A Staggered difference-in-difference approach to studying policy rate influence on exchange rates

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Abstract

For the first time since 2008, we are facing a continuous increase in prices and observing relatively sharp inflation. Many studies show that the optimal policy response to rising inflation is to increase interest rates. Indeed, many central banks have decided to adopt this strategy. These recent events have therefore aroused our curiosity and motivated us to study the impact of such decisions. In this paper, we will attempt to explain how exchange rates behave when a country decides to increase its interest rates through the case of the Global Financial Crisis and the years that followed. To achieve this, we will calculate the average treatment effect of the interest rate change on a country's exchange rate. The model used is a staggered diff-in-diff using a Two-way Fixed effect to account for the country and the reaction speed.

The findings show that an increase in interest rates results in an appreciation of the currency in the short term. A second implication is that the speed at which banks react would seem to have a positive impact on the purchasing power of a currency.

Pushing our research further might lead to a better understanding of a country's international influence that its exchange rate has following its national policy rate changes.

Keywords: Exchange Rate – Interest Rate – Inflation – Staggered DiD – ATT

Summary

Introduction

Inflation has been at the center of global affairs during the last two quarters of 2022. The world has reopened nearly all its frontiers initially closed due to the pandemic; while many rejoice in their hard-earned freedom, the negative impacts of hyperstimulus are being felt. During the pandemic, billions were poured into the world's economy to recover from the massive loss in demand caused by the global lockdowns. Delayed downfalls such as high inflation are threatening the economic balance of most of the planet's countries.

Furthermore, the conflict between Ukraine and Russia has a massive impact on the whole world (Ozili, 2022). Both countries are engaged in military, political and economic battles. These recent events have strongly influenced the choice of our research question. Indeed, in the last two years, the price of commodities such as oil or gas has exploded: it has never been this high since the seventies. In addition to these events, we also observed the fall of the euro against the Swiss franc, so we started to try to understand how all these events could be linked. To find what affects the exchange rates and most precisely analyze if interest rates have a real impact on exchange rates, we decided to study the 2008 financial crisis. This choice was made because of the availability of data compared to the period in which we are living.

In March 2022, the US Federal Reserve was the first to increase its interest rates to curb high inflation (Derby, 2022). It had been 4 years since they had actively changed the rates and many countries acted similarly in the following months. While changing interest rates has long been proven to be an effective weapon in a nation's toolkit to control the economy, we are eager to observe the effect on its currency. When a country goes through inflation, it loses value due to a loss in purchasing power. If all of the planet's currencies inflate at the same rate, none lose buying power. However, the first country to slow its inflation by raising interest rates, reversing the trend compared to other states. The currency thus appreciates.

Many DiD studies often come to a dead-end due to the real-life complexities of applying the same treatments to a purely random group. In the case of a drug administered to patients, it's simple to observe the before and after effects. Interest rates, however, are much more complex. In our case, "treatments" are the changes in interest rate policies by each country. They don't happen at the same time for each country. The diff-in-diff model needed is called a staggered diff-in-diff. This paper used the model put forth by Brent Callaway, Andrew Goodman-Bacon and Pedro H.C. Sant'Anna (2021) in "Differences-in-Differences with a Continuous Treatment". We also constructed our model with the help of another paper from Callaway and Sant'Anna, "Difference-in-Differences with multiple periods" (2021).

Data description

For our observation we decided to choose 7 countries with different socio-economic features. We mainly focused on developed countries that have their own currencies. These were: Sweden, Norway, Australia, Canada, Poland, United Kingdom and Hungary. Several problems have surged while choosing these countries. First, some countries are pegged to the US dollar which makes it impossible to study the impact of interest rates on the exchange rates of these countries. We have many examples such as Hong Kong or Qatar. Secondly, a lot of data was partly or completely unavailable for developing countries, such as unemployment for South Africa or the Balance of Trade for India. A third problem was the fact that there exist different references to calculate public debt. To have this amount of debt we went on different sources across the web. We obtained all our data for the control variables on the OECD website and our data for exchange rates and policy rates from the IMF.

