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* Views expressed are those of the author and do not necessarily reflect official positions of De Nederlandsche Bank.

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US monetary policy spillovers through global commercial real estate*

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Abstract

We provide new evidence on the international spillover effects of US monetary policy through global commercial real estate (CRE) markets. Using a global VAR-X model that exploits both city- and country-level data, we account for spatial dependencies arising from cross-border investor ownership of CRE. A US quantitative easing shock leads to a persistent rise in CRE prices, both within and outside the US, and an expansion of credit, but mostly in the US. To interpret these findings, we develop an open economy New Keynesian model with CRE markets, which highlights the role of increased domestic demand for foreign CRE as a key transmission channel. Moreover, the model reveals that spillover effects can spill back to the US via trade linkages, amplifying the initial effects of US monetary policy.

JEL Classification: C32, E32, E52, F42, R33

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Keywords: monetary policy, commercial real estate, international spillovers, quantitative easing, global VAR-X model, New Keynesian model

1 Introduction

Changes in US monetary policy are often felt, positively or negatively, in many regions outside the US. These international spillover effects find their way through a myriad of complex channels, some of which remain poorly understood. A notable example is the role of global commercial real estate (CRE) markets in spreading the effects of US monetary policy shocks worldwide. Notable because the CRE market is substantial: CRE is the third largest asset class in the US, with an outstanding amount of 90% of US GDP in 2017 (Ghent et al., 2019). CRE is also a key factor driving economic activity. It generally forms a significant share of a firm’s tangible assets and, therefore, is an important driver of investment decisions, risk taking and performance through the collateral channel (Gan, 2007; Chaney et al., 2012; Tuzel and Zhang, 2017). CRE is also an increasingly important investment vehicle for institutional investors, such as pension funds, insurance companies and sovereign wealth funds, who often hold global CRE portfolios, either by acquiring real estate directly or indirectly through fund structures in multiple countries (Andonov et al., 2015). Consequently, CRE markets exhibit a strong international co-movement in both returns and trading volume (Zhu et al., 2024; Van Dijk and Francke, 2025). The role of CRE markets for the transmission of monetary policy is, however, a sparsely studied topic.

This paper aims to fill this gap by providing novel estimates of the international spillover effects of US monetary policy through global CRE markets. We focus on the effects of US quantitative easing (QE) shocks, as CRE prices are likely more strongly affected by changes in long-term interest rates than short-term rates (through the portfolio rebalancing channel), given the often long duration of CRE funding.¹

To identify QE shocks, we follow the proxy variable approach of Paul (2020). Specifically, we obtain QE surprises based on a (rotated) principal component of high frequency yield curve movements around FOMC events from Swanson (2021). These QE surprises then serve

¹We also examined the effects of ‘conventional’ monetary policy on CRE prices and found these to be qualitatively similar as those of a QE shock, provided the unexpected changes in the policy rate are sufficiently large to deliver comparable movements in long-term yields. These results are available upon request.

as an instrument in a rich global VAR-X model that captures the economic dynamics of, and interdependencies between, 22 cities across 11 countries. The cross-sectional interdependencies are captured by unique transaction-level data on the share of properties in a particular city owned by investors that also own properties elsewhere.

We find that a US quantitative easing shock raises CRE prices, not only in the US, but also in CRE markets outside the US. On average across countries, a QE shock that reduces the 10-year US Treasury yield by 10 basis points on impact raises CRE prices by around 4% after two years following the shock. Not surprisingly, we find that the impact on CRE prices is greater in the US (5%) than in other countries (3%). Furthermore, the shock not only eases borrowing conditions in the US, but also lowers long-term interest rates outside the US. However, while QE raises credit in the US, its impact on credit in other countries is relatively modest. This result suggests that the rise in CRE prices in non-US markets is likely driven by an increase in demand by US investors for CRE in those markets, rather than by greater demand from non-US investors, consistent with a portfolio rebalancing channel. Therefore, it seems that international financial linkages arising from global CRE portfolios are key in understanding the spillover effects of QE.

We perform a range of robustness checks to assess the stability of our findings. First, we re-estimate the global VAR model using alternative measures of interconnectedness across CRE markets, including geographic proximity between cities, whether cities are located in the same country or belong to the same currency area, and the extent to which cities share advanced producer service firms. We likewise consider alternative specifications to capture spatial dependencies across countries. In addition, we relax the identifying assumption that only US variables can respond contemporaneously to US monetary policy shocks within a quarter. Finally, we test the sensitivity of the results to the use of an alternative QE shock series that is purged of information effects and by explicitly controlling for asset purchases conducted by the European Central Bank.

