Global Shocks and Exchange Rate Dynamics

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Abstract

This paper sheds light on the long-standing puzzle regarding the exchange rate disconnect. Considering the COVID-19 pandemic as a unique global shock with heterogeneous impacts across countries, we find that a one-percent increase in relative COVID-19 cases depreciates bilateral exchange rates by up to 0.1 percent on impact. The effect often persists and even increases over a three-month horizon. The depreciation is strongest during the first COVID-19 wave and is mitigated in the presence of higher vaccinations. To rationalize these facts, we develop a two-country, two-sector open-economy model with incomplete markets and imperfect labor substitutability. Modeling the COVID-19 pandemic as an asymmetric and adverse labor supply shock, the model quantitatively matches the empirical findings.

Keywords: Exchange rates, uncovered interest parity, safe haven currencies.

JEL Classification Codes: F31, F41, G15, E44.

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1 Introduction

The empirical finding that exchange rates are disconnected from economic fundamentals is a long-standing puzzle in the international macroeconomics and finance literature (Meese and Rogoff, 1983; Engel and West, 2005). Despite theoretical predictions, exchange rates are virtually uncorrelated with most lagged and contemporaneous financial and macroeconomic variables. At the same time, conventional wisdom suggests that in times of global turmoil, currencies of the safe haven countries should appreciate.

In this paper, we contribute to the exchange rate disconnect literature by utilizing the unique empirical setting provided by the COVID-19 crisis and its effects on U.S. bilateral exchange rates. Since the pandemic was a global shock with heterogeneous impacts across countries, it introduced variation in countries' exposure to a global shock. W find that this variation plausibly affected the value of a country's currency in a way consistent with a forward-looking determination of exchange rates, since COVID-19 cases were a leading indicator of the severity of the global shock across countries at a point in time. In addition to being at the daily frequency, the dataset we build covers a large set of countries, enabling us to capture variation in the severity of the global shock across time and economies. All these unique features distinguish the COVID-19 shock from other historical global shocks, such as oil shocks.

In particular, we document that, during 2020 and 2021, U.S. dollar bilateral exchange rates depreciated in response to more COVID-19 cases relative to foreign countries. This result is striking considering the U.S. dollar's role as a safe-haven currency, which thus appreciates during periods of high global uncertainty. These results also shed light on the puzzling behavior of the U.S. dollar during the pandemic. While the dollar initially appreciated in the aftermath of the "dash-for-cash" financial episode in March 2020, the U.S. dollar persistently depreciated against both emerging and developing currencies in subsequent months, in the face of continued uncertainty about the pandemic's fallout. Our framework can rationalize these dynamics insofar as the United States suffered from a particularly acute shock relative to the rest of the world during the initial phase of the pandemic.

In our empirical analysis, we build a panel dataset with 36 countries plus the U.S. (26 currencies plus the U.S. dollar) spanning over 78 weeks from June 1, 2020, until November 30, 2021. We find that increases in U.S. COVID cases relative to country i produce a depreciation in U.S. dollar bilateral exchange rate vis-à-vis country i, both on impact and over the short-run. The cumulative depreciation reaches about 0.16% one month after the shock. The magnitude of the effect is economically relevant, insofar as the elasticity we compute is larger in magnitude than the effects estimated for yield differentials and the VIX, which are two key variables featured in modern empirical models of U.S. dollar exchange rates.

Next, we find the most significant impact of our COVID-19 measures on the bilateral exchange rate during the summer 2020 wave (June 1, 2020, to August 31, 2020). This result is consistent with a more significant unanticipation effect, as uncertainty about the duration, policies, and severity of the crisis were highest at the onset of the pandemic. When we decompose the effect of relative COVID-19 cases between U.S. and foreign cases, we find that the depreciation is driven primarily by U.S. cases. We also find, however, that higher foreign cases statistically significantly *appreciate* the U.S. dollar bilateral exchange rate during the summer 2020 wave.

Furthermore, following the introduction of vaccinations in 2021, we find that the average marginal effect of relative COVID-19 cases on the bilateral nominal exchange rate is positive and statistically significant only when U.S. vaccinations are low. This finding is consistent with the fact that relative COVID-19 cases became less informative about future economic performance as vaccines became increasingly available. In other words, vaccinations provided a buffer against higher relative COVID cases, mitigating the effect on the exchange rate in 2021.

To rationalize the empirical findings, we develop a New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model, which, when calibrated to U.S. data, quantitatively matches our empirical findings. We model COVID-19 as a shock to the labor disutility and the consumption share in the non-tradeable sector. Indeed, COVID-19 had asymmetric negative effects on the non-tradeable sector, which comprises service-intensive industries that require personal interaction.

The mechanism relies on a sluggish monetary policy response to the shock. As the supply-driven shock is inflationary, and monetary policy does not react instantaneously to the pace of inflation, real returns differentials move against bonds denominated in domestic currency, thus producing an exchange rate depreciation. We find empirical evidence consistent with these key elements of the theoretical mechanism. The model we construct builds on Berka, Devereux, and Engel (2018) and is enriched along several dimensions, including distinct currencies in the Home and Foreign countries, incomplete asset markets with endogenous deviations from uncovered interest rate parity, input-output linkages between sectors, supply-chain spillovers, and imperfect labor mobility across the nontradeable and tradeable sectors. To the best of our knowledge, this paper is among the first to model the effects of the COVID-19 pandemic on international variables within an open-economy macroeconomic model.

The rest of this paper is structured as follows. Section 2 reviews the related literature. Section 3 presents the data and empirical analysis. Section 4 presents the theoretical model. Sections 5 and 6 present the calibration and model simulation results. Finally, section 7 concludes.

2 Related Literature

Our work is closely related to the literature on forward-looking exchange rate determination. A seminal paper on this topic is Engel and West (2005), who showed analytically that asset prices manifest near-random walk behavior if fundamentals are nonstationary, and the discount factor on future fundamentals is close enough to one. If these conditions hold in the data, exchange rates and fundamentals should be linked in a way that is broadly consistent with asset-pricing models of the exchange rate, such as Farhi and Gabaix (2016). Similar to our paper, these authors tie dynamics in exchange rates to country- and time-varying exposure to the shock. They derive an asset pricing expression for the exchange rate that depends on the present discounted value of the stream of future relative productivities. Consistently with their theoretical predictions, Chahrour, Cormun, Leo, Guerron-Quintana, and Valchev (2021) provide empirical evidence that variation in expected U.S. productivity explains more than half of G-6 exchange rate fluctuations vis-à-vis the U.S. dollar. Our theoretical approach differs from Farhi and Gabaix (2016) along two dimensions, however. First, we connect the nominal exchange rate to expected monetary policy responses to the COVID-19 shock. Second, our model encompasses several realistic elements of an open economy, such as sticky prices, endogenous deviations from uncovered interest parity, input-output linkages, and imperfect labor mobility across tradeable and nontradeable sectors.

This paper is also naturally connected to the growing literature studying the macroeconomic effects of the pandemic. Generally, the COVID-19 crisis has been regarded in this literature as a mixed combination of supply and demand shocks. For instance, focusing on the supply side aspect of the pandemic, Fornaro and Wolf (2020) considered it a negative shock with persistent effects on the growth rate of productivity to the point of lowering aggregate demand and generating stagnation traps. Our paper differs to the extent that we are interested in the short-run impact of the pandemic on the exchange rate. On the other hand, modeling the COVID-19 crisis as a significant negative shock to the utility of consumption, Faria-e Castro (2020) studied different forms of fiscal policy in a New Keynesian model featuring incomplete markets in the form of borrowers and savers facing financial frictions. Also, studying the COVID-19 shock as a shock that reduces utility stemming from goods that need social interaction, Bigio, Zhang, and Zilberman (2020) compare the advantages of lump-sum transfers versus a credit policy. In contrast, our approach is positive instead of normative as we study the short-run effects of the pandemic on the exchange rate, both empirically and theoretically.

Notably, Brinca, Duarte, and e Castro (2021) empirically decomposed the drop in aggregate growth rate of hours during the COVID-19 outbreak into labor demand and supply shocks. Their estimates suggest that two-thirds of this drop are attributable to labor supply, consistent with our modeling approach to focus on labor supply instead of productivity shocks. Studying the impacts of the pandemic on international trade, Bonadio, Huo, Levchenko, and Pandalai-Nayar (2021) investigated the role of global supply chains in the transmission of the COVID-19 crises to GDP growth. Considering a quantitative trade model subject to labor supply shock across sectors and countries, they found that one-quarter of the total implied real GDP decline is due to transmission through global supply chains. Our paper expands their approach insofar as we model the COVID-19 crisis as an expenditure-switching shock in addition to accounting for adverse labor supply effects.

Also, interpreting the pandemic as a negative supply shock induced by shutdowns, Guerrieri, Lorenzoni, Straub, and Werning (2022) investigated the conditions under which a supply shock can produce adverse demand spillovers that engender a fall in output below its potential level. In a similar vein, Baqaee and Farhi (2022) considered the effects of both supply and demand shocks in a model featuring input-output linkages. Their results show that adverse sectoral supply shocks are stagflationary, negative demand shocks are deflationary, and both can produce Keynesian unemployment. Complementarities in production amplify Keynesian spillovers originating from supply shocks. Our paper extends their general equilibrium analyses to a two-country open-economy setting, also incorporating input-output linkages and imperfect sectoral labor mobility in a new Keynesian framework. By further expanding our analysis to study the macroeconomic effects of the pandemic in an open economy, we can focus on the exchange rate dynamics during the COVID-19 crisis.

3 Empirical Analysis

Daily-frequency data on the COVID-19 pandemic provides a unique setting to study how a country's resilience to a global shock impacts the value of its currency. Indeed, during the COVID-19 crisis, measures like cases and vaccinations quantified the severity of a global shock in a country at a point in time. In addition to being at the daily high-frequency, these variables are available across a large set of countries. These features distinguish COVID-

19 data from data derived from other historical global shocks. The COVID-19 measures capture variation in the intensity of the global shock not only across time—as in oil shocks, for example—but also across countries due to the idiosyncratic spread of the pandemic across economies. Hence, for any pair of countries, we relate the variation in the relative shock between this pair to movements in the bilateral nominal exchange rate.

3.1 Data and Variables

Our empirical analysis utilizes data on 36 economies (26 currencies) in addition to the United States from June 1, 2020, through November 30, 2021. We select this sample period due to data availability and quality concerns, as well as a reasonable end date to the salience of COVID-19 in financial markets and the macroeconomy.[1] In the developed world, we consider 20 countries plus the United States, whereas, in the emerging markets world, we consider 16 countries. In the sample of countries, 11 are in the Eurozone.[2] The complete set of countries is reported in Table A.1 in the appendix.

We obtain daily data on spot nominal exchange rates from the Federal Reserve Bank of St. Louis database (FRED) and Bloomberg. Exchange rates are defined with respect to the U.S. dollar. We define the U.S. dollar nominal bilateral exchange rate against country i, $\mathcal{E}_i$, as U.S. dollars per unit of country i's currency, so an increase in $\mathcal{E}_i$ refers to a depreciation of the U.S. dollar against the currency of country i. Our country-specific COVID-19 data comes from the Our World in Data (OWID) cross-country COVID-19 dataset.[3] The main COVID measures utilized in our analysis are cases, which are available across countries at the daily frequency. In robustness checks we also consider the role of vaccinations. We focused our empirical analysis on the U.S. dollar for two reasons. First, most currencies are traded with respect to the U.S. dollar, so the underlying source of variation in bilateral exchange rates ties heavily to U.S. dollar exchange rates. And, second, our empirical finding that the U.S. dollar *depreciated* in response to an increase in U.S. COVID-19 cases is particularly striking, considering the dollar's role as a safe haven currency, especially during times of high global uncertainty.

It is well known that the pandemic had direct and indirect spillovers economically through travel restrictions, lockdowns, stay-at-home orders, and business and school closures. These

[1] November 30, 2021, is when the Delta wave subsided, and the less-virulent Omicron variant first appeared. At this point, the population of most countries was broadly vaccinated, and governments were already relaxing lockdown and social distancing measures as policy tools to contain the disease spread.

[2] We selected a number of countries in the Eurozone comprising more than 90 percent of its GDP. As a result, we omitted eight countries in the Eurozone: Cyprus, Estonia, Latvia, Lithuania, Luxembourg, Malta, Slovakia, and Slovenia.

[3] Accessed via the following link: https://covid.ourworldindata.org/.

restrictions also varied in intensity and scope across countries and over time. Because these stringency measures correlate with the severity of the COVID-19 pandemic and, plausibly, with the exchange rate through their impact on the economy, we include the COVID stringency index as a control in our analysis.

The key explanatory variable of interest is the relative COVID cases between the United States and other countries. We define the relative COVID cases between the United States and country i:

$$rel\ cases_{i,t} \equiv \log(cases_t^{USA}) - \log(cases_{i,t}). \tag{1}$$

By definition, the variable *rel cases* increases when cases in the United States increase relative to country i, which may happen if (i) $cases_t^{USA}$ increases, (ii) $cases_{i,t}$ decreases, or (iii) both (i) and (ii). To disentangle these effects, we also investigate U.S. and foreign cases as separate covariates in the regression. To account for seasonality in the reporting of COVID-19 data, we build a country-weekday grid. We then detrend exchange rates and the COVID measures by taking day-of-week on day-of-week log-differences. Specifically, for a variable $X_{i,t}$, we define $\Delta x_{i;t-k,t} \equiv \log(X_{i,t}) - \log(X_{i,t-k})$ for $k = 5, 10, 15, 20, \ldots$. This approach ensures that countries' reported COVID-19 measures on Monday are always compared with their level from previous Mondays, and so on for each day of the week.

In addition to the stringency index, we control for the five-year Treasury yield differential to account for monetary policy impacts on exchange rates, which we obtain at the daily frequency from Datastream and Bloomberg. We used Treasury yields in place of effective policy interest rates due to the zero-lower-bound constraint effectively binding for many countries during the sample period, and chose longer-term Treasury yields to capture the effects of unconventional monetary policy. Finally, to account for a measure of global uncertainty, we also control for the VIX, since it typically correlates with the U.S. dollar during crises periods. We obtained the VIX from CBOE.

Our final dataset is at the country-weekday level, spans 392 weekdays (approximately 78 weeks), and includes 36 (26) unique foreign countries (currencies). The descriptive statistics for the variables utilized the analysis that follows are presented in Table A.2 in the appendix. Panel A reports statistics for the daily panel over the full sample. Despite the relatively short time period, we have more than 12,000 observations due to the rich country-panel structure. There is substantial variation in bilateral exchange rates and relative COVID severity across countries, which is precisely what we wish to exploit in our empirical analysis.

The average five-day change in the U.S. dollar bilateral exchange rate is five basis points, with a standard deviation of 95 basis points over the full sample. The average weekly change is larger (smaller) during the summer of 2020 (latter half of 2021). Also from the full sample, the five-day change in the relative COVID cases is -0.5 percent on average, with a standard deviation of 5.6 percent.

Notably, the distribution of the change in U.S. cases is similar to that for other countries, with average changes in cases standing at 4.2 and 4.7 percent in the U.S. and foreign countries, respectively. The variation in foreign cases is slightly larger at 5.6 percent, compared to 3.7 percent in the U.S. Changes in relative cases and U.S. cases are markedly higher in the summer 2020 wave. Finally, average and median day-of-week on day-of-week log-changes in relative stringency indices are, respectively, 3.5 and 0 basis points, with a standard deviation of 10 percent. The balanced distribution of U.S. and foreign cases ensures substantial variation of cases in the cross-country cross-time panel dataset and is particularly important to rule out any possibility that our results were driven by cases being persistently higher in the U.S. in comparison to foreign countries.

Finally, in addition to our daily panel, we also build a dataset at the monthly frequency, given that our model is calibrated at the monthly frequency. Descriptive statistics for variables in this frequency can be found in Table A.3 in the Appendix.

3.2 Empirical Strategy and Results

To motivate the empirical analysis, we begin by considering the dynamics of the U.S. dollar during the COVID-19 crisis, which are particularly puzzling in light of its role as a safe haven currency, as a large body of literature has emphasized. As it can be observed in Figure 1, though the U.S. dollar acutely appreciated in the aftermath of the COVID-19 crisis during March 2020, it steadily depreciated afterward, especially against currencies in the developed world despite still high levels of global uncertainty. The figure shows that the U.S. dollar index experienced a peak-to-trough decline of approximately 12.5% and 10% against developed and emerging economies, respectively. At the same time, the United States suffered a particularly acute shock, especially in the early phase of the pandemic, relative to other countries. In this section, we investigate how the severity of the pandemic in the United States, as measured by COVID cases, in the United States and other countries affected the U.S. dollar bilateral exchange rate.

In our baseline specification, we estimate the following panel regressions:

$$\Delta\varepsilon_{i;t-5,t} = \boldsymbol{\alpha}_i + \beta_1 \Delta rel\ cases_{i;t-5,t} + \beta_2 \Delta rel\ string_{i;t-5,t} + \beta_3 \log(VIX_t) + \beta_4 (y_t^{USA} - y_{i,t}) + u_{i,t} \tag{2}$$

$$\Delta\varepsilon_{i;t-5,t} = \boldsymbol{\alpha}_i + \gamma_1 \Delta cases^{USA}_{t-5,t} + \gamma_2 \Delta cases_{i;t-5,t} + \gamma_3 \Delta rel\ string_{i;t-5,t} + \gamma_4 \log(VIX_t) + \gamma_5 (y_t^{USA} - y_{i,t}) + u_{i,t}. \tag{3}$$

Specification in (2) focuses on the change in relative cases, as defined in (1), whereas the specification in (3) decomposes the change in relative cases into the change in U.S. and foreign cases. In each regression, the outcome variable is the log-change in the U.S. dollar bilateral exchange rate from $t-5$ to t weekdays, $\Delta\varepsilon_{i;t-5,t} \equiv \log(\mathcal{E}_{i,t}) - \log(\mathcal{E}_{i,t-5})$. The specifications also control for a country fixed effect, $\boldsymbol{\alpha}_i$; the change in the relative stringency indexes, $\Delta rel\ string_{i;t-5,t}$; and the yield differential between the U.S. and country i, $y^{USA} - y_i$. The coefficients of interest are β_1, γ_1, and γ_2, which capture the effect on impact of a one-percent increase in COVID cases on the change in the U.S. dollar bilateral exchange rate. Regressions are trade-weighted using weights from the Bank of International Settlements (BIS).

Although we do not claim causality in our reduced form specifications, we interpret coefficients as economically meaningful correlations, which we will rationalize later using simulated data generated by our two-country general equilibrium model.

As a second step in our empirical analysis, we run UIP-style regressions, projecting the cumulative change in the bilateral exchange rate up to 65 weekdays ahead (roughly three months) on the innovation in the COVID-19 cases variables:

$$\Delta\varepsilon_{i;t,t+h} = \boldsymbol{\alpha}_{i,h} + \beta_{1,h} \Delta rel\ cases_{i;t-5,t} + \beta_{2,h} \Delta rel\ string_{i;t-5,t} + \beta_{3,h} \log(VIX_t) + \beta_{4,h} (y_t^{USA} - y_{i,t}) + u_{i,t+h} \tag{4}$$

$$\Delta\varepsilon_{i;t,t+h} = \boldsymbol{\alpha}_{i,h} + \gamma_{1,h} \Delta cases^{USA}_{i;t-5,t} + \gamma_{2,h} \Delta cases_{i;t-5,t} + \gamma_{3,h} \Delta rel\ string_{i;t-5,t} + \gamma_{4,h} \log(VIX_t) + \gamma_{5,h} (y_t^{USA} - y_{i,t}) + u_{i,t+h}. \tag{5}$$

The outcome variable, $\Delta\varepsilon_{i;t,t+h} \equiv \varepsilon_{i,t+h} - \varepsilon_{i,t}$, is distinct from that in (2) and (3) in that it cumulates the exchange rate change from t to $t+h$ weekdays. Here, our focus is on the coefficients $\beta_{1,h}$, $\gamma_{1,h}$, and $\gamma_{2,h}$, $h = 5, 10, \ldots, 65$. Each coefficient captures the effect of a one-percent increase in COVID cases from $t-5$ to t on the cumulative change in the bilateral exchange rate from t to $t+h$.

The first set of regression results is reported in Table 1 and Figure 2. The table reports the regression results for (2) and (3), while the figure plots the point estimates at each horizon from (4) and (5), $\hat{\beta}_{1,h}$, $\hat{\gamma}_{1,h}$, and $\hat{\gamma}_{2,h}$ for $h = 5, 10, \ldots, 65$, and the associated 90-percent confidence intervals. Standard errors in all regressions are robust to heteroskedasticity autocorrelation and spatial correlation (Driscoll and Kraay, 1998). We introduce the COVID cases measures, *rel cases* and ($cases^{USA}$, $cases_i$) in columns (1) and (2), respectively. The results indicate that a one percent increase in U.S. COVID cases *relative to* country i leads to a weekly 3 basis-point percent depreciation in the U.S. dollar bilateral nominal exchange rate on impact. When we decompose the effect by examining U.S. and foreign cases separately, we find that a one percent increase in U.S. cases produces a 0.11 percent depreciation over the same period. On the other hand, a one percent increase in foreign cases does not statistically significantly affect the exchange rate, even though the coefficient displays the expected negative sign. The magnitudes of these coefficients are economically meaningful, as the elasticity of the exchange rate to relative cases and U.S. cases is much larger than the coefficients on the interest rate differentials and the VIX, which are the two preeminent variables featured in modern empirical work to explain U.S. dollar exchange rate dynamics.

In turn, the negative coefficients on relative yields suggest a substantial violation of UIP in the sample. According to our estimates, a one-percent increase in U.S. yields relative to country i produces an appreciation of the corresponding bilateral exchange rate of -0.013 (column 1) and -0.116 (column 2) over a week, though the results are not statistically significantly different than zero. The coefficient on the VIX is also negative and statistically significant in both estimations. The sign of the coefficient is consistent with the stylized fact that U.S. currency appreciates in times of high global uncertainty.

In sum, our results suggest that excess returns on the U.S. dollar against developing and developed countries' currencies correlated with a non-fundamental variable (i.e., COVID-19 cases) even if we account for monetary policy responses, global uncertainty, and government policies imposed to contain the disease spread. As we argue later, we explain this striking fact through the signal COVID-19 cases provided about future fundamentals affecting the exchange rate, particularly inflation differentials relative to nominal interest rate differentials.

Figure 2a portrays the coefficients $\hat{\beta}_{1,h}$ associated with (4), while figure 2b plots the coefficients ($\hat{\gamma}_{1,h}$, $\hat{\gamma}_{2,h}$). The dynamic responses are hump-shaped and indicate that a one-percent increase in cases in the U.S. relative to country i depreciates the bilateral exchange rate by an additional 5 basis points 2 to 3 weeks following the shock. Thereafter, the cumulative depreciation reverts, resulting in a muted response three months following the shock. Figure 2b indicates that U.S. cases are the main driver of the depreciation: A one percent increase in U.S. cases produces up to a 0.22 percent depreciation in the U.S. dollar bilateral exchange rate approximately one month later. Similar to the effect of relative cases, the short-run depreciation reverts after two months, with no statistically significant effect surviving at a three-month horizon. These results suggest that U.S. cases were meaningfully related to the contemporaneous and short-run future dynamics of U.S. dollar exchange rates during the sample period.

3.3 Robustness

We conduct additional exercises that shed further light on the factors influencing the effect of COVID-19 cases on the dynamics of bilateral exchange rates. First, we consider how unanticipation affects our results. As the public gradually anticipated adverse economic impacts associated with the pandemic and policy responses, we focused on a subsample comprising the summer 2020 wave, the first in our sample and the second COVID-19 wave generally. By that period, health authorities across countries were still learning about disease transmission and how to appropriately respond to it, so the macroeconomic impacts of the pandemic were still largely unknown and unanticipated by the public. In much of the remainder of the sample, however, changes in COVID cases were less surprising for the opposite reasons and were eventually mirrored by the availability of vaccines. Hence, one should expect the effect of COVID-19 to be much more prominent in the first wave relative to results from our baseline regressions.