The data has been collected every quarter as most of the macroeconomic variables listed below are not released on a higher frequency. Furthermore, to have a stationary time series, all variables listed below except the policy rate have been transformed into growth rate between t-1 and t.

Our study covers the period from 01.01.2007 to 01.04.2014 written as $t = 1, \ldots, \mathcal{T}$. We define 01.07.2010 as the time t=T from which a change in Policy Rates is considered as a treatment. We chose this date as it is followed by increases in rates and because the non-negativity of the treatment condition would not hold if a decrease in rates were observed. Indeed, during the Global Financial Crisis of 2008, many central banks lowered their interest rates. However, the rates were not cut anymore, which allows us to consider only positive variations. While analyzing the recent increase in rates could have been interesting, there would be a lack of data for the post-treatment period.

Exchange rates

The exchange rate is the dependent variable (Y) in our model. It is defined as the price of one country's currency in relation to another one. Inflation is a key determinant of exchange rates. We, therefore, decided to interpret it as a measure of inflation, by comparing all currencies to the US dollar.

Policy rates

We used the Policy rates for their stickiness: they are fixed in time because they are set by the Central Bank of each country. These can influence the exchange rate. As most changes in policy rates are made on a 0.25 points basis, we transformed it into a binary variable that observes if there is an increase in interest rate (1) or not (0).

Balance of trade

The difference between all exportations and importations of a given country, also known as trade balance, makes exchange rates fluctuate. In the case of a positive trade balance, the local currency is appreciated because investors want to sell all the foreign currency that they receive for selling abroad. And vice versa if there is a negative trade balance.

Government Debt

The debt allows us to measure what a country owes. When the national debt is high, it implies that the local currency will depreciate due to financial uncertainty in domestic and international markets in case of financial instability. However, the low national debt will be favored by markets, increasing investments in the currency.

The national debt of a country is exogenous to the exchange rate of a country: countries increase their public borrowing by looking at inflation but not currency.

Unemployment rate

The unemployment rate is defined by the percentage of people unemployed in the labor force. According to the famous economic model, called “The Phillips curve”, the inflation and unemployment rate are inversely correlated. This gives us information about the condition of the economy, therefore the value of the local currency.

GDP growth rate

The GDP growth rate provides us with information on the average rate of change in the value of goods and services produced in a given period. A positive GDP growth rate indicates an increase in the country’s production, resulting in a higher demand for its products and currency. It also reassures the investors about the economic stability of the country.

Empirical strategy

Our model

A simple version of our regression would be to establish a moment in time that we would call time 0, see how long it took for a central bank to change its interest rate, and see how that affected the currency. We could then compare each country through a diff-in-diff to observe which central bank had the biggest impact on its currency and figure out if it is correlated to its response time. This strategy would correspond to a classic diff-in-diff where we have a comparable "before" and an "after" happening around an event. Our case, however, is much more complicated. Not only is the change in interest rate different from country to country, central banks usually increase them many times in varying degrees. We use a Staggered diff-in-diff to overcome this problem.

A staggered difference-in-difference regression is a type of regression used to analyze the effect of a treatment on an outcome variable. It is a form of the difference-in-difference approach, which compares the difference between the pre and post-treatment outcomes for the treatment group and the control group. A staggered difference-in-difference regression adds a temporal dimension to the analysis by dividing the treatment and control groups into two or more groups, each of which experiences the treatment at a different time. This allows the researcher to measure the impact of the treatment over time and compare the patterns of change in the treatment and control groups (OpenAI, 2022)[1].

