

[252] Richard P Taylor, Adam P Micolich, and David Jonas. Fractal expressionism. *Physics World*, 12(10):25, 1999.

[253] Sergios Theodoridis. *Machine learning: a Bayesian and optimization perspective*. Academic press, 2015.

[254] George C Tiao and Ruey S Tsay. Some advances in non-linear and adaptive modelling in time-series. *Journal of Forecasting*, 13(2):109–131, 1994.

[255] Waldo Tobler. On the first law of geography: A reply. *Annals of the Association of American Geographers*, 94(2):304–310, 2004.

[256] Howell Tong. *Non-linear time series: a dynamical system approach*. Oxford University Press, 1990.

[257] Adrien Verdelhan. The share of systematic variation in bilateral exchange rates. *The Journal of Finance*, 73(1):375–418, 2018.

[258] Veronica J Vieland and Susan E Hodge. Statistical evidence: A likelihood paradigm. *The American Journal of Human Genetics*, 63(1):283–289, 1998.

[259] Paolo Vitale. A guided tour of the market microstructure approach to exchange rate determination. *Journal of Economic Surveys*, 21(5):903–934, 2007.

[260] John Williamson. *Estimating equilibrium exchange rates*. Peterson Institute, 1994.

[261] SC Woon. Riemann zeta function is a fractal. *arXiv e-prints*, pages chao–dyn/9406003, 1994.

[262] Renhong Wu et al. A new method of estimating equilibrium real exchange rate in developing countries. *International Journal of Economics and Finance*, 8(3):171–177, 2016.

Appendix A

Derivation of full conditional distribution of parameters

$$
\begin{aligned}
&p(U_t|\alpha_0,\alpha_1,\sigma_0^2,\sigma_1^2,\theta,U_1,\ldots,U_{t-1},U_{t+1},\ldots,U_T) \propto \\
&\propto \left(\theta \exp\left\{-\frac{1}{2\sigma_1^2}(X_t-\alpha_1)^2\right\}\right)^{U_t}\left((1-\theta)\exp\left\{-\frac{1}{2\sigma_0^2}(X_t-\alpha_0)^2\right\}\right)^{1-U_t} \\
&\propto \mathcal{B}in(1,\bar{\xi}_t) \qquad \text{(A.1)}
\end{aligned}
$$

$$
\begin{aligned}
&p(\alpha_j|\sigma_j^2,\theta,\underline{U},\underline{X}) \propto \exp\left\{-\sum_{t\in\mathcal{T}_j}\frac{1}{2\sigma_j^2}(X_t-\alpha_j)^2-\frac{1}{2\gamma_j^2}(\alpha_j-m_j)^2\right\} \\
&\propto \mathcal{N}(\bar{m}_j,\bar{\gamma}_j^2) \qquad \text{(A.2)}
\end{aligned}
$$

with

$$
\bar{m}_j=\bar{\gamma}_j^2\left(\frac{1}{\sigma_j^2}\sum_{t\in\mathcal{T}_j}X_t+\frac{m_j}{\gamma_j^2}\right), \quad \bar{\gamma}_j^2=\left(\frac{T_j}{\sigma_j^2}+\frac{1}{\gamma_j^2}\right)^{-1}
$$

$$
\begin{aligned}
&p(\sigma_0^2,\sigma_1^2|\alpha_0,\alpha_1,\theta,\underline{U},\underline{X}) \propto \left(\frac{1}{\sigma_0^2}\right)^{\frac{T_0}{2}+a_0-1}\exp\left\{-\frac{1}{\sigma_0^2}\left(b_0+\frac{1}{2}\sum_{t\in\mathcal{T}_0}(X_t-\alpha_0)^2\right)\right\} \\
&\cdot\left(\frac{1}{\sigma_1^2}\right)^{\frac{T_1}{2}+a_1-1}\exp\left\{-\frac{1}{\sigma_1^2}\left(b_1+\frac{1}{2}\sum_{t\in\mathcal{T}_1}(X_t-\alpha_1)^2\right)\right\} \\
&\propto \mathcal{IG}(\bar{a}_0,\bar{b}_0)\mathcal{IG}(\bar{a}_1,\bar{b}_1)\mathbb{I}(\sigma_0^2<\sigma_1^2)
\end{aligned}
$$

where

$$\bar{a}_j = a_j + \frac{T_j}{2}, \quad \bar{b}_j = b_j + \frac{1}{2}\sum_{t\in\mathcal{T}_j}(X_t - \alpha_j)^2 \tag{A.3}$$

$$\begin{aligned} &p(\theta|\alpha_0, \alpha_1, \sigma_0^2, \sigma_1^2, \theta, \underline{U}, \underline{X}) \propto \theta^{c+\sum_{t=1}^{T} U_t - 1}(1-\theta)^{d+T-\sum_{t=1}^{T} U_t - 1} \\ &\propto \mathcal{B}e(\bar{c}, \bar{d}) \end{aligned} \tag{A.4}$$