To inspect the effect of COVID-19 cases during the summer 2020 wave, we estimate (2)–(5) on a subsample restricting the dates between June 1, 2020 and August 31, 2020. The results from these regressions are reported in Table 2 and Figure 3. We find that, on impact, a one-percent increase in relative cases in the summer 2020 wave produced a 0.062 percent depreciation compared to 0.026 percent over the full sample; the effect of a one-percent increase in U.S. (foreign) cases produced a statistically significant 0.114 percent (-0.030 percent) change in the U.S. dollar bilateral exchange rate.

Over a three-month horizon, a one-percent increase in relative cases produces up to a 25 basis point depreciation in the summer 2020 wave, compared to a 5 basis point depreciation in the baseline sample. In contrast to the baseline sample, bilateral exchange rate remains depreciated by 0.10 percent after three months. Considering U.S. cases separately, we find a similar shape as in the baseline specification, yet much more pronounced, with a one-percent increase in U.S. cases leading to a short-run depreciation of 0.5 percent one month later. Remarkably, an increase in foreign cases leads to a long-run cumulative *appre-*

ciation in the bilateral exchange rate of almost 0.2 percent after three months. These results confirm our hypothesis that anticipation played a significant role in dampening exchange rate responses during the following waves.

Accordingly, in the appendix, we examine whether vaccinations mitigated the effects documented above during 2021, as people gradually became less afraid of contagion risk and governments began relaxing lockdown and social distancing policies. To this end, we interact the measure of relative Covid cases with U.S. vaccinations, and compute average marginal effects of relative cases on the bilateral nominal exchange rate, conditional on vaccines being higher or lower. The results, summarized in the appendix in Table A.5 and Figure A.3, indicate that cases only continued playing a role in the depreciation of U.S. dollar bilateral exchange rates in 2021 when U.S. vaccinations were low.

Finally, as mentioned before, we build and analyze the effects of Covid cases in a monthly-frequency dataset. This analysis carries a few advantages. First, our theoretical model (see Section 4) is calibrated at the monthly frequency; monthly regressions, therefore, provide a meaningful benchmark against which to evaluate our model. Second, monthly data allow us to control for inflation differentials ($\pi^{USA}_{t-1,t} - \pi_{i;t-1,t}$), which are crucial in determining monetary policy stances and, thus, exchange rates.[4]. Furthermore, monthly-frequency regressions allow us to inspect the robustness of the baseline results to potential noise from the daily frequency regressions.

The results are reported in the appendix in Table A.4 and Figure A.2 and are broadly consistent with the results from the daily analysis. The results indicate that the effect of relative COVID-19 cases loads mostly contemporaneously, with little effect coming through future exchange rate changes. Furthermore, the effect is driven primarily through U.S. rather than foreign cases.

In summary, we conduct several robustness exercises probing the main result concerning the effect of COVID-19 cases on the dynamics of the exchange rate. We find evidence that when COVID-19 was most salient in the summer of 2020, the effect of relative COVID-19 cases was particularly pronounced. This result is also consistent with the evidence we find concerning the mitigating role played by vaccinations in 2021. Finally, we find consistent and robust evidence for our main result in monthly-frequency regressions.

[4]See, e.g., Engel, Kazakova, Wang, and Xiang (2022), who show that the inflation differentials explain excess returns of the U.S. dollar against a set of major currencies in the developed world. In our sample, inflation differentials were not statistically significant.

4 Theoretical Model

In this paper, we model the COVID-19 crisis as an asymmetric shock to nontradeable labor supply and an expenditure switching shock away from nontradeable towards tradeable consumption. Our choice to model the macroeconomic impacts of the pandemic stems from the data and the empirical literature on the impacts of the COVID-19 pandemic on macroeconomic outcomes, as we will discuss in section 5.2 below. In the model, the nontradeable labor supply shock endogenously generates spillovers to the tradeable sector via input-output linkages and to the foreign country via supply chain impacts. The complete production network is illustrated in Figure 4. Specifically, due to the imposition of lockdown and social distancing policies or simply due to a reduced willingness to engage in in-person interaction because of the fear of infection, the pandemic effectively shifted consumption away from nontradeable goods and reduced the supply of usable labor across sectors with an asymmetrical impact on economic activities more labor-intensive and requiring more in-person interaction.

We use as a starting point the two-country, two-sector general equilibrium open-economy model laid out in Berka, Devereux, and Engel (2018). We augment their model along three dimensions. First, we introduce endogenous deviations from uncovered interest parity via portfolio adjustment costs, as in Benigno (2009) and Schmitt-Grohé and Uribe (2022), instead of modeling a currency union. Second, following Horvath (2000) and Cardi and Restout (2015), we introduce imperfect substitutability in hours worked in the tradeable and nontradeable sectors. The Home and Foreign countries are fully symmetric, so the following exposition focuses on the Home country. Foreign variables are denoted with an $*$.

4.1 Households

The Home economy is populated by a large number of identical households with measure one, who choose consumption, C_t, and hours worked in the tradeable (L_{Ht}) and nontradeable (L_{Nt}) sectors to maximize the lifetime utility

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{\mathcal{L}_t^{1+\psi}}{1+\psi} \right), \tag{6}$$

where C_t is the Home consumption basket, which is an aggregation of tradeable (C_{Tt}) and nontradeable (C_{Nt}) consumption baskets, and $\mathcal{L}_t$ aggregates hours worked across the tradeable and nontradeable sectors. In particular, the tradeable consumption bundle is an aggregation of Home and Foreign retail consumption goods, each assembled using a combination of traded and nontraded inputs to be specified later. The overall consumption basket is

$$C_t = \left(\nu_t^{1/\theta} C_{Tt}^{1-1/\theta} + (1-\nu_t)^{1/\theta} C_{Nt}^{1-1/\theta}\right)^{\frac{\theta}{\theta-1}},$$

where θ is the elasticity of substitution between tradeable and nontradeable consumption, and ν_t is the time-varying share of tradeable consumption. The corresponding static demand equations are

$$\begin{aligned} C_{Tt} &= \nu_t \left(\frac{P_{Tt}}{P_t}\right)^{-\theta} C_t, \text{ and} \\ C_{Nt} &= (1-\nu_t) \left(\frac{P_{Nt}}{P_t}\right)^{-\theta} C_t, \end{aligned} \tag{7}$$

where ν_t is the time-varying tradeable expenditure share. We assume that $\hat{\nu}_t \equiv \nu_t - \nu$ follows an auto-regressive process:

$$\hat{\nu}_t = \rho_\nu \hat{\nu}_{t-1} + e_{\nu t}. \tag{8}$$

4.1.1 Preferences over the tradeable consumption basket

The consumption of tradeables is an aggregation of Home and Foreign traded retail goods:

$$C_{Tt} = \left(\omega^{1/\lambda} C_{Ht}^{1-1/\lambda} + (1-\omega)^{1/\lambda} C_{Ft}^{1-1/\lambda}\right)^{\frac{\lambda}{\lambda-1}},$$

where λ is the elasticity of substitution between C_{Ht} and C_{Ft}, and ω is the weight assigned to Home traded goods. Notice that $\omega > 1/2$ implies that households display home bias in consumption.[5] Since distribution margins play a significant role in retail consumption (Goldberg and Campa, 2010), the retail consumption bundle of Home and Foreign goods combines traded and nontraded inputs, which are assembled according to

$$\begin{aligned} C_{Ht} &= \left(\kappa^{1/\mu} I_{Ht}^{1-1/\mu} + (1-\kappa)^{1/\mu} V_{Ht}^{1-1/\mu}\right)^{\frac{\mu}{\mu-1}}, \text{ and} \\ C_{Ft} &= \left(\kappa^{1/\mu} I_{Ft}^{1-1/\mu} + (1-\kappa)^{1/\mu} V_{Ft}^{1-1/\mu}\right)^{\frac{\mu}{\mu-1}}. \end{aligned}$$

Here, I_{Ht} (I_{Ft}) and V_{Ht} (V_{Ft}) are the Home (Foreign) traded and nontraded inputs, respectively, and μ measures the elasticity of substitution between traded and nontraded inputs. Thus, distribution services generate input-output linkages across sectors, capturing the realistic fact that tradeable consumption depends on distribution and other nontraded services

[5] i.e., they prefer consuming goods produced in their own country.

which are incorporated in the price of the retail consumption good.

The above assumptions on preferences imply the following static demand equations for Home and Foreign retail consumption:

$$\begin{aligned} C_{Ht} &= \omega \left(\frac{\tilde{P}_{Ht}}{P_{Tt}} \right)^{-\lambda} C_{Tt}, \text{ and} \\ C_{Ft} &= (1-\omega) \left(\frac{\tilde{P}_{Ft}}{P_{Tt}} \right)^{-\lambda} C_{Tt}, \end{aligned} \tag{9}$$

where $\tilde{P}_{Ht}$ and $\tilde{P}_{Ft}$ are the retail prices of Home and Foreign traded goods. The equations for Home and Foreign traded and nontraded inputs are analogous:

$$\begin{aligned} I_{Ht} &= \kappa\omega \left(\frac{P_{Ht}}{\tilde{P}_{Ht}} \right)^{-\mu} \left(\frac{\tilde{P}_{Ht}}{P_{Tt}} \right)^{-\lambda} C_{Tt}, \\ V_{Ht} &= (1-\kappa)\omega \left(\frac{P_{Nt}}{\tilde{P}_{Ht}} \right)^{-\mu} \left(\frac{\tilde{P}_{Ht}}{P_{Tt}} \right)^{-\lambda} C_{Tt}, \\ I_{Ft} &= \kappa(1-\omega) \left(\frac{P_{Ft}}{\tilde{P}_{Ft}} \right)^{-\mu} \left(\frac{\tilde{P}_{Ft}}{P_{Tt}} \right)^{-\lambda} C_{Tt}, \text{ and} \\ V_{Ft} &= (1-\kappa)(1-\omega) \left(\frac{P_{Nt}}{\tilde{P}_{Ft}} \right)^{-\mu} \left(\frac{\tilde{P}_{Ft}}{P_{Tt}} \right)^{-\lambda} C_{Tt}. \end{aligned} \tag{10}$$

In turn, the above demand schedules imply the following ideal price indexes for consumption bundles:

$$\begin{aligned} P_t &= \left(\nu_t P_{Tt}^{1-\theta} + (1-\nu_t) P_{Nt}^{1-\theta} \right)^{\frac{1}{1-\theta}}, \\ P_{Tt} &= \left(\omega \tilde{P}_{Ht}^{1-\lambda} + (1-\omega) \tilde{P}_{Ft}^{1-\lambda} \right)^{\frac{1}{1-\lambda}}, \\ \tilde{P}_{Ht} &= \left(\kappa P_{Ht}^{1-\mu} + (1-\kappa) P_{Nt}^{1-\mu} \right)^{\frac{1}{1-\mu}}, \text{ and} \\ \tilde{P}_{Ft} &= \left(\kappa P_{Ft}^{1-\mu} + (1-\kappa) P_{Nt}^{1-\mu} \right)^{\frac{1}{1-\mu}}. \end{aligned} \tag{11}$$

Therefore, due to the input-output linkages structure, the retail prices of consumption of Home and Foreign goods—$\tilde{P}_{Ht}$ and $\tilde{P}_{Ft}$, respectively—depend not only on prices of traded inputs at the dock (P_{Ht} and P_{Ft}) but also on prices of nontraded inputs (P_{Nt}).

4.1.2 Imperfect labor substitutability

Our first departure from Berka, Devereux, and Engel (2018) is to introduce imperfect labor substitutability across the tradeable and nontradeable sectors. As we discussed before, the pandemic had asymmetric effects across sectors, and the short-run nature of lockdowns and social distancing measures imposed a higher cost on workers employed in activities more severely affected by those policies.[6] Following a specification close to Horvath (2000), we assume that hours worked across sectors are aggregated following a constant elasticity of substitution (CES) structure:

$$\mathcal{L}_t = \left[\phi^{-1/\gamma}(X_{Ht}L_{Ht})^{\frac{1+\gamma}{\gamma}} + (1-\phi)^{-1/\gamma}(X_{Nt}L_{Nt})^{\frac{1+\gamma}{\gamma}}\right]^{\frac{\gamma}{1+\gamma}}, \ \phi \equiv \kappa\nu,$$

where $\gamma > 0$ is the elasticity of substitution between traded and nontraded sectors, and X_{Ht} and X_{Nt} are sectoral and, thus, heterogeneous labor disutility shocks. Notice that, by imposing $X_{Ht} \equiv X_{Nt} = X_t$, the limiting case $\gamma \longrightarrow \infty$ nests the standard labor preferences structure followed by workhorse new Keynesian general equilibrium models, while the opposite case $\gamma \longrightarrow 0$ imposes perfect complements in preferences.[7]

The households' sectoral labor supply decisions follow:

$$\begin{aligned} L_{Ht} &= \phi(X_{Ht})^{-(1+\gamma)}\left(\frac{W_{Ht}}{W_t}\right)^{\gamma}\mathcal{L}_t, \text{ and} \\ L_{Nt} &= (1-\phi)(X_{Nt})^{-(1+\gamma)}\left(\frac{W_{Nt}}{W_t}\right)^{\gamma}\mathcal{L}_t. \end{aligned} \tag{12}$$

By combining equations, we get:

$$\frac{W_{Ht}}{W_{Nt}} = \left(\frac{\phi}{1-\phi}\right)^{-1/\gamma}\left(\frac{L_{Ht}}{L_{Nt}}\right)^{1/\gamma}\left(\frac{X_{Ht}}{X_{Nt}}\right)^{\frac{1+\gamma}{\gamma}}. \tag{13}$$ [8]

We normalize $X_{Ht} = 1$, so that X_{Nt} is interpreted as the relative labor disutility across sectors. Thus, deviations of X_{Nt} from the steady state level imply asymmetric effects of

[6] For a discussion in the closed economy macroeconomics literature about the importance of labor immobility across sectors for the propagation of supply shocks into demand, see Guerrieri, Lorenzoni, Straub, and Werning (2022).

[7] More generally, the aggregator $\mathcal{L} \equiv \mathcal{L}(L_H, L_N)$ has the following properties:

$$\partial\mathcal{L}(L_H, L_N)/\partial L_m > 0, \ \partial^2\mathcal{L}(L_H, L_N)/\partial L_{mt}^2 > 0, \text{ and } \partial^2\mathcal{L}(L_H, L_N)/\partial L_H \partial L_N < 0,$$

for $m = H, N$. So, the worker wants to minimize the total amount of hours supplied and has a preference for smoothing out the number of hours across sectors even in the presence of wage disparities.

[8] It follows from this equation that $\partial \log\left(L_{Ht}/L_{Nt}\right)/\partial \log\left(W_{Ht}/W_{Nt}\right) = \gamma$. Given our parametric restriction $\gamma > 0$, hours are substitutes across sectors.

labor disutility shocks across sectors. Since preferences are homothetic, total labor income is $W_{Ht}L_{Ht} + W_{Nt}L_{Nt} = \mathcal{W}_t\mathcal{L}_t$, so the *ideal* aggregate nominal wage index follows:

$$\mathcal{W}_t = \left[\phi\left(\frac{W_{Ht}}{X_{Ht}}\right)^{1+\gamma} + (1-\phi)\left(\frac{W_{Nt}}{X_{Nt}}\right)^{1+\gamma}\right]^{\frac{1}{1+\gamma}}. \tag{14}$$

Notice that, according to equation (14), an increase in labor disutility across sectors produces a decrease in the aggregate nominal wage perceived by households. Finally, we assume that $\chi_{Nt} \equiv \log(X_{Nt})$ follows an auto-regressive process:

$$\chi_{Nt} = (1-\rho_{\chi_N})\chi_N + \rho_{\chi_N}\chi_{Nt-1} + e_{Nt}, \tag{15}$$

which, together with equation (8), summarizes the exogenous processes we consider in the model. Given the lifetime utility function defined in (6), the Home households' aggregate labor supply decision is summarized by

$$C_t^{\sigma}\mathcal{L}_t^{\psi} = \frac{\mathcal{W}_t}{P_t}. \tag{16}$$

4.1.3 Asset markets structure

We also introduce incomplete markets. In particular, households are permitted to trade Home and Foreign bonds, but they must pay a portfolio-adjustment cost in Foreign bond holdings. Even though a few papers have explicitly microfounded shocks to the UIP (Gabaix and Maggiori, 2015; Fanelli and Straub, 2021; Itskhoki and Mukhin, 2021), Yakhin (2022) have theoretically demonstrated that segmented market models are isomorphic to models encompassing portfolio adjustment costs as we introduce here. The representative household's budget constraint is:

$$P_tC_t + \frac{\mathcal{E}_tB_{Ft}}{1+i_t^*} + \frac{B_{Ht}}{1+i_t} = \mathcal{W}_t\mathcal{L}_t + \mathcal{E}_t\left(B_{Ft-1} - \varphi\left(B_{Ft-1}\right)\right) + B_{Ht-1} + \Pi_t, \tag{17}$$

where $\mathcal{E}_t$ is the nominal exchange rate, B_{Ht} and B_{Ft} are, respectively, the Home and Foreign bonds held by households in the Home country, Π_t are Home firms' profits distributed to households, and $\varphi\left(B_{Ft}\right)$ is the portfolio-adjustment cost paid on Foreign bond holdings. $\varphi\left(\cdot\right)$ is a convex function satisfying $\varphi\left(\bar{B}_F\right) = \varphi'\left(\bar{B}_F\right) = 0$, where $\bar{B}_F = 0$ is the Home country's steady-state position in the Foreign bond.[9] Home and Foreign bonds pay nominal

[9] In our two-country setting, we impose complete symmetry in the Foreign household's problem so that Foreign households also pay a portfolio-adjustment cost on their Home bond holdings. An implication of the UIP deviation for the Home and Foreign countries is $B_{Ht}^* + B_{Ft} = 0$. More details on this equilibrium condition

interest rates i_t and i_t^*, which are set by the central banks in the Home and Foreign countries, respectively.

The optimality conditions for bond holdings yield the following Euler equations

$$\begin{aligned} &\mathbb{E}_t\left[\beta\left(\frac{C_t}{C_{t+1}}\right)^{\sigma}\left(\frac{P_t}{P_{t+1}}\right)(1+i_t)\right]=1, \text{ and} \\ &\mathbb{E}_t\left[\beta\left(\frac{C_t}{C_{t+1}}\right)^{\sigma}\left(\frac{P_t}{P_{t+1}}\right)\left(\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right)(1+i_t^*)\left(1-\varphi'(B_{Ft})\right)\right]=1. \end{aligned} \tag{18}$$

Together, they imply the uncovered interest rate differential (UID):

$$\mathbb{E}_t\left\{\beta\left(\frac{C_t}{C_{t+1}}\right)^{\sigma}\left(\frac{P_t}{P_{t+1}}\right)\left[(1+i_t)-\left(\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right)(1+i_t^*)\left(1-\varphi'(B_{Ft})\right)\right]\right\}=0, \tag{19}$$

After log-linearizing (19), we obtain

$$i_t - i_t^* - \mathbb{E}_t\left[\Delta\varepsilon_{t+1}\right] = -\varphi''\left(\bar{B}_F\right)\left(B_{Ft}-\bar{B}_F\right),$$

where $\Delta\varepsilon_{t+1} \equiv \log(\mathcal{E}_{t+1}) - \log(\mathcal{E}_t)$ is the nominal exchange rate depreciation, and $-\varphi''\left(\bar{B}_F\right)\left(B_{Ft} - \bar{B}_F\right)$ gives the deviation from uncovered interest rate parity.

4.2 Firms

The production sector follows a standard structure in the new Keynesian paradigm, but we assume local currency pricing (LCP) in our baseline structure, so exporters will set prices in the currency of the destination market. Firms in the tradeable and nontradeable sectors operate in monopolistic competition by producing differentiated goods according to a linear technology in labor:

$$Y_{Ht}(\mathrm{i}) = A_H L_{Ht}(\mathrm{i}), \text{ and } Y_{Nt}(\mathrm{i}) = A_N L_{Nt}(\mathrm{i}), \tag{20}$$

where $\mathrm{i} \in [0,1]$, and A_H and A_N are sectoral aggregate productivity levels in the traded and nontraded sectors, respectively. Because our analysis is short-run in nature, we abstract away relative productivity changes across sectors.[10] In each country, firms in the tradeable sector set prices in the currency of the destination market and follow a Calvo price-adjustment technology in which the price adjustment probability, $1 - \zeta$, is homo-

can be found in Appendix A.8.

[10]Brinca, Duarte, and e Castro (2021) find supportive evidence that the pandemic mostly affected hours worked through labor supply rather than labor demand.

geneous across sectors H and N. In a flexible price environment, the constant elasticity of substitution between varieties within each sector implies that firms set their prices equal to their marginal cost adjusted by a constant markup:

$$P_{Nt}^{flex} = \left(\frac{\theta}{\theta - 1}\right)\left(\frac{W_{Nt}}{A_N}\right) \qquad P_{Ht}^{flex} = \left(\frac{\mu}{\mu - 1}\right)\left(\frac{W_{Ht}}{A_H}\right) \qquad P_{Ht}^{*,flex} = \left(\frac{\mu}{\mu - 1}\right)\left(\frac{W_{Ht}}{\mathcal{E}_t A_H}\right)$$

where $\Omega \equiv \theta/(\theta - 1)$ is the constant mark-up over marginal cost depending on the elasticity of substitution between varieties. Therefore, whenever firms can adjust their prices, the reset price is equal to a present discounted value of current and anticipated future flexible prices:

$$P_{Nt} = \frac{\mathbb{E}_t \sum_{\tau=t}^{\infty} \Gamma_{N,\tau} P_{N,\tau}^{flex}}{\mathbb{E}_t \sum_{\tau=t}^{\infty} \Gamma_{N,\tau}}, \qquad P_{Ht} = \frac{\mathbb{E}_t \sum_{\tau=t}^{\infty} \Gamma_{H,\tau} P_{H,\tau}^{flex}}{\mathbb{E}_t \sum_{\tau=t}^{\infty} \Gamma_{H,\tau}}, \qquad P_{Ht}^{*} = \frac{\mathbb{E}_t \sum_{\tau=t}^{\infty} \Gamma_{H,\tau}^{*} \mathcal{E}_\tau P_{H,\tau}^{*,flex}}{\mathbb{E}_t \sum_{\tau=t}^{\infty} \Gamma_{H,\tau}^{*} \mathcal{E}_\tau}$$

where Γ_{Nt} and Γ_{Tt} are the adjusted stochastic discount factors that incorporate the Calvo probability of not resetting the price each period. Since we assume an LCP paradigm, the law of one price (LOP) does not hold for traded goods prices at the dock, and, as we will discuss further in the section below, the LCP assumption has relevant implications for the quantitative performance of the model.[11]

4.3 Market clearing conditions and monetary policy

Given the above market structure, the goods market-clearing conditions in the Home and Foreign countries are

$$\begin{aligned} Y_{Ht} &= I_{Ht} + I_{Ht}^{*}, \\ Y_{Nt} &= V_{Ht} + V_{Ft} + C_{Nt}, \\ Y_{Ft}^{*} &= I_{Ft}^{*} + I_{Ft}, \text{ and} \\ Y_{Nt}^{*} &= V_{Ft}^{*} + V_{Ht}^{*} + C_{Nt}^{*}. \end{aligned} \tag{21}$$

Bond market-clearing conditions imply

$$B_{Ft} + B_{Ht}^{*} = 0, \tag{22}$$

so that the net foreign asset position of the Home country is given by $\mathcal{E}_t B_{Ft} - B_{Ht}^{*}$. We

[11]Even under a producer currency pricing (PCP) assumption in which the LOP holds for traded goods prices at the dock, violations of LOP would still occur in retail tradeable prices due to the presence of nontraded distribution services.

define the real exchange rate as $Q_t \equiv \mathcal{E}_t P_t^* / P_t$. We close the model with the Home country's budget constraint, in which we substitute firms' profits:

$$P_t C_t + \frac{\mathcal{E}_t B_{Ft}}{1+i_t^*} - \frac{B_{Ht}^*}{1+i_t} = P_{Ht} Y_{Ht} + P_{Nt} Y_{Nt} + \mathcal{E}_t (B_{Ft-1} - \varphi(B_{Ft-1})) - B_{Ht-1}^*. \tag{23}$$

Finally, we close the model by introducing a Taylor-type interest-rate feedback rule:

$$\begin{aligned} i_t &= \phi_i i_{t-1} + (1-\phi_i)(\rho + \phi_\pi \pi_t + \phi_y \hat{y}_t) \text{ and} \\ i_t^* &= \phi_{i^*} i_{t-1}^* + (1-\phi_{i^*})(\rho^* + \phi_\pi^* \pi_t^* + \phi_y^* \hat{y}_t^*), \end{aligned} \tag{24}$$

where $\pi_t \equiv \log(P_t) - \log(P_{t-1})$, and $\hat{y}_t \equiv \phi \hat{y}_{Ht} + (1-\phi)\hat{y}_{Nt}$. $\hat{y}_{Ht}$ and $\hat{y}_{Nt}$ represent, respectively, log-deviations in Y_{Ht} and Y_{Nt} from their corresponding deterministic steady-state values. ϕ_i is the degree of interest rate smoothing, and ϕ_π (ϕ_y) represents the long-run response of the nominal interest rate to a permanent 1-percentage point (1-percent) increase in inflation (output) relative to its steady-state value.[12] The introduction of persistence in monetary policy decisions is particularly realistic in our context as the model is in monthly frequency. A detailed model derivation is laid out in the Appendix A.7.