We will estimate our diff-in-diff with a Two Way Fixed Effect (TWFE) regression given by the following equation (Callaway et al., 2021, p26):

$$Y_{it} = \theta_t + \eta_i + \beta^{TWFE} W_{it} + \sum_{k=1}^{K} a_k Z_{kit} + \upsilon_{it}$$

Where:

– Y_{it} is our dependent variable, exchange rate growth rate for a country i at time t.

– θ_t is the time-fixed effect. η_i is our unit fixed effect $\beta^{TWFE} W_{it}$ is our main control variable, interest rate, weighted with the Two Way Fixed Effect Beta.

– The β^{TWFE} is the weighted sum of the Average Treatment effect of the "dose" on the treated.

– W_{it} is a binary that equals 1 if the unit i has been treated in period t and 0 else.

– Z_{kit} is a (K x $\mathcal{T}$ x n) tensor containing the control variables, with n the amount of countries.

– a_k are the parameters of the control variables.

– υ_{it} is the error term.

We obtain $\ddot{W}_{it}$:

$$\ddot{W}_{it} := (W_{it} - \overline{W}_i) - (E[Wt] - \frac{1}{\mathcal{T}}\sum_{t=1}^{\mathcal{T}} E[W_t]) \text{ , where } \overline{W}_i := \frac{1}{\mathcal{T}}\sum_{t=1}^{\mathcal{T}} W_{its}$$

1 This definition was provided by OpenAI's new ChatGPT feature which can generate text from samples. Imputed sample was "Explain what a staggered difference-in-difference regression is."

Where $\mathcal{T}$ is the number of Time-periods and $\overline{W}_i$ the average treatment for each country.
And the β^{TWFE}:

$$\beta^{TFWE} = \left(\frac{1}{\mathcal{T}} \sum_{t=1}^{\mathcal{T}} E[Y_{it}\ddot{W}_{it}] \right) / \left(\frac{1}{\mathcal{T}} \sum_{t=1}^{\mathcal{T}} E[\ddot{W}^2_{it}] \right)$$

Our model aims to calculate the average treatment on the treated (ATT). In our case, the treated are the countries and the treatments are increasing policy rates. The ATT calculates how much the exchange rate moves after an increase in interest rates compared to the control group that didn’t receive the treatment. The comparison is the basis of the difference-in-difference.
To correctly extrapolate results from our regression and identify our ATT, we must first establish some crucial assumptions.

Assumptions

Our model aims to calculate the average treatment on the treated (ATT). In our case, the treated are the countries and the treatments are increasing policy rates. The ATT calculates how much the exchange rate moves after an increase in interest rates compared to the control group that didn’t receive the treatment. The comparison is the basis of the difference-in-difference.
To correctly extrapolate results from our regression and identify our ATT, we must first establish some crucial assumptions.

- **1. Random Sampling**

We have selected mostly developed countries with different currencies. The exchange rates used are independent and identically distributed. We assume that no change in the exchange rate at the time t-1 will affect exchange rates at a time t, as central banks constantly readjust policy rates. Dosage and first treatment timings are exogenous to the exchange rate. In other word,

We observe $\{Y_{i1},\ldots,Y_{it},W_{it},G_i\}$ which is independent and identically distributed. (A.1)

- **2. Support**

Secondly, we assume that there is a unit that did not receive the treatment: this is our control group. It is the UK as it did not move its interest rate from 2010 to 31.08.2016. In addition, we assume that in period t-1, no units are treated. This implies that at time t, the first group receives the treatment and the control group doesn’t get any treatment, for the rest of the time period. More formally,

$The\ support\ of\ W,\ W = \{0\}\ and\ W_+.\ In\ addition,\ P(W = 0) > 0.$

$and\ dF_W(w) > 0\ for\ all\ w \in W_+,\ No\ units\ are\ treated\ in\ period\ t - 1.$ (A.2)