with

$$\bar{c} = c + \sum_{t=1}^{T} U_t, \quad \bar{d} = d + T - \sum_{t=1}^{T} U_t$$

$$\begin{aligned} &p(\alpha_j|\beta_j, \sigma_j^2, \theta, \underline{U}, \underline{X}) \\ &\propto \exp\left\{-\frac{1}{2\sigma(t)^2}\left((X_t - \alpha(t) - \beta(t)Z_{t-1})\right)^2\right\}\exp\left\{-\frac{1}{2\gamma_0^2}\left((\alpha_0 - m_0)\right)^2\right\} \\ &\exp\left\{-\frac{1}{2\gamma_1^2}\left((\alpha_1 - m_1)\right)^2\right\} \\ &\propto exp\left\{-\frac{1}{2\sigma_0^2}\sum_{t\in\mathcal{T}_0}(X_t - \alpha_0 - \beta_0 Z_{t-1})^2 - \frac{1}{2\gamma_0^2}\left((\alpha_0 - m_0)\right)^2\right\} \\ &exp\left\{-\frac{1}{2\sigma_1^2}\sum_{t\in\mathcal{T}_1}(X_t - \alpha_1 - \beta_1 Z_{t-1})^2 - \frac{1}{2\gamma_1^2}\left((\alpha_1 - m_1)\right)^2\right\} \\ &\propto exp\left\{-\frac{1}{2\sigma_0^2}\left(T_0\alpha_0^2 - 2\alpha\sum_{t\in\mathcal{T}_0}X_t - \beta_0 Z_{t-1}\right) - \frac{1}{2\gamma_0^2}\left((\alpha_0^2 - 2\alpha_0 m_0)\right)\right\} \\ &exp\left\{-\frac{1}{2\sigma_1^2}\left(T_1\alpha_1^2 - 2\alpha\sum_{t\in\mathcal{T}_1}X_t - \beta_1 Z_{t-1}\right) - \frac{1}{2\gamma_1^2}\left((\alpha_1^2 - 2\alpha_1 m_1)\right)\right\} \\ &\propto exp\left\{-\frac{1}{2}\left[\alpha_0^2\left(\frac{T_0}{\sigma_0^2} + \frac{1}{\gamma_0^2}\right) - 2\alpha_0\left(\frac{1}{\sigma_0^2}\sum_{t\in\mathcal{T}_0}X_t - \beta_0 Z_{t-1} + \frac{m_0}{\gamma_0^2}\right)\right]\right\} \\ &exp\left\{-\frac{1}{2}\left[\alpha_1^2\left(\frac{T_1}{\sigma_1^2} + \frac{1}{\gamma_1^2}\right) - 2\alpha_1\left(\frac{1}{\sigma_1^2}\sum_{t\in\mathcal{T}_1}X_t - \beta_1 Z_{t-1} + \frac{m_1}{\gamma_1^2}\right)\right]\right\} \end{aligned}$$

$$\propto \mathcal{N}(\bar{m}_j, \bar{\gamma}_j^2) \tag{A.5}$$

with

$$\bar{m}_j = \bar{\gamma}_j^2 \left(\frac{1}{\sigma_j^2} \sum_{t \in \mathcal{T}_j} (X_t - \beta_j Z_{t-1}) + \frac{m_j}{\gamma_j^2} \right), \quad \bar{\gamma}_j^2 = \left(\frac{T_j}{\sigma_j^2} + \frac{1}{\gamma_j^2} \right)^{-1}$$

where $\mathcal{T}_j = \{t | U_t = j\}$ and $T_j = \text{Card}(\mathcal{T}_j)$, $j = 0, 1$, where $\text{Card}(A)$ denotes the cardinality of A, that is the number of elements of the set A.

$$p(\beta_j | \alpha_j, \sigma_j^2, \theta, \underline{U}, \underline{X})$$

$$\propto \exp\left\{ -\frac{1}{2\sigma(t)^2} \left((X_t - \alpha(t) - \beta(t) Z_{t-1}) \right)^2 \right\} \exp\left\{ -\frac{1}{2s_0^2} (\beta_0)^2 \right\} \exp\left\{ -\frac{1}{2s_1^2} (\beta_1)^2 \right\}$$

$$\propto exp\left\{ -\frac{1}{2\sigma_0^2} \sum_{t \in \mathcal{T}_0} (X_t - \alpha_0 - \beta_0 Z_{t-1})^2 - \frac{1}{2s_0^2} (\beta_0)^2 \right\}$$

$$exp\left\{ -\frac{1}{2\sigma_1^2} \sum_{t \in \mathcal{T}_1} (X_t - \alpha_1 - \beta_1 Z_{t-1})^2 - \frac{1}{2s_1^2} (\beta_1)^2 \right\}$$

$$\propto exp\left\{ -\frac{1}{2} \left[\beta_0^2 \left(\frac{1}{\sigma_0^2} \sum_{t \in \mathcal{T}_0} Z_{t-1}^2 + \frac{1}{s_0^2} \right) - 2\beta_0 \left(\frac{1}{\sigma_0^2} \sum_{t \in \mathcal{T}_0} (X_t - \alpha_0) Z_{t-1} \right) \right] \right\}$$

$$exp\left\{ -\frac{1}{2} \left[\beta_1^2 \left(\frac{1}{\sigma_1^2} \sum_{t \in \mathcal{T}_1} Z_{t-1}^2 + \frac{1}{s_1^2} \right) - 2\beta_1 \left(\frac{1}{\sigma_1^2} \sum_{t \in \mathcal{T}_1} (X_t - \alpha_1) Z_{t-1} \right) \right] \right\}$$

$$\propto \mathcal{N}(\bar{v}_j, \bar{s}_j^2)$$

with

$$\bar{v}_j = \bar{s}_j^2 \left(\frac{1}{\sigma_j^2} \sum_{t \in \mathcal{T}_j} (X_t - \alpha_j) Z_{t-1} \right), \quad \bar{s}_j^2 = \left(\frac{1}{\sigma_j^2} \sum_{t \in \mathcal{T}_j} Z_{t-1}^2 + \frac{1}{s_j^2} \right)^{-1} \tag{A.6}$$