5 Calibration

5.1 Preference and technology parameters

Table 3 lists all the parameter values used in the simulations. While most parameter values we use are standard in the literature, others deserve further discussion. The weight of distribution services in the tradeable consumption basket $(1-\kappa)$ follows Goldberg and Campa (2010), who find a share of 43% of wholesale and retail services in household consumption, thus giving a value $\kappa = 0.6$. Considering the average ratio of exports plus imports over GDP in the U.S. (25%), we set $\phi \equiv \kappa \nu = 0.25$, which is also consistent with the estimated share of tradeable GDP in Obstfeld and Rogoff (2005). The values assigned for κ and ϕ imply that the share of tradeable goods in the consumption basket (ν) is 0.4. Finally, we calibrate the weight of Home traded goods in the tradeable consumption basket (ω) to 0.6.

Concerning the parameter γ governing imperfect labor substitutability, Cardi and Restout (2015) estimated a value of 1.8 for the United States, so we set $\gamma = 2$. Estimates

[12]While the empirical evidence also suggests that central banks are often not forward-looking, De Grauwe and Ji (2020) theoretically argue that the forward-looking Taylor rule leads to greater output and inflation variability in a regime of extreme uncertainty. The authors show that the central bank should optimally use currently observed output and inflation instead to set the interest rate.

of the elasticity of substitution between tradeable and nontradeable goods range between 0.5 and 1.3.[13] We set it to $\mu = 1.05$, which corresponds to a value towards the higher end of those values. The calibration of the elasticity of substitution between Home and Foreign retail traded goods ($\lambda = 8$) follows Berka, Devereux, and Engel (2018). We calibrate the parameter governing portfolio adjustment costs (φ) to 0.0014 so that the model matches the standard deviation of the net foreign asset position over quarterly GDP in the U.S.[14] The discount factor was converted to a monthly frequency, implying an annual real interest rate of 4 percent.

Finally, we calibrated the parameters of the monetary policy rule according to the empirical evidence found for the U.S., adjusting them to a monthly frequency accordingly. In particular, we set $\phi_\pi = 1.5$, $\phi_y = 0.5/12 = 0.04$, and $\phi_i = 0.965$, which gives a quarterly persistence of 0.9 to nominal interest rates as in Coibion and Gorodnichenko (2011).

5.2 Labor disutility and tradeable expenditure share processes

All data are in monthly frequency, and we applied the Hamilton (2017) filtering method to extract cyclical components from the seasonally adjusted series. In particular, we used the aggregate weekly hours and average hourly earnings from the Bureau of Labor Statistics (BLS), and the personal consumption expenditures on services excluding financial services and insurance from the Bureau of Economic Analysis (BEA). From the BLS, we considered the total private sector, durable goods, and other services. The choice of durable goods and other services was an attempt to proxy hours worked in the tradeable and nontradeable sectors, respectively.[15]

Figures 5a and 5b present the resulting cyclical components of the relative labor disutility and tradeable expenditure share processes, respectively. In particular, to extract the former process from the observable time series, we used the log-linearized optimality conditions (13) in the baseline model and the standard consumption-hours choice in a model with perfect labor mobility:

$$\chi_{Nt} = \frac{\gamma(\hat{w}_{Nt} - \hat{w}_{Ht}) - (\hat{\ell}_{Nt} - \hat{\ell}_{Ht})}{1 + \gamma}, \tag{25}$$

Both figures display a pronounced increase between 2020 and 2021, suggesting a sizable

[13] See Obstfeld and Rogoff (2005) for a discussion.

[14] In the model, the NFA is given by $\mathcal{E}_t B_{Ft} - B^*_{Ht}$. The standard deviation of the quarterly NFA-GDP ratio is 4.5% in 2006q1-2019q4 using data from the Bureau of Economic Analysis (BEA).

[15] To compare the predictions of our baseline model to standard workhorse general equilibrium models, we also report results assuming a homogeneous adverse labor supply shock across the board, denoted by χ_t, in figure A.7.

increase in the relative labor disutility and shift away from nontradeable towards tradeable consumption. Given these estimates, we computed the pre-COVID (i.e. up to December 2019) autocorrelation associated to each of these three stochastic processes, and their implied standard deviation:

$$\begin{aligned} \hat{\chi}_{Nt} &= \rho_{\chi_N}\hat{\chi}_{Nt-1} + \sigma_{\chi_N} e_{Nt}, \text{ and} \\ \hat{v}_t &= \rho_v \hat{v}_{t-1} + \sigma_v e_{vt} \end{aligned} \tag{26}$$

Finally, to connect these exogenous autoregressive processes to the COVID-19 shock, we imposed an AR(1) structure to the end-of-month number of COVID-19 cases in the U.S. relative to the other countries in our sample, and estimated the following specification:

$$\Delta log(rel\ tot\ cases_{it}) = \rho^{COVID}\Delta log(rel\ tot\ cases_{it-1}) + e_{it}^{COVID}, \tag{27}$$

Given the estimated autocorrelation coefficients, we simulated a one percent increase in e_t^{COVID} and fed the exogenous processes $\hat{\chi}_{Nt}$ and $\hat{v}_t$.

6 Simulation Results

In the first set of figures 6 and 7, we present the monthly frequency responses to a one percent increase in relative COVID-19 cases for a two-year horizon, which roughly matches the actual duration of the COVID-19 pandemic between 2020 and 2021.

In Figure 6, the increase in relative cases raises inflation differentials (top first panel) by 0.009 percent on impact in the baseline model, while inflation differentials increase by 0.012 percent in the model including the effect on labor supply only (dashed blue line), as the expenditure shock dampens the inflationary response associated with the drop in hours worked. Because monetary policy response is sluggish, nominal interest rate differentials display a muted contemporaneous response to the shock (second panel on the top), turning negative after six months in the full model as a result of the smaller inflationary response combined with a more pronounced recessionary effect on output, as shown in the third bottom panel. In turn, real interest rate differentials move against the Home currency (third top panel) so that it displays negative excess returns on impact. In the full model, real returns differentials are negative throughout the two-year time horizon considered, while in the alternative specification, real returns turn positive roughly a year after the shock.

As a result, the nominal exchange rate (bottom first panel) depreciates by 0.18 percent on impact under the baseline model, appreciating very gradually afterward. On the other hand, under the alternative model, the depreciation is 0.05 percent on impact, increasing to 0.09 percent after two years. The sizable contrast between these two responses is due to the differences in dynamics of the ex-ante real returns differentials. In the former case, real returns are negative throughout the horizon considered, while in the latter, it switches signs a year after.

Finally, the real exchange rate contemporaneously depreciates in both specifications, but it becomes appreciated after six months in the alternative model due to the increase in the nontradeable relative price. In the full model, however, the expenditure switching towards tradeable consumption offsets this effect, inducing a comovement between nominal and real exchange rates for the whole simulation horizon.

In Figure 7, we present the baseline model responses of the terms-of-trade, and hours worked, real wages, and inflation across sectors, and the COVID-19 shock with associated responses of the labor disutility and expenditure switching exogenous processes. Since the shock induces a deterioration of the terms-of-trade (first panel), labor demand rises in the tradeable sector. On the other hand, nontradeable hours decline due to the increase in relative labor disutility. Both effects raise real wages across the board, increasing firms' marginal costs and, thus, leading to inflation.

As a matter of comparison, we also present simulations under PCP in figures A.8 and A.9 in the Appendix. Under this currency paradigm, the inflationary response associated with the COVID-19 shock is more pronounced, as foreign firms set prices in their currency when exporting to the Home economy. The mechanism, however, leading to an exchange rate depreciation remains intact, and the Home currency depreciates by 0.10 percent on impact. Finally, we also reported responses assuming a homogeneous labor disutility across sectors in Figure A.7 in the Appendix. Again, though the mechanism remains the same, the responses to the shock become sizable under this specification since the variance and persitence associated with the implied labor disutility are quite pronounced, as one can observe in Figure A.6.

6.1 Empirical Evidence for the Theoretical Mechanism

As discussed in the previous section, the critical mechanism underpinning the exchange rate depreciation relies upon a relatively inflationary response to the COVID-19 shock, coupled with a sluggish monetary policy reaction in raising nominal interest rates. Both impacts combined induce negative real return differentials and, thus, a depreciation of the Home currency. This section provides evidence substantiating this theoretical mechanism inducing a nominal exchange rate depreciation.

In other words, did an increase in relative COVID-19 cases actually produce a drop in employment mirrored by an increase in inflation differentials and muted responses in interest rates? To address this question, we estimate a series of univariate, fixed-effects panel regressions, sharpening the focus on the empirical correlations between innovations in relative COVID between the U.S. and foreign countries and the corresponding movements in these variables. In the following analysis, we use a monthly-frequency dataset when possible to be consistent with the monthly calibration of the model introduced in the preceding sections.

Moreover, to compare the model predictions with the empirical correlations, we produced 10,000 observations using Monte Carlo simulations and computed analogous regression coefficients. For that purpose, we estimated two COVID-19 AR(1) processes, one for the U.S. and the other for the "rest-of-the-world", comprising the 35 countries in our sample pooled together.

Table 4 portrays the empirical correlations between the key variables underpinning the mechanism driving the exchange rate depreciation. Column (1) takes month-on-month inflation differentials on the left-hand side of the estimating equation. We find that a one-percent increase in COVID cases in the U.S. relative to foreign countries produces a 0.014 percent increase in U.S. consumer prices relative to those in foreign countries. The result is statistically significant at the one-percent level and consistent with our finding that the COVID shock was relatively inflationary. Column (2) reports a null effect of a one-percent increase in relative COVID cases on 5-year nominal Treasury yield differentials. Because the point estimate is tiny in magnitude and not statistically different from zero, this result further supports a crucial element of our model mechanism that interest rates are sluggish. Column (3) reports the response of *ex-post* real interest rate differentials—constructed as the 5-year nominal yield less the month-on-month inflation differentials—to relative COVID. The point estimate equals -0.0143 and is statistically significant at the one-percent level, indicating that an increase in relative COVID cases was associated with a drop in real interest rate differential on average. The coefficients implied by the simulated data are quite close to the previous estimates. The crucial features to generating quantitatively consistent results in the model are first, the LCP paradigm, which dampens the model's inflationary response in comparison to PCP, and second, the large degree of price stickiness, which softens the price increase and makes it closer to the small coefficient found in the data.

For many countries in our sample, we could not acquire monthly data on employment. Therefore, we use a quarterly-frequency dataset in our study of employment differentials.

Despite having just under 200 observations in the estimating equation, we find a robust negative correlation between employment differentials and relative COVID, consistent with our finding that an increase in relative COVID led to a -.304 drop in relative employment. In the model, the coefficient estimated for output is -.382. In sum, we find supportive evidence that COVID was associated with a drop in employment that was relatively inflationary. The sluggish response in interest rates led to negative real return differentials and a depreciated exchange rate.

Using simulated data, we also computed the nominal exchange rate dynamic response to the relative increase in COVID-19. The results compared to the dynamic responses under the monthly-frequency empirical specification are shown in Figure 7. Even though the model-simulated data cannot capture the swing in the exchange rate's empirical response, it generally captures the depreciation over time well.

6.1.1 Model Performance in Small Samples

Finally, because we have a short time sample consisting of 18 months, we evaluate the model's performance in small samples instead of comparing empirical results to a large single time series as we did before. For that purpose, we simulated our two-country model 10,000 times, collecting an 18-month time series in each simulation. We then ran regressions for each simulated time series and computed histograms of the associated point estimates. The results are summarized in Figures 9. As we can see, the histogram modes get quite close to the empirical point estimates of the one-month ahead nominal exchange rate, inflation, nominal interest rate, and ex-post real returns differentials, while the tails of the distribution are often mostly inside the 95 percent estimates confidence intervals.

We also computed analogous histograms under PCP in Figure A.11, and for the monthly-frequency dynamic response of the exchange rate under the LCP and PCP paradigms, in which we cut the distribution at the 90^{th} and 10^{th} percentiles. Results are shown in figures A.12 and A.13, respectively. Under PCP, the model can still match the nominal exchange rate response, but the coefficients associated with the other variables are off the empirical estimates since the PCP paradigm induces a larger inflationary response to the COVID-19 shock. Concerning the exchange rate dynamic responses, though the simulated data can track the exchange rate response in the first four months under PCP or LCP, the coefficients get close to zero as the sample becomes severely short. However, except for the first coefficient under LCP, the empirical point estimates are always inside the histogram trimmed distribution.

7 Conclusion

Relating the forward-looking determination of exchange rates to COVID-19 indicators, we document that a one-percent increase in measures of relative COVID-19 cases depreciates the bilateral U.S. dollar exchange rates by up to 0.1 percent on impact. The depreciation persists and sometimes increases over a three-month horizon and is more pronounced during the first COVID-19 wave when the economic impacts of the pandemic were still very uncertain. These results are even more striking in light of the safe haven role of the U.S. dollar. We also document that the exchange rate depreciation becomes muted in the presence of higher vaccinations. We interpret that the statistically significant correlation between U.S. dollar bilateral exchange rates and COVID-19 measures stems from the unique characteristics of the global shock due to its heterogeneous impacts across countries, and the dataset, which makes use of a daily-frequency panel.

To rationalize these facts, we develop a two-country, two-sector (tradeable and nontradeable) general equilibrium open-economy model, embedding incomplete markets, endogenous deviations from the uncovered interest rate parity, input-output linkages, and imperfect labor substitutability across sectors. Due to the imposition of lockdown and social distancing policies, or simply because of the fear of infection, the pandemic effectively reduced the supply of usable labor. At the same time, it also shifted demand away from nontradeable toward tradeable consumption since nontradeable economic activities are generally labor-intensive and require more in-person interaction. Thus, modeling the pandemic as a mix of adverse supply and demand shocks, the model can quantitatively match several novel empirical findings, predicting a cumulative nominal exchange rate depreciation of 0.18 percent in a calibration to the U.S. economy.

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Tables and Figures

Table 1
The Contemporaneous Effect of Relative COVID Severity on the Nominal Exchange Rate: Daily Analysis

Notes: This table presents the results from the following regressions:

$$\Delta\varepsilon_{i;t-5,t} = \boldsymbol{\alpha}_i + \beta_1 \Delta rel\ cases_{i;t-5,t} + \beta_2 \Delta rel\ string_{i;t-5,t} + \beta_3 \log(VIX_t) + \beta_4 (y_t^{USA} - y_{i,t}) + u_{i,t} \text{ and}$$

$$\Delta\varepsilon_{i;t-5,t} = \boldsymbol{\alpha}_i + \gamma_1 \Delta cases_{t-5,t}^{USA} + \gamma_2 \Delta cases_{i;t-5,t} + \gamma_3 \Delta rel\ string_{i;t-5,t} + \gamma_4 \log(VIX_t) + \gamma_5 (y_t^{USA} - y_{i,t}) + u_{i,t},$$

where the outcome variable $\Delta\varepsilon_{i;t-5,t}$ is the change from $t-5$ to t weekdays in the U.S. dollar bilateral nominal exchange rate of country i; $\boldsymbol{\alpha}_i$ is a country fixed effect; $\Delta rel\ cases_{i;t-5,t}$ and $\Delta rel\ string_{i;t-5,t}$ are, respectively, the change from $t-5$ to t weekdays in the relative COVID cases and stringency indices between the U.S. and country i, as defined in (1); $\Delta cases_{t-5,t}^{USA}$ and $\Delta cases_{i;t-5,t}$ are, respectively, the change in cases from $t-5$ to t weekdays in the U.S. and country i; $\log(VIX_t)$ is the logarithm of the VIX; $(y^{USA} - y_i)$ is the 5-year treasury yield differential; and u_i is the error term. The outcome variable ε_i is defined as the price of country i's currency in terms of U.S. dollars, implying that an increase in ε_i is a *depreciation* of the U.S. dollar against country i's currency. The sample period runs from June 1, 2020 until November 30, 2021. Regressions are weighted by trade weights. *, **, and *** represent statistical significance at the 10-, 5-, and 1-percent level, respectively. Standard errors are robust to heteroskedastic autocorrelation and spatial correlation (Driscoll and Kraay, 1998).

	(1)	(2)
$\Delta rel\ cases_{i;t-5,t}$	0.026**	
	(0.011)	
$\Delta cases_{t-5,t}^{USA}$		0.111***
		(0.023)
$\Delta cases_{i;t-5,t}$		-0.003
		(0.009)
$\Delta rel\ string_{i;t-5,t}$	-0.005	-0.004
	(0.005)	(0.004)
$\log(VIX_t)$	-0.002	-0.012***
	(0.003)	(0.004)
$y_t^{USA} - y_{i,t}$	-0.005***	-0.003**
	(0.001)	(0.001)
Const.	0.009	0.035
	(0.010)	(0.011)
Obs.	12,563	12,563
Country FE	✓	✓
Within R^2	0.047	0.131

Table 2
Robustness: Summer 2020 Wave

Notes: This table presents the results from a robustness test that restricts the sample to the summer 2020 wave (June 1, 2020 to August 31, 2020):

$$\Delta\varepsilon_{i;t-5,t} = \boldsymbol{\alpha}_i + \beta_1 \Delta rel\ cases_{i;t-5,t} + \beta_2 \Delta rel\ string_{i;t-5,t} + \beta_3 \log(VIX_t) + \beta_4 (y_t^{USA} - y_{i,t}) + u_{i,t} \text{ and}$$
$$\Delta\varepsilon_{i;t-5,t} = \boldsymbol{\alpha}_i + \gamma_1 \Delta cases_{t-5,t}^{USA} + \gamma_2 \Delta cases_{i;t-5,t} + \gamma_3 \Delta rel\ string_{i;t-5,t} + \gamma_4 \log(VIX_t) + \gamma_5 (y_t^{USA} - y_{i,t}) + u_{i,t},$$

where the outcome variable $\Delta\varepsilon_{i;t-5,t}$ is the change from $t-5$ to t weekdays in the U.S. dollar bilateral nominal exchange rate of country i; $\boldsymbol{\alpha}_i$ is a country fixed effect; $\Delta rel\ cases_{i;t-5,t}$ and $\Delta rel\ string_{i;t-5,t}$ are, respectively, the change from $t-5$ to t weekdays in the relative COVID cases and stringency indices between the U.S. and country i, as defined in (1); $\Delta cases_{t-5,t}^{USA}$ and $\Delta cases_{i;t-5,t}$ are, respectively, the change in cases from $t-5$ to t weekdays in the U.S. and country i; $\log(VIX_t)$ is the logarithm of the VIX; $(y^{USA} - y_i)$ is the 5-year treasury yield differential; and u_i is the error term. The outcome variable ε_i is defined as the price of country i's currency in terms of U.S. dollars, implying that an increase in ε_i is a *depreciation* of the U.S. dollar against country i's currency. Regressions are weighted by trade weights. *, **, and *** represent statistical significance at the 10-, 5-, and 1-percent level, respectively. Standard errors are robust to heteroskedastic autocorrelation and spatial correlation (Driscoll and Kraay, 1998).

	(1)	(2)
$\Delta rel\ cases_{i;t-5,t}$	0.0616***	
	(0.0231)	
$\Delta cases_{t-5,t}^{USA}$		0.114**
		(0.0520)
$\Delta cases_{i;t-5,t}$		-0.0297**
		(0.0126)
$\Delta rel\ string_{i;t-5,t}$	0.00638	0.00748
	(0.00662)	(0.00693)
$\log(VIX_t)$	-0.0229**	-0.0236***
	(0.00877)	(0.00823)
$y_t^{USA} - y_{i,t}$	-0.0132	-0.0116
	(0.00885)	(0.00906)
Obs.	2,146	2,146
Country FE	✓	✓
Within R^2	0.138	0.159

Table 3
Calibration

Households & firms			
Discount factor	β	0.997	
Coefficient of R.R.A.	σ	3	
Inverse of Frisch E.L.S.	ψ	2	
Degree of labor mobility	γ	2	Cardi & Restout (2015)
Weight of T in C	ν	0.4	
Weight on H goods in C_T	ω	0.6	
Weight of wholesale traded goods in C_T	κ	0.6	Campa & Goldberg (2010)
E.S. between traded and nontraded goods	μ	1.05	
E.S. between traded good and retail service	$\theta = \mu$	1.05	
E.S. between H and F retail traded goods	λ	8	Corsetti, Dedola, Leduc (2010)
Weight of tradeable output	$\phi = \nu\kappa$	0.25	Obstfeld & Rogoff (2005)
Calvo price stickiness prob.	ζ	0.9	Coibion & Gorodnichenko (2011)
Portfolio adjustment cost	φ	0.0014	
Shock persistence	$\rho_{\chi N}$	0.95	
Monetary policy			
Weight on inflation targeting	ϕ_π	1.5	
Weight on output	ϕ_y	0.04	
Degree of interest smoothing	ϕ_i	0.965	Coibion & Gorodnichenko (2011)
Exogenous processes			
Asymmetric labor disutility persistence	$\rho_{\chi N}$	.897	BLS data
Standard deviation	$\sigma_{\chi N}$	.005	
Tradeable expenditure share persistence	ρ_ν	.949	BEA data
Standard deviation	σ_ν	.003	
COVID-19 cases persistence	ρ^{COVID}	.377	OWID

Table 4
Empirical Correlations

Notes: This table presents the results from the following univariate panel regressions:

$$y_{i,t} = \boldsymbol{\alpha}_i + \beta \Delta rel\ cases_{i,t} + u_{i,t},$$

where the outcome variable $y_{i,t}$ is, in columns (1)–(4) respectively, the differentials between the U.S. and country i in month-on-month inflation differentials, 5-year nominal Treasury yields, *ex-post* real interest rates, and employment; $\boldsymbol{\alpha}_i$ is a country fixed effect; $\Delta rel\ cases_{i,t}$ is the last weekly change between months (or quarters, in column (4)) $t-1$ and t in relative COVID cases between the U.S. and country i, as defined in (1); and $u_{i,t}$ is an error term. Month-on-month inflation differentials are constructed using the CPI; nominal and real interest rate differentials are in monthly, decimal units, where real interest rate differentials are simply the 5-year nominal Treasury yield differentials less the monthly inflation differentials; finally, employment differentials are constructed by taking the difference in the cyclical components of log(Employment), which are extracted via Hamilton filtering. The sample period runs from June 2020 (2020:Q2) until November 2021 (2021:Q4). Regressions are weighted by trade weights. *, **, and *** represent statistical significance at the 10-, 5-, and 1-percent level, respectively. Standard errors are robust to heteroskedastic autocorrelation and spatial correlation (Driscoll and Kraay, 1998).

$y_{i,t} =$	(1) inflation differential $(\pi_t^{mom} - \pi_t^{*,mom})$	(2) 5-year Treasury yield differential $(y_t^{5y} - y_t^{*,5y})$	(3) *ex-post* real interest rate differential $(r_t - r_t^*)$	(4) employment differential $(\ell_t - \ell_t^*)$
$\Delta rel\ cases_{i,t}$	0.0137***	-0.0006	-0.0143***	-0.303***
	(0.0047)	(0.0008)	(0.0046)	(0.101)
Simulated data	0.0218	0.0019	-0.0199	-0.382
Obs.	625	625	625	189
Country FE	✓	✓	✓	✓
Within R^2	0.0516	0.0146	0.0539	0.289

Notes: This figure shows the trade-weighted nominal U.S. dollar index against emerging and developed economies from January 1, 2020 through November 30, 2021.

