Investigating The Effects of Inflation and Inflation Surprise Rate Changes on US Trade Flows Changes Through Exchange Rates:

An LSTM-based Approach to Constructing Inflation Surprise Rate Estimation

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1. Introduction

After decades of low inflation in the U.S., the core inflation has surged to levels above target following the COVID-19 pandemic hit. According to the U.S. Bureau of Labor Statistics, the Consumer Price Index (CPI) rose by 5% in May 2021 compared to the previous year, marking the largest annual increase since August 2008[1]. Several factors can explain this rise. Firstly, the COVID-19 pandemic disrupted the global supply chain in a multifaceted manner. Supply-side disruptions include factory closures due to lockdowns, labor shortages, and logistical challenges, leading to reduced production and delays and this highlights vulnerability of the supply chains across the world. On the demand side, consumer behavior changed significantly, demand for goods and services is shifted from non-essential ones to essential ones. These changes on both the supply side and demand side create widespread shortages of goods and services globally, revealing vulnerabilities in supply chain resilience and management.

The Producer Price Index (PPI) for final demand increased by 6.6% from May 2020 to May 2021[2], reflecting the rising costs faced by producers. This increased cost of production has been passed on to consumers, leading to higher prices.[3] Secondly, the extensive fiscal stimulus measures implemented by the government to combat the economic impact of the pandemic, such as direct payments, enhanced unemployment benefits, and business support programs, have injected a substantial amount of money into the economy. The excess liquidity created by these measures has fueled consumer spending and aggregate demand, contributing to price pressures.[4] Furthermore, expansionary monetary policies, including near-zero interest rates and asset purchase programs pursued by the Federal Reserve, have

[1] U.S. Bureau of Labor Statistics
[2] U.S. Bureau of Labor Statistics
[3] Meier M., Pinto E. COVID-19 supply chain disruptions. *Covid Econ.* 2020;48:139–170.
[4] https://www.ecb.europa.eu/press/blog/date/2022/html/ecb.blog221125~d34babdf3e.en.html

aimed to support economic recovery but have also increased the money supply, leading to inflationary pressures. In other words, the high inflation in the United States after the COVID-19 pandemic is substantiated by data highlighting supply chain disruptions, increased production costs, expansionary fiscal policies, and accommodative monetary policies as contributing factors in this period.

After the post-COVID period, US CPI reached its highest level in the last decades, and it rose by 8.2% in September 2022 compared to the previous year.[5] The main factors that cause this hike are the demand shift from services to goods, the increase in demand for housing because of remote work, and the Russian invasion of Ukraine. Typically, when there is a change in demand between two items, we would expect prices to adjust accordingly. As the economy gradually reopened and consumer demand started returning to pre-pandemic levels for both goods and services, there was an increase in inflation for services while goods inflation was still in the process of normalizing. Consequently, this dynamic also contributed to the overall rise in inflation. Moreover, the Russian invasion of Ukraine can also explain the increase in US inflation because of the increase in energy and food prices. Although many factors affect inflation levels, inflation is also one of the important macroeconomic indicators that are the main driver of the changes in the economy, including international trade.

This paper aims to examine the effects of inflation and inflation surprise rate changes on US exports and imports with its top 10 trading partners (excluding China for the generalizability of the results by focusing on a more homogenous group of countries, allowing for a clearer understanding of the factors affecting US trade without the potential distortion introduced by China's unique situation) via exchange rate by analyzing alterations in exports and imports during two distinct regime periods. The first period termed the "target

[5] U.S. Bureau of Labor Statistics

regime period," spans from April 15, 2002, to August 15, 2012, during which the US Consumer Price Index (CPI) remains below 2%. The second period labeled the "high inflation period," encompasses the time frame from September 15, 2012, to February 15, 2023, characterized by US CPI exceeding 2%. Drawing insights from the historical context of the United States and relevant studies, this research seeks to estimate how fluctuations in inflation and inflation surprise rate influence the dynamics of trade with these key trading partners. The main methodology of this study consists of two steps. In the first step of the analysis, the performances of OLS, Vector Autoregressive (VAR), and Long Short-Term Memory (LSTM) are compared in forecasting US CPI to be used for constructing the inflation surprise rate. In the second stage, the impact of change in inflation and inflation surprise rate on change in US exports and imports is compared in these two periods with panel regression analysis. Results of the empirical analysis show that the impact of U.S. inflation varies between low and high inflationary periods, diminishing changes in U.S. exports in both instances. Additionally, the joint effect of the U.S. Real Effective Exchange Rate and the inflation rate positively impacts changes in both U.S. imports and exports. Additionally, during the low inflationary period, a negative impact of inflation on U.S. exports is observed in comparison to the high inflationary period. However, this distinction is not observed in the context of changes in U.S. imports. Shifting the focus to the analysis employing the inflation surprise rate instead of inflation, the results uphold the significance of U.S. GDP's influence on both U.S. exports and imports. Remarkably, the relationship between the change in surprise rate and changes in U.S. exports lacks statistical significance in the specified target period, while an evident and statistically significant effect on changes in U.S. imports is present. The joint impact of the inflation surprise rate and variations in the Real Effective Exchange Rate remains significant for explaining shifts in U.S. exports but loses significance when examining changes in U.S. imports.

Inflation exerts a multifaceted impact on an economy through several channels, significantly influencing trade flows by affecting exchange rates, price levels, competitiveness, investment attractiveness, and trade policies. Firstly, inflation's impact on interest rates and asset prices affects the attractiveness of a country for foreign investment. High inflation may lead to higher interest rates, deterring foreign investors from seeking stable and low-risk environments. Secondly, inflation influences the overall price level, affecting domestic and foreign demand for goods and services. High inflation may dampen consumer purchasing power, reducing domestic demand and impacting trade performance. Thirdly, inflation can affect a country's competitiveness, making its exports less attractive in the global market. Elevated inflation may lead to higher production costs, diminishing export competitiveness and hindering export-oriented industries. Fourthly, inflation can influence trade policy decisions as governments may respond to rising prices and imbalances by imposing tariffs, quotas, or other trade barriers to protect domestic industries and maintain price stability. In this study, the effects of inflation through exchange rates are investigated. Finally, inflation can influence exchange rates, leading to currency depreciation. A higher inflation rate compared to trading partners can erode a country's purchasing power, resulting in a weaker exchange rate. This depreciation may improve export competitiveness, but it could also lead to higher import costs, potentially worsening a trade deficit. As a result, international comparative advantage patterns and trade flow patterns are changed and the exchange rate initially depreciates, resulting in a trade surplus and capital outflow. However, after some time, the exchange rate depreciates again, and there is a trade deficit.

During the period of the global financial crisis, the United States witnessed a confluence of intricate economic dynamics that engendered a reduction in both exports and imports, despite the concurrent increase in the U.S. Real Effective Exchange Rate (REER). This seemingly paradoxical situation can be comprehended through a multifaceted analysis of various pertinent factors. Firstly, the global economic downturn precipitated by the financial crisis led to a clear diminution in global economic activity, revealing as a contraction in demand for goods and services across international markets. Consequently, US exports encountered a substantive decline due to diminished foreign demand. Secondly, the credit crunch that ensued during this period showed constrained access to trade finance, causing obstacles for businesses to participate in international trade endeavors and thus cutting down both import and export operations. Thirdly, the global supply chains underpinning international trade were broken by the crisis, resulting in disruptions in the availability of essential raw materials and components. This problem in the supply chain translated into supply shortages and production slowdowns, thereby exerting detrimental influences on both exports and imports. Furthermore, the broader reduction in consumer and business expenditures, both within the United States and internationally, contributed to waned demand for imports and concurrently dampened export prospects. Notably, the appreciation of the U.S. REER, indicative of the relative strength of the U.S. dollar, was reflective of complicated dynamics within the global currency markets, including safe-haven capital flows amidst the crisis-induced uncertainty. While the REER appreciation might apparently imply that U.S. goods became costlier in foreign markets, this factor was merely one facet within a broader array of determinants behind the diminished export and import volumes.

2. Conceptual Framework

After decades of low inflation in the U.S., the core inflation has reached to levels above target following the COVID-19 pandemic hit. The U.S. Bureau of Labor Statistics reported that the Consumer Price Index (CPI) rose by 5% in May 2021 compared to the previous year, marking the largest annual increase since August 2008[6]. This increase can be explained by several factors. Firstly, disruptions in the global supply chain due to the pandemic have resulted in various goods and services shortages through a complex interplay of both supply-side and demand-side mechanisms. On the supply side, widespread lockdowns and mobility restrictions forced the closure of factories and manufacturing facilities, leading to reduced production capacity and limited availability of goods. Labor shortages due to infected workers or quarantine measures further exacerbated the production slowdown. Transportation and logistics challenges, including border restrictions and reduced shipping capacity, hindered the smooth flow of goods, causing delays in sourcing raw materials and delivering finished products. Moreover, the complexity of modern supply chains, with multiple interconnected links, made them susceptible to disruptions at various stages. On the demand side, the pandemic induced significant shifts in consumer behavior. Increased demand for essential goods, such as personal protective equipment and medical supplies, coupled with panic buying and stockpiling, overwhelmed supply chains, leading to temporary shortages. Conversely, reduced demand for non-essential items due to economic uncertainties and changing priorities further impacted supply and demand imbalances. The combination of supply-side disruptions and demand-side shifts resulted in a widespread and multifaceted crisis, causing shortages of various goods and services in markets across the globe.

[6] U.S. Bureau of Labor Statistics

The Producer Price Index (PPI) for final demand increased by 6.6% from May 2020 to May 2021[7], reflecting the rising costs faced by producers. This increased cost of production has been passed on to consumers, leading to higher prices.[8] Secondly, the extensive fiscal stimulus measures implemented by the government to combat the economic impact of the pandemic, such as direct payments, enhanced unemployment benefits, and business support programs, have injected a substantial amount of money into the economy. The excess liquidity created by these measures has fueled consumer spending and aggregate demand, contributing to price pressures.[9] Furthermore, expansionary monetary policies, including near-zero interest rates and asset purchase programs pursued by the Federal Reserve, have aimed to support economic recovery but have also increased the money supply, leading to inflationary pressures. In other words, the high inflation in the United States after the COVID-19 pandemic is substantiated by data highlighting supply chain disruptions, increased production costs, expansionary fiscal policies, and accommodative monetary policies as contributing factors in this period.

After the post-COVID period, US CPI reached its highest level in the last decades, and it increased by 8.2% in September 2022 compared to the previous year.[10] The main factors that cause this hike are the demand shift from services to goods, the rise in demand for housing because of remote work, and the Russian invasion of Ukraine. Typically, when there is a change in demand between two items, we would expect prices to adjust accordingly. For example, if the demand for services decreases while the demand for goods increases, we might anticipate a decrease in service prices and an increase in goods prices. However, in this case, the price of services did not decrease despite a significant increase in the price of goods.

[7] U.S. Bureau of Labor Statistics
[8] Meier M., Pinto E. COVID-19 supply chain disruptions. *Covid Econ.* 2020;48:139–170.
[9] https://www.ecb.europa.eu/press/blog/date/2022/html/ecb.blog221125~d34babdf3e.en.html
[10] U.S. Bureau of Labor Statistics

Economists discuss the reasons behind these inflexible prices within specific sectors, considering changes in demand. Nevertheless, data shows that the prices of certain services did not decline even as demand for them decreased. This situation mechanically contributed to higher inflation. As the economy gradually reopened and consumer demand started returning to pre-pandemic levels for both goods and services, there was an increase in inflation for services while goods inflation was still in the process of normalizing. Consequently, this dynamic also contributed to the overall rise in inflation. An increase in housing demand is another key contributor to high inflation in the US. With the COVID period, shifting to remote work increased the demand in the housing market because of shifting preferences toward places with more spaces, rooms or having gardens, etc. Accelerating housing costs contributed to high CPI levels in the US. Moreover, the Russian invasion of Ukraine can also explain the increase in US inflation because of the increase in energy and food prices. Although there are many factors that affect inflation levels, inflation is also one of the important macroeconomic indicators that are the main driver of the changes in the economy, including international trade.