We confirm and rationalize our empirical results in the context of a two-country New

Keynesian model featuring international financial integration (as in [Wu et al., 2024](#)) and CRE markets. In the model, CRE is a composite of real estate capital and land which is used as an input in the production of goods. We proxy global CRE portfolios by having banks hold bonds from both domestic and foreign firms that themselves use these funds to invest in CRE. The model replicates our main empirical finding that both domestic and foreign CRE prices respond to a US QE shock.

The model allows us to distinguish three novel transmission channels of quantitative easing through CRE markets. First, a *direct effect* that boosts domestic CRE prices through a reduction in long-term rates. Second, a *spillover effect* that follows from an increase in demand by domestic investors for global CRE through the portfolio rebalancing channel, rather than an expansion in foreign credit. Third, a *spillback effect* through which some of the spillover effects of QE amplify the effects of the country that engages in QE. Intuitively, quantitative easing leads to a depreciation of the domestic currency which raises exports through an expenditure-switching effect abroad. In addition, the strengthening of foreign CRE markets generates an additional boost in foreign demand for domestic goods. A sensitivity analysis that considers alternative calibrations of a set of key parameters illustrates the importance of both these spillover and spillback effects, as well as the ‘typical’ direct effects of QE that operate through a decline in borrowing rates.

Our finding that the Federal Reserve’s asset purchases lowered US long-term interest rates and raised real GDP and inflation are consistent with a large literature that documents the macroeconomic impact of QE.² In contrast to earlier empirical studies that also employ VAR models, our empirical identification does not rely on sign or zero restrictions as, for instance, [Kapetanios et al. \(2012\)](#), [Baumeister and Benati \(2013\)](#), [Weale and Wieladek \(2016\)](#) and [Boeckx et al. \(2017\)](#), but instead uses rotated principal components constructed

²For estimates on the effects of the Federal Reserve’s asset purchases on US treasury yields, see [Krishnamurthy and Vissing-Jorgensen \(2011\)](#), [d’Amico et al. \(2012\)](#), [Abrahams et al. \(2016\)](#), [Ihrig et al. \(2018\)](#) and [Christensen and Krogstrup \(2019\)](#). With regards the impact on macroeconomic variables, see [Kapetanios et al. \(2012\)](#), [Baumeister and Benati \(2013\)](#), [Weale and Wieladek \(2016\)](#), [Boeckx et al. \(2017\)](#) and [Boehl et al. \(2024\)](#), who find mostly expansionary effects. For an extensive overview of this literature, see [Kuttner \(2018\)](#) and [Bhattarai and Neely \(2022\)](#).

from exogenous high-frequency monetary policy surprises to identify QE shocks in the spirit of [Altavilla et al. \(2019\)](#) and [Swanson \(2021\)](#).

More importantly, by focusing on global CRE markets, our analysis uncovers a new channel through which the US Federal Reserve’s asset purchases transmit internationally. Our paper thus contributes to a strand of the literature that studies the international effects of US quantitative easing. For instance, [Ahmed and Zlate \(2014\)](#), [Neely \(2015\)](#), [Lim and Mohapatra \(2016\)](#), [Tillmann \(2016\)](#) and [Fratzscher et al. \(2018\)](#) find that US quantitative easing resulted in pro-cyclical capital inflows into both developed and emerging markets. Our results further support this evidence by highlighting the increased demand by US investors for CRE in non-US markets.

Finally, our paper also relates to the literature on the effects of monetary policy on real estate prices. However, much of this literature is focused on *residential*, rather than commercial, real estate, such as [Aoki et al. \(2004\)](#), [Iacoviello \(2005\)](#), [Iacoviello and Neri \(2010\)](#), [Monacelli \(2009\)](#) and [Rubio \(2011\)](#). Two notable exceptions are [Coën et al. \(2018\)](#) and [Coën et al. \(2022\)](#), who study the impact of money supply on the London and European office markets. Our study thus contributes to the literature by focusing on commercial real estate, looking broader than conventional interest rate policy and accounting for the international dimension.