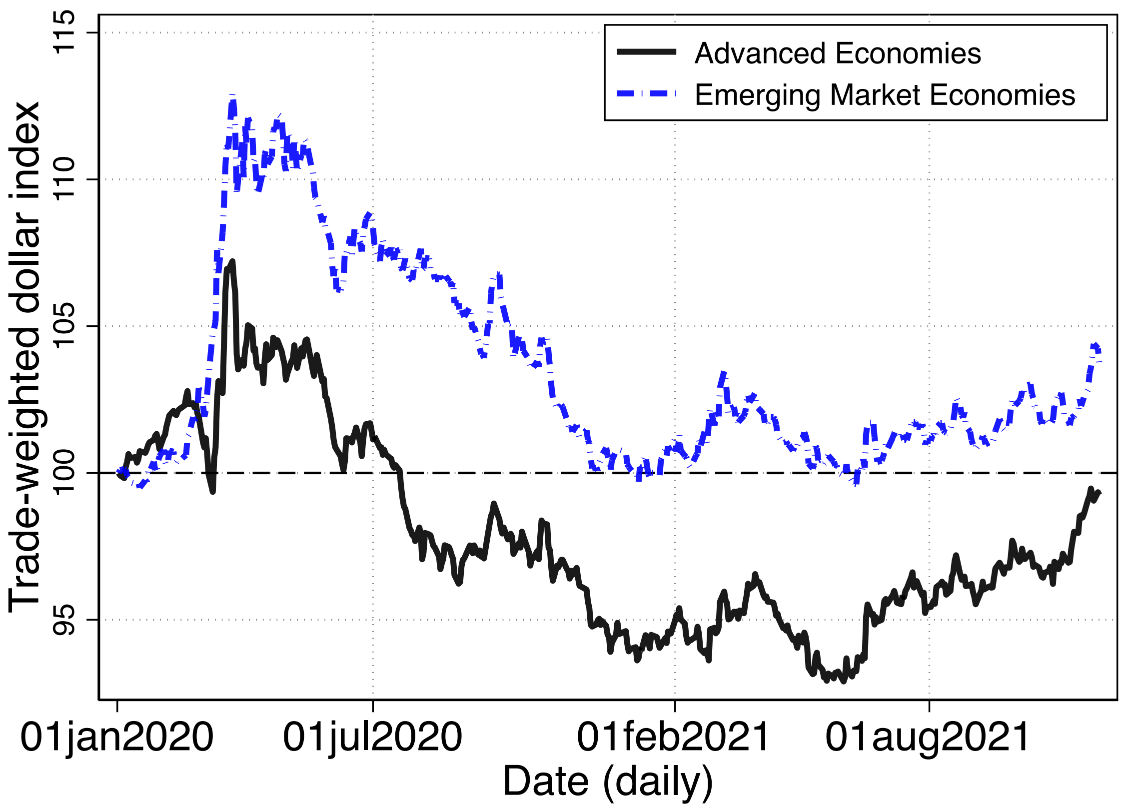
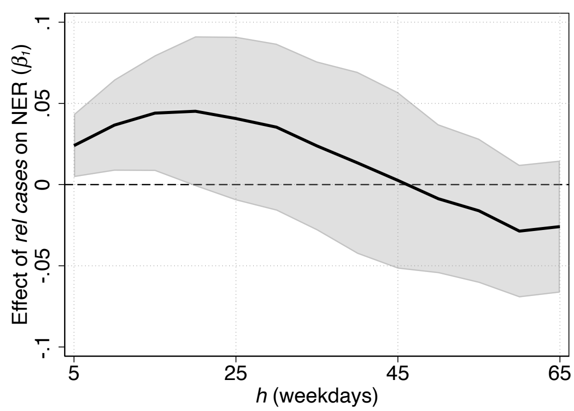


Figure 1: Depreciation of the U.S. Dollar During 2020

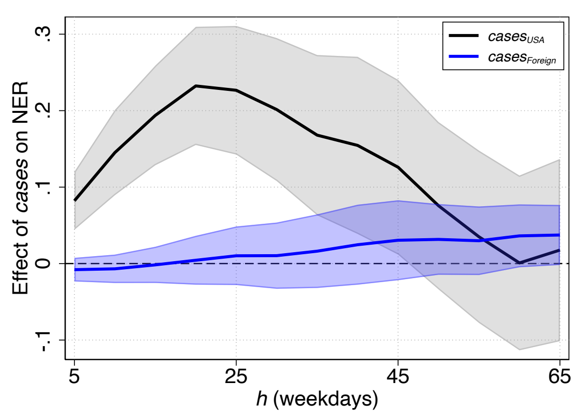
Notes: This figure plots the point estimates $\hat{\beta}_{1,h}$ (subfigure (a)) and $(\hat{\gamma}_{1,h},\hat{\gamma}_{2,h})$ (subfigure (b)) from the following specifications, for $h = 5, 10, \ldots 65$ weekdays:

$$\Delta\varepsilon_{i;t,t+h} = \boldsymbol{\alpha}_{i,h} + \beta_{1,h}\Delta rel\ cases_{i;t-5,t} + \beta_{2,h}\Delta rel\ string_{i;t-5,t} + \beta_{3,h}\log(VIX_t) + \beta_{4,h}(y_t^{USA} - y_{i,t}) + u_{i,t+h} \text{ and}$$
$$\Delta\varepsilon_{i;t,t+h} = \boldsymbol{\alpha}_{i,h} + \gamma_{1,h}\Delta cases_{t-5,t}^{USA} + \gamma_{2,h}\Delta cases_{i;t-5,t} + \gamma_{3,h}\Delta rel\ string_{i;t-5,t} + \gamma_{4,h}\log(VIX_t) + \gamma_{5,h}(y_t^{USA} - y_{i,t}) + u_{i,t},$$

where the outcome variable $\Delta\varepsilon_{i;t,t+h}$ is the change from t to $t+h$ weekdays in the U.S. dollar bilateral nominal exchange rate of country i; $\boldsymbol{\alpha}_i$ is a country fixed effect; $\Delta rel\ cases_{i;t-5,t}$ and $\Delta rel\ string_{i;t-5,t}$ are, respectively, the change from $t-5$ to t weekdays in the relative COVID cases and stringency indices between the U.S. and country i, as defined in (1); $\Delta cases_{t-5,t}^{USA}$ and $\Delta cases_{i;t-5,t}$ are, respectively, the change in cases from $t-5$ to t weekdays in the U.S. and country i; $\log(VIX_t)$ is the logarithm of the VIX; $(y^{USA} - y_i)$ is the 5-year treasury yield differential; and u_i is an error term. The outcome variable ε_i is defined as the price of country i's currency in terms of U.S. dollars, implying that an increase in ε_i is a *depreciation* of the U.S. dollar against country i's currency. The sample period runs from June 1, 2020 until November 30, 2021. Regressions are weighted by trade weights. The shaded area depicts 90% confidence intervals. Standard errors are robust to heteroskedastic autocorrelation and spatial correlation (Driscoll and Kraay, 1998).



(a) Relative Cases



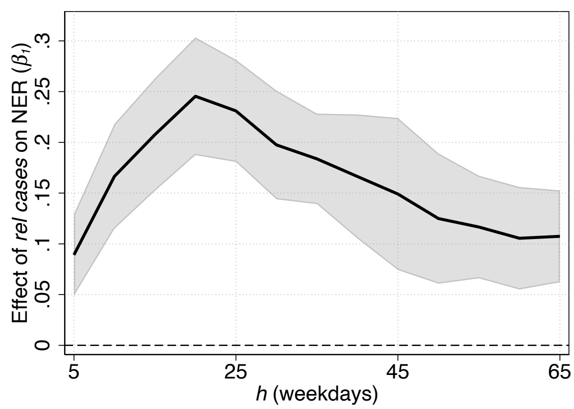
(b) U.S. versus Foreign Cases

Figure 2: The Effect of COVID Cases on the Dynamics of the Nominal Exchange Rate: Daily Analysis

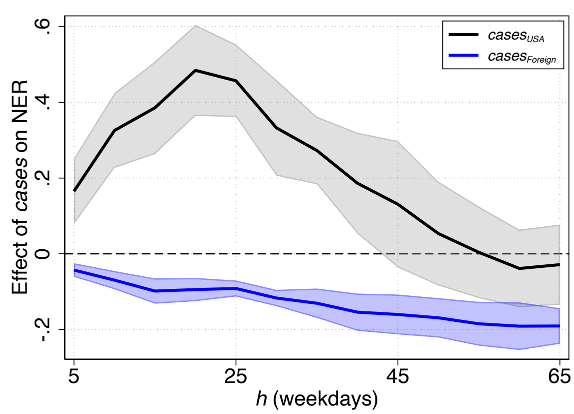
Notes: This figure plots the point estimates $\hat{\beta}_{1,h}$ (subfigure (a)) and $(\hat{\gamma}_{1,h}, \hat{\gamma}_{2,h})$ (subfigure (b)) over a subsample covering the first COVID-19 wave. The sample dates range from June 1, 2020 to August 31, 2020. Within this subsample, we run the following specifications, for $h = 5, 10, \ldots 65$ weekdays:

$$\Delta\varepsilon_{i;t,t+h} = \boldsymbol{\alpha}_{i,h} + \beta_{1,h}\Delta rel\ cases_{i;t-5,t} + \beta_{2,h}\Delta rel\ string_{i;t-5,t} + \beta_{3,h}\log(VIX_t) + \beta_{4,h}(y_t^{USA} - y_{i,t}) + u_{i,t+h} \quad \text{and}$$
$$\Delta\varepsilon_{i;t,t+h} = \boldsymbol{\alpha}_{i,h} + \gamma_{1,h}\Delta cases_{t-5,t}^{USA} + \gamma_{2,h}\Delta cases_{i;t-5,t} + \gamma_{3,h}\Delta rel\ string_{i;t-5,t} + \gamma_{4,h}\log(VIX_t) + \gamma_{5,h}(y_t^{USA} - y_{i,t}) + u_{i,t},$$

where the outcome variable $\Delta\varepsilon_{i;t,t+h}$ is the change from t to $t+h$ weekdays in the U.S. dollar bilateral nominal exchange rate of country i; $\boldsymbol{\alpha}_i$ is a country fixed effect; $\Delta rel\ cases_{i;t-5,t}$ and $\Delta rel\ string_{i;t-5,t}$ are, respectively, the change from $t-5$ to t weekdays in the relative COVID cases and stringency indices between the U.S. and country i, as defined in (1); $\Delta cases_{t-5,t}^{USA}$ and $\Delta cases_{i;t-5,t}$ are, respectively, the change in cases from $t-5$ to t weekdays in the U.S. and country i; $\log(VIX_t)$ is the logarithm of the VIX; $(y^{USA} - y_i)$ is the 5-year treasury yield differential; and u_i is an error term. The outcome variable ε_i is defined as the price of country i's currency in terms of U.S. dollars, implying that an increase in ε_i is a *depreciation* of the U.S. dollar against country i's currency. Regressions are weighted by trade weights. The shaded area depicts 90% confidence intervals. Standard errors are robust to heteroskedastic autocorrelation and spatial correlation (Driscoll and Kraay, 1998).



(a) Relative Cases



(b) U.S. versus Foreign Cases

Figure 3: The Effect of COVID Cases on the Dynamics of the Nominal Exchange Rate During the First COVID Wave

Notes: This figure portrays the network structure of the two-country, two sector model presented in Section 2. The economies are symmetric across the countries, with the nontradeable sector in blue, and the tradeable sector in red. There are linkages between the two sectors insofar as production in the nontradeable sector is used as input into consumption in the tradeable sector. There are also linkages across the two tradeable sectors between the countries. I_F represents home imports and foreign exports, and I_H^* represents foreign imports and home exports.

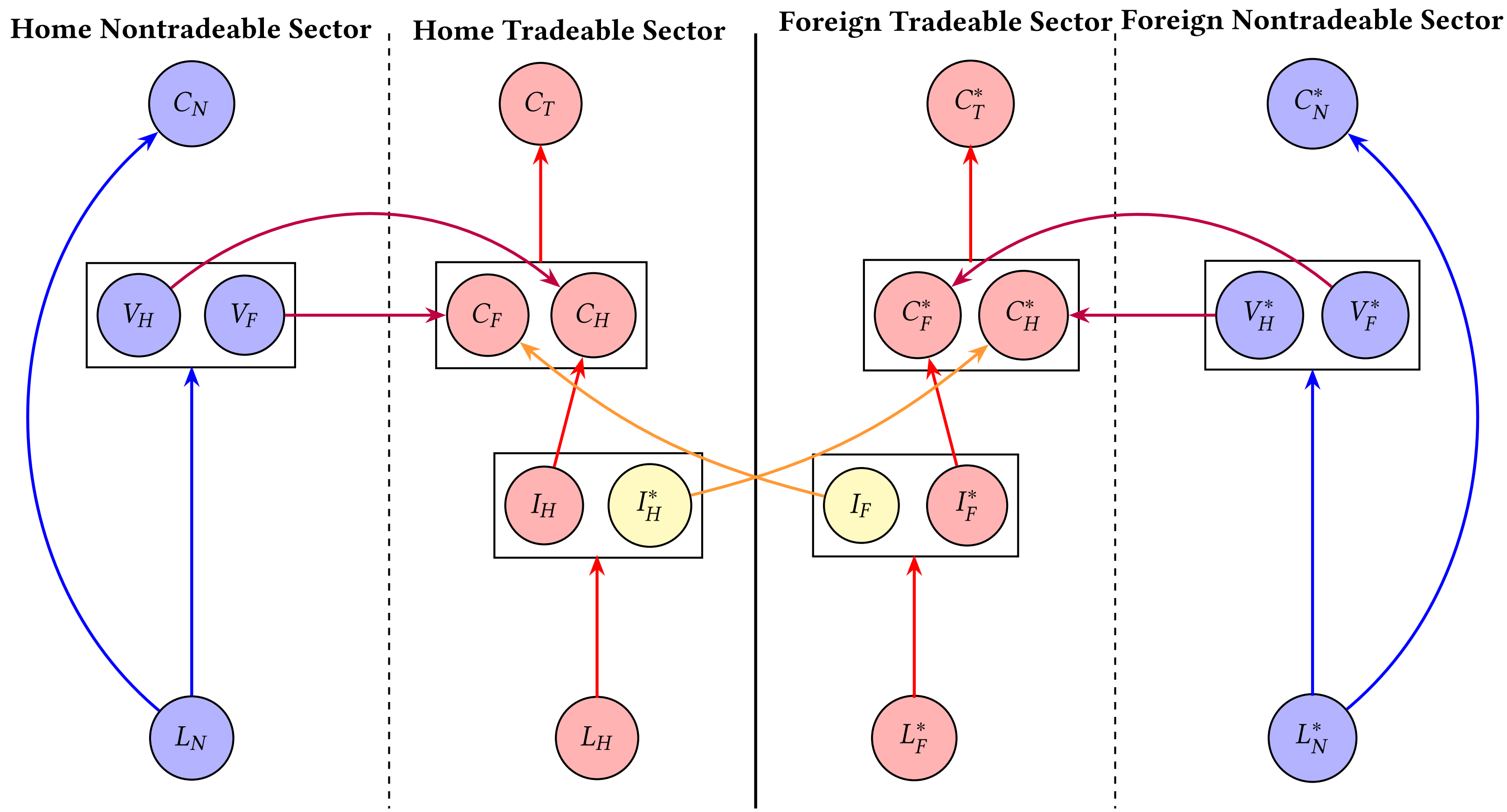
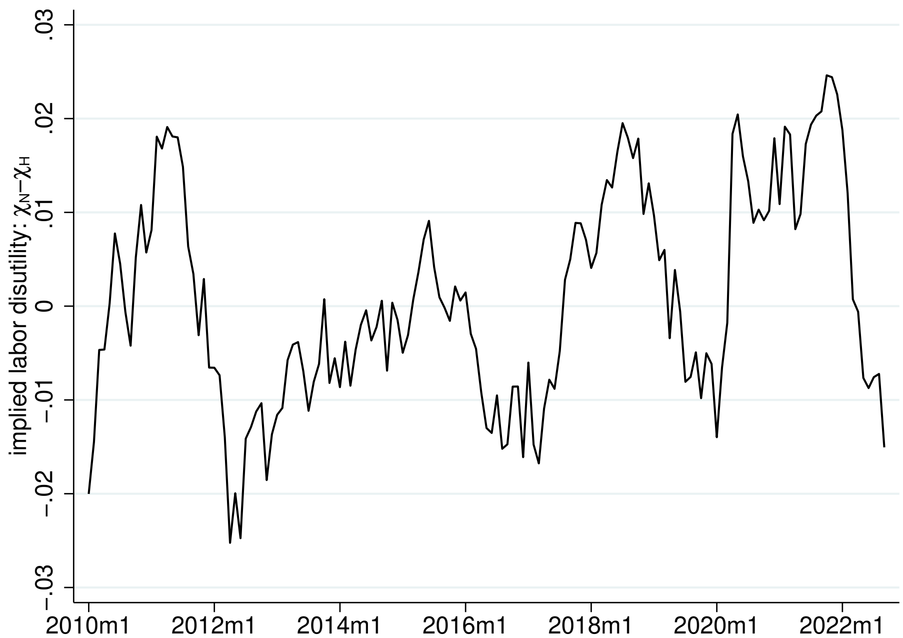


Figure 4: Network Structure of Economy

Calibration

Cyclical Components Extracted from the Data



(a) Asymmetric labor disutility: $\chi_N - \chi_H$

(b) Tradeable expenditure share, ν

Figure 5: Cyclical components of the implied relative labor disutility between tradeable and nontradeable sectors (panel (a)) and tradeable expenditure share (panel (b)).

Simulation Results

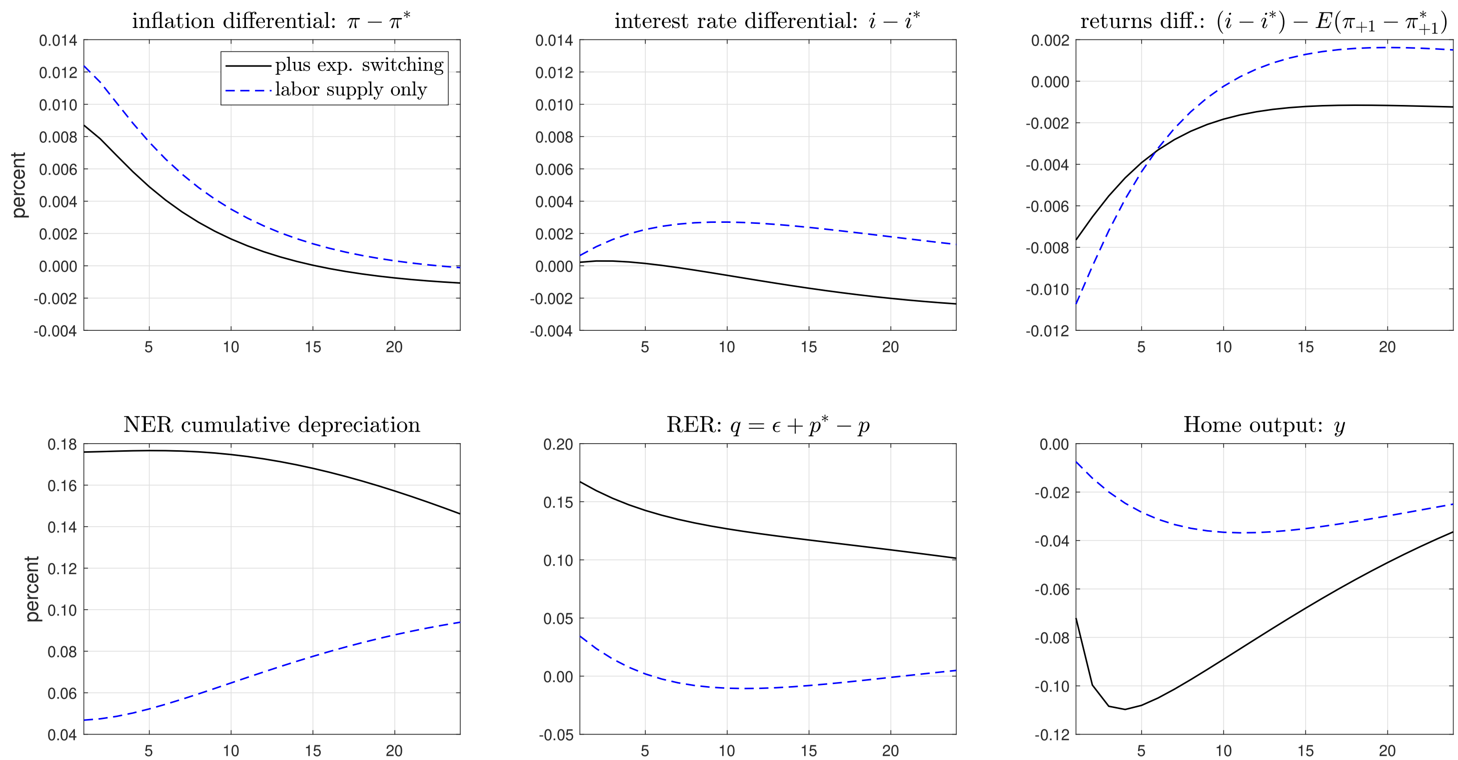


Figure 6: Impulse response functions to a one percent increase in relative COVID-19 cases. Solid and dashed lines present dynamics for the inflation differentials (first panel), nominal interest rate differentials (second panel), real returns differentials (third panel), cumulative nominal exchange rate depreciation (fourth panel), real exchange rate (fifth panel), and output (sixth panel) responses under the basline calibration in Table 3. Solid lines display dynamics under the full model while dashed lines consider the effects of COVID-19 on labor supply only.

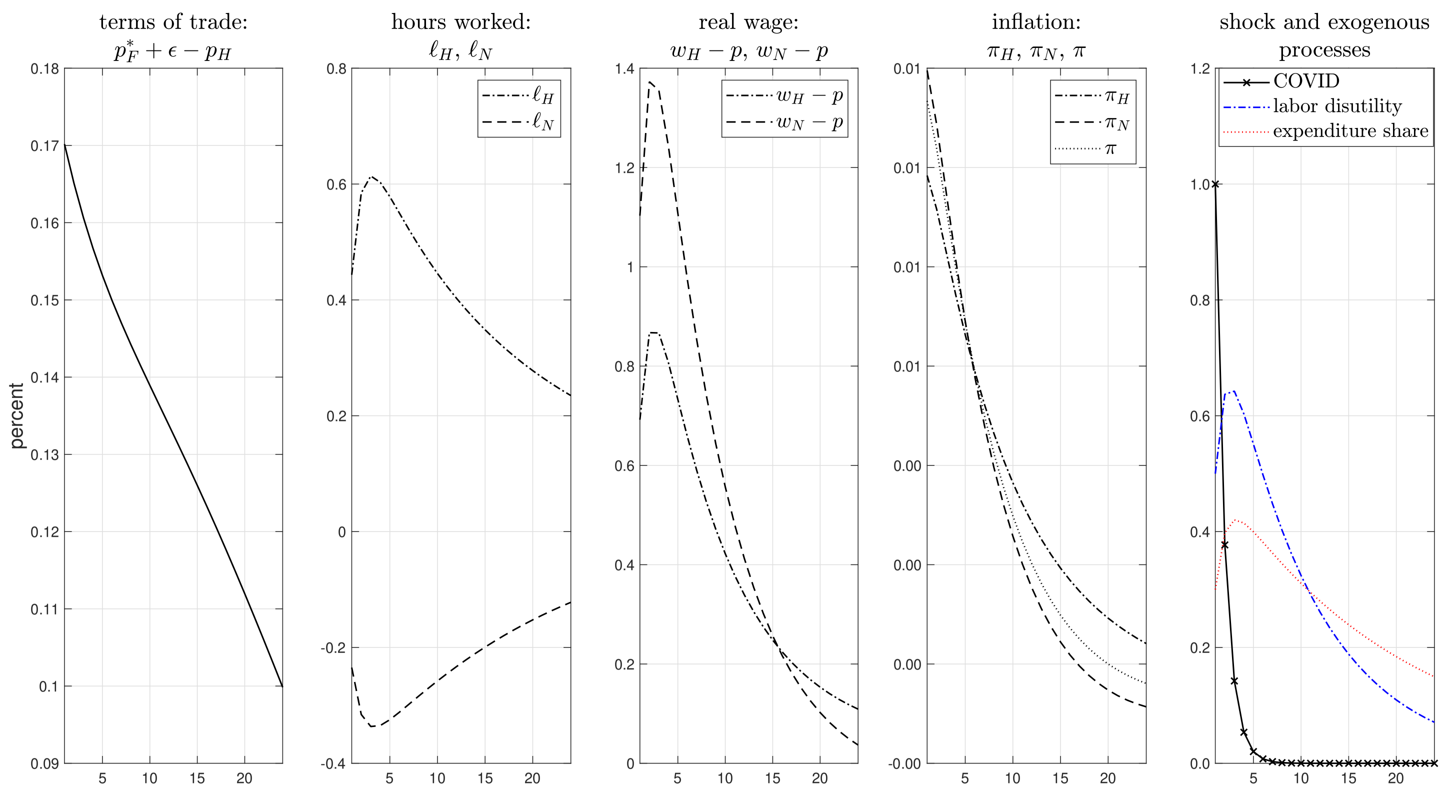


Figure 7: Impulse response functions to a one percent increase in COVID-19 cases. Curves present dynamics under the calibration in Table 3 for the terms-of-trade (first panel), hours worked in the tradeable (dotted-dashed) and nontradeable (dashed) sectors (second panel), real wages (third panel), inflation and its decomposition across sectors (fourth panel). The fifth panel displays the COVID-19 shock and its transmission to the relative labor disutility and expenditure switching exogenous processes.