- **3. No anticipation/Staggered Outcome**

This assumption implies that each unit does not anticipate the treatment. In our case, it would imply that exchange rates do not take into account future policy rate changes. This holds under the efficient market hypothesis. During the run-up, until the central bank changes its rates, the information is private and cannot be reflected in the market price of exchange rates. This assumption should have been relaxed to allow for some anticipation if the data was collected at a higher frequency. Since we focus on quarterly data, assuming the absence of anticipation is perfectly realistic. The second part defines that there is no treatment in the first period and that once a unit becomes treated it stays treated for the following periods. We can write:

$$\text{For all } g \in G \ \& \ t=1,\ldots,\mathcal{T} \text{ with } t < g,\ Y_{it}(g) = Y_{it}(0). \qquad \text{(A.3.1)}$$

$$\text{For } t = 1,\ldots,\mathcal{T} \text{ if } W_{t-1} = 1 \text{ then } W_t = 1 \qquad \text{(A.3.2)}$$

- **4. Parallel Trends**

The parallel trends assumption is a pillar of every DiD regression. It assumes that all the units that received treatment would have followed the same outcome as the control group if the former had not been treated. Due to the prominent effect interest hikes have on inflation and exchange rates, we assume here that if central banks hadn't changed their rates, the currency would have followed the path it was initially following.

$$E[Y_t(0) - Y_{t-1}(0)|G = g] = E[Y_t(0) - Y_{t-1}(0)|C = 1]$$

- **5. Exogeneity**

The exogeneity assumption implies that the treatment rollout is exogenous. In our case, it implies that central banks didn't move their rates depending on the country's exchange rates. This holds as the main reason for changing rates is to curb inflation. (Rude, 2020)

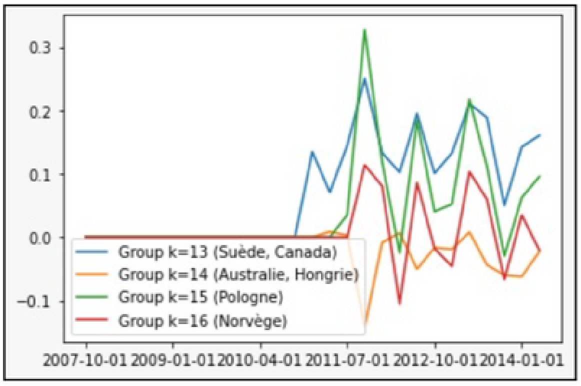
Under these assumptions, we can identify the ATT as the following:

$$ATT(g,t) = E[Y_t - Y_{g-1}|G = g] - E[Y_t - Y_{g-1}|C = 1]$$

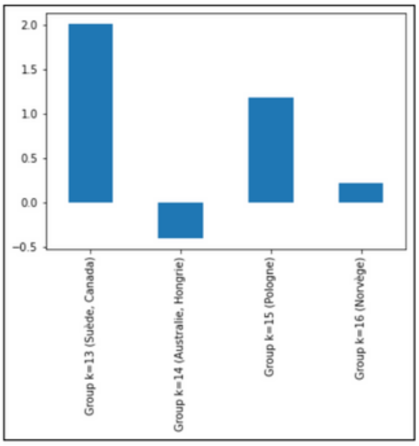
Where Ci is an indicator for all never-treated units. As the United Kingdom experiences no change in the policy rate during the chosen period, its C=1 and it will act as a control group for the model. Gi indicates the timing at which a unit i becomes treated for the first time.

Results

We use Average Treatment on the Treated (ATT) to infer results from our model. ATT gives the difference in treatment between groups that received treatment compared to the group that didn't receive treatment. Based on treatment timings, the first group of countries to be "treated", i.e. receive an increase in interest rate are Sweden and Canada. Controlling for our variables, we observe an increase in the exchange rates of these countries, compared to our control country, the United Kingdom.



Average Treatment on the Treated by group



Sum of ATTs per group

Another observation we can infer from our graphs is that countries that received treatment earlier than others observe a higher overall appreciation in their currency than countries that got treated later. However, most countries that got treated saw a short-term appreciation in their exchange rate. Most currencies saw a depreciation in the long term following the initial rate hike.