3. Related Literature

Inflation is one of the most significant economic challenges faced by countries around the world. It affects various aspects of the economy, including international trade. Inflation has an impact on trade networks through several channels i.e., exchange rate channel, price level channel, competitiveness, investment attractiveness, and trade policies. There are many studies investigating the relationship between inflation and international trade. Firstly, inflation can cause a country's currency to depreciate, which can make its exports more competitive on the global market but can also increase the cost of imports. Alan C. Stockman is one the earliest researchers who (1981)[11] analyze the correlation between inflation, exchange rates, international trade, and payments within an economy. He argues that anticipated inflation has a significant impact on the real world by acting as a tax on money and consequently affecting monetary transactions. According to the results, when there is an increase in monetary expansion, the value of domestic output tends to decrease, and there is a change in the composition of domestic production. This change leads to alterations in the pattern of international comparative advantage and trade flows. When there is an increase in monetary expansion, the exchange rate initially depreciates, resulting in a trade surplus and capital outflow. However, after some time, the exchange rate depreciates again, and there is a trade deficit.

Secondly, inflation can increase the prices of goods and services in a country, which can make its exports less competitive and reduce demand for imports. The inflation-based increase in production costs, spanning labor, raw materials, and operational inputs elevates

[11] Stockman, Alan C. "Effects of Inflation on the Pattern of International Trade." The Canadian Journal of Economics / Revue Canadienne d'Economique, vol. 18, no. 3, 1985, pp. 587–601. JSTOR, https://doi.org/10.2307/135021.

the domestically produced goods and services prices. It erodes the cost competitiveness of a country's exports on the global market, rendering them comparatively more expensive than offerings from other countries that have lower inflation rates. Consequently, the diminished competitiveness of exports reduces demand from other markets, leading to contraction in export-oriented industries. This mechanism is examined in several studies in which empirical analyses are provided. In 2013, Islam examines the relationship between inflation and import in Prime Bank Limited, Khulna Branch from 1980 to 2010. He shows that inflation is an excessive and sustained increase in prices that affects the overall average price of all goods, not just one item and there is a very insignificant correlation between inflation and imports. Additionally, the paper suggests that inflation is not the only factor that affects import trade; other factors such as demand, exchange rate, population, natural disasters, government policies, and the inflation rate of exporting countries also play a role. Additionally, inflation can affect investment decisions by foreign investors, who may be hesitant to invest in a country experiencing high inflation, reducing its attractiveness as a trading partner because of higher uncertainty and expectation of lower return on investment. This can lead to a reduction in export production and ultimately negative impact on a country`s export potential.

The effect of inflation on international trade is not limited only to shifts in export competitiveness and import demand, its effects can be seen through investment channels. For example, A. Thirlwall and C. Barton (1971) investigate the relationship between inflation and two important determinants of growth: the investment ratio and the balance of payments situation. They find that countries with mild inflation of prices of between 3 and 10 percent per annum invest a higher proportion of their gross national product than countries with price stability. R. Barro also shows that an increase in average inflation by 10 percentage points per year causes a reduction of the growth rate of real per capita GDP by 0.2-0.3 percentage points per year and a decrease in the ratio of investment to GDP by 0.4-0.6 percentage points.

Moreover, Sushanta Mallick and Mohammed Mohsin's (2010) findings support previous results by showing that inflation negatively affects consumption and investment and has a positive influence on the current account.

Governments may respond to inflation by implementing protectionist trade policies, such as import tariffs or quotas, to limit the inflow of cheaper foreign goods, or by subsidizing domestic industries to increase competitiveness. One of the earliest studies on this issue is done by Krueger in 1980. Krueger examines the relationship between macroeconomic objectives of controlling inflation and trade-regime objectives in stabilization programs of developing countries.[12] She shows that trade regime objectives are linked with inflation-reducing objectives, often to the detriment of resource allocation and growth. Afterward, Goldstein and Khan(1985)[13] also evaluate the main methodological and policy issues that have surrounded the estimation of trade equations based on the time-series behavior of the quantities and prices of merchandise imports and exports to investigate the relation between inflation and trade policies. Later studies do not only provide theoretical analysis for them, but also they give evidence for it. K. Wong and T. Chong[14] offer empirical evidence to shed light on the trade creation effect of the inflation targeting regime. They find that an inflation-targeting regime has a trade creation effect on bilateral trade, but the effect is much more moderate than that under exchange-rate targeting. Unlike a direct peg, however, the moderate effect of inflation targeting exists in the bilateral trade between an inflation targeter and all of its trading partners. This moderate effect is therefore much larger at the multilateral level,

[12] Anne O. Krueger, 1980. "Interactions Between Inflation and Trade-Regime Objectives in Stabilization Programs," NBER Working Papers 0475, National Bureau of Economic Research, Inc.

[13] Goldstein, Morris & Khan, Mohsin S., 1985. "Income and price effects in foreign trade," Handbook of International Economics, in: R. W. Jones & P. B. Kenen (ed.), Handbook of International Economics, edition 1, volume 2, chapter 20, pages 1041-1105, Elsevier.

[14] Wong, Kin-Ming & Chong, Terence Tai-Leung, 2016. "Does monetary policy matter for trade?," International Economics, Elsevier, vol. 147(C), pages 107-125.

suggesting the inflation-targeting regime may not have a lower level of total trade than the exchange-rate targeting regime.

The exchange rate is an important channel through which inflation impacts trade. Inflation can cause a country's currency to depreciate, which can make its exports more competitive on the global market but can also increase the cost of imports. Early studies investigate the relationship between inflation and exchange rate and the impacts of price levels on international trade through exchange rates by using theoretical analysis and they highlight that the exchange rate adjustments may not fully offset the inflationary impact on trade since other parameters play a role in determining the effects of inflation on trade patterns such as the composition of the country´s exports and imports.

Alan C. Stockman (1981)[15] analyzes the correlation between inflation, exchange rates, and international trade and payments within a small economy by integrating a transactions-based model of money with a real trade model. He argues that anticipated inflation has a significant impact on the real world by acting as a tax on money and consequently affecting monetary transactions. When there is an increase in monetary expansion, the value of domestic output tends to decrease, and there is a change in the composition of domestic production. This change leads to alterations in the pattern of international comparative advantage and trade flows. When there is an increase in monetary expansion, the exchange rate initially depreciates, resulting in a trade surplus and capital outflow. However, after some time, the exchange rate depreciates again, and a trade deficit occurs. He also highlights those real changes in comparative advantage may not be seen in trade patterns changes because of

[15] Stockman, Alan C,1981. "Effects of Inflation on the Pattern of International Trade." The Canadian Journal of Economics / Revue Canadienne d'Economique, vol. 18, no. 3, 1985, pp. 587–601. JSTOR, https://doi.org/10.2307/135021.

changes in inflation. Another early study is developed by Krueger (1980)[16] that explores the trade-offs between inflation and trade objectives in stabilization programs by highlighting the effect of inflation on trade policies through exchange rates. The paper argues that while stabilizing inflation is important, trade objectives such as promoting exports and reducing import dependency should also be considered. She suggests that in countries with fixed exchange rates, inflation can lead to a loss of competitiveness because goods in the home country become more expensive relative to foreign countries. This leads to a decrease in exports since its trading partners can buy these goods at cheaper prices from other countries with lower inflation. Similarly, in the case of high inflation, goods in the home country are relatively expensive compared to imported goods. As a result, the incentive to buy imported goods at cheaper prices increases leading to a trade deficit. On the other hand, countries with floating exchange rates may experience a depreciation of their currency because of inflation, which can improve their trade balance. An economy with higher inflation compared to its trading partners makes its goods relatively more expensive leading to increasing prices of its exports and less competitive in the global market. Meanwhile, the prices of imported goods from trading partners with lower inflation stay relatively stable or appreciate slower. It decreases exports and increases imports, resulting in a trade deficit. It might be a depreciation in the exchange rate makes a country's exports cheaper and more attractive to foreign buyers, while also making imports relatively more expensive. This exchange rate adjustment helps improve the country's trade balance by boosting exports and reducing imports. Moreover, if a country faces inflationary pressure, it might result in decreasing demand for its currency. It´s because the currency is perceived as less valuable due to reduced purchasing power by higher inflation. In the economy, there might be an incentive to sell the currency leading its value to

[16] Anne O. Krueger, 1980. "Interactions Between Inflation and Trade-Regime Objectives in Stabilization Programs," NBER Working Papers 0475, National Bureau of Economic Research, Inc.

depreciate relative to other currencies of trading partners. Hence, a depreciation in the exchange rate because of inflation makes export goods relatively cheaper while making import goods relatively more expensive. Consequently, it enhances the trade balance. Kruger emphasizes the importance of considering the effects of inflation on the exchange rate when designing stabilization programs, particularly in countries with fixed exchange rates. In contrast with the previous studies, J. P. Houck (1979)[17] argues that the inflation rate for one country is impacted by another country´s inflation level and currency exchange rate and there are no systematic international trade changes to flow from differential rates since markets neutralize the effect by using Purchasing Power Parity principle. However, he also suggests that in the case of a time lag in adjusting in response to differential inflation levels, exports drop while imports increase in a more rapid inflationary economy. The reason behind this is that its currency value doesn't decrease fast enough to keep goods prices relative at the same level.

The following studies provide empirical evidence for these theoretical hypotheses. Cihan Bilginsoy (1993)[18] finds that high inflation in Turkey had a negative impact on the country's exports and the value of the Turkish lira against foreign currencies. The depreciation of the lira increased the cost of imported inputs, which in turn increased the cost of production, making Turkish exports less competitive in foreign markets. Additionally, Jeannine Bailliu and Eiji Fujii (2014)[19] estimate the exchange rate pass-through impact on import price and international trade in different inflation environments by using panel data for ten industrialized countries from 1990 to 2002 and they find that exchange rate pass-through is

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[17] J.P. Houck(1079), "Inflation and International Trade", AgEcon Search

[18] Bilginsoy, Cihan, 1993. "Inflation, growth, and import bottlenecks in the Turkish manufacturing industry," Journal of Development Economics, Elsevier, vol. 42(1), pages 111-131, October.

[19] Jeannine Bailliu & Eiji Fujii, 2004. "Exchange Rate Pass-Through and the Inflation Environment in Industrialized Countries: An Empirical Investigation," Staff Working Papers 04-21, Bank of Canada.

lower in an environment of low inflation. The study suggests that low inflation can stabilize international relative prices and reduce exchange rate pass-through to domestic prices. Hence, it enhances the trade balance.

Naser Elahi, Farshid Salimi, and Elahe Masoomzadeh (2016)[20] also examine the relationship between monetary shocks on the real exchange rate and the trade balance in some industrial and developing countries. Their findings show that the existence of a liquidity shock and inflation increases the real exchange rate in these countries and increasing exchange rate (devaluation of national currency) improves the country's competitiveness in foreign markets and develops the country's exports and so has a positive effect on the trade balance. However, Yuko Imura and Malik Shukayev (2019)[21] show that currency depreciation and inflationary effects of the policy stimulus have a negative impact on the competitiveness of exporters and lead to a contraction in firms' export participation. Juin-Jen Chang, Wen-ya Chang, Hsueh-fang Tsal, and Ping Wang (2018)[22] distinguish the long-run and short-run effects of inflation-targeting policies on international trade patterns through exchange rates and investigate them separately. Their study is based on the dynamic H-O (The Heckscher-Ohlin) theory of comparative advantage, inflation targeting, and open-economy monetary theory. Their findings suggest that a temporary increase in the domestic inflation target might play a crucial role in generating permanent effects by changing the

[20] Naser Elahi, Farshid Salimi, Elahe Masoomzadeh ,2016."Investigating Asymmetric Effects of Monetary Shocks on the Exchange Rate and Trade Balance, with an Emphasis on Inflation Targeting", Procedia Economics and Finance 36 (2016) 165 – 176

[21] Imura, Yuko & Shukayev, Malik, 2019. "The extensive margin of trade and monetary policy," Journal of Economic Dynamics and Control, Elsevier, vol. 100(C), pages 417-441.
[22] Chang, Juin-jen & Chang, Wen-ya & Tsai, Hsueh-fang & Wang, Ping, 2019. "Inflation Targeting, Pattern Of Trade, And Economic Dynamics," Macroeconomic Dynamics, Cambridge University Press, vol. 23(7), pages 2748-2786, October.

trade patterns because of increasing incentives to export capital-intensive goods to the home country.