(A.7)

$$p(\sigma_0^2, \sigma_1^2 | \alpha_0, \alpha_1, \beta_0, \beta_1, \theta, \underline{U}, \underline{X})$$

$$\propto \prod_{t=1}^{T} \frac{1}{\sqrt{\sigma(t)^2}} \exp\left\{ -\frac{1}{2\sigma(t)^2} \left((X_t - \alpha(t) - \beta(t) Z_{t-1}) \right)^2 \right\} \left(\frac{1}{\sigma(t)^2} \right)^{a-1} \exp\left\{ -\frac{1}{\sigma(t)^2} b \right\}$$

$$\propto \left(\frac{1}{\sigma_0^2} \right)^{\frac{T_0}{2} + a_0 - 1} \exp\left\{ -\frac{1}{2\sigma_0^2} \left(b_0 + \frac{1}{2} \sum_{t \in \mathcal{T}_0} (X_t - \alpha_0 - \beta_0 Z_{t-1}) \right)^2 \right\}$$

$$\left(\frac{1}{\sigma_1^2} \right)^{\frac{T_1}{2} + a_1 - 1} \exp\left\{ -\frac{1}{2\sigma_1^2} \left(b_1 + \frac{1}{2} \sum_{t \in \mathcal{T}_1} (X_t - \alpha_1 - \beta_1 Z_{t-1}) \right)^2 \right\}$$

$$\propto \mathcal{IG}a(\bar{a}_0, \bar{b}_0) \cdot \mathcal{IG}a(\bar{a}_1, \bar{b}_1) \quad \mathbb{I}(\sigma_0^2 < \sigma_1^2) \tag{A.8}$$

where

$$\bar{a}_j = a_j + \frac{T_j}{2}, \quad \bar{b}_j = b_j + \frac{1}{2}\sum_{t \in \mathcal{T}_j} (X_t - \alpha_j - \beta_j Z_{t-1})^2 \tag{A.9}$$

$$\begin{aligned} & p(\theta | \alpha_0, \alpha_1, \beta_0, \beta_1, \sigma_0^2, \sigma_1^2, \theta, \underline{U}, \underline{X}) \\ & \propto \prod_{t=1}^{T} \theta^{U_t} (1-\theta)^{1-U_t} \theta^{c-1} (1-\theta)^{d-1} \\ & \propto \theta^{c + \sum_{t=1}^{T} U_{t-1}} (1-\theta)^{d+T-\sum_{t=1}^{T} U_{t-1}} \end{aligned}$$

$$\propto \mathcal{B}e(\bar{c}, \bar{d}) \tag{A.10}$$

with

$$\bar{c} = c + \sum_{t=1}^{T} U_t, \quad \bar{d} = d + T - \sum_{t=1}^{T} U_t \tag{A.11}$$

$$\begin{aligned} & p(U_t | \alpha_0, \alpha_1, \sigma_0^2, \sigma_1^2, \theta, U_1, \ldots, U_{t-1}, U_{t+1}, \ldots, U_T \\ & \propto \exp\left\{ -\frac{1}{2} \left((X_t - \alpha(t) - \beta(t) Z_{t-1}) \right)^2 \right\} \theta^{U_t} (1-\theta)^{1-U_t} \\ & \propto \theta^{U_t} (1-\theta)^{1-U_t} \left(\exp\left\{ -\frac{1}{2\sigma_1^2} (X_t - \alpha_1 - \beta_1 Z_{t-1})^2 \right\} \right)^{U_t} \\ & \qquad \left(\exp\left\{ -\frac{1}{2\sigma_0^2} (X_t - \alpha_0 - \beta_0 Z_{t-1})^2 \right\} \right)^{1-U_t} \\ & \propto \left(\theta \exp\left\{ -\frac{1}{2\sigma_1^2} (X_t - \alpha_1 - \beta_1 Z_{t-1})^2 \right\} \right)^{U_t} \\ & \qquad \left((1-\theta) \exp\left\{ -\frac{1}{2\sigma_0^2} (X_t - \alpha_0 - \beta_0 Z_{t-1})^2 \right\} \right)^{1-U_t} \end{aligned}$$

$$\propto \mathcal{B}in(1, \bar{\xi}_t) \tag{A.12}$$

where

$$\bar{\xi}_t = \frac{\theta \exp\left\{ -\frac{1}{2\sigma_1^2} (X_t - \alpha_1 - \beta_1 Z_{t-1})^2 \right\}}{\theta \exp\left\{ -\frac{1}{2\sigma_1^2} (X_t - \alpha_1 - \beta_1 Z_{t-1})^2 \right\} + (1-\theta) \exp\left\{ -\frac{1}{2\sigma_0^2} (X_t - \alpha_0 - \beta_0 Z_{t-1})^2 \right\}}$$