2 Empirical framework

2.1 A global VAR-X model

We estimate the cross-border spillover effects of US monetary policy through global commercial real estate markets using a rich global VAR-X model that exploits both city- and country-level data. The framework crucially allows for spatial dependencies between CRE markets across cities and countries.

The model consists of two blocks. The first block describes *city-level* dynamics of CRE

prices in city i in period t , denoted by $y_{i,t}$ for $i \in \{1, \dots, N\}$, with N being the total number of cities in our sample. CRE prices are assumed to evolve according to the following equation:

$$\begin{aligned} \Delta y_{i,t} = & a_i + \iota_i t + \underbrace{\psi_i \Delta y_{i,t-1}}_{\text{own lagged prices}} + \underbrace{\psi_i^s \Delta y_{i,t-1}^s}_{\text{short-run other cities}} + \underbrace{\lambda_i^x \Delta x_{i,t-1}}_{\text{short-run macro fundamentals}} \\ & + \underbrace{\phi_i^s (y_{i,t-1} - y_{i,t-1}^s)}_{\text{error correction other cities}} + \underbrace{\phi_{i,z}^x \beta_i' z_{i,t-1}}_{\text{error correction macro fundamentals}} + \varepsilon_{i,t}^y. \end{aligned} \quad (1)$$

The first term, a_i , denotes a city-specific intercept. The second term, $\iota_i t$, represents a linear trend. The third and fourth terms reflect the assumption that CRE prices of city i depend on their own lags and on lagged CRE prices in other cities. In order to reduce the dimensionality of the model, we capture the latter by a ‘spatial dependency term’, $y_{i,t}^s = \sum_{j \in \{1, \dots, N\} \setminus \{i\}} s_{i,j,t} y_{j,t}$, which is a weighted average of CRE prices in other markets. The weights, $s_{i,j,t} \in [0, 1]$, are a crucial determinant of this spatial dependency of CRE markets and account for the empirically observed co-movement of CRE prices across similar markets (Zhu and Lizieri, 2021; Zhu et al., 2024). The construction of the weights is discussed in more detail in Section 2.3.

City-level CRE prices also depend on a $K \times 1$ vector of country-level macroeconomic aggregates, $x_{i,t}$, of the country to which city i belongs. A cointegration relationship between CRE prices and macroeconomic fundamentals is captured through the term $\beta_i' z_{i,t}$, where $z_{i,t} \equiv (y_{i,t} x_{i,t})'$ and β_i' is a $K \times R_i$ matrix of coefficients, with R_i the cointegration rank of city i as determined by the Johansen test with a constant and a deterministic trend. Lag lengths are set equal to 1 based on the Akaike information criterion.³ Finally, note that the coefficient $\phi_{i,s}$ captures the long-term effect of CRE prices in other cities, while the coefficients ψ_i capture their short-term dynamic effects. Therefore, the model essentially reflects an error correction relationship between local CRE prices and weighted global CRE prices.

³Using other criteria, such as adjusted R^2 , the Hannan-Quinn information criterion or the Bayesian information criterion, generates robust results in terms of the spatial diffusion of real estate prices. The results based on these other selection criteria are available on request.

The second block of the model describes *country-level* dynamics of the macroeconomic variables, denoted by $x_{g,t}$ for country $g \in \{1, \dots, M\}$, with M being the total number of countries in our sample. Note the shift in notation from $x_{i,t}$, which refers to the city level, to $x_{g,t}$, which refers to the country level. If city i belongs to country g , $x_{i,t}$ will take the corresponding value of $x_{g,t}$. Country-level macroeconomic dynamics are then governed by the following equation:

$$\Delta x_{g,t} = \alpha_g + \iota_g^x t + \underbrace{\lambda_g^y \Delta y_{g,t-1}}_{\text{domestic CRE price}} + \underbrace{\delta_g \Delta x_{g,t-1}}_{\text{home lagged macro}} + \underbrace{\delta_g^W \Delta x_{g,t-1}^W}_{\text{foreign short-run macro}} + \underbrace{\kappa_g \ddot{\eta}_g' \ddot{z}_{g,t-1}}_{\text{error correction}} + \varepsilon_{g,t}^x. \quad (2)$$