Recent studies also support previous studies` findings on the relationship between inflation and international trade for different countries. For example, Jalil Mehtiyev, R. Magda, and L. Vasa (2021)[23] examine the correlation between inflation and devaluation and their impact on trade balance via the case study about the devaluation of the currency of Azerbaijan. According to their results, the study provides evidence for a correlation between inflation and exchange rate and shows that exchange rate volatility has a significant impact on the trade balance in terms of imports and exports. Additionally, they argue that inflation should be considered to have exchange rate volatility in balance since high inflation causes devaluation in the long run and has a negative impact on the trade balance. Naptania Ilmas, Mia Amelia, and Rafli Risandi (2022) [24] provide evidence that these findings hold for Asian countries too and inflation reduces the competitiveness of export goods through the exchange rate in these economies.

[23] Mehtiyev, J., Magda, R., & Vasa, L. ,2021. "Exchange rate impacts on international trade", Economic Annals-XXI, 190(5-6(2)), 12-22. doi: https://doi.org/10.21003/ea.V190-02
[24] Ilmas ,Naptania & Amelia ,Mia & Risandi, Rafli,2022." Analysis Of The Effect Of Inflation And Exchange Rate On Exports In 5-Year Asean Countries (Years 2010–2020)", Jurnal Ekonomi Trisakti ,Vol. 2 No.1 April 2022 hal: 121-132

4. Data

4.1 Data for Inflation Surprise Rate Construction

In the first step of the analysis, OLS, Vector Autoregressive (VAR), and Long Short-Term Memory (LSTM) models are compared in terms of their prediction power in US CPI forecasting. The forecasted values obtained by the best-performing model are used for inflation surprise rate construction which is the difference between the actual inflation values and the forecasted inflation values to be used in the next step. For this analysis, a new dataset at monthly frequency is conducted by collecting variables from different data sources. It consists of US Core Consumer Price Index (Core CPI) data from the Bureau of Labor Statistics, US output gap data from Oxford Economics, World CPI and NEER from IMF, oil prices from Refinitiv, US Michigan 5y inflation expectations from the University of Michigan Surveys of Consumer from 01/1982 to 03/2023.

The Core CPI is a variant of the Consumer Price Index used as an economic indicator to assess the rate of inflation within an economy. Employed primarily for analytical and policy purposes, Core CPI serves the specific function of mitigating the impact of short-term price fluctuations arising from volatility in the components. In general, food and energy prices are excluded. The rationale for this exclusion lies in the recognition that food and energy prices might be subject to sudden fluctuations due to factors such as supply disruption, geopolitical events, and shocks in the energy markets, which can obscure the underlying trend in inflation. When these more volatile components are omitted, a more stable and consistent measure of the ongoing inflationary pressure is obtained, facilitating a more precise analysis.

The output gap is also an economic indicator that measures the difference between the actual level of economic output and the potential economic activity in an economy. If the actual output exceeds the potential output that means a positive output gap, which indicates that the economy is running at or above its capacity. It might cause an increase in demand for goods and services, which generally translates into higher prices and inflationary pressures. However, there is a negative output gap, which suggests that the economy is below its capacity which reduces inflationary pressures.

Nominal Effective Exchange Rate (NEER) is a macroeconomic indicator that is used to measure the value of the U.S. dollar (USD) relative to a basket of foreign currency.[25] The US NEER takes into account the exchange rates of the U.S. dollar against multiple trading partners, weighted by the importance of each trading partner to the U.S. It's designed to capture the overall changes in the value of the U.S. dollar relative to these currencies and gives insights regarding the competitiveness of U.S. goods and services in international markets, impacts on trade balances, and effects on inflation.

US Michigan 5-year Inflation Expectations are the survey results conducted by the University of Michigan in which consumer sentiment is assessed and questions on inflation expectations for the average annual inflation rate in the US over the next five years are included. In other words, it seeks to investigate what consumers anticipate as the rate of price increases over the medium term.

Oil prices are another important variable that has an impact on US inflation due to the energy cost in the economy. They refer to the Brent crude oil prices in USD per barrel prices. When oil prices experience an upward trend, it leads to increased expenses in some specific fields such as transportation, energy generation, and fuel consumption. These increased energy costs affect both businesses and consumers. Consequently, it leads to inflationary

[25] https://data.imf.org/?sk=4c514d48-b6ba-49ed-8ab9-52b0c1a0179b

pressures through the escalation of production costs for goods and services. Moreover, this contributes to an increase in the overall price levels in the economy.

4.2.Data for Panel Regression Analysis for US exports and imports

Data for the main analysis relies on different data sources for the variables. US exports and import data of all 2-digit HS commodities for the US top 10 trading partners are collected from the UN Comtrade Database from 04/2002 to 03/2023 in monthly frequency. These two variables are the main outcome variables of the analysis. The explanatory variables i.e., US GDP data from BEA - Bureau of Economic Analysis, US CPI from Bureau of Labor Statistics, US real effective exchange rate data from OECD Economic Outlook, and oil prices data from Refinitiv are collected from 04/2002 to 03/2023 and merged with the US country level trade data to build the panel dataset. Inflation surprise data is calculated as the difference between actual inflation data and forecasted values obtained by the LSTM model developed in the first stage.

4.2.1 Summary of the Data

US data shows that imports and exports experienced a decline due to an economic slowdown that ensued after the worldwide financial crisis in 2008. US and global demand for imports significantly declined. While the US has a shrinking deficit, US GDP also declined. Due to the COVID-19 pandemic hit, a similar pattern has been seen in 2019-2020. The observation that US GDP, exports, and imports moved together throughout history in Figure 1 indicates a strong interdependence between these variables. In essence, the decline in imports and exports following both the global financial crisis of 2008 and the COVID-19 pandemic can be attributed to a combination of reduced economic activity, decreased consumer and business spending, and a shrinking global demand for goods and services. However, Figure 2 shows that after decades of low inflation in the U.S., the core inflation has surged to levels above target following the COVID-19 pandemic hit. According to the U.S. Bureau of Labor Statistics, the Consumer Price Index (CPI) rose by 5% in May 2021 compared to the previous year, marking the largest annual increase since August 2008 (Figure 2).[26]

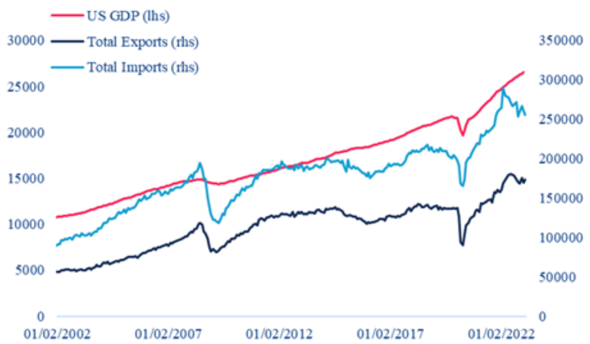

Figure 1
Notes: US exports and import data of all 2-digit HS commodities for the US top 10 trading partners are collected from the UN Comtrade Database and US GDP data from BEA - Bureau of Economic Analysis is collected from 04/2002 to 03/2023 in monthly frequency.

Figure 2
Notes: US Core Consumer Price Index (Core CPI) data from the Bureau of Labor Statistics, US exports and import data of all 2-digit HS commodities for the US top 10 trading partners are collected from the UN Comtrade Database from 04/2002 to 03/2023 in monthly frequency.

Real Effective Exchange rate fluctuations play a crucial role in the relationship between US imports, exports, and CPI (Figure 3). During the COVID-19 pandemic, global supply chain disruptions, along with altered consumer spending patterns due to lockdowns,

[26] Meier M., Pinto E. COVID-19 supply chain disruptions. *Covid Econ.* 2020;48:139–170.

resulted in shortages and trade imbalances. Lockdowns, restrictions, and changes in spending patterns collectively contributed to a contraction in the production and distribution of goods and services, thereby leading to shortages in key sectors. Such supply-demand imbalances were instrumental in curtailing trade activities, leading to diminished import and export volumes. Government stimulus measures impacted demand dynamics, causing shifts in trade flows. Movement restrictions reduced economic activities, affecting consumer spending and business investments, which further impacted US trade. The US REER, influenced by central bank actions and capital flows, played a role in trade competitiveness but was overshadowed by the pandemic's broader disruptions during the pandemic. (Figure 3). [27]

Figure 4 shows that the relationship between U.S. exports, imports, and oil prices is a fundamental aspect of international trade dynamics, underscored by the significant role that energy products, particularly crude oil, and refined petroleum products, play in global commerce. Fluctuations in oil prices exert an influence on various facets of U.S. trade. Notably, as a major importer of crude oil and petroleum products, changes in global oil prices reverberate through the U.S. economy, directly impacting the cost of imported energy resources. This, in turn, bears implications for the trade balance, as heightened oil prices correspondingly amplify import expenditures. Moreover, the US's position as a notable exporter of refined petroleum products engenders a link between oil prices and export profitability. When oil prices decline, the cost of producing refined products diminishes, potentially enhancing the attractiveness of U.S. exports in international markets. During the financial crisis period in 2008, the increase in oil prices, which reached unprecedented heights during the first half of the year, significantly impacted the U.S. trade landscape. High oil prices contributed to increased import costs for crude oil and petroleum products, thereby

[27] Hayakawa K, Mukunoki H. The impact of COVID-19 on international trade: Evidence from the first shock. J Jpn Int Econ. 2021 Jun;60:101135. doi: 10.1016/j.jjie.2021.101135. Epub 2021 Mar 4. PMID: 36567795; PMCID: PMC9759680.

amplifying the U.S. trade deficit. Furthermore, the increased energy expenses exerted pressure on various energy-intensive industries, impacting their production costs and competitiveness. This phenomenon, coupled with the broader economic downturn arising from the financial crisis, led to reduced consumer spending and overall demand, influencing import patterns. Conversely, the export of petroleum products experienced mixed effects; while higher oil prices increased the value of these exports, the overall global economic slowdown tempered demand. The intricate interplay of these dynamics underscores how oil prices during 2008 played a pivotal role in shaping U.S. trade patterns, while simultaneously reflecting the broader economic challenges of the time.[28]

Figure 3
Notes: US exports and import data of all 2-digit HS commodities for the US top 10 trading partners are collected from the UN Comtrade Database and US REER are collected from OECD from 04/2002 to 03/2023 in monthly frequency.

Figure 4
Notes: Oil prices data from Refinitiv, US exports and import data of all 2-digit from the UN Comtrade Database from 04/2002 to 03/2023 in monthly frequency.

[28] Table 8.1 in the Appendix

5. Methodology

The main methodology of this study consists of two steps. In the first step of the analysis, the performances of OLS, Vector Autoregressive (VAR), and Long Short-Term Memory (LSTM) are compared in forecasting US CPI to be used for constructing the inflation surprise rate. In the second stage, the estimation strategy relies on panel regressions to compare differences in change in US exports and imports for two periods i.e. low inflation period (below 2) and high inflation period (above 2).

5.1. Inflation Surprise Rate Construction

The inflation surprise rate is calculated by the difference between actual inflation rate values and forecasted inflation values. Firstly, Ordinary Least Square regression (OLS), Vector Autoregressive (VAR), and Long Short-Term Memory (LSTM) are developed for the US inflation forecast for 12 months (starting from the period of 04/2022-03/2023 and then forecasting previous 12 months and so forth until 01/1982) by using the same monthly dataset consisting of data for US CPI, output gap, oil prices, NEER, US Michigan 5y inflation expectations, and world CPI from 01/1982 to 03/2023.