Appendix B

Commodity base of currency and exchange rates

Past researches have an argument that the main driver of the stabilization of exchange rate is a global convergence in monetary policy, short or long-term interest rate differentials and expectations on zero bound being significantly binding for advanced economies[153]. This limited point of view is also challenged given the sharp-reduction of inflation reflected now turned into a dramatic rapid inflation going on, and systemic economic crises usually trigger vital turning points, therefore a crumple of the extended Bretton Woods II regime cannot be ruled out. We could be witnessing the birth of Bretton Woods III – a new world (monetary) order centered around commodity-based currencies in the East that will likely weaken the Eurodollar system and also contribute to inflationary forces in the West[1]. The notion that countries should view their currencies as tools of foreign economic policy became unfashionable. As a result, few politicians in Europe took note that, after quickly establishing itself as a global currency, the euro gradually lost international standing from the mid-2000s onwards. Exchange rate dynamics redux reveals international welfare spillovers due to monetary and fiscal policies[224]. As established by U.S. Congress, there are three key objectives for monetary policy in terms of Federal Reserve Act: 1)maximizing employment and 2)stabilizing prices(the dual mandate), and 3)moderating long-term interest rates. Among the institutions, St. Louis FED amasses the most fame as a maverick for its espousal of monetarism, which is summarized as "inflation is always and everywhere a monetary phenomenon"[111] and attribute deflationary spirals to the reverse effect of a failure of a central bank to support the money supply during a liquidity crunch[33]. Upon whether fiscal or monetary policy was the more effective tool of demand management, it is argued that the Great Depression of the 1930s was caused by a massive contraction of the money supply (they deemed it "the Great Contraction"), and not by the lack of investment as Keynes assumed, and that post-war inflation was caused by an over-expansion of the money supply. Most monetarists oppose the gold standard. Friedman, for

[1] citing from Zoltan Pozsar's internal report, who is the Global Head of Short-Term Interest Rate Strategy at Credit Suisse

example, viewed a pure gold standard as impractical[83]. Now our insight into the exchange rate shall close this debate by re-attaching international money supply to commodities under a global budgeting of energy supply. Economists are now actively co-jealous of the originality, pushing the new version of what exactly caused the world crisis - bubble the US housing market, non-financial regulation perfection market or anything else. The answers to these questions in due course They will certainly be given. However it is clear that the world economy can not develop without crises which, in fact, are the tools of purification of inefficient industries and sectors. In such way again, the beginning of the global crisis was only a matter of time[213].

Figure 26: Russian crude oil pipeline and storage system. Source: IHS Markit.

Behaviorally, the recovery of Ruble could be due to the restabilization of banking system as hysteria withdrawals subside. This channel of recovery is considered to be artificial as the central bank(the Bank of Russia) has required exporting companies to exchange 80 percent of their hard-currency revenue for rubles and placed strict restrictions on withdrawals, currency exchange and overseas transfers, but this for sure is not the major reason. The true factor still boosting Russia's strategy and currency strength is its strong oil and gas exports amid high global prices that carry in floods of hard currency and this steady stream in turn supports the state-mandated exchange[2].

[2]There are a few papers studied the correlations between oil prices and exchange rates. For single currency, for example the Yen we studied in later chapter, no time-varying relationship is found on the predictability of oil prices on Yen[72], while the same methodology, Bayesian Markov Switching-VAR analysis could be applied to study, for example, the impact of oil price on GDP

As an important issue of example, let us take a look at the Crude oil pipelines and natural gas pipelines from Russia to other countries shown in Figure26[3]. Some other details of facts reflecting how exchange rate is closely connected to energy(and more generally commodity) trading: during the same time of the observed performance of Russian Ruble, Saudi Arabia, following Iran, is in active contact with Beijing to price its oil sale contracts to China by Chinese currency RMB, to diversify its economical base and eventually repin the Riyal to a basket of currencies, similar to Kuwait's Dinar, which embodies an indentation of U.S. $'s global market dominance and shift of world's top crude exporters towards Asia, and China purchases now over 25% of Saudi Arabia's oil exports, which has been on for six years followed by the introduction of Petroyuan[198] and especially accelerated this year as U.S. retreating from the region[4], tempting other China's oil partner such as Angola and Iraq as well and fragmenting the sovereignty of $ in international financial system, which U.S. has counted on for half century to print Treasury bills to finance its budget deficit. As a measure of the total number of contracts outstanding in the world's largest importer of crude oil, open interest in oil futures on the Shanghai International Energy Exchange (INE), paralleling to contracts for copper aimed to rival London's dominance in metals trading, leapt to a daily average of 118,249 in 2020, four times higher than in 2019 and trading volumes climbed more than 20 per cent year on year, forming part of a longer-term establishment of RMB-denominated markets ultimately seeking to challenge U.S. dollar. As the U.S. import of oil from Saudis is diminishing from once 2 million barrels per day in early 1990s to less than 500,000 barrels per day in December 2021[5] and by contrast, Saudi Arabia holding China's top crude supplier in 2021 with 1.76 million barrels selling per day, followed by Russia at 1.6 million barrels per day[6], a trendency of de-dollarization is becoming indisputable, as it is happening globally[2]. In the midst of the pandemic, overseas purchases of Chinese bonds and stocks through Hong Kong amounted to about RMB 1tn as China increase foreign investor access to futures markets on the mainland. Though around 80% of global oil sales are still done in dollars before the global pandemics, are we ready to be confronted a losing-majority low fair in near future?

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growth[19]. In a multi-country level, results from connectedness measures with structural vector auto-regressive model indicate that all countries are generally more sensitive to oil-specific demand shocks, which specifically have a stronger slumping effect on exchange rates of crude oil exporters than its importers, and meanwhile, this sensitivity entails a conspicuous esteem in real exchange rates, except in UK pound and Japanese Yen and the spillover effect between exchange rates and oil price shocks has been strengthening since the global financial crisis in 2008[157]. Another recent research based on quantile analysis (which naturally also belong to a Bayesian inference methodology) proves Granger-causality unidirectional from geopolitical risk to oil price at the extreme quantiles with an observation on a substantial causality bi-directional from oil price to green bond index during the lower quantiles[178], which reminds us of the prevalence of corporate green bonds in industries where the environment is financially material to firm operations[105].