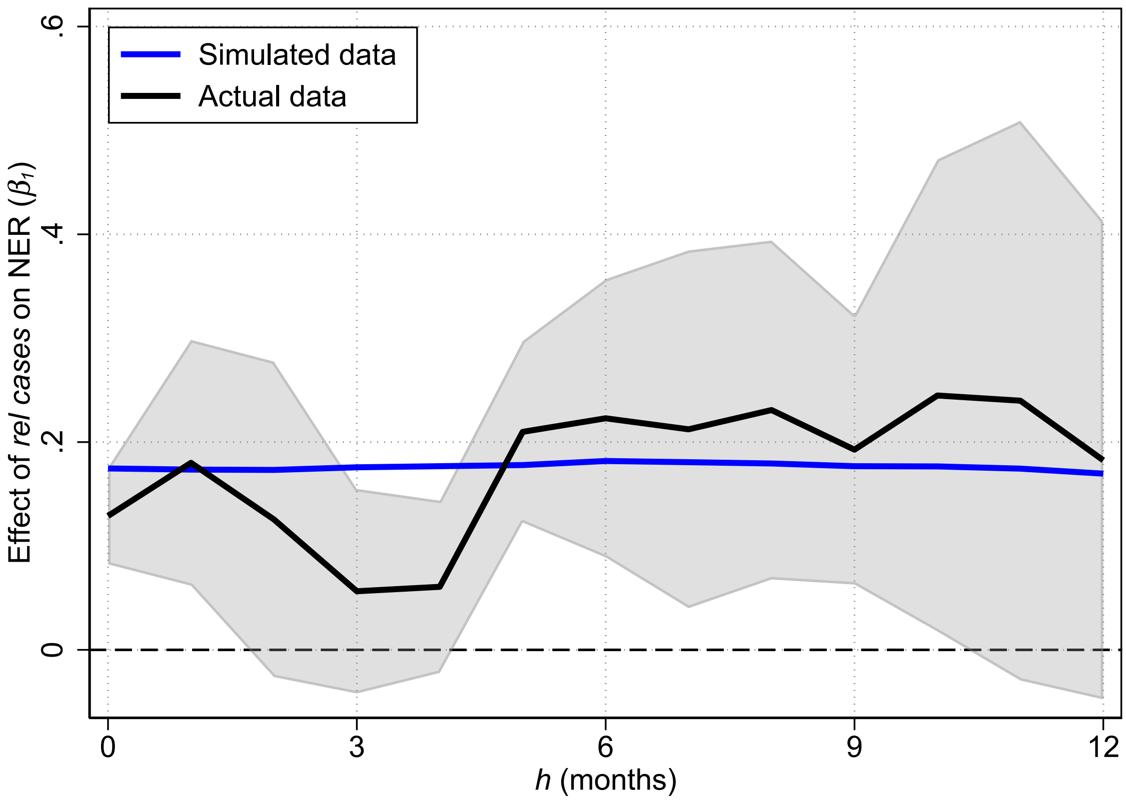


Figure 8: Cumulative nominal exchange rate responses with the associated 90% CI compared to point estimates generated by the simulated data.

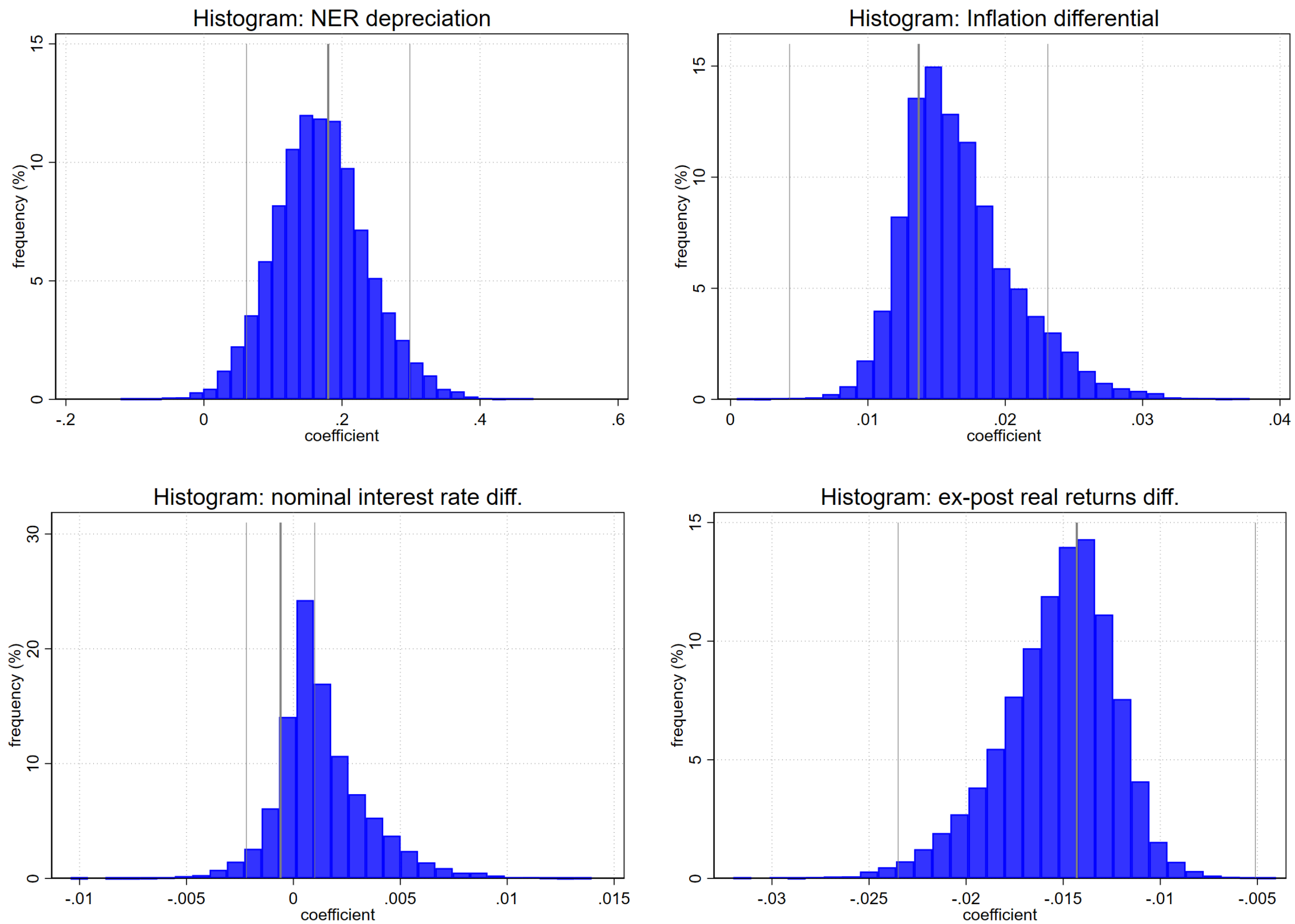


Figure 9: Histograms of estimated coefficients using simulated data generated by the baseline model. Vertical lines are the empirical point estimates with the associated 95% CI.

Appendix A

A.1 Descriptive Statistics

Table A.1
List of Countries

Developed	Emerging
Australia	Brazil
Austria	Chile
Belgium	Colombia
Canada	Croatia
Denmark	Czech Republic
Finland	Greece
Germany	Hungary
France	Indonesia
Iceland	Korea
Israel	Mexico
Italy	Philippines
Japan	Poland
Netherland	Romenia
New Zealand	Russia
Norway	South Africa
Portugal	Thailand
Spain	
Sweden	
Switzerland	
U.K.	

Table A.2
Descriptive Statistics

Notes: This table presents descriptive statistics for the main variables utilized in the empirical analysis.

Variables	*N*	*Mean*	*Std. Dev.*	*Median*	*Max.*	*Min.*
Panel A: June 1, 2020 - November 30, 2021						
$\Delta\varepsilon_{i;t-5,t}$	12,563	0.0002	0.0095	0.0004	0.095	-0.073
$\Delta rel\ cases_{i;t-5,t}$	12,563	-0.005	0.056	-0.0025	0.131	-0.358
$\Delta cases^{USA}_{t-5,t}$	12,563	0.042	0.037	0.026	0.135	0.002
$\Delta cases_{i;t-5,t}$	12,563	0.047	0.056	0.028	0.405	-0.051
$\Delta rel\ string_{i;t-5,t}$	12,563	-0.0003	0.100	0.000	1.034	-1.466
$\log(VIX_t)$	12,563	3.077	0.222	3.072	3.708	2.709
$y^{USA}_t - y_{i,t}$	12,563	0.698	1.725	1.212	1.956	-11.193
Panel B: June 1, 2020 - August 31, 2020						
$\Delta\varepsilon_{i;t-5,t}$	2,146	0.005	0.011	0.005	0.095	-0.073
$\Delta rel\ cases_{i;t-5,t}$	2,146	0.049	0.062	0.065	0.131	-0.313
$\Delta cases^{USA}_{t-5,t}$	2,146	0.093	0.026	0.085	0.135	0.050
$\Delta cases_{i;t-5,t}$	2,146	0.045	0.052	0.025	0.398	0.000
$\Delta rel\ string_{i;t-5,t}$	2,146	0.009	0.107	0.000	0.619	-1.133
$\log(VIX_t)$	2,146	3.283	0.155	3.251	3.708	3.061
$y^{USA}_t - y_{i,t}$	2,146	0.483	1.495	1.005	1.087	-6.560
Panel C: April 01, 2021 - November 30, 2021						
$\Delta\varepsilon_{i;t-5,t}$	4,907	-0.0010	0.0084	-0.0010	0.045	-0.051
$\Delta rel\ cases_{i;t-5,t}$	4,907	-0.0072	0.022	-0.0024	0.056	-0.268
$\Delta cases^{USA}_{t-5,t}$	4,907	0.013	0.0079	0.012	0.030	0.0024
$\Delta cases_{i;t-5,t}$	4,907	0.021	0.021	0.013	0.280	-0.051
$\Delta vacc^{USA}_{t-5,t}$	4,907	0.0309	0.031	0.016	0.138	0.009
$\Delta rel\ string_{i;t-5,t}$	4,907	0.004	0.104	0.000	0.700	-1.4665
$\log(VIX_t)$	4,907	2.890	0.119	2.870	3.354	2.709
$y^{USA}_t - y_{i,t}$	4,907	0.706	2.050	1.449	1.956	-11.193

Table A.3
Descriptive Statistics: Monthly Data

Variables	*N*	*Mean*	*Std. Dev.*	*Median*	*Max.*	*Min.*
$\Delta\varepsilon_t$	625	0.00115	0.025	-0.0007	0.080	-0.075
$\Delta rel\ cases_{i,t}$	625	-0.010	0.055	-0.0029	0.117	-0.337
$\Delta cases_t^{USA}$	625	0.039	0.035	0.018	0.120	0.003
$\Delta cases_{i,t}$	625	0.049	0.059	0.030	0.401	0.0001
$\Delta rel\ string_{i,t}$	625	-0.015	0.115	0.000	0.680	-0.837
$\log(VIX_t)$	625	3.122	0.256	3.142	3.638	2.762
$y_t^{USA} - y_{i,t}$	625	-0.692	2.578	0.179	1.813	-10.944
$\pi_{t-1,t}^{USA} - \pi_{i;t-1,t}$	625	0.0097	0.018	0.012	0.067	-0.045

Notes: This figure portrays the distribution of the main explanatory variable used in the analysis: The five-weekday change in relative Covid cases:

$$\Delta rel\ cases_{i;t-5,t} = \Delta cases_{t-5,t}^{USA} - \Delta cases_{i;t-5,t}.$$

The histogram illustrates the substantial variation captured across countries and over time in relative Covid cases, which we wish to exploit in our analysis.

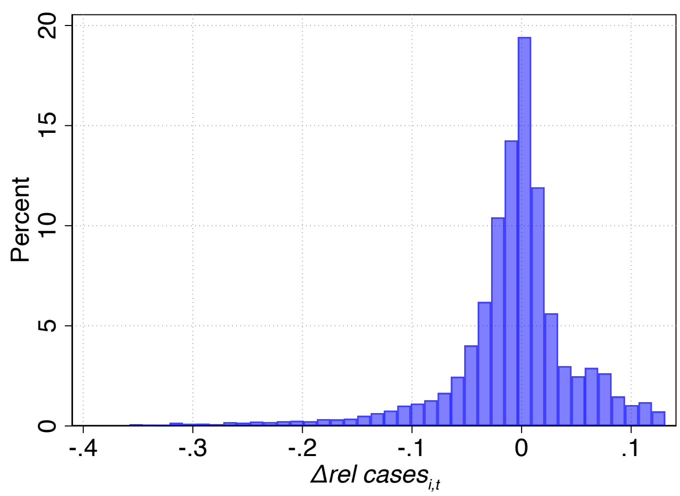


Figure A.1: The Distribution of Relative Cases

A.2 Monthly analysis

Table A.4
The Contemporaneous Effect of Relative COVID Severity on the Nominal Exchange Rate: Monthly Analysis

Notes: This table presents the results from the following regressions:

$$\Delta\varepsilon_{i;t-1,t} = \boldsymbol{\alpha}_i + \beta_1 \Delta rel\ cases_{i,t} + \beta_2 \Delta rel\ string_{i,t} + \beta_3 \log(VIX_t) + \beta_4 (y_t^{USA} - y_{i,t}) + \beta_5 (\pi_{t-1,t}^{USA} - \pi_{i;t-1,t}) + u_{i,t} \quad \text{and}$$

$$\Delta\varepsilon_{i;t-1,t} = \boldsymbol{\alpha}_i + \gamma_1 \Delta cases_t^{USA} + \gamma_2 \Delta cases_{i,t} + \gamma_3 \Delta rel\ string_{i,t} + \gamma_4 \log(VIX_t) + \gamma_5 (y_t^{USA} - y_{i,t}) + \gamma_6 (\pi_{t-1,t}^{USA} - \pi_{i;t-1,t}) + u_{i,t},$$

where the outcome variable $\Delta\varepsilon_{i;t-1,t}$ is the change in the U.S. dollar bilateral nominal exchange rate of country i; $\boldsymbol{\alpha}_i$ is a country fixed effect; $\Delta rel\ cases_{i,t}$ and $rel\ string_{i,t}$ are, respectively, the last weekly change between months $t-1$ and t in relative COVID cases and stringency indices between the U.S. and country i, as defined in (1); $\Delta cases_t^{USA}$ and $\Delta cases_{i,t}$ are, respectively, the last weekly change in cases from $t-1$ to t months in the U.S. and country i; $\log(VIX_t)$ is the logarithm of the VIX; $(y^{USA} - y_i)$ is the 5-year treasury yield differential; $(\pi_{t-1,t}^{USA} - \pi_{i;t-1,t})$ is the month-on-month inflation differential between the U.S. and country i; and u_i is an error term. The outcome variable ε_i is defined as the price of country i's currency in terms of U.S. dollars, implying that an increase in ε_i is a *depreciation* of the U.S. dollar against the currency of country i. The sample period runs from June 2020 until November 2021. Regressions are weighted by trade weights. *, **, and *** represent statistical significance at the 10-, 5-, and 1-percent level, respectively. Standard errors are robust to heteroskedastic autocorrelation and spatial correlation (Driscoll and Kraay, 1998).

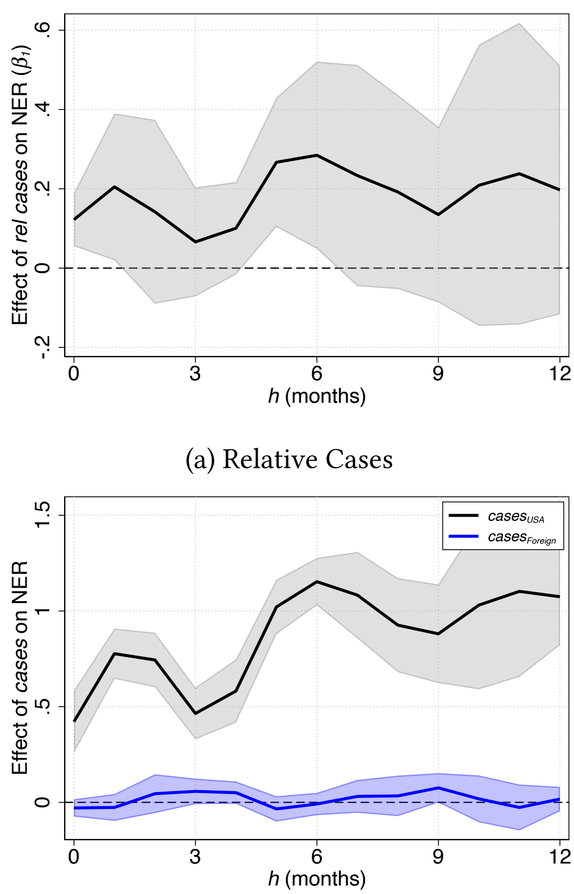
	(1)	(2)
$\Delta rel\ cases_{i,t}$	0.122**	
	(0.039)	
$\Delta cases_t^{USA}$		0.422***
		(0.0940)
$\Delta cases_{i,t}$		-0.0290
		(0.0261)
$\Delta rel\ string_{i,t}$	-0.0238	-0.0221
	(0.0152)	(0.0149)
$\log(VIX_t)$	0.00268	-0.0259**
	(0.00931)	(0.00891)
$y_t^{USA} - y_{i,t}$	-0.0148**	-0.00459
	(0.00470)	(0.00507)
$\pi_{t-1,t}^{USA} - \pi_{i;t-1,t}$	1.602	1.293
	(1.021)	(0.828)
Obs.	625	625
Country FE	✓	✓
Within R^2	0.250	0.460

Notes: This figure plots the point estimates $\hat{\beta}_{1,h}$ (subfigure (a)) and ($\hat{\gamma}_{1,h}$,$\hat{\gamma}_{2,h}$) (subfigure (b)) from the following specifications, for $h = 1, 2, \ldots 12$ months:

$$\Delta\varepsilon_{i;t-1,t+h} = \boldsymbol{\alpha}_{i,h} + \beta_{1,h}\Delta rel\ cases_{i,t} + \beta_{2,h}\Delta rel\ string_{i,t} + \beta_{3,h}\log(VIX_t) + \beta_{4,h}(y_t^{USA} - y_{i,t}) + \beta_{5,h}(\pi_{t-1,t}^{USA} - \pi_{i;t-1,t}) + u_{i,t+h} \text{ and}$$

$$\Delta\varepsilon_{i;t-1,t+h} = \boldsymbol{\alpha}_{i,h} + \gamma_{1,h}\Delta cases_t^{USA} + \gamma_{2,h}\Delta cases_{i,t} + \gamma_{3,h}\Delta rel\ string_{i,t} + \gamma_{4,h}\log(VIX_t) + \gamma_{5,h}(y_t^{USA} - y_{i,t}) + \gamma_{6,h}(\pi_{t-1,t}^{USA} - \pi_{i;t-1,t}) + u_{i,t+h},$$

where the outcome variable $\Delta\varepsilon_{i;,t-1,t}$ is the change in the U.S. dollar bilateral nominal exchange rate of country i; $\boldsymbol{\alpha}_i$ is a country fixed effect; $\Delta rel\ cases_{i,t}$ and $rel\ string_{i,t}$ are, respectively, the last weekly change between months $t-1$ and t in relative COVID cases and stringency indices between the U.S. and country i, as defined in (1); $\Delta cases_t^{USA}$ and $\Delta cases_{i,t}$ are, respectively, the last weekly change in cases between $t-1$ to t months in the U.S. and country i; $\log(VIX_t)$ is the logarithm of the VIX; $(y^{USA} - y_i)$ is the 5-year treasury yield differential; $(\pi_{t-1,t}^{USA} - \pi_{i;t-1,t})$ is the month-on-month inflation differential between the U.S. and country i; and u_i is an error term. The outcome variable ε_i is defined as the price of country i's currency in terms of U.S. dollars, implying that an increase in ε_i is a *depreciation* of the U.S. dollar against the currency of country i. The sample period runs from June 2020 until November 2021. Regressions are weighted by trade weights. The shaded area depicts 90% confidence intervals. Standard errors are robust to heteroskedastic autocorrelation and spatial correlation (Driscoll and Kraay, 1998).



(b) U.S. versus Foreign Cases

Figure A.2: The Effect of COVID Cases on the Dynamics of the Nominal Exchange Rate: Monthly Analysis

A.3 The mitigating role of vaccinations

Table A.5
The Mitigating Role of Vaccinations: Contemporaneous Effect

Notes: This table investigate the role of vaccinations by running the following regression:

$$\Delta\varepsilon_{i;t-5,t} = \boldsymbol{\alpha}_i + \beta_1 \Delta rel\ cases_{i;t-5,t} + \beta_2(\Delta rel\ cases_{i;t-5,t} \times \Delta vacc^{USA}_{t-10,t-5}) + \beta_3 \Delta rel\ string_{i;t-5,t} + \beta_4 \log(VIX_t) + \beta_5(y^{USA}_t - y_{i,t}) + u_{i,t},$$

where $\Delta vacc^{USA}_{t-10,t-5}$ is the change in U.S. vaccinations from $t-10$ to $t-5$ weekdays. The sample period runs from April 1, 2021 until November 30, 2021. All regressions are weighted by trade weights. *, **, and *** represent statistical significance at the 10-, 5-, and 1-percent level, respectively. Standard errors are robust to heteroskedastic autocorrelation and spatial correlation (Driscoll and Kraay, 1998).