The first and second terms again represent a country-specific intercept and a linear trend, respectively. The third and fourth terms postulate that macroeconomic aggregates in country g depend on the (average) domestic CRE price, $y_{g,t}$, and their own lags. As in the first block, we allow, by the fifth term, for spatial dependencies across countries through a weighted average of macroeconomic variables from other countries, i.e. $x_{g,t}^W = \sum_{h \in \{1, \dots, M\} \setminus \{g\}} w_{g,h,t} x_{h,t}$, where $w_{g,h,t} \in [0, 1]$ determines the importance of country h for macroeconomic conditions in country g . Furthermore, the model allows for a cointegration relationship between domestic macroeconomic variables, foreign macroeconomic variables and country-level CRE prices, as captured by the term $\ddot{\eta}_g' \ddot{z}_{g,t}$, where $\ddot{z}_{g,t} \equiv [x_{g,t-1} \ x_{g,t-1}^W \ y_{g,t-1}]$ and $\ddot{\eta}_g$ is a $(2K+1) \times R_g^X$ matrix of coefficients, with R_g^X the cointegration rank of country g .⁴

⁴Due to the limited number of observations, the maximum lag lengths are set equal to 1. It should also be noted that, in the baseline model, we allow macroeconomic variables to co-move contemporaneously only with their foreign counterpart ($\delta_{g,0}^W \Delta x_{g,t}^W$). Cross-country dependence between different macroeconomic variables occurs with at least a one-period lag ($\delta_{g,1}^W \Delta x_{g,t-1}^W$). This implies that, for instance, a US interest rate shock affects UK GDP starting in the following quarter rather than immediately. In contrast, US and UK interest rates are allowed to co-move both contemporaneously and with a lag. Results based on less stringent assumptions — including contemporaneous co-movement in real estate prices across cities ($b_{i,0} \Delta y_{i,t}^s$) as well as contemporaneous co-movement across different macroeconomic variables and countries (e.g., a US interest rate shock affects UK GDP immediately and also in the following quarters) — are qualitatively similar to our main results and reported in the Appendix.

Combining Equations (1) and (2), we can write our global VAR as:

$$\Delta z_t = \mathbf{H}_0 z_{t-1} + a + \mathbf{A} \Delta z_{t-1} + \mathbf{C}_0 \Delta z_t + \varepsilon_t. \quad (3)$$

The coefficient matrices in Equation (3) are defined and discussed in more detail in Appendix A. We estimate the model in two steps. First, we estimate the cointegration relationships and ranks. Second, we estimate the system's short run dynamics and error correction using seemingly unrelated regressions (SUR).

2.2 Shock identification

To identify the structural shocks, u_t , let $\mathbf{V}$ be a $(N + K \times M) \times (N + K \times M)$ matrix collecting the contemporaneous effects of the structural shocks on endogenous variables Δz_t , such that $u_t = \mathbf{V} \varepsilon_t$. We can then write (3) in structural form:

$$\mathbf{V} \Delta z_t = \mathbf{V} \mathbf{H}_0 z_{t-1} + \mathbf{V} a + \mathbf{V} \mathbf{A} \Delta z_{t-1} + \mathbf{V} \mathbf{C}_0 \Delta z_t + \mathbf{V} \varepsilon_t, \quad (4)$$

Further, let $u_{1,t}$ denote the structural shock of interest. The reduced-form residuals, ε_t , can then be decomposed as follows:

$$\varepsilon_t = \nu u_{1,t} + \underline{\mathbf{V}} u_{2,t}, \quad (5)$$

where ν is the impulse vector associated with $u_{1,t}$ and $u_{2,t}$ is the $(N + K \times M - 1) \times 1$ vector that collects all other structural shocks. According to [Stock and Watson \(2012\)](#) and [Mertens and Ravn \(2013\)](#), the identification of $u_{1,t}$ can be based on information from external sources if a proxy, F_t , exists that is correlated with $u_{1,t}$, i.e. $\mathbf{E}[F_t u_{1,t}] \neq 0$, and uncorrelated with the other shocks, i.e. $\mathbf{E}[F_t u_{2,t}] = 0$. Our monetary policy shocks satisfy those conditions, see Section 2.4. [Paul \(2020\)](#) further suggests integrating F_t into the first-stage estimation as

follows:

$$\Delta z_t = \mathbf{H}_0 z_{t-1} + a + \mathbf{A} \Delta z_{t-1} + \mathbf{C}_0 \Delta z_t + \Upsilon_0 F_t + \varepsilon_t, \quad (6)$$

with Υ_0 being a $(N + K \times M) \times 1$ coefficient vector. The ratio of any two elements $k \neq l$ in Υ_0 , with v_{0k} denoting the k -th element of Υ_0 , gives consistent estimates of the contemporaneous relative impulse response r_{kl} :

$$\hat{r}_{kl} = \frac{\hat{v}_{0k}}{\hat{v}_{0l}}. \quad (7)$$

In our baseline model, we assume that the instrument F_t only contemporaneously influences the domestic economy (and CRE markets), while it affects other economies contemporaneously only through US macroeconomic variables.⁵