As mentioned above, the US Core CPI, a special version of the Consumer Price Index, is a vital economic indicator used to evaluate inflation rates excluding short-term price shocks, particularly those stemming from volatility in food and energy prices within the economy. It is a useful and consistent measurement tool to capture inflation trends. Additionally, The U.S. output gap is calculated as the difference between the U.S. potential economic activity and the U.S. actual economic output, and the U.S. nominal Effective Exchange Rate (NEER) is calculated as the relative value of the U.S. dollar against a basket of foreign currencies, weighted by the significance of each trading partner to the United States by IMF. Moreover, the U.S. Michigan 5-year Inflation Expectations survey data, conducted by the University of Michigan, investigates consumer sentiment regarding inflation expectations over the next five years. Oil prices are determined by demand and global supply and they show the Brent crude oil prices in USD per barrel prices. By using these macroeconomic indicators that are determinant components for the overall price levels, US inflation values are predicted using three methodologies mentioned previously.

At the end of this analysis, their performances are compared according to their mean square errors to select the best forecasting model for constructing the inflation surprise rate. The model that has minimum MSE is chosen, and the inflation surprise rate is calculated as the difference between actual inflation rates and its forecasted values by the model. The inflation surprise rate is used as an explanatory variable in the second stage of the analysis. The models are conducted as follows:

- *Ordinary Least Square regression (OLS)*

Firstly, the regression model below is estimated:

$Inflation_t = \alpha + ß\ OutputGap_t + \Theta\ OilPrices_t + \mu\ NEER_t + \varphi\ WorldCPI_t + \sigma\ US\ Michigan_t + \varepsilon$, where $\alpha,\Theta,\mu,\varphi$ and σ are unknown coefficients, t is time i.e. $t \in (01/1982, 03/2022)$ and ε is error term.

This Ordinary Least Square(OLS) regression, is employed to investigate the factors influencing inflation dynamics over the specified period. In this model, $Inflation_t$ is the dependent variable, denoting the inflation rate at a given time "t", which I aim to explain and predict. The equation incorporates several independent variables, including "$OutputGap_t$", reflecting the US Output Gap calculated as the difference between actual and potential economic output; "$OilPrices_t$ ", referring to oil prices; "$NEER_t$ ", representing the Nominal Effective Exchange Rate; "$WorldCPI_t$ ", reflecting the World Consumer Price Index and US

$Michigan_t$, denoting the U.S Michigan 5-year Inflation Expectations survey data conducted by the University of Michigan. The coefficients (α, ß, Θ, μ, φ, and σ) accompanying these variables are estimated to reveal the magnitude and direction of their influence on inflation. Additionally, the error term (ε) contains unexplained variation in inflation not accounted for by the model's variables. This comprehensive analysis seeks to elucidate how changes in output gaps, oil prices, exchange rates, global inflation trends, and consumer expectations collectively impact inflation trends from January 1982 to March 2022. By using the coefficients in the regression result (Table 8.2)[29] , forecasted values of US CPI from 04/2022 to 03/2023 are calculated as the following:

$Inflation_t = -8.7 + 0.1 * OutputGap_t + 0.01 * OilPrices_t + 0.05 * NEER_t + 0.1 * WorldCPI_t + 2.2 * US\ Michigan_t$, where t ∈ (04/2022, 03/2023). The same process is followed to forecast previous periods until 04/2002.

- *Vector Autoregressive Model (VAR(11))*

Vector Autoregressive (VAR) model is a multivariate time series modeling approach involving n-equations. In this model, each variable is explained by its own lagged values, as well as the current and past values of the other variables in the system.[30] This is a useful model because my analysis is based on multivariate time series forecasting and the variables are more likely to be affected by their previous values. For example, oil prices are not only determined by current supply and demand conditions but are significantly affected by their historical trajectories. Market psychology and behavioral factors are crucial, since people extrapolate from past price trends when making decisions, thereby contributing to self-fulfilling prophecies. Additionally, production and supply-side responses are affected by past

[29] Table 8.2 in Appendix
[30] James H. Stock & Mark W. Watson, 2001. "Vector Autoregressions," Journal of Economic Perspectives, American Economic Association, vol. 15(4), pages 101-115, Fall.

price changes, with producers adjusting output levels to maximize their revenues or stabilize the prices.

Before building a VAR model, it´s important to be sure that its assumptions are satisfied: (i) the variables are stationary. (ii) The conditional mean of the error term is zero. (iii) Large outliers are unlikely (iv) No perfect multicollinearity(Table 8.3)[31]. According to Augmented Dickey-Fuller test results for stationarity, all variables are stationary. (Table 8.4 and Table 8.5)[32] For the second assumption, the Jarque Bera unit root test is used. (Table 5.7)[33] Results show that the null hypothesis stating that the data is normally distributed cannot be rejected at 0.01 level with a p-value of 0.04369. The third and fourth assumptions are satisfied too when the data is checked. Hence, the VAR model can be used for US inflation forecasting. Lag selection is decided according to the Akaike Information Criterion (AIC) (Table 5.5)[34] and the VAR (11) model is constructed as follows:

$$\begin{aligned} \text{Inflation}_t = {} & ß_{10} + \alpha_{11}\,\text{Inflation}_{(t-1)} + \alpha_{12}\,\text{Inflation}_{(t-2)} + \ldots + \alpha_{1\,11}\,\text{Inflation}_{(t-11)} \\ & + ß_{11} X_{1(t-1)} + ß_{12} X_{1(t-2)} + ß_{13} X_{1(t-3)} + \ldots + ß_{1\,11} X_{1(t-11)} \\ & + \ldots + \\ & + ß_{k1} X_{k(t-1)} + ß_{k2} X_{k(t-2)} + ß_{k3} X_{k(t-3)} + \ldots + ß_{k\,11} X_{k(t-11)} + \varepsilon_t, \qquad (1) \end{aligned}$$

where $ß_{10}$, α_{11}, $\alpha_{12}, \ldots, \alpha_{1\,11}$, $ß_{11}, ß_{12}, \ldots, ß_{1\,11}, \ldots, ß_{k1}, ß_{k2}, \ldots, ß_{k\,11}$ are unknown coefficients, Xis are explanatory variables(Output Gap, Oil Prices, NEER, World CPI, and US Michigan) i.e. i $\in(1,k)$ where k is the number of explanatory variables, t is the date of observation i.e. t

[31] Table 8.3 in Appendix
[32] Table 8.4 and Table 8.5 in Appendix
[33] Table 5.7 in Appendix
[34] Table 5.5 in Appendix

$\in$(04/2022, 03/2023) and ε_t is the error term. The same process is followed to forecast previous periods until 04/2002.

The mechanism in this model is used to analyze the relationships and dynamics between variables over time, with a focus on predicting inflation. In the model, inflation at the time "t" $Inflation_t$ is the dependent variable, and it's regressed on its own lagged values (inflation at time "t-1","t-2","t-3" up to "t-11") using coefficients ($\alpha_{1\ 11}$, ß$_{11}$, ß$_{12}$, ..., ß$_{1\ 11}$) to capture the effect of past inflation on current inflation. Additionally, the model includes other explanatory variables (X_1, X_2, X_3,.., X_k) consisting of Output Gap, Oil Prices, US Nominal Effective Exchange Rate (NEER), World Consumer Price Index, and US Michigan 5-year Inflation Expectations as in the previous model. These independent variables are also lagged from "t-1" to "t-11" to account for their historical influences on inflation. Coefficients of ß$_{11}$, ß$_{12}$, ..., ß$_{1\ 11}$,..., ß$_{k1}$, ß$_{k2}$,..., ß$_{k\ 11}$ capture these impacts in the model. Error term (ε_t) covers unexplained variations in inflation that are not captured by the explanatory variables and their lagged values and also lagged values of inflation. It represents the random and unobservable factors that affect inflation. This VAR(11) model specifically captures the dynamic relationships between inflation and the explanatory variables, allowing for the analysis of how past values of these variables affect the current inflation level. The coefficients in the equation give insights into the direction and magnitude of these relationships. The model is used for forecasting inflation by plugging in the values of the explanatory variables for other periods. Similar to analysis with OLS regression, the same process is applied to obtain forecasted inflation values for previous periods until 04/2002.

- *Long Short-Term Memory (LSTM) Networks*

LSTM Networks model is a special type of recurrent neural networks model that allows for capturing long-term dependencies. LSTM networks are different from basic RNNs because recurrent neural networks have short-term memory problems. This problem occurs because RNNs use data from recent history for forecasting and they cannot transfer important information from earlier periods to later ones when the data sequence is long.[35] However, in the Long-Short Term Memory (LSTM) networks, “gates” are introduced to preserve relevant long-term memory, allowing us to combine inflation from long-term with short-term data.[36] An LSTM unit “memorizes” or “forgets” information through a special memory cell state regulated by three gates: an input gate, a forget gate, and an output gate. Information is carried or out of the memory cell according to the decisions of these three gates. An LSTM unit is defined by the following set of equations:

$$i = \sigma\,(x_t u^i + s_{t-1} w^i + b^i)\,, \tag{1}$$

$$f = \sigma\,(x_t u^f + s_{t-1} w^f + b^f)\,, \tag{2}$$

$$o = \sigma\,(x_t u^o + s_{t-1} w^o + b^o)\,, \tag{3}$$

$$c\sim = \tanh((x_t u^c + s_{t-1} w^c + b^c), \tag{4}$$

$$C_t = f_t * C_{t-1} + i_t * C_t\,, \tag{5}$$

$$s_t = o * \tanh(c_t)\,, \tag{6}$$

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[35] Oren Barkan & Jonathan Benchimol & Itamar Caspi & Allon Hammer & Noam Koenigstein, 2021. "Forecasting CPI Inflation Components with Hierarchical Recurrent Neural Networks," Bank of Israel Working Papers 2021.06, Bank of Israel.
[36] Hochreiter, S., Schmidhuber, J., 1997. “Long short-term memory”, Neural Computation 9, 1735–1780

where $\sigma(x) = 1/1+e^{-x}$ is the sigmoid and logistic activation function. u^i, $w^{i,}$ and b^i refer to the learned parameters controlling the input gate i while u^f, $w^{f,}$ and b^f are the learned parameters controlling the forgot gate f. Similarly, u^o, w^o and b^o are the learned parameters controlling the output gate o. C_t is the cell state and it`s updated the following relation $f_t * C_{t-1} + i_t * Ct$ (5) where c_{t-1} is the previous cell state value and $t \in (04/2022, 03/2023)$. The memory cell is modified according to the input gate i which decides which part of the C~ will be used and forgot gate f which decides which part of the C_{t-1} will be ignored. The next step is TanH which squashes the modified C_t through a nonlinear hyperbolic tangent. Finally, it is exposed to the output gate o that decides which parts of it will be presented in the output s_t.[37] This model is trained to forecast US CPI from 04/2022 to 03/2023. The same procedure is followed to forecast previous periods until 04/2002.

The Long Short Term Memory (LSTM) model serves as an advanced neural network model designed to deal with the short-term memory limitations commonly found in basic recurrent neural networks (RNNs). It's particularly useful when overcoming long sequences of historical data for forecasting US inflation. Traditional Recurrent Neural Networks struggle with retaining important information over extended periods, often leading to inaccuracies in predictions due to their reliance on recent data. LSTM addresses this limitation through the introduction of specialized "gates" that enable the preservation of significant long-term memory.

[37] Oren Barkan & Jonathan Benchimol & Itamar Caspi & Allon Hammer & Noam Koenigstein, 2021. "Forecasting CPI Inflation Components with Hierarchical Recurrent Neural Networks," Bank of Israel Working Papers 2021.06, Bank of Israel.

- Cell:

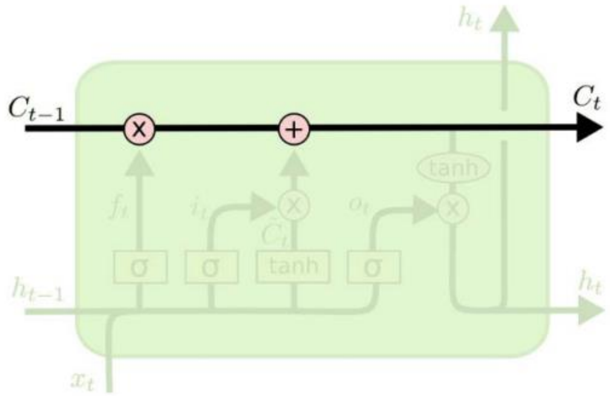

Figure 5: Architecture of a Long-Term Memory unit [38]

Figure 5 shows a cell in which the LSTM model removes or adds information. Then, it updates the cell and transports information through units.