	(1)
$\Delta rel\ cases_{i;t-5,t}$	0.0702**
	(0.0341)
$\Delta rel\ cases_{i;t-5,t} \times \Delta vacc^{USA}_{t-5,t}$	-1.853***
	(0.356)
$\Delta rel\ string_{i;t-5,t}$	-0.0118*
	(0.00586)
$\log(VIX_t)$	-0.00597
	(0.00644)
$y^{USA}_t - y_{i,t}$	-0.00233
	(0.00271)
Obs.	4,907
Country FE	✓
Within R^2	0.0695

Notes: This figure plots the average marginal effects of relative COVID severity on the nominal exchange rate, conditional on relative vaccinations being fixed at various levels of its distribution. In particular, we run the following specification:

$$\Delta\varepsilon_{i;t,t+h} = \boldsymbol{\alpha}_i + \beta_{1,h}\Delta rel\ cases_{i;t-5,t} + \beta_{2,h}\left(\Delta rel\ cases_{i;t-5,t} \times \Delta vacc^{USA}_{t-10,t-5}\right) + \\ \beta_{3,h}\Delta rel\ string_{i;t-5,t} + \beta_{4,h}\log(VIX_t) + \beta_{5,h}(y_{USA,t} - y_{i,t}) + u_{i;t+h},$$

where the outcome variable $\Delta\varepsilon_{i;t,t+h}$ is the change in the U.S. dollar bilateral nominal exchange rate of country i from t to $t+h$ weekdays; $\boldsymbol{\alpha}_i$ is a country fixed effect; $\Delta rel\ cases_{i;t-5,t}$ and $rel\ string_{i;t-5,t}$ are, respectively, the change from $t-5$ to t weekdays in the relative COVID cases and stringency indices as defined in (1); $\Delta vacc^{USA}_{t-10,t-5}$ is the change in U.S. vaccinations from $t-10$ to $t-5$ weekdays; $(y_{USA} - y_i)$ is the 5-year treasury yield differential; and u_i is an error term. The outcome variable ε_i is defined as the price of country i's currency in terms of U.S. dollars, implying that an increase in $\Delta\varepsilon_{i;t,t+h}$ is a *depreciation* of the U.S. dollar against the currency of country i. The average marginal effect of relative COVID cases on the nominal exchange rate is given by

$$\text{AME of } \Delta rel\ cases_{i;t-5,t}(\Delta vacc^{USA}_{t-10,t-5}) \equiv \left.\frac{\partial(\Delta\varepsilon_{i;t-5,t+h})}{\partial(\Delta rel\ cases_{i;t-5,t})}\right|_{\Delta vacc^{USA}_{t-10,t-5}=vacc} = \beta_{1,h} + \beta_{2,h} \times vacc,$$

where we fix the change in U.S. vaccinations, $\Delta vacc^{USA}_{t-5,t-10}$ at two points in its conditional sample distribution: two standard deviation above its sample average and at its sample average. The sample period runs from April 1, 2021 until November 30, 2021. Regressions are weighted by trade weights. The shaded area depicts 90% confidence intervals. Standard errors are robust to heteroskedastic autocorrelation and spatial correlation (Driscoll and Kraay, 1998).

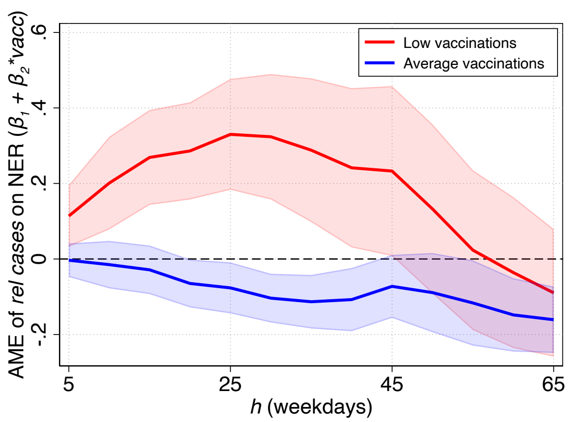


Figure A.3: The Average Marginal Effects of COVID Cases on the Dynamics of the Nominal Exchange Rate Conditional on U.S. Vaccinations

A.4 Calibration

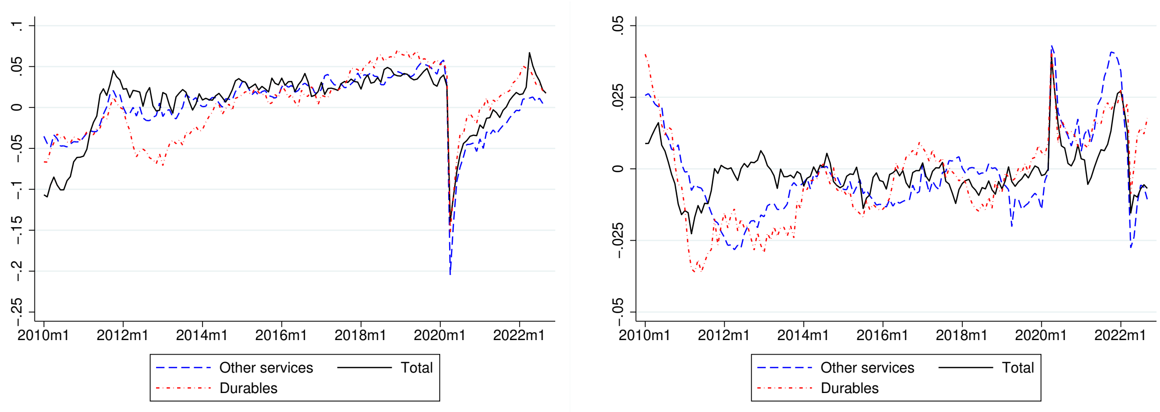
BLS time series: Hours worked and average hourly earnings

Notes: The series from BLS are

(i) "Indexes of Aggregate Weekly Hours of All Employees, Total Private, Index 2007=100, Monthly, Seasonally Adjusted"

(ii) "Indexes of Aggregate Weekly Hours of All Employees, Durable Goods, Index 2007=100, Monthly, Seasonally Adjusted"

(iii) "Indexes of Aggregate Weekly Hours of All Employees, Other Services, Index 2007=100, Monthly, Seasonally Adjusted"



(a) Hours worked (b) Average hourly earnings

Figure A.4: Indexes of Aggregate Weekly Hours and Average Hourly Earnings of All Employees, Durable Goods, and Other Services.

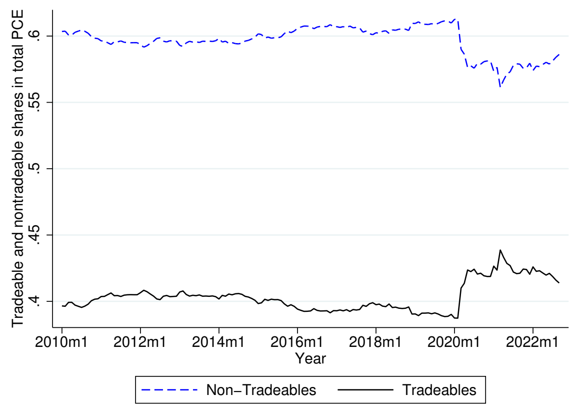
BEA time series: Personal Consumption Expenditures (PCE)

Notes: The series from BEA are

(i) "Real Personal Consumption Expenditures, Billions of Chained 2012 Dollars, Monthly, Seasonally Adjusted Annual Rate"

(ii) "Personal Consumption Expenditures Excluding Food and Energy (Chain-Type Price Index) Index 2012=100, Monthly, Seasonally Adjusted"

(iii) "Personal Consumption Expenditures by Major Type of Product and by Major Function (Table 2.3.5U)"



(a) Tradeable and nontradeable expenditure shares

Figure A.5: Nontradeable consumption spending share is services consumption excluding financial services and insurance over total personal consumption expenditures (PCE).

Homogeneous labor supply disutility: χ

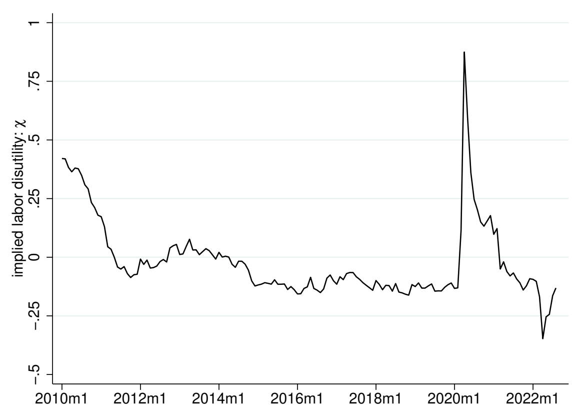


Figure A.6: Cyclical component of the implied labor disutility assuming a homogeneous shock across tradeable and nontrdeable sectors.

A.5 The role of imperfect labor substitutability

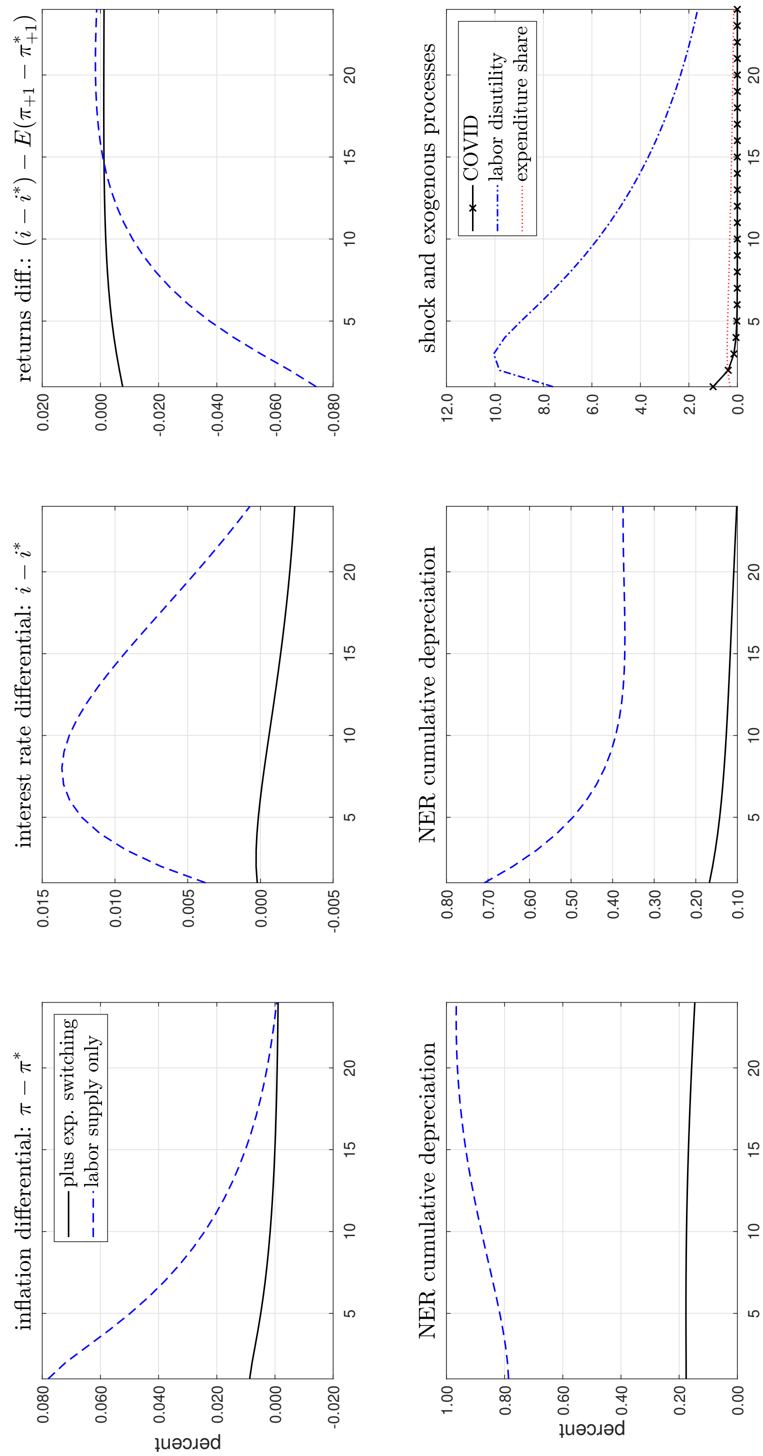


Figure A.7: Impulse response functions to a one percent increase in relative COVID-19 cases. Solid and dashed lines present dynamics for the nominal exchange rate depreciation (first panel), cumulative depreciation (second panel), real exchange rate (third panel), nominal interest rate differential (fourth panel), inflation differential (fifth panel), and real returns differential (sixth panel) under the calibration in Table 3. Solid lines display dynamics under the model with perfect labor mobility while dashed lines consider imperfect mobility with a homogeneous labor supply disutility across sectors.

A.6 Simulation Results under Producer Currency Pricing (PCP)

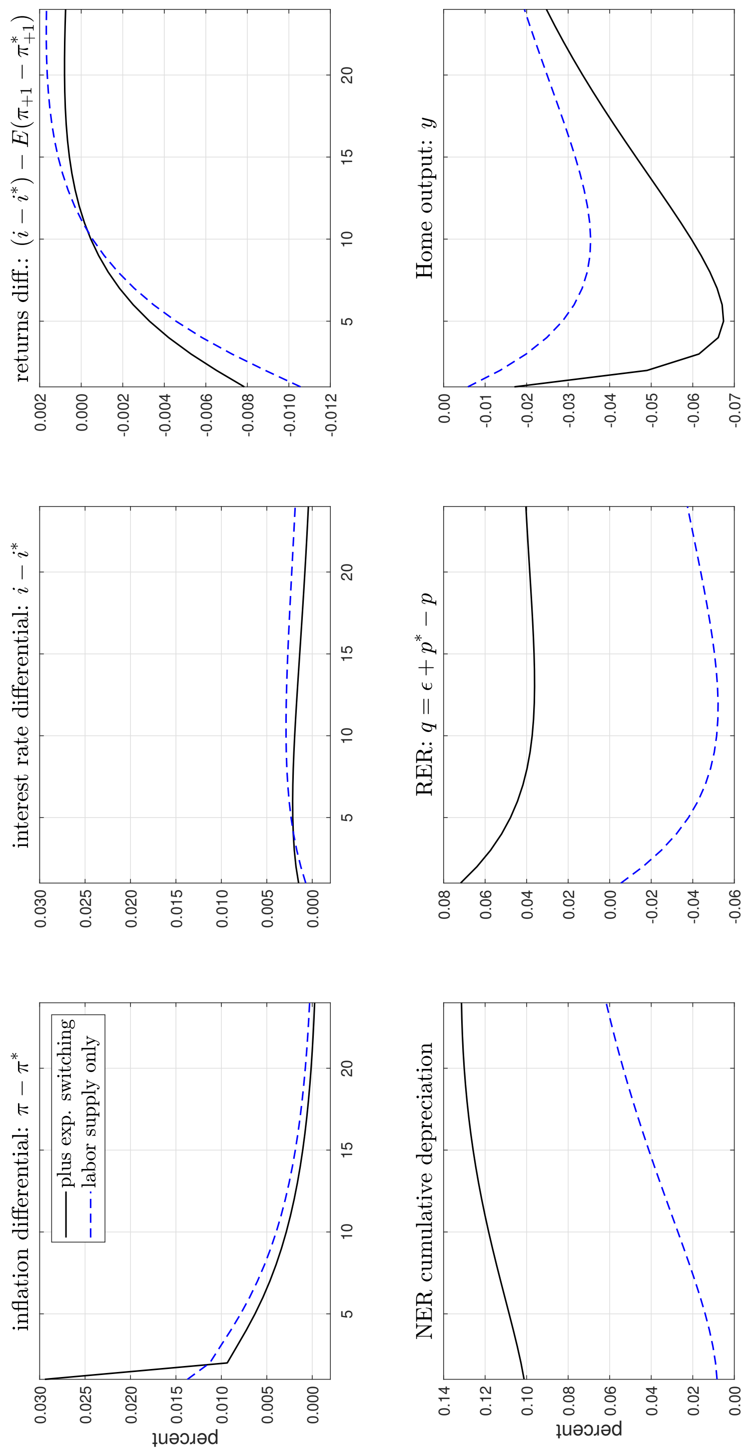


Figure A.8: Impulse response functions to a one percent increase in relative COVID-19 cases. Solid and dashed lines present dynamics for the inflation differentials (first panel), nominal interest rate differentials (second panel), real returns differentials (third panel), cumulative nominal exchange rate depreciation (fourth panel), real exchange rate (fifth panel), and output (sixth panel) responses under PCP and the calibration table 3. Solid lines display dynamics under the full model while dashed lines consider the effects of COVID-19 on labor supply only.

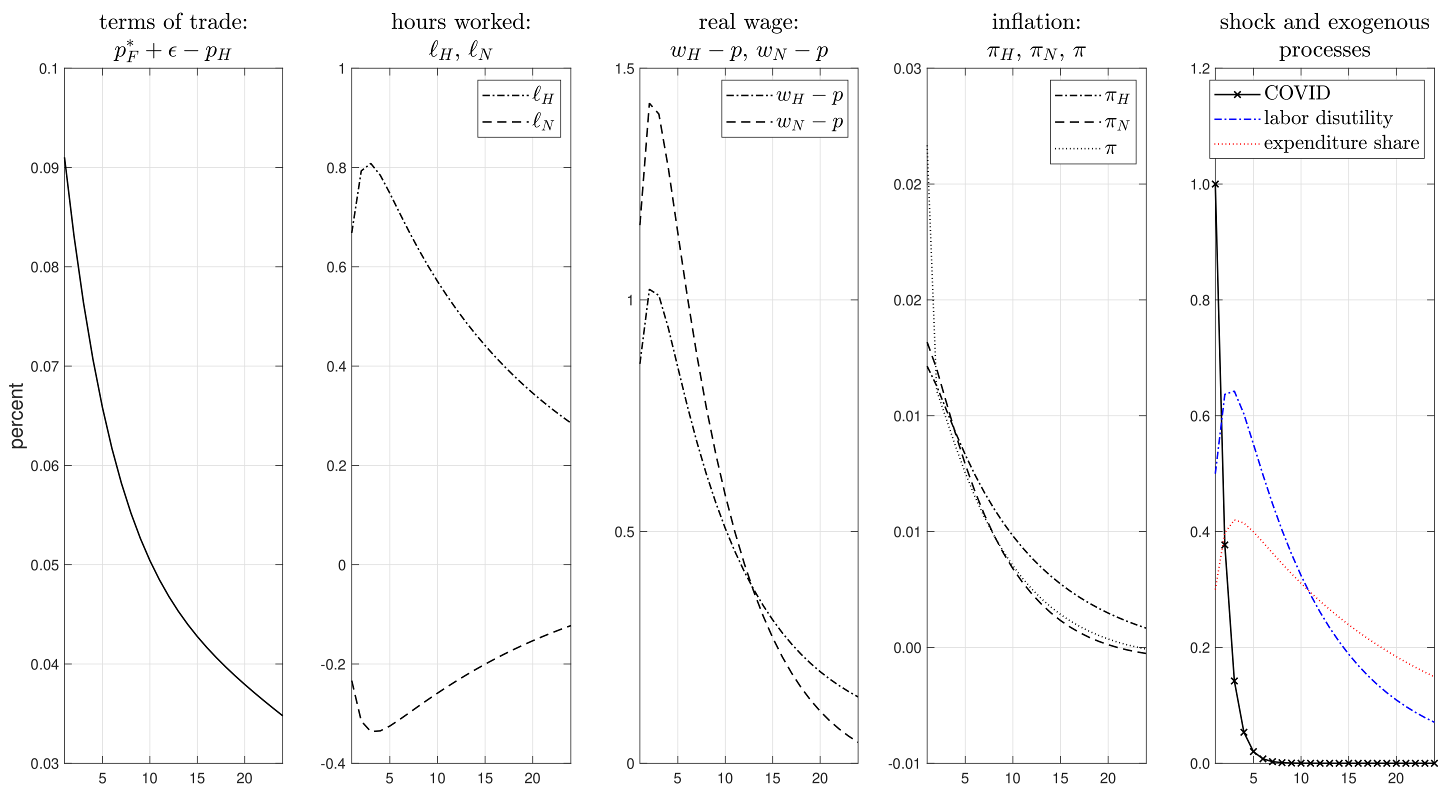


Figure A.9: Impulse response functions to a one percent increase in COVID-19 cases. Curves present dynamics under PCP and the calibration table 3 for the terms-of-trade (first panel), hours worked in the tradeable (dotted-dashed) and nontradeable (dashed) sectors (second panel), real wages (third panel), inflation and its decomposition across sectors (fourth panel). The fifth panel displays the COVID-19 shock (solid line) and its transmission to the relative labor disutility (dotted-dashed line) and expenditure switching (dotted line) exogenous processes.

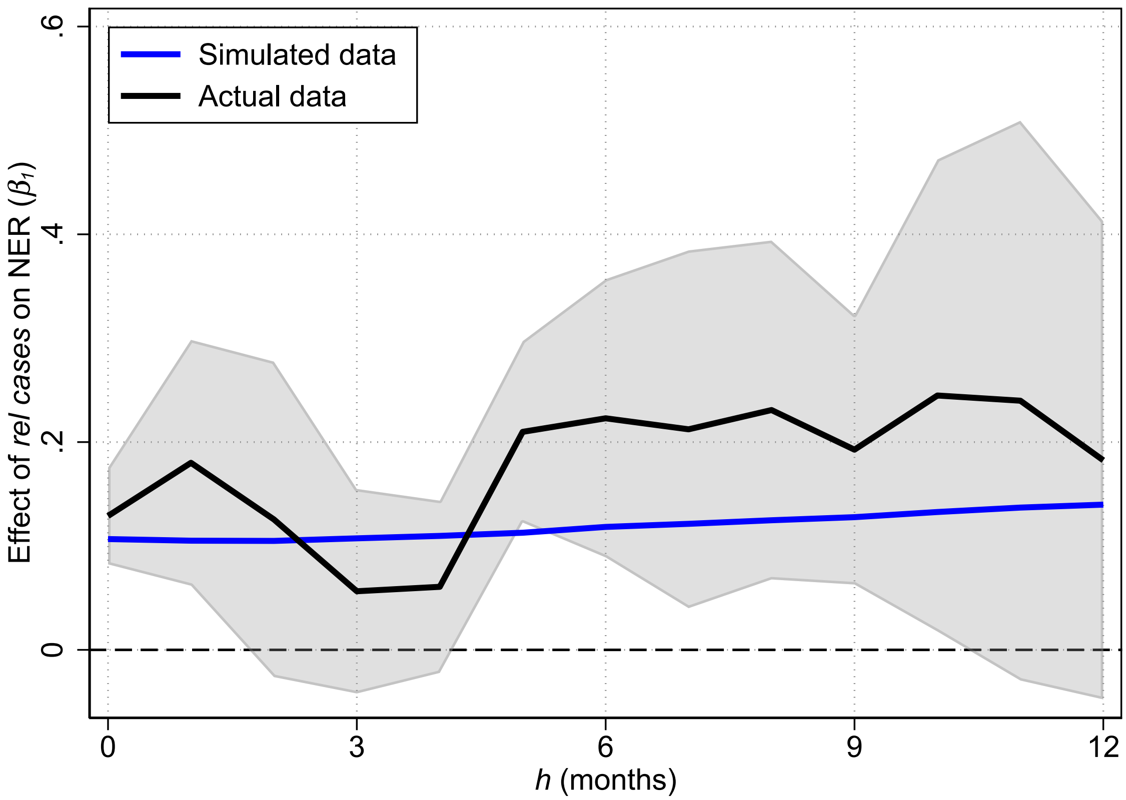


Figure A.10: Cumulative nominal exchange rate responses with the associated 90% CI compared to point estimates generated by the simulated data under PCP.