2.3 Spatial dependence and weighting scheme

What makes our model a *global* model is the dependence of local CRE prices on CRE prices and macroeconomic fundamentals in other cities and countries. We follow [Zhu and Lizieri \(2021\)](#) and use individual transactions data to derive patterns of overlapped ownership. Prices in city i are affected by those in city j . These weights are based on the concept of ‘overlapping ownership’ and are calculated as the dollar value of properties in city i whose owner also owns property in another city divided by the total number of properties in city i observed over the full sample.⁶ Therefore, a high weight implies that a large share of the properties in a particular city are owned by investors that also own properties elsewhere. To be more specific, let $L_{i,t}$ be the total number of transacted properties in city i in year t , $q_{i,l,j,t}$

⁵Relaxing this assumption does not affect our main results, although the resulting confidence intervals are somewhat larger amid the larger number of parameters that need to be estimated, as we briefly discuss in Section 4.

⁶Results are robust to using counts instead of dollar-weighted value and using indexed prices (i.e. converting the price in year t , $P_{i,l,t1}$, to the price in the initial year, $P_{i,l,1}$) instead of nominal transaction values. These results are available upon request.

a dummy that equals 1 if the owner of property $l = 1, 2, \dots, L_{i,t}$ in city i transacted in year t also owns property in city j , and $P_{i,l,t}$ the transaction price of property l in city i in year t . The weight $s_{i,j,t}$ is then calculated as

$$s_{i,j,t} = \frac{\sum_{t1=1}^t \sum_{l=1}^{L_{i,t1}} q_{i,l,j,t} P_{i,l,t1}}{\sum_{t1=1}^t \sum_{l=1}^{L_{i,t1}} P_{i,l,t1}}. \quad (8)$$

This weighting scheme captures the observation that private, institutional and real estate investors – such as occupational pension funds, insurance companies and sovereign wealth funds – increasingly hold global real estate portfolios by acquiring real estate in different cities and countries, either directly or through fund structures (see e.g. [Andonov et al., 2015](#)). Global real estate investors, thereby, establish a link between commercial real estate markets across the globe, through which shocks from one region can be transmitted to others. For example, a housing crisis in one region may cause investors that own properties in that region to face collateral write-downs or refinancing issues that could force them to liquidate investments in other regions, putting downward pressure on asset prices in those other regions. Commercial real estate markets may also be exposed to one another through information spillovers that cause price determination in one region be affected by what investors know about economic conditions in other regions. Such links between CRE markets can, of course, be captured by other, more traditional, measures of interconnectedness, such as geographic distance between cities, trade openness, similarity of the legal system of different cities, or whether cities use the same currency. However, [Zhu and Lizieri \(2021\)](#) show that a weighting scheme based on overlapped ownership holds greater explanatory power of CRE market interconnectedness than those (and other) measures.⁷

The construction of the weights that capture the dependency of country g on macroeconomic conditions in country h , denoted by $w_{g,h}$, is based on bilateral portfolio investment positions. Bilateral portfolio investment has been widely used in the literature as a mea-

⁷As a robustness check, we also considered the more traditional measures of interconnectedness, see Section 4.

sure of financial asset exposure to identify the international transmission of financial shocks (Abbate et al., 2016), exchange rate movements (Lane and Shambaugh, 2010), and other macro-financial spillovers within the GVAR framework.⁸

Formally, $w_{g,h}$ is computed using the outward portfolio investment position of the financial sector in country g vis-à-vis the total economy of country h . Financial sector investment is calculated as the total position from the whole economy net of positions held by non-financial corporations, households and the government. Let $\text{PII}_{g,h,t}$ denote this bilateral portfolio investment position in year t . The weight is then defined as the share of country g 's portfolio investment exposure to country h relative to its total outward portfolio investment exposure to all other countries in the sample:

$$w_{g,h,t} = \frac{\text{PII}_{g,h,t}}{\sum_{k \neq g} \text{PII}_{g,k,t}}. \quad (9)$$

We standardize $w_{g,h,t}$ such that it lies between 0 and 1.