- Forget Gate

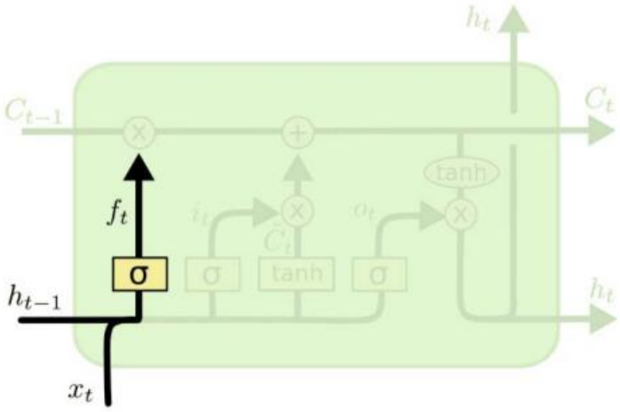

Figure 6: Architecture of a Long-Term Memory Unit[39]

[38] Oren Barkan & Jonathan Benchimol & Itamar Caspi & Allon Hammer & Noam Koenigstein, 2021. "Forecasting CPI Inflation Components with Hierarchical Recurrent Neural Networks," Bank of Israel Working Papers 2021.06, Bank of Israel.
[39] Oren Barkan & Jonathan Benchimol & Itamar Caspi & Allon Hammer & Noam Koenigstein, 2021. "Forecasting CPI Inflation Components with Hierarchical Recurrent Neural Networks," Bank of Israel Working Papers 2021.06, Bank of Israel.

In Figure 6, f_t is forget gate decides which parts of Ct-1 will be ignored or kept from the previous cell state. The sigmoid layer (forget gate layer) lies between 0 to 1,i.e. 0 being forget, and 1 being keep.

- Input Gate:

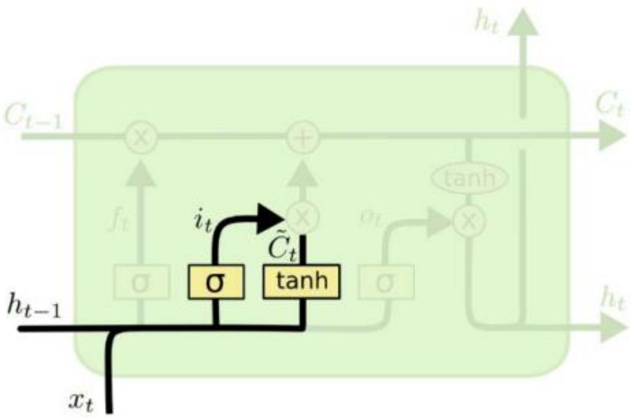

Figure 7: Input Gate of a Long-Term Memory unit[40]

In the input gate, the sigmoid layer selectively decides which values are updated in the cell state C_t while the TanH layer creates a vector of new candidate values that might be added to the cell state.

[40] Oren Barkan & Jonathan Benchimol & Itamar Caspi & Allon Hammer & Noam Koenigstein, 2021. "Forecasting CPI Inflation Components with Hierarchical Recurrent Neural Networks," Bank of Israel Working Papers 2021.06, Bank of Israel.

- Cell Update:

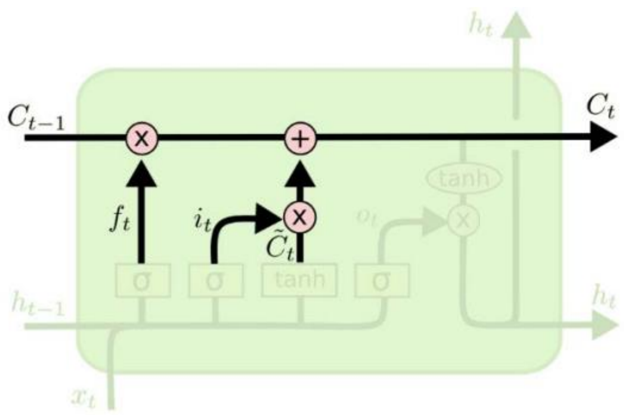

Figure 8: Cell Update of a Long-Term Memory Unit[41]

By combining the sigmoid layer and tanh layer in the previous step, the cell is updated according to the function below:

$C_t = f_t * C_{t-1} + i_t * C_t$

In this step, the old cell state, C_{t-1} is updated into the new cell state C_t by multiplying the old state by f_t means forgetting some information that is decided in forget earlier step. Then, new candidate values are added by $i_t * C_t$, scaled by how much decided to be updated each state value.

[41] Oren Barkan & Jonathan Benchimol & Itamar Caspi & Allon Hammer & Noam Koenigstein, 2021. "Forecasting CPI Inflation Components with Hierarchical Recurrent Neural Networks," Bank of Israel Working Papers 2021.06, Bank of Israel.

- Output Gate:

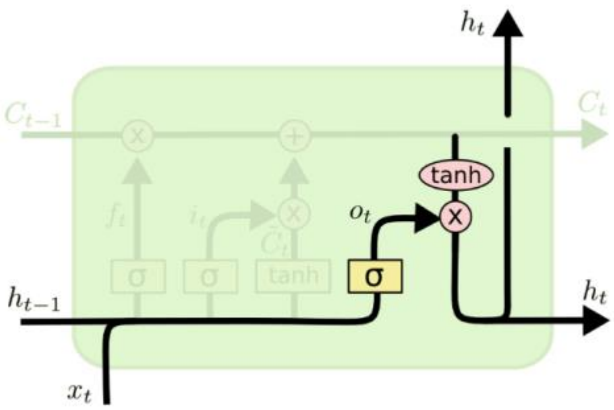

Figure 9: Input Gate of a Long-Term Memory Unit[42]

Figure 9 shows the output gate of the model. It decides which parts are transported. It might be considered as a filtered version of the cell state. The figure below shows the whole process of a cell. In the LSTM model, there are many cells, and information is transferred from one to the next one such that time dependency is kept. For forecasting US inflation, LSTM(12,12) is developed so that the previous 12 periods are used to predict the next 12 periods with many hidden layers to make the analysis comparable with the VAR model and OLS model.

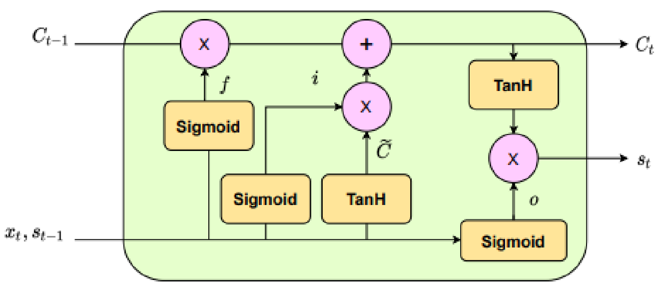

Figure 10: Cell of a Long-Term Memory unit[43]

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[42] Oren Barkan & Jonathan Benchimol & Itamar Caspi & Allon Hammer & Noam Koenigstein, 2021. "Forecasting CPI Inflation Components with Hierarchical Recurrent Neural Networks," Bank of Israel Working Papers 2021.06, Bank of Israel.
[43] Oren Barkan & Jonathan Benchimol & Itamar Caspi & Allon Hammer & Noam Koenigstein, 2021. "Forecasting CPI Inflation Components with Hierarchical Recurrent Neural Networks," Bank of Israel Working Papers 2021.06, Bank of Israel.

5.1.1. Comparison of the Models

For US inflation forecasting, LSTM(12,12), VAR(11) and OLS models encompass various dimensions to ascertain the strengths and weaknesses inherent. Firstly, model complexity levels differ. VAR(11) exhibits moderate complexity while LSTM (12,12) captures high complexity thanks to its deep learning architecture. However, OLS maintains a relatively low-complexity linear framework. It might be argued that VAR and LSTM can capture shocks and complex relationships among the explanatory variables better than the OLS model.

The second aspect of the comparison is the ability to capture non-linear relationships, revealing the limited non-linear capturing capacity of VAR(11), the proficiency of LSTM (12,12) in handling complex and non-linear patterns, and the linear assumption inherent to OLS. Additionally, the interpretability of the models is different. VAR(11) and OLS offer a degree of interpretability due to their simplicity, while LSTM (12,12) is inherently less interpretable results due to its intricate structure. Moreover, VAR(11) is designed for multivariate time series and LSTM(12,12) is capable of handling multivariate time series too while OLS is traditionally used for univariate forecasting, though extension for multivariate analysis is possible. When the performances of the models are compared, it might be suggested that VAR(11) captures linear relationships while the LSTM(12,12) model is better at capturing intricate patterns, relationships, and non-linearity. However, OLS provides optimal results when inflation relationships are linear. As a result, the LSTM model and VAR model are expected to work better in inflation forecasting since it's known that inflation is an indicator affected by various economic components in the economy. Before comparing the power of the models, firstly predicted values are calculated from each model. After receiving forecasted values from these three models, they are evaluated according to their Mean Square Error which is defined as follows:

MSE = $\Sigma(y_i - \hat{y}_i)^2/n$, where y_i is the observed value, $\hat{y}_i$ is the predicted value and n is the number of observations i.e. n=12*20. The Mean Square Error (MSE) is a widely used metric within the field of statistics and machine learning, serving as a fundamental measure to qualify the overall accuracy of predictive models. As mentioned above, it calculates the average of squared differences between forecasted values and the actual observations. Since these differences are squared, MSE ensures that all errors, regardless of direction. Since, a lower MSE indicates a better model fit, the model that has the lowest MSE values among OLS, VAR(11), and LSTM (12,12) models is selected to construct the inflation surprise rate.

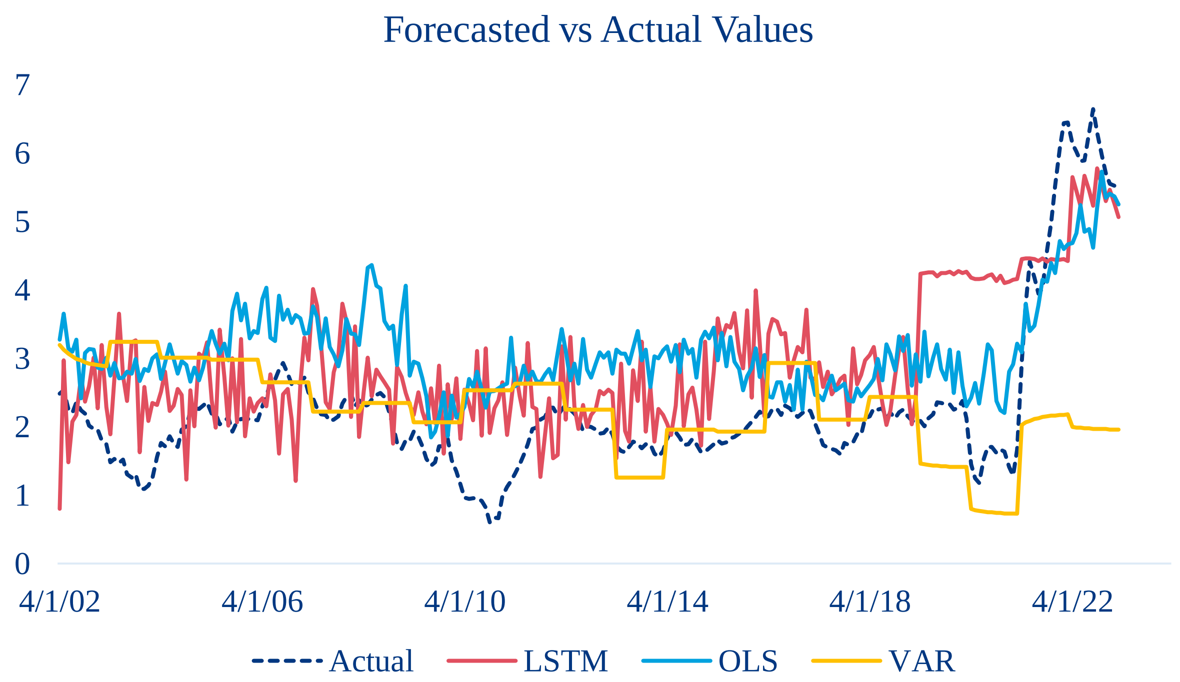


Figure 11: Forecasted Values vs. Actual Values
Notes: US Core Consumer Price Index (Core CPI) data is collected from the Bureau of Labor Statistics from 04/2002 to 03/2023 in monthly frequency. Forecasted values are obtained from VAR, OLS, and LSTM models using a dataset at monthly frequency is conducted by collecting variables from different data sources. It consists of US Core Consumer Price Index (Core CPI) data from the Bureau of Labor Statistics, US output gap data from Oxford Economics, World CPI and NEER from IMF, oil prices from Refinitiv, US Michigan 5y inflation expectations from the University of Michigan Surveys of Consumer from 01/1982 to 03/2023.