We have 2 outliers, Australia and Hungary. They have a short-term negative ATT, implying that their currency depreciated following the hikes. We cannot infer if this is due to an external cause, or if these countries have characteristics where an increase in hikes is negative for their currency. It's important to mention that both of these countries had the highest policy rates of our data: Australia and Hungary were respectively 9 and 10.5 times higher than the U.K., our control. One hypothesis is that positive policy rate hikes appreciate exchange rates as long as the policy rates were low to begin with.

Robustness

Control variable P-values

	Coef.	Std. error	t	P>|t|	[0.025	0.0975]
GDP Growth	1.5685	0.758	2.069	0.040	0.071	3.066
Balance of trade	-0.0078	0.008	-1.011	0.314	-0.023	0.007
Debt	0.1218	0.110	1.110	0.269	-0.095	0.338
Unemployment	0.0873	0.148	0.592	0.555	-0.204	0.379

We observe generally insignificant p-values for our control variables. Only GDP growth stands out at the 5% level, which implies that a country's GDP plays an important role in evaluating a country's exchange rate movements in the face of policy rate movement.

Country P-values

	Coef.	Std. error	t	P>|t|	[0.025	0.0975]
Australia	-0.2962	0.156	-1.897	0.060	-0.605	0.012
Canada	-0.3386	0.162	-2.089	0.038	-0.659	-0.018
Hungary	-0.3325	0.160	-2.080	0.039	-0.648	-0.017
Norway	-0.3271	0.158	-2.072	0.040	-0.639	-0.015
Poland	-0.2806	0.162	-1.728	0.086	-0.601	0.040
Sweden	-0.3760	0.159	-2.361	0.020	-0.691	-0.061
U.K.	-0.3290	0.157	-2.090	0.038	-0.640	-0.018

Most of our countries are statistically significant at the 5% level. This shows that our results are specific to the countries of our sample. Had we taken other countries, we might not have obtained these results.

There are a few issues in our results. Our model tells us there are probably strong-multicollinearity problems, and our R-squared (0.2) isn't high. This is due to the many limitations of our model and our data.

Limitations

The main goal was to construct a baseline model putting in relation monetary policies and exchange rates based on Brent Callaway & al,(2021). For these reasons, we did a few simplifications on the model. At first, we used a binary model to simplify our model and to give us some freedom in figuring out our results. However, changes in policy rates are continuous as they vary in intensity. We only chose to give the value 1 to countries that received a positive interest hike and kept it this way. We did it this way because of Assumption 2 which says that no treatment can be negative: you can't take a pill away from a patient, so we couldn't include rate declines in our model.

Furthermore, this paper focuses only on ATT as the main result. However, researchers often consider the Average Treatment Effect (ATE) as an important result. To be able to identify these, one would need to define stronger parallel trends that are based on the potential outcome of a unit if it would be treated instead of the potential outcome if a unit were not treated.

We also did not evaluate the average causal response on the treated (ACRT). This represents the impact of a marginal change in the dose d on already treated units. In our case, a second treatment probably affects exchange rates less than the first dose. This paper doesn't take ACRT into account because we would need a second treatment on the treated to look at the marginal effect.

Conclusion

With this paper, we attempted to establish a macroeconomic baseline case that uses the relatively new model that Callaway, Goodman Bacon and SantAnna have created. The added complexity of studying staggered timings forced us to make assumptions that might not hold in every circumstance. However, our initial goal came from seeing that the United States had been the first to raise its interest rates following the pandemic of 2020, and its exchange rate subsequently skyrocketed. Our results show that there is indeed a correlation between interest hikes and currency appreciation in the short term.