[3]Data Source: S&P Global's Oil Markets, Midstream, and Downstream research and analysis at IHS Markit.

[4]lack of support and intervention in Yemen civil war, Biden administration's attempt to reach a deal with Iran over nuclear program and U.S. withdrawal from Afghanistan, while China has been helping Saudi Arabia to construct its own ballistic missiles, consulting on a nuclear program and investing in Salman's pet projects, such as Neom, the futuristic new city.

[5]data from U.S. EIA

[6]data from China's General Administration of Customs

In fact, preceding the dollar, five successive currencies has in turn ruled the global markets, each belonging to a superpower of the time and predominated for roughly 80-100 years, ending up with tumbling and accelerating the decline of the sovereignty behind it[103].

Essentially, a crisis of commodities is unfolding. Commodities are collateral, and more precisely at the moment. Russian commodities are like subprime collateral and everything else is prime. And collateral is the essence of money[7], hence the intricacy of this crisis is about the rising attractiveness of outside money over inside money. Every crisis, 1997, 1998, 2008 and 2020[35] till the crises currently taking place, unfold at the intersection of funding and collateral markets. This logic is ironically the same to the previous contrary concluded work, in which is analyzed the fact that unlike the 1970s, the numeraire for reserves is not connected to a sluggishly expanding supply of gold; in the modern context, the numeraire is connected to the sluggishly expanding supply of US goods and services and not driven by the demand for reserves by other advanced economies but by the demand from emerging markets[152]. Now from the Bretton Woods system backed by gold bullion, to Bretton Woods II backed by inside money[76] (Treasuries with un-hedgeable confiscation risks), we are arriving ultimately at "Bretton Woods III" backed by outside money (gold bullion and more importantly other commodities). Bretton Woods II was built on inside money, and its mainstays are now crumbled when the G7 countries seized Russia's foreign exchange reserve[8] and the "Commodities basis" is climbing. Standing in background of this crisis is the stigmatic list of top countries by proven oil reserves[9] in table3 and more generally most fundamental commodities as total energy supply[10] in table4 below, with regards to Special Drawing Rights percentage[11].

A surface indication of this re-polarization of commodity markets is a re-tracking of real effective exchange rate, as published by the World Bank, the Eurostat, the BIS, the OECD without combining consumer prices, which essentially measure the dynamics of the real value of a country's currency against a basket of the trading

[7]from the four prices of money - Par, Interest, Exchange rate and Price level - we see a recurring motif: 1)"Par" identity of money is broken in 2008 when money funds broke the buck and funding markets froze from fearing subprime mortgage collateral; 2)"Interest" collapsed in 2020 when bond Relative-Value trades failed as the drawdown of credit lines pulled funding away from good collateral; 3)Exchange rate is what broke in 1997 when foreign exchange reserves went missing and U.S. dollar funding staged a sudden stop in Asia; 4)Price level– as happening right now.

[8]same statements appear in Zoltan Pozsar's report

[9]Differences result from different classes of oil included and different definitions of proven.

[10]Total Energy Supply (TES) indicates the sum of production and imports subtracting exports and storage changes. For the whole world TES nearly equals primary energy PE because imports and exports cancel out, but for countries/regions TES and PE differ in quantity, and also in quality as secondary energy is involved, e.g., import of an oil refinery product. TES is all energy required to supply energy for end users. The table lists TES and PE for some countries/regions where these differ much, and - for similar ones as US and Africa. The amounts are rounded and given in Mtoe(million tonnes of oil equivalent) per year (1 Mtoe = 11.63 TWh). The data are of 2018 from US IEA.

[11]IMF Members' Quotas and Voting Power, and IMF Board of Governors. www.imf.org. [2021-03-09].

Table 3: Proven oil reserves (millions of barrels)

Country	**by US EIA data**	**by OPEC data**
Venezuela(OPEC)	303,806	302,809
Saudi Arabia(OPEC)	258,600	266,260
Iran(OPEC)	208,600	208,600
Canada	170,300	4,421
Iraq(OPEC)	145,019	147,223
Kuwait(OPEC)	101,500	104,000
United Arab Emirates(OPEC)	97,800	98,630
Russia	80,000	80,000
United States	47,107	32,773
China	26,022	25,627

Table 4: %SDR; Total Energy Supply and Primary Energy in Mtoe/year

Region	**%SDR**	**TSE**	**PE**	**Coal**	**Oil&Gas**	**Nuclear**	**Renewable**
World	100	14280	14420	3890	7850	707	1972
China	6.41	3210	2560	1860	325	77	300
U.S.	17.44	2178	2170	369	1400	219	180
Mid-East	3.51	760	2040	1	2030	2	4
Europe	17.25	1984	1111	171	398	244	296
Russia	2.71	760	1484	240	1165	54	25
Africa	7.98	1170	1169	157	611	3	397
India	2.76	919	574	289	67	10	208

partners of the country as assessing the equilibrium value of a currency, the development of price or cost competitiveness, the trend of trading flows, or incentives and reallocation of production due to the non-tradable and the tradable sectors to a most up to date version rather than obsolete estimations based on unit root testing in real exchange rates, nominal exchange rate forecasting[69]. Further more, we could draw a world currency network and commodity map, never anymore limited to the network structure and pricing in the "G3" economies practicing an informal variant of inflation targeting referred to as "don't ask, don't tell"[125], "just do it"[209], "covert"[195], or "eclectic"[45] full-fledged inflation targeters'[248] market[143], but a real global one.