The figure above shows the forecasted values of each model. It might be suggested that the LSTM model can capture better fluctuations in inflation data compared to the VAR(11) model and the OLS model. MSE values of each model are as follows:

	MSE
OLS	1.256501
VAR(11)	1.732560
LSTM(12,12)	0.124445

Table 1: MSE values of the models

Notes: Mean Square Error values are calculated As the average of squared differences between forecasted values obtained by OLS, VAR(11), LSTM(12,12) and the actual observations.

According to the results above, the LSTM model is the best model for the analysis since it has the lowest MSE value (0.124445). Hence, its forecasted values for US CPI from 04/2002 to 03/2023 are used to construct inflation surprise data for the second step.

5.2. Panel Regression Analysis for US exports and imports

The estimation strategy relies on panel regressions to compare differences in change in US exports and imports for two periods i.e. low inflation period (below 2) and high inflation period (above 2). Hence, these two periods are constructed as 15/04/2002-15/08/2012 and 15/09/2012-15/02/2023 respectively since all observations in the first period satisfy the conditions of below 2 inflation rate and all observations in the second period satisfy the condition of above 2 inflation rate.

Panel data is created by merging US national data consisting of Real Effective Exchange Rate (REER), inflation, GDP, and oil prices with US monthly trade data consisting of US exports and imports (2 digits) across the top 10 trading partner countries (Canada, Mexico, Japan, United Kingdom, Germany, Netherlands, South Korea, Brazil, India, Vietnam- excluding China). A dummy variable called "target" is constructed as target=1 for a low inflation period i.e. below 2 and as target=0 for a high inflation period. (15/04/2002-15/08/2012& 15/09/2012-15/02/2023)

The country-monthly level analysis involves the following panel regression equations for change in US exports:

$$\Delta\, \text{exports}_{(US)\ c,m,t} = \beta 0 + \beta 1 \cdot \Delta\, \text{inflation}_{(US)\ m,t} + \beta 2\, \Delta\, \text{gdp}_{(US)\ m,t} + \beta 3\, \Delta\, \text{reer}_{(US)\ c,m,t} + \beta 4 \cdot \Delta\, \text{oil}_{\,c,m,t} + \beta 5 \cdot \Delta \text{inflation}_{(US)\ m,t} * \Delta\, \text{reer}_{(US)\ c,m,t} + \beta 6 \cdot \Delta \text{inflation}_{(US)\ m,t} * \text{target}_{\,c,m,t} + \beta 7 \cdot \text{target} * \Delta\, \text{reer}_{(US)\ c,m,t} + \gamma_c + \gamma_m + \gamma_t + \varepsilon_{\,c,m,t}\,, \qquad (1)$$

where Δ exports$_{(US)\ c,m,t}$ represents the difference in exports from the US for a specific country c at monthly m and year t as the dependent variable; while Δ inflation$_{(US)\ m,t}$ is an independent variable that represents the change in US inflation at monthly m and year t. Similarly, Δ gdp$_{(US)\ m,t}$ is the change in US GDP at monthly m and year t, Δ reer$_{(US)\ c,m,t}$ represents the change in US Real Effective Exchange Rate (REER) and Δ oil$_{\,c,m,t}$ is the change in oil prices for a specific country c at monthly m and year t. Moreover, there are interaction terms i.e. Δinflation$_{(US)\ m,t}$ * Δ reer$_{(US)\ c,m,t}$, Δinflation$_{(US)\ m,t}$ *target$_{\,c,m,t}$, target* Δ reer$_{(US)\ c,m,t}$. Firstly, Δinflation$_{(US)\ m,t}$ * Δ reer$_{(US)\ c,m,t}$ is an interaction term between change in US inflation and change in US Real Effective Exchange Rate for a specific country c at monthly m and year t. Δinflation$_{(US)\ m,t}$ *target$_{\,c,m,t}$ represents an interaction term between change in US inflation and dummy target variable for a specific country c at monthly m and year t. The last interaction term is target* Δ reer$_{(US)\ c,m,t}$ which represents the interaction between the change in US Real Effective Exchange Rate and the target variable. The coefficients $\beta 0, \beta 1, \beta 2, \beta 3, \beta 4, \beta 5, \beta 6$, and $\beta 7$ represent the estimated effects of the corresponding explanatory variables on the change in US exports. Finally, γ_c, $\gamma_{m,}$ and γ_t are country, monthly, and yearly fixed effects. γ_m captures seasonality while γ_t captures the business cycle development. $\varepsilon_{c,m,t}$ is the error term. The country-monthly level analysis for change in US imports has been developed by replacing the change in US exports in the panel regression equation for US exports (1) above.

The next step of the empirical strategy is panel regression analysis with the equations above by replacing the change in inflation with the change in inflation surprise rate constructed in the first step.

This comprehensive empirical strategy provides a structured framework for analyzing the dynamic relationships between US trade flows and the key macroeconomic indicators. However, potential methodological challenges, including endogeneity, measurement errors, omitted variables, selection bias, etc. should be taken into consideration to ensure the robustness and reliability of findings in the analysis. Firstly, endogeneity may arise if there are unobserved factors influencing both changes in US inflation and trade flows simultaneously. For instance, changes in exchange rates or fiscal policies might affect both inflation and trade flows, leading to endogeneity concerns. mitted variables represent another challenge. Secondly, failure to include relevant control variables that affect both the dependent and independent variables can result in omitted variable bias. For example, variations in trade agreements or geopolitical factors that are not considered in the analysis may confound the results. Additionally, sample selection bias could occur if the chosen set of top 10 trading partner countries is not fully representative of all trade relationships. If these countries have unique characteristics or trade dynamics that differ from the broader population of trading partners, the analysis may not generalize well.

The specification of periods is also critical. If the low and high inflation periods chosen do not adequately represent underlying economic conditions or if structural changes occur during these periods that are not accounted for, the results may be skewed. Finally, the issue of causality is crucial. While your analysis examines associations between variables, establishing causation requires careful consideration of potential reverse causality or omitted causal factors. For instance, changes in trade patterns may not necessarily be driven solely by changes in inflation but could also be influenced by broader economic factors not accounted for in the model.

6. Empirical Results

The main interested variables of the analysis are the joint impact of change in inflation and change in REER and the joint impact of change in inflation and the target variable. The Panel Regression Analysis results in Table 2 show that coefficients for the joint effect of change in inflation and change in Real Effective Exchange Rate (12.24 and 11.9) are statistically significant in explaining the change in US exports and imports respectively. The reason behind it can be explained by competitive advantage and currency depreciation effect. An increase in change in inflation combined with an increase in change in REER might result in a competitive advantage for US exports. A higher inflation rate relative to trading partners could lead to a depreciation in the real effective exchange rate, making US exports relatively more competitive in international markets. Hence, it might lead to increased demand for US exports and higher export growth(change). Additionally, both inflation and the real effective exchange rate might result in the depreciation of the domestic currency in real terms, making exports more attractive to foreign buyers, as they can purchase more goods with their own currencies. It boosts US exports too. In terms of change in US imports, a depreciated currency makes imports relatively more expensive, potentially incentivizing consumers and businesses to shift towards domestically produced goods. However, the simultaneous increase in change in REER might offset this effect, leading to a less pronounced appreciation of the currency that keeps imports relatively affordable and encourages higher import levels.

An increase in change in inflation might also raise the costs of domestic goods. Businesses that rely on imported inputs might experience higher production costs due to increased import prices. However, if the exchange rate also appreciates, it might partially offset the cost increase, making imported inputs relatively cheaper and thereby encouraging businesses to continue importing these inputs. The results in Table 2 show that the joint effect of inflation and the real effective exchange rate has a positive impact on change in US imports too. Hence, these results support the initial assumptions and expectations in the analysis.

According to the results in Table 2, a change in GDP has a stronger impact on change in US exports and US imports with statistically significant coefficients of 1.6 and 2.6, respectively. It means that a 1 unit increase in change in GDP raises the change in US exports by 1.6 units while it increases the change in US imports by 2.6 units. Moreover, the effect of change in US CPI on change in US exports is different during the target period i.e. inflation <2 with a statistically significant coefficient of -1.8. It might be interpreted that the effect of change in inflation on US exports is expected to decrease by 1.8 units during the target period compared to the high inflation period (inflation rate >2). However, there is no statistically significant difference in change in US imports. The effect of change in inflation on US exports is expected to decrease by 35.2 units during the target period compared to the high inflation period (inflation rate >2). However, there is no statistically significant difference in effects on change in US imports. These results are aligned with the initial assumptions.

Regression Results

	Dependent variable:	
	deltaExport	deltaImport
	(1)	(2)
delta inflation	-0.2	-0.1
	(0.2)	(0.3)
delta gdp	1.6^{***}	2.6^{***}
	(0.5)	(0.6)
delta reer	15.1	19.2
	(13.0)	(17.4)
delta oil	0.01	-0.01
	(0.01)	(0.01)
delta inflation: target	-1.8^{*}	-0.04
	(1.1)	(1.5)
delta inflation: delta reer	12.24^{***}	11.9^{**}
	(3.8)	(5.0)
delta reer: target	-35.2^{*}	-11.9
	(20.6)	(29.0)
Country FE	Yes	Yes
Monthly Time FE	Yes	Yes
Yearly Time FE	Yes	Yes
Observations	560	560
R^2	0.5	0.4
Adjusted R^2	0.5	0.3
F Statistic	6.5^{***} (df = 7; 304)	8.0^{***} (df = 7; 328)
Note:		$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 2:
Notes: Regressions estimating equations (1&2) using US exports and imports data of All 2-digit HS commodities for the US top 10 trading partners are collected from the UN Comtrade Database from 04/2002 to 03/2023 in monthly frequency.
The explanatory variables i.e., US GDP data from BEA - Bureau of Economic Analysis, US CPI from Bureau of Labor Statistics, US real effective exchange rate data from the OECD Economic Outlook, and oil prices data from Refinitiv are collected from 04/2002 to 03/2023 and merged with the US country-level trade data to build the panel dataset.

Panel regression results by using the inflation surprise rate as an explanatory variable instead of inflation in Table 3 show that while the coefficient for the joint effect of change in inflation surprise rate and change in Real Effective Exchange Rate (18.0) is statistically significant in explaining the change in US exports, it´s not statistically significant in explaining the change in US imports. One unit increase in this interaction term increases the change in US exports by 18.0 units. Similarly, the effect of change in inflation on US exports is expected to decrease by 40.1 units during the target period compared to the high inflation period (inflation rate >2). However, there is no statistically significant difference in effects on change in US imports.

Table 3 shows that changes in US GDP still have a statistically significant and positive impact on both changes in US exports and changes in US imports. An increase in US GDP by one unit increases the change in US exports by 1.6 units while increasing the change in US exports by 2.3 units. As opposed to results for the effect of change in inflation rate on change in US exports during the target period, the effect of change in surprise rate on change in US exports during the target period is not statistically significant. However, there is a statistically significant difference in impact on change in US imports. During the target period, one unit increase in change in inflation surprise rate decreases change in US exports by -0.5 unit.