There are, though, known disadvantages to raising rates. It increases borrowing costs, lowering investments and potentially affecting employment like we're seeing in 2022 in the tech industry. Countries cannot go around raising rates as quickly as they can. Additionally, uniquely high appreciation might slow down exports.

Following our research, we think it would be interesting to expand our model to include continuous treatment and see if the same conclusions are obtained about the 2022 hikes.

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Annex

Adjusted exhange rates

Results summary

Dep. Variable:	y	R-squared:	0.199
Model:	OLS	Adj. R-squared:	0.010
Method:	Least Squares	F-statistic:	1.052
Date:	Sat, 03 Dec 2022	Prob (F-statistic):	0.402
Time:	13:17:51	Log-Likelihood:	238.17
No. Observations:	189	AIC:	-402.3
Df Residuals:	152	BIC:	-282.4
Df Model:	36		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
x1	-1.2647	0.606	-2.089	0.038	-2.461	-0.068
x2	-1.2262	0.598	-2.052	0.042	-2.407	-0.046
x3	-1.2756	0.607	-2.103	0.037	-2.474	-0.077
x4	-1.2351	0.607	-2.035	0.044	-2.434	-0.036
x5	-1.2272	0.605	-2.027	0.044	-2.423	-0.031
x6	-1.2315	0.603	-2.042	0.043	-2.423	-0.040
x7	-1.2222	0.606	-2.015	0.046	-2.420	-0.024
x8	-0.3048	0.159	-1.915	0.057	-0.619	0.010
x9	-0.3181	0.162	-1.961	0.052	-0.638	0.002
x10	-0.2856	0.160	-1.781	0.077	-0.602	0.031
x11	-0.3360	0.159	-2.108	0.037	-0.651	-0.021
x12	-0.3259	0.160	-2.034	0.044	-0.642	-0.009
x13	-0.2961	0.161	-1.843	0.067	-0.614	0.021
x14	-0.3429	0.155	-2.206	0.029	-0.650	-0.036
x15	-0.3608	0.159	-2.263	0.025	-0.676	-0.046
x16	-0.3309	0.159	-2.087	0.039	-0.644	-0.018
x17	-0.2911	0.160	-1.814	0.072	-0.608	0.026
x18	-0.3484	0.157	-2.224	0.028	-0.658	-0.039
x19	-0.3148	0.163	-1.929	0.056	-0.637	0.008
x20	-0.2874	0.160	-1.797	0.074	-0.603	0.029
x21	-0.3278	0.160	-2.046	0.042	-0.644	-0.011
x22	-0.3208	0.158	-2.025	0.045	-0.634	-0.008
x23	-0.3171	0.163	-1.950	0.053	-0.638	0.004
x24	-0.3023	0.154	-1.959	0.052	-0.607	0.003
x25	-0.3485	0.151	-2.301	0.023	-0.648	-0.049
x26	-0.3480	0.160	-2.178	0.031	-0.664	-0.032
x27	-0.2954	0.163	-1.811	0.072	-0.618	0.027
x28	-0.2962	0.156	-1.897	0.060	-0.605	0.012
x29	-0.3386	0.162	-2.089	0.038	-0.659	-0.018
x30	-0.3325	0.160	-2.080	0.039	-0.648	-0.017
x31	-0.3271	0.158	-2.072	0.040	-0.639	-0.015
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x34	-0.3290	0.157	-2.090	0.038	-0.640	-0.018
x35	1.5685	0.758	2.069	0.040	0.071	3.066
x36	-0.0078	0.008	-1.011	0.314	-0.023	0.007
x37	0.1218	0.110	1.110	0.269	-0.095	0.338
x38	0.0873	0.148	0.592	0.555	-0.204	0.379

Omnibus:	4.523	Durbin-Watson:	1.924
Prob(Omnibus):	0.104	Jarque-Bera (JB):	5.107
Skew:	0.173	Prob(JB):	0.0778
Kurtosis:	3.727	Cond. No.	2.10e+16