The profound indication of this macro-finance logic then naturally touches the most crucial topics of asset pricing and sustainable finance. As a counterpart to the Global Systemically Important Banks (G-SIBs), we expect to codify the Global Systemically Important Assets stressing the fundamental energy and resources. The ranking and valuation among the commodities needed to codify this "G-SIB" of Commodities indeed poses a criticism to classical theories on consumption and our real preferences and decision-making, which is paralleling to the radical changes going beyond capitalism, growth and consumerism[32]. As the importance of climate risks for investors[171] revealed, and strong regulatory actions needed to combat climate policy uncertainty[151], we need to construct a consumption weighting based on production and energy budgeting, rather than hedonism and cyberpunk, and then arriving at commodities based exchange rate model. Standard bilateral gross trade flows can no longer accurately appraise Global value chains (GVCs), there is a striking rise of China as a supplier of value added, while Germany and the United States maintain a central role in GVCs over the whole[9]. This research would interesting to be revisited after the pandemic and tracked during the war, given the role of currency as an important factor shaping global portfolios and capital allocation[190] and international bond portfolios[180].

The relative research approaches to comprehend and theorize the topic in fact almost touches the majority of the future of asset pricing[39]. Financial markets have become increasingly global while the forward rate predicts the wrong sign of future movements in the exchange rate, implying that the changing foreign exchange premium over time fails to reconcile with consumption variability[182]. The oil futures return news decomposition[44] revealing the underlying dynamics in the structure of real economy such as oil production are key drivers for the accounted 79% of the time-varying correlation between stock-oil co-movement beyond the financialization of commodities[205] and the exchange rate dynamics is indeed related to equity market development. An equilibrium model in which equity prices, capital flows and exchange rates are jointly determined under incomplete foreign exchange risk trading induced that higher returns in the home equity market correlations to the foreign equity market are associated with a home currency depreciation and foreign currency appreciation with net equity flows, especially countries with higher equity market capitalization relative to GDP[145]. Thus equity market capitalization is positively related to an appreciation of U.S. dollar. The expectations of future dividends and discount factors involves one of the most poplularly studied finance topic, the term structure. We could apply the model-free international stochastic discount factor[245] to more currencies in the perspective of minimum dispersion conditional portfolios, relate the facts of exchange rate to the tendency in researches on studying the term structure of almost everything, given the universality of its conceptualization of time. The trading of currency is as essential as the increasing volume of trading of financial assets (stocks and bonds)[259].

It shall be outdatedly weird to divide our scope into macro-economic variables such as economic growth, inflation and productivity and micro-structure drivers of currency movements, if we equip ourselves with fully trackable exchange transactions, such as digital currency regime. As a mutual consequence, it would be interesting to

study how the rise of digital currencies might be shrinking the other markets, particularly equities. The task of taming the term structure zoo (borrowing the phrase from[211][102]) could never be completed without, probably would be insightful when starting from, the currencies on which we run the whole system. In the context of corporate finance, firms' export and price setting decisions in response to fluctuations in exchange rates and credit conditions, literally, the instantaneous response of firms to changing financial constraints and the bilateral exchange rate is considerably huge. Primarily big companies' behavior correlate with the exchange rate "puzzles" in aggregate data and credit affects exports not only via trading finance, but also international relative prices by constraining feasible pricing policies[249].

Appendix C

More comments on the conceptualization of uncertainty

When we are talking about asset prices and and asset-pricing models, we are actually talking about a forward-looking perspective, where investors price assets based on their beliefs and preferences about the joint distribution of stochastic discount factors and payoffs. The core of asset pricing theory is essentially the formation of belief: how beliefs are generated, embodied and traded. Therefore, one might guess, as a "non-academician" or "non-professinist", the field of asset pricing, that a major endeavors of the research in asset pricing are dedicated to investigating how investors form beliefs. This is, at least so far, not the case within the RE paradigm, theoretically, beliefs are implied by the model; empirically, econometricians recover beliefs from the large-sample empirical distribution, there's no more space left[39]. The vast majority of theoretical and empirical work in asset pricing and macroeconomics is almost universally based on the rational expectations paradigm, see modeling exchange rate dynamics[78]. Under the hypothesis of rational expectations, investors are assumed to know the economy's underlying model and the model parameters, and to forecast rationally[188]. However, the econometric evaluation of the model is shown to be extremely sensitive[183] regarding to how expectations are modeled in computational models of belief dynamics[117]. Beliefs are mostly characterized by large and persistent individual heterogeneity[122] such as exponential quadratic in differences in beliefs[42]. In the case of investigating New Keynesian monetary DSGE model under different expectational assumptions[1], the posterior distributions for the structural parameters significantly shift when the assumption of rational expectations is modified, and the model actually achieves its worse fit under rational expectations[208]. The deviation from RE does not imply irrationality, see models of Bayesian learning relax the RE assumption while retaining the rational forecasting assumption. Cognitive limitations, bounded rationality, and heuristics integrating social and cognitive aspects of belief dynamics[116] have promising insights for our

[1]Namely, the benchmark case of rational expectations, rational expectations extended to allow for 'news' about future shocks, near-rational expectations and learning, and observed subjective expectations from surveys.