In addition to the analysis above, panel regression models are conducted by using lag differences of the variables in the main models. However, the results are not used since they are not robust.

Regression Results

	Dependent variable:	
	deltaExport	deltaImport
	(3)	(4)
delta surprise rate	-0.1	0.2
	(0.1)	(0.2)
delta gdp	1.6^{***}	2.3^{***}
	(0.5)	(0.6)
delta reer	12.1	6.4
	(13.0)	(17.3)
delta oil	-0.001	-0.01
	(0.01)	(0.01)
delta surprise rate: target	-0.2	-0.5^{**}
	(0.2)	(0.2)
delta surprise rate: delta reer	18.0^{*}	21.9
	(10.6)	(14.0)
delta reer: target	-40.1^{*}	-9.3
	(21.0)	(29.0)
Country FE	Yes	Yes
Monthly Time FE	Yes	Yes
Yearly Time FE	Yes	Yes
Observations	560	560
R^2	0.5	0.3
Adjusted R^2	0.4	0.3
F Statistic	5.3^{***} (df = 7; 304)	8.2^{***} (df = 7; 328)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 3:

Notes: Regressions estimating equations (1&2) using US exports and imports data of all 2-digit HS commodities for the US top 10 trading partners are collected from the UN Comtrade Database from 04/2002 to 03/2023 in monthly frequency. The explanatory variables i.e., US GDP data from BEA - Bureau of Economic Analysis, US CPI from Bureau of Labor Statistics, US real effective exchange rate data from OECD Economic Outlook and oil prices data from Refinitiv are collected from 04/2002 to 03/2023 and merged with the US country-level trade data to build the panel dataset. Inflation surprise data is calculated as the difference between actual inflation data and forecasted values obtained by the LSTM model developed in the first stage.

7. Conclusion

Inflation is one of the key indicators that have effects on trade flows in an economy through several channels i.e., exchange rates, price levels, competitiveness, investment attractiveness, and trade policies. Inflation might result in currency depreciation in a country, which can make its exports more competitive on the global market. However, it can also increase the cost of imports. Additionally, it has an impact on the overall prices in the economy which changes not only domestic demand in the economy but also foreign demand for goods and services. Consumer purchasing power might be reduced because of high inflation and domestic demand is affected negatively. Moreover, inflation is a crucial economic component for competitiveness across countries. It makes exports less attractive because of increased production costs. Another impact of inflation on trade flows is being effective for trade policy decisions. Governments can impose tariffs, quotas, or other trade barriers to protect domestic industries from high price levels and imbalances and to create price stability in their economies. Finally, it might affect exchange rates and cause currency depreciation which enhances export competitiveness and increases import costs. In this study, the impacts of inflation and inflation surprise rate on US exports and imports through exchange rate is investigated target period i.e. low inflation period in which the inflation rate is below target rate 2 and a high inflation period in which the inflation period is above target rate 2. Hence the target period is constructed from 15/04/2002 to 15/08/2012 while the high inflation period is constructed from 15/09/2012 to 15/02/2023.

The empirical strategy of this analysis consists of two steps. Firstly, OLS, Vector Autoregressive model (VAR), and Long Short Term Memory Model (LSTM) are compared to create the data for the inflation surprise rate which is the difference between the actual inflation rate and forecasted inflation values. Firstly, these three models are used to obtain inflation prediction values from April 2022 to March 2023. Then, their performances are measured by Mean Square Errors. The results show that the Long Short Term Memory model is the best model for inflation forecasting among these three models since it has minimum MSE and its predicted values are used to construct the inflation forecast rate dataset.

In the second step of the analysis, panel regression models are developed to compare differences in change in US exports and imports for two periods i.e. low inflation period (below 2) and high inflation period (above 2). Hence, these two periods are determined as 15/04/2002-15/08/2012 and 15/09/2012-15/02/2023 respectively since all observations in the first period satisfy the conditions of below 2 target rates and all observations in the second period satisfy the condition of above 2 inflation rates.

Panel data is created by merging US national data consisting of Real Effective Exchange Rate (REER), inflation, GDP, and oil prices with US monthly trade data consisting of US exports and imports (2 digits) across the top 10 trading partner countries (Canada, Mexico, Japan, United Kingdom, Germany, Netherlands, South Korea, Brazil, India, Vietnam-excluding China). A dummy variable called "target" is constructed as target=1 for a low inflation period i.e. below 2 and as target=0 for a high inflation period. (15/04/2002-15/08/2012& 15/09/2012-15/02/2023). Panel regression results show that GDP has a statistically significant and positive impact on both changes in US imports and exports. Moreover, the effect of change in US inflation is statistically different during the low inflationary period compared to the high inflationary period and it dampens change in US exports in both periods. Additionally, the results suggest that the change in the US Real Effective Exchange Rate and the change in the US inflation rate jointly have a positive impact on both changes in US imports and exports. During the low inflationary period, the negative impact of change in inflation on US exports is found compared to the high inflationary period. However, there is no statistically significant difference in effects on change in US imports.

The outcomes of the panel regression analysis, which employs the inflation surprise rate as an explanatory variable instead of the conventional inflation metric, reveal noteworthy insights. Despite this change, the results affirm that shifts in U.S. GDP continue to exert a statistically significant and positive influence on both alterations in U.S. exports and modifications in U.S. imports. However, it is noteworthy that the association between the change in surprise rate and the change in U.S. exports during the specified target period does not attain statistical significance. In contrast, there is a discernible and statistically significant variance in the effect of the change in U.S. imports. Notably, while the coefficient signifying the combined impact on changes in the inflation surprise rate and variations in the Real Effective Exchange Rate is statistically significant in elucidating shifts in U.S. exports, its statistical significance is not upheld when examining the alterations in U.S. imports. These findings underscore the nuanced and differentiated relationships that unfold within the realm of changes in economic variables and their effects on the dynamics of U.S. exports and imports.

8. Appendix

8.1. Summary Statistics

- **Summary Statistics For Us Trade Data of All Trading Partners**

Summary Statistics

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
US CPI	0.603	1.711	2.020	2.226	2.271	6.643
exports	56,789	88,931	122,932	113,417.200	134,237.600	180,766.600
imports	96,395	152,919	185,321	177,882.300	197,957.900	289,568.200
GDP	10,887.460	14,403.780	16,420.390	17,100.620	19,981.660	26,399.180
REER	0.821	0.903	1.010	0.992	1.045	1.200
Oil prices	18.490	47.020	64.390	67.404	82.930	135.470

Notes: US exports and import data of all 2-digit HS commodities for the US top 10 trading partners are collected from the UN Comtrade Database from 04/2002 to 03/2023 in monthly frequency. These two variables are the main outcome variables of the analysis. The explanatory variables i.e., US GDP data from BEA - Bureau of Economic Analysis, US CPI from Bureau of Labor Statistics, US real effective exchange rate data from OECD Economic Outlook, and oil prices data from Refinitiv are collected from 04/2002 to 03/2023 and merged with the US country level trade data to build the panel dataset.

- **Summary Statistics For Trade Data of Top 10 Countries**

Summary Statistics

	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
US CPI	0.603	1.711	2.020	2.226	2.271	6.643
exports	1.257e+09	3.716e+09	4.847e+09	9.006e+09	8.459e+09	3.274e+10
imports	1.320e+09	3.464e+09	8.011e+09	1.181e+10	1.496e+10	4.126e+10
GDP	10,887.460	14,403.780	16,420.390	17,100.620	19,981.660	26,399.180
REER	0.821	0.903	1.010	0.992	1.045	1.200
Oil prices	18.490	47.020	64.390	67.404	82.930	135.470

Notes: US exports and import data of all 2-digit HS commodities for the US top 10 trading partners are collected from the UN Comtrade Database from 04/2002 to 03/2023 in monthly frequency. These two variables are the main outcome variables of the analysis. The explanatory variables i.e., US GDP data from BEA - Bureau of Economic Analysis, US CPI from Bureau of Labor Statistics, US real effective exchange rate data from OECD Economic Outlook, and oil prices data from Refinitiv are collected from 04/2002 to 03/2023 and merged with the US country level trade data to build the panel dataset.

8.2. OLS Regression Result Table For The Inflation Surprise Rate Construction Step

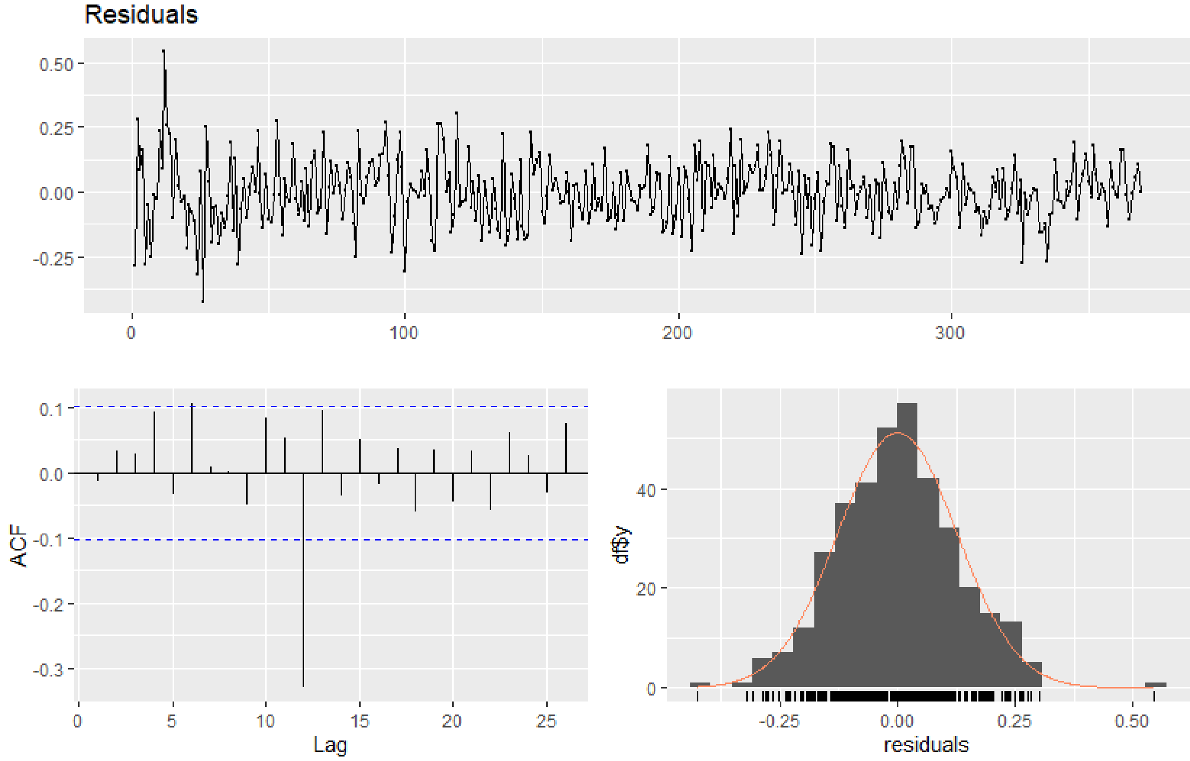
OLS

Regression Result

	Dependent variable:
	CPI
Output_gap	0.1^{***}
	(0.02)
`Crude oil`	0.01^{***}
	(0.002)
NEER	0.05^{***}
	(0.004)
World_cpi	0.1^{***}
	(0.01)
US_Michigan_5y	2.2^{***}
	(0.1)
Constant	-8.7^{***}
	(0.7)
Observations	496
R^2	0.7
Adjusted R^2	0.7
Residual Std. Error	0.8 (df = 490)
F Statistic	216.2^{***} (df = 5; 490)
Note:	$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

The dataset at monthly frequency is conducted by collecting variables from different data sources. It consists of the US Core Consumer Price Index (Core CPI) data from the Bureau of Labor Statistics, US output gap data from Oxford Economics, World CPI, and NEER from IMF, oil prices from Refinitiv, US Michigan 5y inflation expectations from the University of Michigan Surveys of Consumer from 01/1982 to 03/2023.