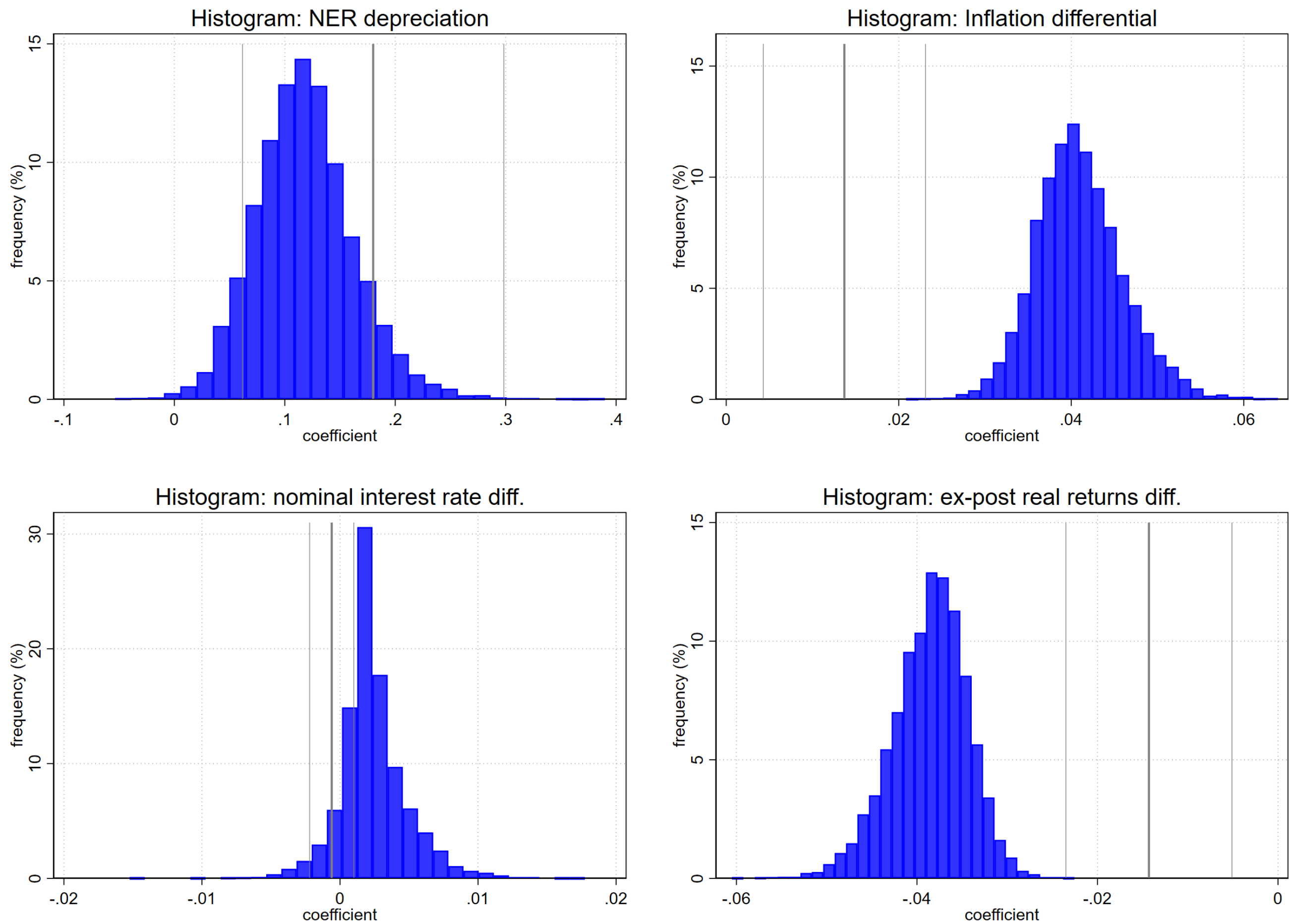


Figure A.11: Histograms of estimated coefficients using simulated data generated by the baseline model. Vertical lines are the empirical point estimates with the associated 95% CI under PCP.

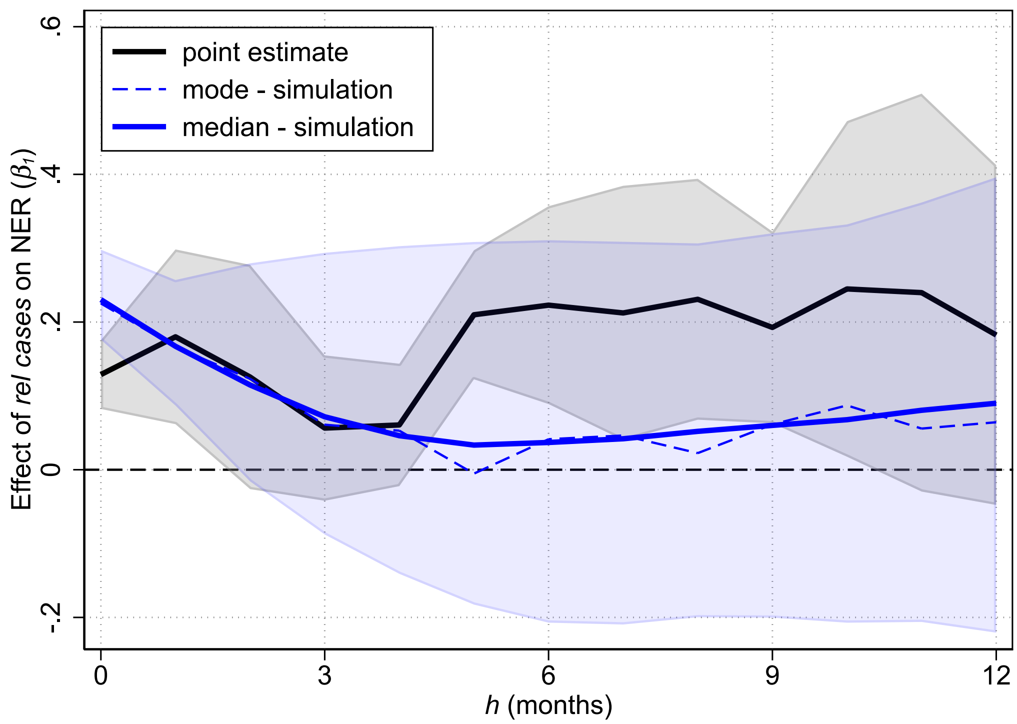


Figure A.12: Cumulative nominal exchange rate responses with the associated 90% CI compared to point estimates generated by the simulated data under LCP.

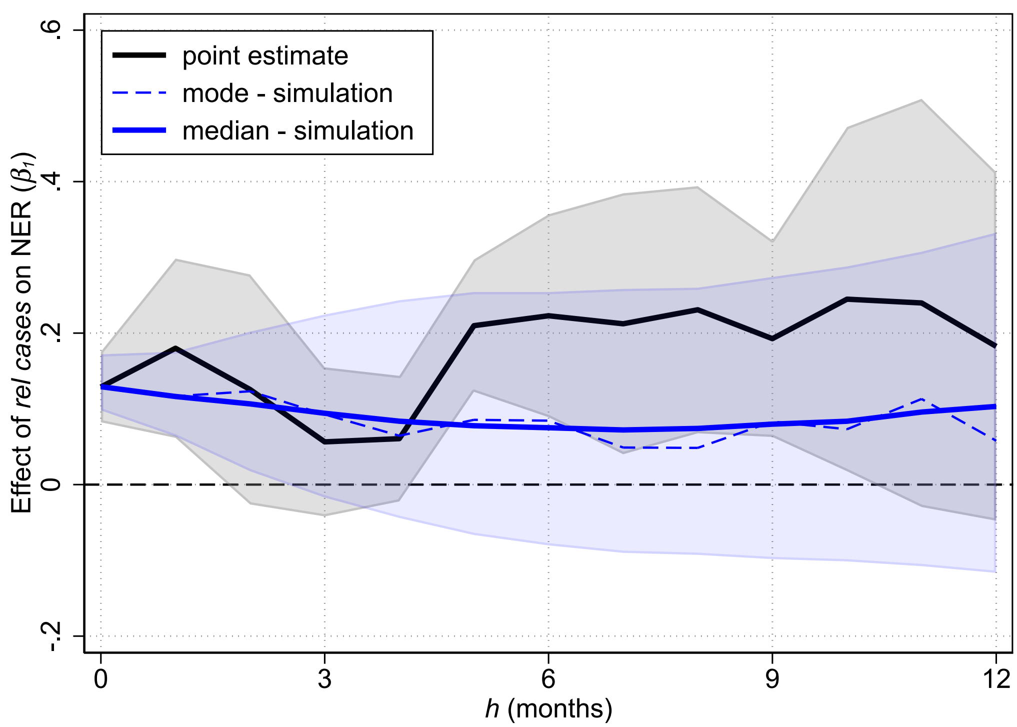


Figure A.13: Cumulative nominal exchange rate responses with the associated 90% CI compared to point estimates generated by the simulated data under PCP.

A.7 Model Solution

A.7.1 Households

We start with the intratemporal problem. Households choose tradeable and nontradeable consumption bundles according to

$$\begin{aligned} \max_{\{C_{Tt}, C_{Nt}\}} \quad & \left(\nu_t^{1/\theta} C_{Tt}^{1-1/\theta} + (1-\nu_t)^{1/\theta} C_{Nt}^{1-1/\theta} \right)^{\frac{\theta}{\theta-1}} \\ \text{s.t.} \quad & P_{Tt} C_{Tt} + P_{Nt} C_{Nt} = P_t C_t, \;\; (\lambda_t) \end{aligned} \tag{A.1}$$

which yields the following first order conditions (FOC)

$$C_t^{1/\theta} \nu_t^{1/\theta} C_{Tt}^{-1/\theta} - \lambda_t P_{Tt} = 0 \;\text{ and }\; C_t^{1/\theta} (1-\nu_t)^{1/\theta} C_{Nt}^{-1/\theta} - \lambda_t P_{Nt} = 0.$$

Given the result $\lambda_t = P_t^{-1}$, one can find that

$$C_{Tt} = \nu_t \left(\frac{P_{Tt}}{P_t} \right)^{-\theta} C_t \;\text{ and }\; C_{Nt} = (1-\nu_t) \left(\frac{P_{Nt}}{P_t} \right)^{-\theta} C_t.$$

The problem is analogous for Home and Foreign traded retail goods:

$$\begin{aligned} \max_{\{C_{Ht}, C_{Ft}\}} \quad & \left(\omega^{1/\lambda} C_{Ht}^{1-1/\lambda} + (1-\omega)^{1/\lambda} C_{Ft}^{1-1/\lambda} \right)^{\frac{\lambda}{\lambda-1}} \\ \text{s.t.} \quad & \tilde{P}_{Ht} C_{Ht} + \tilde{P}_{Ft} C_{Ft} = P_{Tt} C_{Tt}, \end{aligned} \tag{A.2}$$

giving similar demand schedules

$$C_{Ht} = \omega \left(\frac{\tilde{P}_{Ht}}{P_{Tt}} \right)^{-\lambda} C_{Tt}\,, \text{ and } \; C_{Ft} = (1-\omega) \left(\frac{\tilde{P}_{Ft}}{P_{Tt}} \right)^{-\lambda} C_{Tt}.$$

A final layer in the structure of preferences defines the demand schedule for traded and nontraded inputs:

$$\begin{aligned} \max_{\{I_{Ht}, V_{Ht}\}} \quad & \left(\kappa^{1/\mu} I_{Ht}^{1-1/\mu} + (1-\kappa)^{1/\mu} V_{Ht}^{1-1/\mu} \right)^{\frac{\mu}{\mu-1}} \\ \text{s.t.} \quad & P_{Ht} I_{Ht} + P_{Nt} V_{Nt} = \tilde{P}_{Ht} C_{Ht}, \end{aligned} \tag{A.3}$$

yielding

$$I_{Ht} = \kappa \left(\frac{P_{Ht}}{\tilde{P}_{Ht}}\right)^{-\mu} C_{Ht} = \kappa\omega \left(\frac{P_{Ht}}{\tilde{P}_{Ht}}\right)^{-\mu} \left(\frac{\tilde{P}_{Ht}}{P_{Tt}}\right)^{-\lambda} C_{Tt} \text{ and}$$

$$V_{Ht} = (1-\kappa) \left(\frac{\tilde{P}_{Nt}}{\tilde{P}_{Ht}}\right)^{-\mu} C_{Ht} = (1-\kappa)\omega \left(\frac{\tilde{P}_{Nt}}{\tilde{P}_{Ht}}\right)^{-\mu} \left(\frac{\tilde{P}_{Ht}}{P_{Tt}}\right)^{-\lambda} C_{Tt},$$

while the demand schedules for Foreign traded and nontraded inputs—I_{Ft} and V_{Ft}—are symmetric:

$$I_{Ft} = \kappa(1-\omega) \left(\frac{P_{Ft}}{\tilde{P}_{Ft}}\right)^{-\mu} \left(\frac{\tilde{P}_{Ft}}{P_{Tt}}\right)^{-\lambda} C_{Tt} \text{ and}$$

$$V_{Ft} = (1-\kappa)(1-\omega) \left(\frac{\tilde{P}_{Nt}}{\tilde{P}_{Ft}}\right)^{-\mu} \left(\frac{\tilde{P}_{Ft}}{P_{Tt}}\right)^{-\lambda} C_{Tt}.$$

Labor supply decisions for the tradeable and nontradeable sectors follow:

$$\min_{\{L_{Ht}, L_{Nt}\}} \left(\phi^{-1/\gamma}(X_{Ht}L_{Ht})^{1+1/\gamma} + (1-\phi)^{-1/\gamma}(X_{Nt}L_{Nt})^{1+1/\gamma}\right)^{\frac{\gamma}{1+\gamma}} \quad \text{s.t. } W_{Ht}L_{Ht} + W_{Nt}L_{Nt} = \mathcal{W}_t\mathcal{L}_t, \ (\xi_t) \tag{A.4}$$

giving analogous FOC for L_{Ht} and L_{Nt}

$$\mathcal{L}_t^{-1/\gamma}\phi^{-1/\gamma}(X_{Ht})^{\frac{1+\gamma}{\gamma}}\mathcal{L}_{Ht}^{1/\gamma} - \xi_t W_{Ht} = 0 \text{ and } \mathcal{L}_t^{-1/\gamma}(1-\phi)^{-1/\gamma}(X_{Nt})^{\frac{1+\gamma}{\gamma}}\mathcal{L}_{Nt}^{1/\gamma} - \xi_t W_{Nt} = 0.$$

Again using the fact that $\xi_t = W_t^{-1}$, one finds

$$L_{Ht} = \phi X_{Ht}^{-(1+\gamma)} \left(\frac{W_{Ht}}{\mathcal{W}_t}\right)^{\gamma} \mathcal{L}_t \text{ and } L_{Nt} = (1-\phi) X_{Nt}^{-(1+\gamma)} \left(\frac{W_{Nt}}{\mathcal{W}_t}\right)^{\gamma} \mathcal{L}_t.$$

A.7.2 Firms

Given the linear technology in labor, $Y_{Ht} = A_{Ht} L_{Ht}$, the firm's problem in the tradeable sector is

$$\max_{\{P^o_{Ht}, Y_{Ht}\}} \sum_{j=0}^{\infty} \zeta^j \mathbb{E}_t \left\{ \Lambda_{t,t+j} \left(P^o_{Ht} - \frac{W_{Ht+j}}{A_{Ht+j}} \right) Y_{Ht+j} \right\}$$

$$\begin{aligned} \text{s.t. } \; & Y_{Ht+j} = I_{Ht+j} + I^*_{Ht+j}, \\ & I_{Ht+j} = \kappa\omega \left(\frac{P^o_{Ht}}{\tilde{P}_{Ht+j}} \right)^{-\mu} \left(\frac{\tilde{P}_{Ht+j}}{P_{Tt+j}} \right)^{-\lambda} C_{Tt+j}, \\ & I^*_{Ht+j} = \kappa(1-\omega) \left(\frac{P^o_{Ht}}{\mathcal{E}_t \tilde{P}^*_{Ht+j}} \right)^{-\mu} \left(\frac{\tilde{P}^*_{Ht+j}}{P^*_{Tt+j}} \right)^{-\lambda} C^*_{Tt+j}, \text{ for } j = 0, 1, \ldots \end{aligned} \tag{A.5}$$

where we omit (i) subscripts since firms are identical except for the variety they produce, and $\Lambda_{t,t+j} \equiv \beta^j \left(C_t / C_{t+j} \right)^{\sigma} \left(P_t / P_{t+j} \right)$. Substituting constraints into the objective function and rearranging terms gives

$$\begin{aligned} \max_{P^o_{Ht}} \sum_{j=0}^{\infty} \zeta^j \mathbb{E}_t \Bigg\{ & \Lambda_{t,t+j} \left((P^o_{Ht})^{1-\mu} - \frac{W_{Ht+j}}{A_{Ht+j}} (P^o_{Ht})^{-\mu} \right) \kappa \Big[\omega (\tilde{P}_{Ht+j})^{\mu-\lambda} (P_{Tt+j})^{\lambda} C_{Tt+j} + \\ & + (1-\omega) \mathcal{E}^{\mu}_{t+j} (\tilde{P}^*_{Ht+j})^{\mu-\lambda} (P^*_{Tt+j})^{\lambda} C^*_{Tt+j} \Big] \Bigg\}. \end{aligned} \tag{A.6}$$

Setting $\Psi_{Ht+j} \equiv \kappa \left[\omega (\tilde{P}_{Ht+j})^{\mu-\lambda} (P_{Tt+j})^{\lambda} C_{Tt+j} + (1-\omega) \mathcal{E}^{\mu}_{t+j} (\tilde{P}^*_{Ht+j})^{\mu-\lambda} (P^*_{Tt+j})^{\lambda} C^*_{Tt+j} \right]$, the FOC yields

$$P^o_{Ht} = \frac{\mathbb{E}_t \left[\sum_{j=0}^{\infty} \zeta^j \Lambda_{t,t+j} \Psi_{Ht+j} \frac{\mu}{\mu-1} \frac{W_{Ht}}{A_{Ht}} \right]}{\mathbb{E}_t \left[\sum_{j=0}^{\infty} \zeta^j \Lambda_{t,t+j} \Psi_{Ht+j} \right]},$$

where we define $\Gamma_{Ht,t+j} \equiv \zeta^j \Lambda_{t,t+j} \Psi_{Ht+j}$, and $P^{flex}_{Ht} = \left(\frac{\mu}{\mu-1} \right) \left(\frac{W_{Ht}}{A_{Ht}} \right)$.

Finally, a firm in the nontradeable sector solves

$$\max_{\{P^o_{Ht}, Y_{Ht}\}} \sum_{j=0}^{\infty} \zeta^j \mathbb{E}_t \left\{ \Lambda_{t,t+j} \left(P^o_{Nt} - \frac{W_{Nt+j}}{A_{Nt+j}} \right) Y_{Nt+j} \right\}$$

$$\begin{aligned} \text{s.t.} \quad Y_{Nt+j} &= V_{Ht+j} + V_{Ft+j} + C_{Nt+j}, \\ V_{Ht+j} &= (1-\kappa)\omega \left(\frac{P^o_{Nt}}{\tilde{P}_{Ht+j}} \right)^{-\mu} \left(\frac{\tilde{P}_{Ht+j}}{P_{Tt+j}} \right)^{-\lambda} C_{Tt+j}, \\ V_{Ft+j} &= (1-\kappa)(1-\omega) \left(\frac{P^o_{Nt}}{\tilde{P}_{Ft+j}} \right)^{-\mu} \left(\frac{\tilde{P}_{Ft+j}}{P_{Tt+j}} \right)^{-\lambda} C_{Tt+j}, \\ C_{Nt+j} &= (1-\nu) \left(\frac{P^o_{Nt}}{P_{t+j}} \right)^{-\theta} C_{t+j}, \text{ for } j = 0, 1, \ldots \end{aligned} \tag{A.7}$$

Similarly to the tradeable firms' problem, we can rewrite the above maximization problem as

$$\max_{P^o_{Nt}} \sum_{j=0}^{\infty} \zeta^j \mathbb{E}_t \Bigg\{ \Lambda_{t,t+j} \left[(P^o_{Nt})^{1-\theta} - \frac{W_{Nt+j}}{A_{Nt+j}} (P^o_{Nt})^{-\theta} \right] \Big[(1-\nu)(P_{t+j})^{\theta} C_{t+j} + (1-\kappa)\omega (\tilde{P}_{Ht+j})^{\theta-\lambda} (P_{Tt+j})^{\lambda} C_{Tt+j} + \\ + (1-\kappa)(1-\omega)(\tilde{P}_{Ft+j})^{\theta-\lambda}(P_{Tt+j})^{\lambda} C_{Tt+j} \Big] \Bigg\}, \tag{A.8}$$

where we have imposed $\theta = \mu$ so that the maximization problem yields a closed form solution. Hence, taking FOC with respect to P^o_{Nt} yields

$$P^o_{Nt} = \frac{\mathbb{E}_t \left[\sum_{j=0}^{\infty} \Gamma_{Nt,t+j} \frac{\mu}{\mu-1} \frac{W_{Nt}}{A_{Nt}} \right]}{\mathbb{E}_t \left[\sum_{j=0}^{\infty} \Gamma_{Nt,t+j} \right]},$$

where $\Gamma_{Nt,t+j} \equiv \zeta^j \Lambda_{t,t+j} \Psi_{Nt+j}$, and

$$\Psi_{Nt+j} \equiv (1-\nu)(P_{t+j})^{\theta} C_{t+j} + (1-\kappa)\omega (\tilde{P}_{Ht+j})^{\theta-\lambda} (P_{Tt+j})^{\lambda} C_{Tt+j} + (1-\kappa)(1-\omega)(\tilde{P}_{Ft+j})^{\theta-\lambda} (P_{Tt+j})^{\lambda} C_{Tt+j}.$$

A.7.3 Steady state

In the deterministic steady state, we assume zero inflation and

$$X_N = X_N^* = 1, v_t = v, \text{ and } \bar{B}_H = \bar{B}_F^* = 0,$$

where we have imposed the normalization $X_H = X_F^* = A_H = A_N = A_F^* = A_N^* = 1$. In steady state, price stickiness becomes irrelevant, so that nominal prices are indeterminate. Since sectors and countries are fully symmetric, without loss of generality we impose $P_H = P_N = P_F^* = P_N^* = 1$. Hence, from firms' optimal pricing decisions, wages are

$$W_H = W_N = W_F^* = W_N^* = \Omega^{-1}, \text{ where } \Omega \equiv \frac{\theta}{\theta - 1}, \tag{A.1}$$

implying $\mathcal{W}_t = \Omega^{-1}$. Then,

$$C^\sigma \mathcal{L}^\psi = \Omega^{-1}, \tag{A.2}$$

and, from the optimal sectoral consumption and labor supply decisions,

$$\begin{aligned} C_N &= (1 - v)\left(\Omega^{-1}\mathcal{L}^{-\psi}\right)^{1/\sigma}, \\ V_H &= (1 - \kappa)\omega v\left(\Omega^{-1}\mathcal{L}^{-\psi}\right)^{1/\sigma}, \\ V_F &= (1 - \kappa)(1 - \omega)v\left(\Omega^{-1}\mathcal{L}^{-\psi}\right)^{1/\sigma}, \text{ and} \\ L_N &= (1 - \phi)\mathcal{L}. \end{aligned} \tag{A.3}$$

Using the market-clearing conditions for the nontradeable sector:

$$Y_N = C_N + V_H + V_F = (1 - \kappa v)\left(\Omega^{-1}\mathcal{L}^{-\psi}\right)^{1/\sigma}, \tag{A.4}$$

where $Y_N = L_N = (1 - \phi)\mathcal{L}$, and $\phi = \kappa v$, thus yielding

$$C = \mathcal{L} = \Omega^{-\frac{1}{\sigma+\psi}}, \text{ and} \tag{A.5}$$

$$
\begin{aligned}
L_H &= \kappa \nu \Omega^{-\frac{1}{\sigma+\psi}}, \\
L_N &= (1-\kappa\nu)\Omega^{-\frac{1}{\sigma+\psi}}, \\
C_T &= \nu \Omega^{-\frac{1}{\sigma+\psi}}, \\
C_N &= (1-\nu)\Omega^{-\frac{1}{\sigma+\psi}}, \\
V_H &= (1-\kappa)\omega\nu\Omega^{-\frac{1}{\sigma+\psi}}, \\
V_F &= (1-\kappa)(1-\omega)\nu\Omega^{-\frac{1}{\sigma+\psi}}.
\end{aligned} \tag{A.6}
$$