understanding of uncertainty: the brain is shown to integrate multisensory information in a Bayes' optimal way and that integration can be represented using Bayesian causal inference modeling with attention alters processing of multisensory stimuli and are distractor modality dependent[173]. In our study of exchange rates and currencies, we realize believes itself contain a hierarchy, and what especially draw our attention are "macro-" believes such as disagreement about inflation and the yield curve[86], agents uncertain and disagree about the length of business cycles[11], inference-forecast gap in belief updating[98], dynamics of subjective risk premia[217] and health externalities[7]. How could we one day develop the economics of leisure and laissez-faire[200]? "Awareness," "attention," and "mindfulness" of one's own self are all key concepts when it comes to moving with optimal efficiency. What will this financial and economical educate us? Selfish, gluttonous and lazy individuals? Rapacious appetites and covetous stares? Voracious predators and an acquisitive society? But love[75]? The story hidden, the power driving beyond equilibrium, the fundamental anti-entropy of our world? "Therefore, the superior man honors his virtuous nature, and maintains constant inquiry and study, seeking to carry it out to its breadth and greatness, so as to omit none of the more exquisite and minute points which it embraces, and to raise it to its greatest height and brilliancy, so as to pursue the course of the Mean. He cherishes his old knowledge, and is continually acquiring new. He exerts an honest, generous earnestness, in the esteem and practice of all propriety"(Zhongyong)[10]. Only without emotion, a state of still mind could flow with the system while cognizing it as a whole and do the computation.

Witnessing such prevailing activeness of "network(here as a verb) the object models", the actual theoretical achievement called complexity economics[13] that claims the death of attempt as General equilibrium theory to develop a universal formalism on axiomatic foundations of economics is the Gödel's incompleteness theorems[54] and non-computability as formulated by Alan Turing[197] proving the coherence-incompleteness trap in general equilibrium theory and similarly dynamic stochastic general equilibrium (DSGE) models[176]. Philosophically they can be taken as Plato's Ideas(Forms), examples of which includes small world network[223], zipf-law[112][3], scale-free distributions and network(though proved to be rare recently[37]), fractal geometry[252] and chaos theory[101], the situation follows as well described in speculative realism[142] as a Non-tout of possible World[204], where we have a Mathematics of the Transcendental[17] which is good news that not everyone is stuck with Emmanuel Kant. However, going beyond the regime of causality again lead us back to the metaphysics behind the epistemology of probability theory we touched in the first paragraph: How shall we interpret the origin of such fundamental randomness of the world, as such fundamental randomness indeed appears in the modelling of the foundation of the world in quantum physics? Artificial intelligence and development of computation methods applied in variety[229] should be better viewed as structural estimation[150], especially machine learning in a Bayesian and optimization perspective[253]. It worth noticing that the fundamental uncertainty roots from struogony. Randomness of prime numbers, as revealed in Riemann function and applied with module in generating MCMC random numbers. It also worth thinking upon vectorial Boolean function mapping from $\mathbb{F}_2^n$ Galois field (GF) to model the book of changes, as also revealed in Cantor's proofs of "Transfinite

Cardinals" and rank of infinity[242]. Consider partition function for Goldbach's Conjecture G(n)[2] and Zipf–Mandelbrot-Pareto distribution:

$$f(k; N, a, s) = \frac{1/(k+q)^s}{H_{N,a,s}} \tag{C.1}$$

where

$$H_{N,a,s} = \sum_{i=1}^{N} \frac{1}{(i+a)^s}$$

We have

$$\lim_{N\to\infty} f(k; N, a, s) = \zeta(s, a) \tag{C.2}$$

$$\begin{aligned} \zeta(s,a) &= \sum_{n=0}^{\infty} \frac{1}{(n+a)^s} \\ &= \frac{1}{\Gamma(s)} \int_0^{\infty} \frac{x^{s-1}e^{-ax}}{1-e^{-x}} dx \end{aligned} \tag{C.3}$$

$$\zeta(s,a)\Gamma(s) = \sum_{n=0}^{\infty} \frac{1}{(n+a)^s} \int_0^{\infty} x^s e^{-x} \frac{dx}{x} = \sum_{n=0}^{\infty} \int_0^{\infty} y^s e^{-(n+a)y} \frac{dy}{y} \tag{C.4}$$

Let

$$\Delta[f](x) = f(x+1) - f(x).$$

Then we have

$$\begin{aligned} \zeta(s,a) &= \frac{1}{s-1} \sum_{n=0}^{\infty} \frac{(-1)^n}{n+1} \Delta^n a^{1-s} \\ &= \frac{1}{s-1} \frac{\log(1+\Delta)}{\Delta} a^{1-s} \end{aligned} \tag{C.5}$$

$$\zeta(s, N) = \sum_{k=0}^{\infty} \left[N + \frac{s-1}{k+1} \right] s + k - 1s - 1(-1)^k \zeta(s+k, N) \tag{C.6}$$

$$\lim_{n\to\infty} \frac{G(n)}{\int_2^n \frac{1}{(lnx)^2} dx \prod_{k=2, p_k|n} \frac{p_k-1}{p_k-2}} = 2 \prod_{k=2}^{\infty} \frac{p_k(p_k-2)}{(p_k-1)^2} = 2C \tag{C.7}$$

C = 0.6601618158 is the Hardy-Little wood constant. Voronin's theorem on the "Universality"[3] of Riemann zeta function is shown to imply that Riemann zeta function is a fractal (in the sense of Mandelbrot set)[261]. We have:

[2]defined as the number of representations of an even integer n as the sum of two primes p and q

[3]A concrete "representation" of the "giant book of theorems" that Paul Halmos referred to.