8.3. VAR Residual Charts for Number of Lags Selection Process for VAR model to construct the Inflation Surprise Rate



Notes: The VAR(11) model is developed for the construction of inflation surprise rate by using a new dataset at monthly frequency collected variables from different data sources. It consists of US Core Consumer Price Index (Core CPI) data from the Bureau of Labor Statistics, US output gap data from Oxford Economics, World CPI and NEER from IMF, oil prices from Refinitiv, US Michigan 5y inflation expectations from the University of Michigan Surveys of Consumer from 01/1982 to 03/2023. To be sure that the assumptions of the VAR model are satisfied, the distribution of residuals is checked. Additionally, the number of lags is decided according to the ACF values.

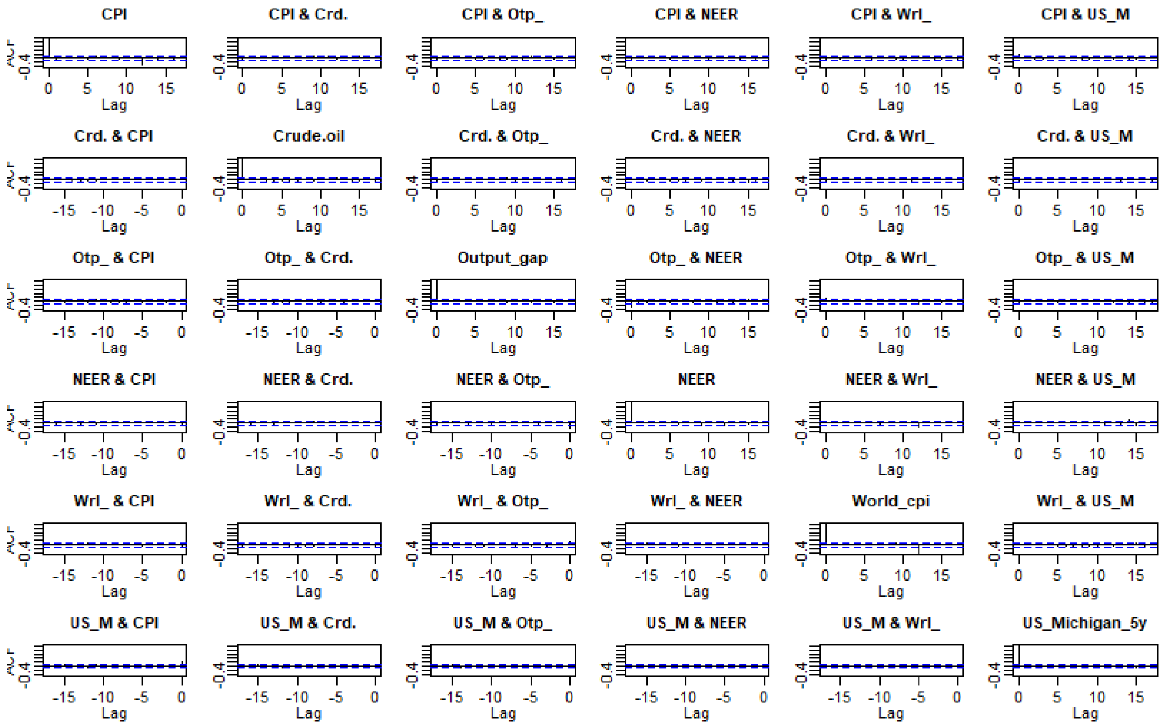
8.3. ADF Test results for VAR model

Augmented Dickey-Fuller Test

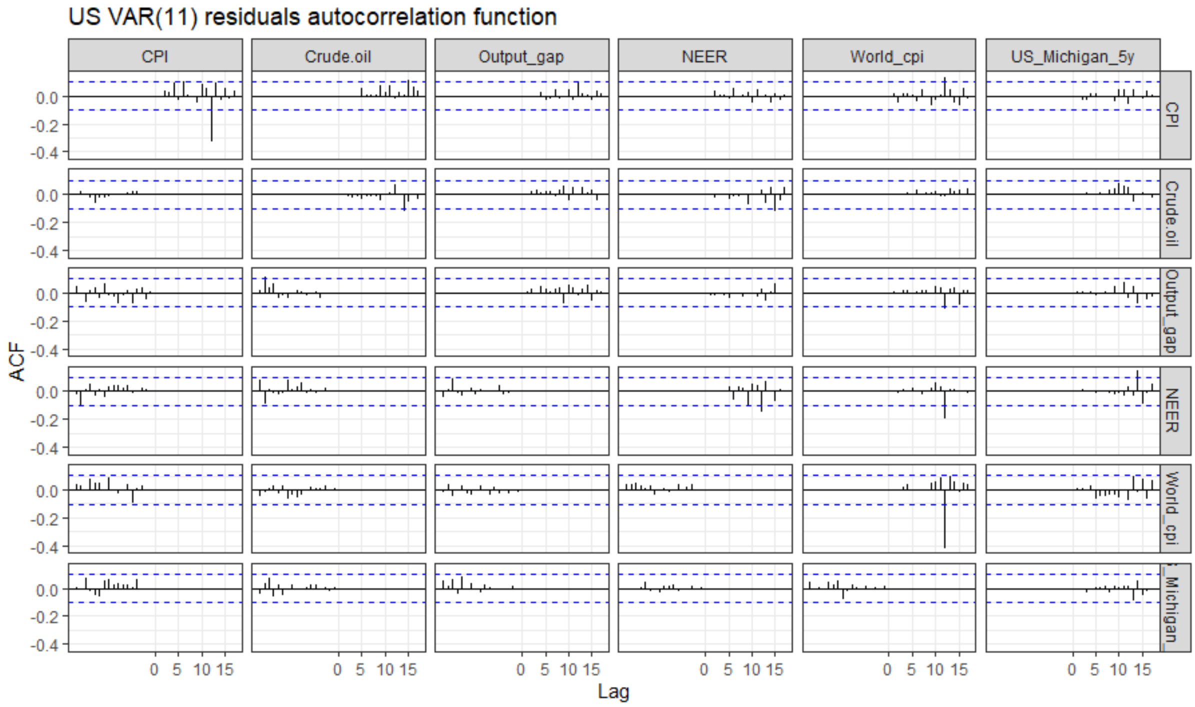
Difference of	Dickey-Fuller	Lag order	p-value
CPI	-6.5343	7	0.01
Crude oil	8.6782	7	0.01
Output gap	-5.6631	7	0.01
NEER	-5.4046	7	0.01
World CPI	-6.7254	7	0.01
US Michigan 5y Inflation Expect.	-8.2208	7	0.01

Notes: The assumption of stationarity for the VAR model is checked by the Augmented Dickey-Fuller Test. According to the results above, all p-values are 0.01which is smaller than at 0.05 significance level. Hence, the null hypothesis that there is a unit root can be rejected. As a result, all series are stationary, and a VAR model can be developed by using these variables. VAR(11) model is developed for the construction of inflation surprise rate by using a new dataset at monthly frequency collected variables from different data sources. It consists of US Core Consumer Price Index (Core CPI) data from the Bureau of Labor Statistics, US output gap data from Oxford Economics, World CPI and NEER from IMF, oil prices from Refinitiv, US Michigan 5y inflation expectations from the University of Michigan Surveys of Consumer from 01/1982 to 03/2023.

8.4.Residual ACF graphs:

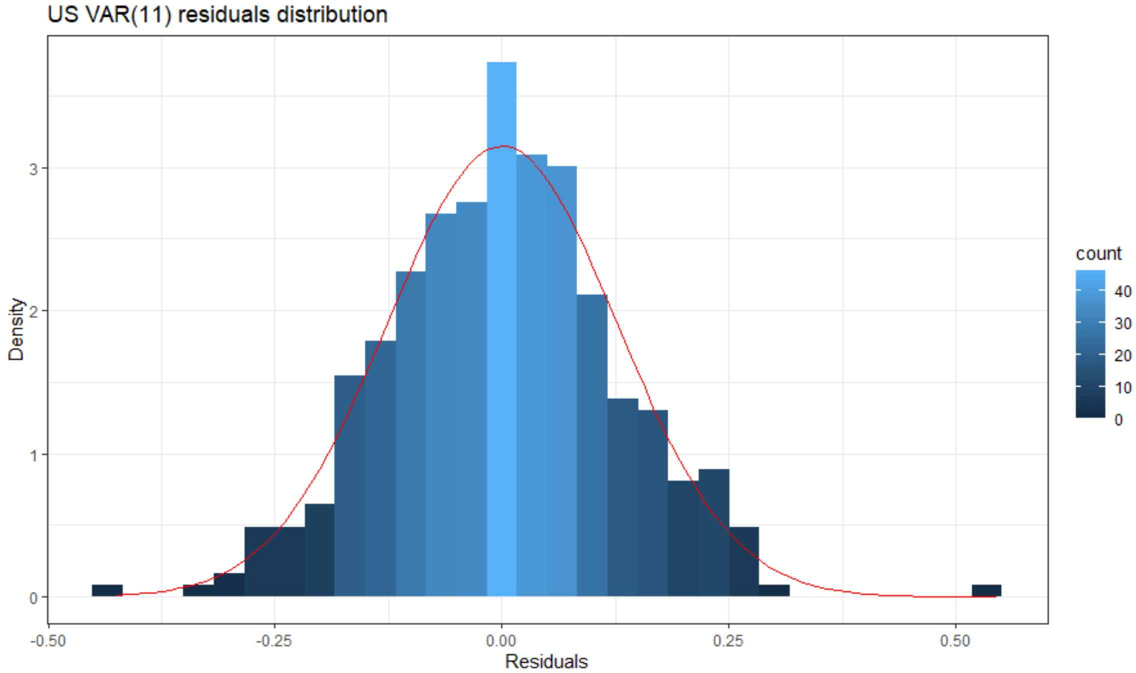


Notes: The VAR(11) model is developed for the construction of inflation surprise rate by using a new dataset at monthly frequency collected variables from different data sources. It consists of US Core Consumer Price Index (Core CPI) data from the Bureau of Labor Statistics, US output gap data from Oxford Economics, World CPI and NEER from IMF, oil prices from Refinitiv, US Michigan 5y inflation expectations from the University of Michigan Surveys of Consumer from 01/1982 to 03/2023. The number of lags is decided according to the ACF values of residuals.



Notes: The VAR(11) model is developed the for construction of inflation surprise rate by using a new dataset at monthly frequency collected variables from different data sources. It consists of US Core Consumer Price Index (Core CPI) data from the Bureau of Labor Statistics, US output gap data from Oxford Economics, World CPI and NEER from IMF, oil prices from Refinitiv, US Michigan 5y inflation expectations from the University of Michigan Surveys of Consumer from 01/1982 to 0The number. Number of lags is decided according to ACF values of residuals.

8.5 VAR(11) Residuals Distribution



The Notes: The VAR(11) model is developed for the construction of inflation surprise rate by using a new dataset at monthly frequency collected variables from different data sources. It consists of US Core Consumer Price Index (Core CPI) data from the Bureau of Labor Statistics, US output gap data from Oxford Economics, World CPI and NEER from IMF, oil prices from Refinitiv, US Michigan 5y inflation expectations from the University of Michigan Surveys of Consumer from 01/1982 to 03/2023. To be sure that the assumptions of VAR mode are satisfied, the distribution of residuals is checked and it's likely to be normally distributed.

8.6 Jarque Bera Test

Data: residuals

X-squared =	6.2615	**df =**	2	**p-value =**	0.0436The9

Notes: The VAR(11) model is developed for the construction of inflation surprise rate by using a new dataset at monthly frequency collected variables from different data sources. It consists of US Core Consumer Price Index (Core CPI) data from the Bureau of Labor Statistics, US output gap data from Oxford Economics, World CPI and NEER from IMF, oil prices from Refinitiv, US Michigan 5y inflation expectations from the University of Michigan Surveys of Consumer from 01/1982 to 03/2023. To be sure that the assumptions of the VAR model are satisfied, the Jarque Bera Test is done. According to the results above, **it** failed to reject the null that the data is normally distributed at 0.01 level since the p-value is 0.04369.

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