A.7.4 Log-linearized system of equations

1. Home households optimality conditions:

$$\sigma\hat{c}_t + \psi\hat{\ell}_t = \hat{w}_t - \hat{p}_t, \tag{A.1}$$

$$\hat{\imath}_t = \mathbb{E}_t\left[\hat{\pi}_{t+1} + \sigma\left(\hat{c}_{t+1} - \hat{c}_t\right)\right], \tag{A.2}$$

$$\hat{\imath}^*_t = \mathbb{E}_t\left[\hat{\pi}_{t+1} + \sigma(\hat{c}_{t+1} - \hat{c}_t) - \Delta\hat{\varepsilon}_{t+1}\right] + \varphi''(\bar{B}_F)\hat{b}_{Ft+1}, \tag{A.3}$$

$$\hat{w}_t - \hat{p}_t = \phi\left((\hat{w}_{Ht} - \hat{p}_t) - \hat{\chi}_{Ht}\right) + (1-\phi)\left((\hat{w}_{Nt} - \hat{p}_t) - \hat{\chi}_{Nt}\right), \tag{A.4}$$

$$\hat{\ell}_{Ht} = -(1+\gamma)\hat{\chi}_{Ht} + \gamma\left((\hat{w}_{Ht} - \hat{p}_t) - (\hat{w}_t - \hat{p}_t)\right) + \hat{\ell}_t, \tag{A.5}$$

$$\hat{\ell}_{Nt} = -(1+\gamma)\hat{\chi}_{Nt} + \gamma\left((\hat{w}_{Nt} - \hat{p}_t) - (\hat{w}_t - \hat{p}_t)\right) + \hat{\ell}_t, \tag{A.6}$$

$$\hat{c}_{Tt} = \frac{\nu_t - \nu}{\nu} - \theta(\hat{p}_{Tt} - \hat{p}_t) + \hat{c}_t, \tag{A.7}$$

$$\hat{c}_{Nt} = -\frac{\nu_t - \nu}{1-\nu} - \theta(\hat{p}_{Nt} - \hat{p}_t) + \hat{c}_t, \tag{A.8}$$

$$\hat{c}_{Ht} = -\lambda\left((\hat{\tilde{p}}_{Ht} - \hat{p}_t) - (\hat{p}_{Tt} - \hat{p}_t)\right) + \hat{c}_{Tt}, \tag{A.9}$$

$$\hat{c}_{Ft} = -\lambda\left((\hat{\tilde{p}}_{Ft} - \hat{p}_t) - (\hat{p}_{Tt} - \hat{p}_t)\right) + \hat{c}_{Tt}, \tag{A.10}$$

$$\hat{\imath}_{Ht} = -\mu\left((\hat{p}_{Ht} - \hat{p}_t) - (\hat{\tilde{p}}_{Ht} - \hat{p}_t)\right) - \lambda\left((\hat{\tilde{p}}_{Ht} - \hat{p}_t) - (\hat{p}_{Tt} - \hat{p}_t)\right) + \hat{c}_{Tt}, \tag{A.11}$$

$$\hat{\imath}_{Ft} = -\mu\left((\hat{p}_{Ft} - \hat{p}_t) - (\hat{\tilde{p}}_{Ft} - \hat{p}_t)\right) - \lambda\left((\hat{\tilde{p}}_{Ft} - \hat{p}_t) - (\hat{p}_{Tt} - \hat{p}_t)\right) + \hat{c}_{Tt}, \tag{A.12}$$

$$\hat{v}_{Ht} = -\mu\left((\hat{p}_{Nt} - \hat{p}_t) - (\hat{\tilde{p}}_{Ht} - \hat{p}_t)\right) - \lambda\left((\hat{\tilde{p}}_{Ht} - \hat{p}_t) - (\hat{p}_{Tt} - \hat{p}_t)\right) + \hat{c}_{Tt}, \tag{A.13}$$

$$\hat{v}_{Ft} = -\mu\left((\hat{p}_{Nt} - \hat{p}_t) - (\hat{\tilde{p}}_{Ft} - \hat{p}_t)\right) - \lambda\left((\hat{\tilde{p}}_{Ft} - \hat{p}_t) - (\hat{p}_{Tt} - \hat{p}_t)\right) + \hat{c}_{Tt}. \tag{A.14}$$

2. Foreign households optimality conditions:

$$\bar{C}\hat{c}_t + \beta(\hat{b}_{Ft} - \hat{b}^*_{Ht}) = \hat{b}_{F,t-1} - \hat{b}^*_{H,t-1} + \bar{Y}_H(\hat{y}_{Ht} + \hat{p}_{Ht} - \hat{p}_t) + \bar{Y}_N(\hat{y}_{Nt} + \hat{p}_{Nt} - \hat{p}_t), \tag{A.15}$$

$$\sigma\hat{c}^*_t + \psi\hat{\ell}^*_t = \hat{w}^*_t - \hat{p}^*_t, \tag{A.16}$$

$$\hat{\imath}^*_t = \mathbb{E}_t\left[\hat{\pi}^*_{t+1} + \sigma(\hat{c}^*_{t+1} - \hat{c}^*_t)\right], \tag{A.17}$$

$$\hat{\imath}_t = \mathbb{E}_t\left[\hat{\pi}^*_{t+1} + \sigma(\hat{c}^*_{t+1} - \hat{c}^*_t) + \Delta\hat{\varepsilon}_{t+1}\right] + \varphi''(\bar{B}^*_H)\hat{b}^*_{Ht+1}, \tag{A.18}$$

$$\hat{w}^*_t - \hat{p}_t = \phi\left((\hat{w}^*_{Ft} - \hat{p}^*_t) - \hat{\chi}^*_{Ft}\right) + (1-\phi)\left((\hat{w}^*_{Nt} - \hat{p}^*_t) - \hat{\chi}^*_{Nt}\right), \tag{A.19}$$

$$\hat{\ell}^*_{Ft} = -(1+\gamma)\hat{\chi}^*_{Ft} + \gamma\left((\hat{w}^*_{Ft} - \hat{p}^*_t) - (\hat{w}^*_t - \hat{p}^*_t)\right) + \hat{\ell}^*_t, \tag{A.20}$$

$$\hat{\ell}^*_{Nt} = -(1+\gamma)\hat{\chi}^*_{Nt} + \gamma\left((\hat{w}^*_{Nt} - \hat{p}^*_t) - (\hat{w}^*_t - \hat{p}^*_t)\right) + \hat{\ell}^*_t, \tag{A.21}$$

$$\hat{c}^*_{Tt} = \frac{\nu^*_t - \nu}{\nu} - \theta(\hat{p}^*_{Tt} - \hat{p}^*_t) + \hat{c}^*_t, \tag{A.22}$$

$$\hat{c}^*_{Nt} = -\frac{\nu^*_t - \nu}{1-\nu} - \theta(\hat{p}^*_{Nt} - \hat{p}^*_t) + \hat{c}^*_t, \tag{A.23}$$

$$\hat{c}^*_{Ft} = -\lambda\left((\hat{\bar{p}}^*_{Ft} - \hat{p}^*_t) - (\hat{p}^*_{Tt} - \hat{p}^*_t)\right) + \hat{c}^*_{Tt}, \tag{A.24}$$

$$\hat{c}^*_{Ht} = -\lambda\left((\hat{\bar{p}}^*_{Ht} - \hat{p}^*_t) - (\hat{p}^*_{Tt} - \hat{p}^*_t)\right) + \hat{c}^*_{Tt}, \tag{A.25}$$

$$\hat{\imath}^*_{Ft} = -\mu\left((\hat{p}^*_{Ft} - \hat{p}^*_t) - (\hat{\bar{p}}^*_{Ft} - \hat{p}^*_t)\right) - \lambda\left((\hat{\bar{p}}^*_{Ft} - \hat{p}^*_t) - (\hat{p}^*_{Tt} - \hat{p}^*_t)\right) + \hat{c}^*_{Tt}, \tag{A.26}$$

$$\hat{\imath}^*_{Ht} = -\mu\left((\hat{p}^*_{Ht} - \hat{p}^*_t) - (\hat{\bar{p}}^*_{Ht} - \hat{p}^*_t)\right) - \lambda\left((\hat{\bar{p}}^*_{Ht} - \hat{p}^*_t) - (\hat{p}^*_{Tt} - \hat{p}^*_t\right) + \hat{c}^*_{Tt}, \tag{A.27}$$

$$\hat{v}^*_{Ft} = -\mu\left((\hat{p}^*_{Nt} - \hat{p}^*_t) - (\hat{\bar{p}}^*_{Ft} - \hat{p}^*_t)\right) - \lambda\left((\hat{\bar{p}}^*_{Ft} - \hat{p}^*_t) - (\hat{p}^*_{Tt} - \hat{p}^*_t)\right) + \hat{c}^*_{Tt}, \tag{A.28}$$

$$\hat{v}^*_{Ht} = -\mu\left((\hat{p}^*_{Nt} - \hat{p}^*_t) - (\hat{\bar{p}}^*_{Ht} - \hat{p}^*_t)\right) - \lambda\left((\hat{\bar{p}}^*_{Ht} - \hat{p}^*_t) - (\hat{p}^*_{Tt} - \hat{p}^*_t)\right) + \hat{c}^*_{Tt}. \tag{A.29}$$

3. Home prices & monetary policy:

$$0 = \nu(\hat{p}_{Tt} - \hat{p}_t) + (1-\nu)(\hat{p}_{Nt} - \hat{p}_t), \tag{A.30}$$

$$\hat{p}_{Tt} - \hat{p}_t = \omega(\hat{\bar{p}}_{Ht} - \hat{p}_t) + (1-\omega)(\hat{\bar{p}}_{Ft} - \hat{p}_t), \tag{A.31}$$

$$\pi_{Ft} = \pi^*_{Ft} + \Delta\hat{\varepsilon}_t, \tag{A.32}$$

$$\hat{\bar{p}}_{Ht} - \hat{p}_t = \kappa(\hat{p}_{Ht} - \hat{p}_t) + (1-\kappa)(\hat{p}_{Nt} - \hat{p}_t), \tag{A.33}$$

$$\hat{\bar{p}}_{Ft} - \hat{p}_t = \kappa(\hat{p}_{Ft} - \hat{p}_t) + (1-\kappa)(\hat{p}_{Nt} - \hat{p}_t), \tag{A.34}$$

$$\hat{\imath}_t = \phi_i\hat{\imath}_{t-1} + (1-\phi_i)(\phi_\pi\pi_t + \phi_y\hat{y}_t), \text{ where } \hat{y}_t = \kappa\nu\hat{y}_{Ht} + (1-\kappa\nu)\hat{y}_{Nt}, \tag{A.35}$$

$$\pi_{Ft} = (\hat{p}_{Ft} - \hat{p}_t) - (\hat{p}_{Ft-1} - \hat{p}_{t-1}) + \pi_t, \tag{A.36}$$

$$\pi_{Ht} = (\hat{p}_{Ht} - \hat{p}_t) - (\hat{p}_{Ht-1} - \hat{p}_{t-1}) + \pi_t, \tag{A.37}$$

$$\pi_{Nt} = (\hat{p}_{Nt} - \hat{p}_t) - (\hat{p}_{Nt-1} - \hat{p}_{t-1}) + \pi_t. \tag{A.38}$$

4. Foreign prices & monetary policy:

$$0 = \nu(\hat{p}^*_{Tt} - \hat{p}^*_t) + (1-\nu)(\hat{p}^*_{Nt} - \hat{p}^*_t), \tag{A.39}$$

$$\hat{p}^*_{Tt} - \hat{p}^*_t = \omega(\hat{\tilde{p}}^*_{Ft} - \hat{p}^*_t) + (1-\omega)(\hat{\tilde{p}}^*_{Ht} - \hat{p}^*_t), \tag{A.40}$$

$$\pi^*_{Ht} = \pi_{Ht} - \Delta\hat{\varepsilon}_t, \tag{A.41}$$

$$\hat{\tilde{p}}^*_{Ft} - \hat{p}^*_t = \kappa(\hat{p}^*_{Ft} - \hat{p}^*_t) + (1-\kappa)(\hat{p}^*_{Nt} - \hat{p}^*_t), \tag{A.42}$$

$$\hat{\tilde{p}}^*_{Ht} - \hat{p}^*_t = \kappa(\hat{p}^*_{Ht} - \hat{p}^*_t) + (1-\kappa)(\hat{p}^*_{Nt} - \hat{p}^*_t), \tag{A.43}$$

$$\hat{i}^*_t = \phi_{i^*}\hat{i}^*_{t-1} + (1-\phi_{i^*})(\phi^*_\pi \pi^*_t + \phi^*_y \hat{y}^*_t),\ \hat{y}^*_t = \kappa\nu\hat{y}^*_{Ft} + (1-\kappa\nu)\hat{y}^*_{Nt}, \tag{A.44}$$

$$\pi^*_{Ht} = (\hat{p}^*_{Ht} - \hat{p}^*_t) - (\hat{p}^*_{Ht-1} - \hat{p}^*_{t-1}) + \pi^*_t, \tag{A.45}$$

$$\pi^*_{Ft} = (\hat{p}^*_{Ft} - \hat{p}^*_t) - (\hat{p}^*_{Ft-1} - \hat{p}^*_{t-1}) + \pi^*_t, \tag{A.46}$$

$$\pi^*_{Nt} = (\hat{p}^*_{Nt} - \hat{p}^*_t) - (\hat{p}^*_{Nt-1} - \hat{p}^*_{t-1}) + \pi^*_t, \tag{A.47}$$

$$\hat{q}_t = \hat{q}_{t-1} + \Delta\hat{\varepsilon}_t + \pi^*_t - \pi_t. \tag{A.48}$$

5. Home production

$$\hat{y}_{Ht} = \hat{a}_{Ht} + \hat{\ell}_{Ht}, \tag{A.49}$$

$$\hat{y}_{Nt} = \hat{a}_{Nt} + \hat{\ell}_{Nt}, \tag{A.50}$$

$$\pi_{Nt} = \frac{(1-\zeta)(1-\zeta\beta)}{\zeta}\left((\hat{w}_{Nt} - \hat{p}_t) - \hat{a}_{Nt} - (\hat{p}_{Nt} - \hat{p}_t)\right) + \beta\mathbb{E}_t[\pi_{Nt+1}], \tag{A.51}$$

$$\pi_{Ht} = \frac{(1-\zeta)(1-\zeta\beta)}{\zeta}\left((\hat{w}_{Ht} - \hat{p}_t) - \hat{a}_{Ht} - (\hat{p}_{Ht} - \hat{p}_t)\right) + \beta\mathbb{E}_t[\pi_{Ht+1}]. \tag{A.52}$$

6. Foreign production

$$\hat{y}^*_{Ft} = \hat{a}^*_{Ft} + \hat{\ell}^*_{Ft}, \tag{A.53}$$

$$\hat{y}^*_{Nt} = \hat{a}^*_{Nt} + \hat{\ell}^*_{Nt}, \tag{A.54}$$

$$\pi^*_{Nt} = \frac{(1-\zeta)(1-\zeta\beta)}{\zeta}\left((\hat{w}^*_{Nt} - \hat{p}^*_t) - \hat{a}^*_{Nt} - (\hat{p}^*_{Nt} - \hat{p}^*_t)\right) + \beta\mathbb{E}_t[\pi^*_{Nt+1}], \tag{A.55}$$

$$\pi^*_{Ft} = \frac{(1-\zeta)(1-\zeta\beta)}{\zeta}\left((\hat{w}^*_{Ft} - \hat{p}^*_t) - \hat{a}^*_{Ft} - (\hat{p}^*_{Ft} - \hat{p}^*_t)\right) + \beta\mathbb{E}_t[\pi^*_{Ft+1}]. \tag{A.56}$$

7. Market clearing

$$\hat{y}_{Ht} = \frac{\bar{I}_H}{\bar{Y}_H}\hat{\imath}_{Ht} + \frac{\bar{I}^*_H}{\bar{Y}_H}\hat{\imath}^*_{Ht} = \omega\hat{\imath}_{Ht} + (1-\omega)\hat{\imath}^*_{Ht}, \tag{A.57}$$

$$\hat{y}_{Nt} = \frac{\bar{C}_N}{\bar{Y}_N}\hat{c}_{Nt} + \frac{\bar{V}_H}{\bar{Y}_N}\hat{v}_{Ht} + \frac{\bar{V}_F}{\bar{Y}_N}\hat{v}_{Ft} = \frac{1-\nu}{1-\kappa\nu}\hat{c}_{Nt} + \frac{(1-\kappa)\omega\nu}{1-\kappa\nu}\hat{v}_{Ht} + \frac{(1-\kappa)(1-\omega)\nu}{1-\kappa\nu}\hat{v}_{Ft}, \tag{A.58}$$

$$\hat{b}_{Ht} + \hat{b}^*_{Ht} = 0, \text{ where } \hat{b}_{Ht} \equiv B_{Ht} - \bar{B}_H, \tag{A.59}$$

$$\hat{y}^*_{Ft} = \frac{\bar{I}^*_F}{\bar{Y}^*_F}\hat{\imath}^*_{Ft} + \frac{\bar{I}_F}{\bar{Y}^*_F}\hat{\imath}_{Ft} = \omega\hat{\imath}^*_{Ft} + (1-\omega)\hat{\imath}_{Ft}, \tag{A.60}$$

$$\hat{y}^*_{Nt} = \frac{\bar{C}^*_N}{\bar{Y}^*_N}\hat{c}^*_{Nt} + \frac{\bar{V}^*_F}{\bar{Y}^*_N}\hat{v}^*_{Ft} + \frac{\bar{V}^*_H}{\bar{Y}^*_N}\hat{v}^*_{Ht} = \frac{1-\nu}{1-\kappa\nu}\hat{c}^*_{Nt} + \frac{(1-\kappa)\omega\nu}{1-\kappa\nu}\hat{v}^*_{Ft} + \frac{(1-\kappa)(1-\omega)\nu}{1-\kappa\nu}\hat{v}^*_{Ht}, \tag{A.61}$$

$$\hat{b}_{Ft} + \hat{b}^*_{Ht} = 0, \tag{A.62}$$

$$\bar{C}\hat{c}_t + \beta(\hat{b}_{Ft} - \hat{b}^*_{Ht}) = \hat{b}_{Ft-1} - \hat{b}^*_{Ht-1} + \bar{Y}_H(\hat{y}_{Ht} + \hat{p}_{Ht} - \hat{p}_t) + \bar{Y}_N(\hat{y}_{Nt} + \hat{p}_{Nt} - \hat{p}_t). \tag{A.63}$$

A.8 Uncovered Interest Parity Deviations and Equilibrium Bond Holdings

Our asset markets structure assumes both the home and foreign countries' bonds are internationally traded. The budget constraints for the home and foreign countries are:

$$P_tC_t + \frac{\mathcal{E}_t B_{Ft}}{1+i_t^*} + \frac{B_{Ht}}{1+i_t} = \mathcal{W}_t\mathcal{L}_t + \mathcal{E}_t\left(B_{Ft-1} - \varphi\left(B_{Ft-1}\right)\right) + B_{Ht-1} + \Pi_t, \quad \text{and}$$
$$P_t^*C_t^* + \frac{B_{Ht}^*}{\mathcal{E}_t(1+i_t)} + \frac{B_{Ft}^*}{1+i_t^*} = \mathcal{W}_t^*\mathcal{L}_t^* + \frac{1}{\mathcal{E}_t}\left(B_{Ht-1}^* - \varphi\left(B_{Ht-1}^*\right)\right) + B_{Ft-1}^* + \Pi_t^*.$$

$\varphi\left(B_{F,t-1}\right)$ ($\varphi(B_{H,t-1}^*)$) is a portfolio-adjustment cost borne by the home (foreign) country, where $\varphi(\cdot)$ is a convex function satisfying $\varphi(\bar{B}_F) = \varphi(\bar{B}_H^*) = \varphi'(\bar{B}_F) = \varphi'(\bar{B}_H^*) = 0$. Note that here we impose that the functional form governing the cost borne by the home country for holding the foreign bond is the same as that governing the cost borne by the foreign country for holding the home bond.

The intertemporal household problem in the home economy is:

$$\max_{\{C_t,\mathcal{L}_t,B_{Ht},B_{Ft}\}\forall t} \left\{\mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta^t\left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{\mathcal{L}_t^{1+\psi}}{1+\psi}\right)\right]\right\}$$
subject to
$$P_tC_t + \frac{\mathcal{E}_t B_{Ft}}{1+i_t^*} + \frac{B_{Ht}}{1+i_t} = \mathcal{W}_t\mathcal{L}_t + \mathcal{E}_t\left(B_{Ft-1} - \varphi\left(B_{Ft-1}\right)\right) + B_{Ht-1} + \Pi_t.$$

The intertemporal household problem in the foreign economy is:

$$\max_{\{C_t^*,\mathcal{L}_t^*,B_{Ht}^*,B_{Ft}^*\}\forall t} \left\{\mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta^t\left(\frac{(C_t^*)^{1-\sigma}}{1-\sigma} - \frac{(\mathcal{L}_t^*)^{1+\psi}}{1+\psi}\right)\right]\right\}$$
subject to
$$P_t^*C_t^* + \frac{B_{Ht}^*}{\mathcal{E}_t(1+i_t)} + \frac{B_{Ft}^*}{1+i_t^*} = \mathcal{W}_t^*\mathcal{L}_t^* + \frac{1}{\mathcal{E}_t}\left(B_{Ht-1}^* - \varphi\left(B_{Ht-1}^*\right)\right) + B_{Ft-1}^* + \Pi_t^*.$$

Bond market clearing conditions specify that

$$B_{H,t} + B_{H,t}^* = 0 \;\forall t, \text{ and}$$
$$B_{F,t} + B_{F,t}^* = 0 \;\forall t.$$

The optimality conditions for bond holdings yield the Euler equations:

$$\begin{aligned}
&\mathbb{E}_t\left[\beta\left(\frac{C_t}{C_{t+1}}\right)^{\sigma}\left(\frac{P_t}{P_{t+1}}\right)(1+i_t)\right]=1, \text{ and}\\
&\mathbb{E}_t\left[\beta\left(\frac{C_t}{C_{t+1}}\right)^{\sigma}\left(\frac{P_t}{P_{t+1}}\right)\left(\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right)(1+i_t^*)\left(1-\varphi'(B_{Ft})\right)\right]=1.
\end{aligned} \tag{A.64}$$

Together, they imply the following no arbitrage condition:

$$\mathbb{E}_t\left\{\beta\left(\frac{C_t}{C_{t+1}}\right)^{\sigma}\left(\frac{P_t}{P_{t+1}}\right)\left[(1+i_t)-\left(\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right)(1+i_t^*)\left(1-\varphi'(B_{Ft})\right)\right]\right\}=0. \tag{A.65}$$

After log-linearizing (A.65), we obtain the uncovered interest differential:

$$i_t - i_t^* - \mathbb{E}_t\left[\Delta\varepsilon_{t+1}\right] = -\varphi''\left(\bar{B}_F\right)\left(B_{Ft}-\bar{B}_F\right),$$

where $\Delta\varepsilon_{t+1} \equiv \log(\mathcal{E}_{t+1}) - \log(\mathcal{E}_t)$ is the nominal exchange rate depreciation, and $-\varphi''\left(\bar{B}_F\right)\left(B_{Ft} - \bar{B}_F\right)$ is the deviation from uncovered interest rate parity.

For the Foreign country, we get symmetric optimality conditions:

$$\begin{aligned}
&\mathbb{E}_t\left[\beta\left(\frac{P_t^*}{P_{t+1}^*}\right)\left(\frac{C_t^*}{C_{t+1}^*}\right)^{\sigma}(1+i_t^*)\right]=1, \quad \text{and}\\
&\mathbb{E}_t\left[\beta\left(\frac{P_t^*}{P_{t+1}^*}\right)\left(\frac{C_t^*}{C_{t+1}^*}\right)^{\sigma}\left(\frac{\mathcal{E}_t}{\mathcal{E}_{t+1}}\right)(1+i_t)\left(1-\varphi'(B_{Ht}^*)\right)\right]=1.
\end{aligned} \tag{A.66}$$

The two first-order conditions for the foreign country yield the no-arbitrage condition:

$$\mathbb{E}_t\left[\beta\left(\frac{P_t^*}{P_{t+1}^*}\right)\left(\frac{C_t^*}{C_{t+1}^*}\right)\left(\frac{\mathcal{E}_t}{\mathcal{E}_{t+1}}\right)(1+i_t)\left(1-\varphi'(B_{Ht}^*)\right)-(1+i_t^*)\right]=0. \tag{A.67}$$

Log-linearizing (A.67) yields a symmetric uncovered interest differential equation in the Foreign country:

$$\hat{i}_t - \hat{i}_t^* - \mathbb{E}_t\left[\Delta\hat{\varepsilon}_{t+1}\right] = \varphi''\left(\bar{B}_H^*\right)\left(B_{Ht}^*-\bar{B}_H^*\right).$$

Therefore, combining the two log-linearized uncovered interest rate differential equations, the symmetric structure of the Home and Foreign household problems admits the following restriction on equilibrium bond holdings:

$$\hat{b}_{Ft} = -\frac{\varphi''\left(\bar{B}_H^*\right)}{\varphi''\left(\bar{B}_F\right)}\hat{b}_{Ht}^*.$$