$$\zeta(s) = -\frac{(2\pi)^s}{2} w^(s-1) \lim_{\hat{S}\to S} \left\{ \frac{\left(\frac{1}{2} + \sum_{n=1}^{\infty}(-1)^n \binom{\hat{s}-1}{n}\left[\frac{1}{2} + \sum_{m=1}^{n}(\frac{-1}{w})^m \binom{n}{m} \frac{B_{m+1}}{(m+1)!}\right]\right)}{cos(\frac{\pi\hat{s}}{2})} \right\} \tag{C.8}$$

The more we apply math to economics, the more certainty we expect and the more uncertainty we get from reality. From intermediate value theorem to chaos (period three[184]), on the other hand of mathematical struogony, we have "Book of Changes" (I Ching)[26] introduce the interdependent contradiction between Yin and Yang, also leading one's intelligence into the approachable yet unspeakable Tian Dao[155]. The contradicted nature of yin and yang unfolds the way and demonstrates the eternal changing, while in the mean time denying that this dialectic system of Yin and Yang is not the way itself. Commanding these abstracts and mastering the scriptures may be still far from truly understanding the actual state of the change and the way, just the Nirvana in Buddhism is not reached by narrative concepts. True understanding requires empirical evidence to develop people's spiritual functions that transcend sensibility and rationality, in order to be in harmony with the ultimate reality. Therefore, the dialectics[25] of Eastern philosophy is the dialectics of practice, and the dialectics of non-Western philosophical[94] thinking concepts as Xun Zi[169] interprets[4].

Should it concern for the welfare of the majority or only create a parsimonious, niggardly and avaricious system? The silence and division of value and researches seems to guarantee the safety of technicians' empiricism approach while actually cultivates true ignorance and hidden space of manipulation. Who is driving and employing the techniques of statistics and mathematics, and dominating the system? As in our subject, the influence of political factors (political instability and government temptation to inflate), adequacy of reserves, dollarization (currency substitution) on exchange rate regime selection is proven to be deterministic[230]. Governments whose local currency debt provides them with greater hedging benefits tends to be risk-averse lenders and lack of monetary policy commitment, and actually borrow more in foreign currency[80]. **The values, tastes and aesthetics amidst these economics and financial issues are the true priors of our researches.** No matter what conceptualization of uncertainty we employ, we are absolutely certain about that preliminarily. The impressive evidence that liquidity yield (yield farming) are significant in explaining exchange rate changes for all of the G10 countries[93] is not that crucial confronted with the analysis of environmental costs and benefits of high-yield farming[20]. Shall we honest think about "democracy" and the growth in the twenty-first century[136]?

[4] "The learning of the gentleman enters through his ears, fastens to his heart, spreads through his four limbs, and manifests itself in his actions. His slightest word, his most subtle movement, all can serve as a model for others. The learning of the petty person enters through his ears and passes out his mouth. From mouth to ears is only four inches—how could it be enough to improve a whole body much larger than that? Students in ancient times learned for their own sake, but the students of today learn for the sake of impressing others. Thus the learning of the gentleman is used to improve his own person, while the learning of the petty man is used like gift oxen."

On the one hand, tiny and uncommon topics such as offshore issuance in tax havens that escape mainstream macro-micro theories actually considerably affect our understanding of the currency composition, external portfolio liabilities and the nature of foreign investment. Global firms financed with foreign subsidiaries often shell themselves in tax havens to obscure their true economic location in official statistics. When traded securities issued by firms in tax havens are associated with their issuer's ultimate parent and restate bilateral investment positions, bilateral portfolio investment from developed countries to firms in large emerging markets is revealed to be dramatically larger than previously thought: the national accounts understate the U.S. position in Chinese firms by nearly $600 billion[67]. On the other hand, modern economists do have generally overlooked the profession's precious legacy — a tradition that goes back at least to Adam Smith[148] — that emphasises the grand, unified theories of political economy and moral philosophy - the "values" that are **certain**, the values that certainly is driving our economic researches. It is cunning if we revisit the history following the spirit of some philosophers[107] to see how this absence of statement of values, silent discourse is formed through history and network of power, should we call it the U.S. finance power[106]? No matter what it is, it is always significant to point it out. Only using the current mainstream division of micro- and macroeconomic models is not enough to explore the dynamic and complex interaction between people, institutions and nature in the real economy, whereas the logic of Bayesian methods is omnipotent from statistical tests, mechanism inferences to games and decision-making. Actually, just as the methodology of Bayesian Paradigm we applied in this thesis, such an object as exchange rate naturally breaks up the micro-macro division and touches the boundary of monetary policies in an international, open, trans-macro point of view and navigates through the major aspects of what finance as a discipline concerns.

I would not waste time repeating in the above paragraphs these facts if they could be found in our education, which, for me, are the most important motif of our era and the fact that we should inform the young generation, especially the younger generation in U.S.: they should know that they could free ride no more as their fathers and grandfathers did. Thus if they do not work hard and create their own value for this planet, there is no right for them to complain anything or waving their moral dogma personal attack weapons. Unfortunately economics as a discipline is deeply ill and poisoned by politics. The pervading laziness and slackness of reflecting upon the facts mentioned above directly entails the poor, time-wasting education of economics. We could learn and enjoy mathematics and coding by ourselves or with the help of tutors. The education is sometimes even harmful cause they are cultivating such laziness and slackness of reflecting among the elites. Shame of silence. The professors' role should be standing out against the political authorities. They are paid to work these out and speak publicly.