2.4 Data

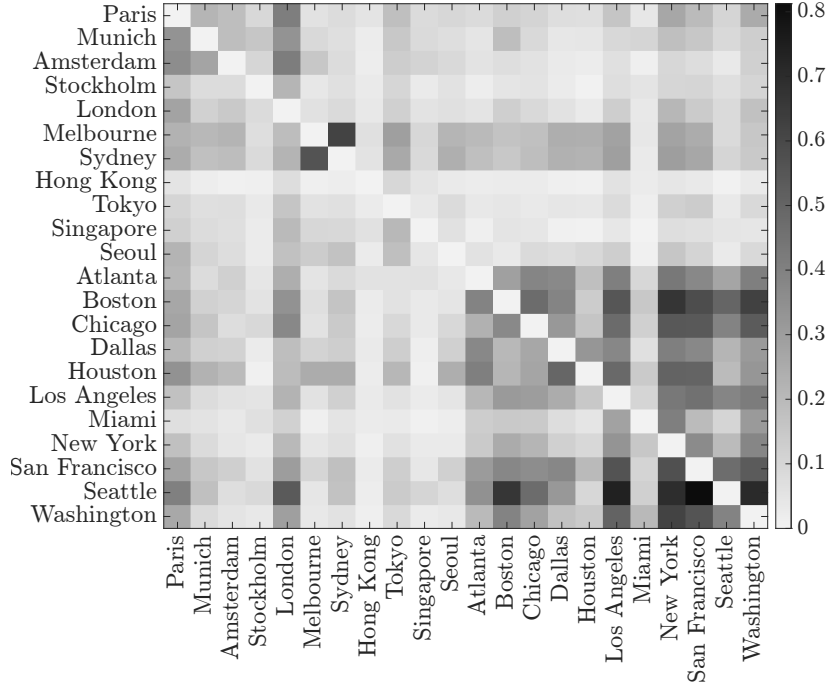
We estimate our global VAR-X model for a panel of 22 commercial real estate markets that are located in 11 countries.⁹ City-level commercial real estate price indices are obtained from MSCI/Real Capital Analytics and span the period 2007Q2–2019Q2.¹⁰ We also use transaction-level data from Real Capital Analytics on commercial property prices over the same period to construct the intercity weights that help us capture the interconnectedness of CRE markets. Figure 1 illustrates the average ownership overlap ratios across the cities in our sample, with a darker color implying a larger overlap in ownership across any two cities. With half of the cities in our sample being located in the US, the largest weights are

⁸Furthermore, Eickmeier and Ng (2015) consider foreign direct investments to study the international transmission of credit supply shocks.

⁹The 22 cities included in our dataset are Atlanta, Boston, Chicago, Dallas, Houston, Los Angeles, Miami, New York, San Francisco, Seattle, Washington, Paris, Munich, Amsterdam, Stockholm, London, Melbourne, Sydney, Hong Kong, Tokyo, Singapore and Seoul.

¹⁰These concern the RCA CPPI®, the commercial property price indices from MSCI and formerly Real Capital Analytics (RCA).

Figure 1: Ownership overlap ratios across cities, 2007Q2-2019Q2 average



Notes: The ownership overlap ratio is measured as the dollar-weighted number of properties in city i whose owner also owns property in another city divided by the total number of properties in city i .

found for US cities, as evidenced by the relatively darker bottom-right corner.

The monetary policy surprises are taken from [Swanson \(2021\)](#), who constructs three orthogonal factors from intraday changes in a set of Federal Funds futures, Eurodollar futures, Treasury bond yields, the stock market and exchange rates around FOMC events (i.e. FOMC statements, minutes, press conferences, data releases and speeches).¹¹ Out of these three identified factors, labeled ‘Federal Funds rate’, ‘Forward Guidance’ (FG) and ‘Large-Scale Asset Purchases’ (LSAP), we use the latter, which we shall refer to as a QE shock, as our baseline instrument for the monetary policy surprises. Given that we work with quarterly data, we convert the monetary policy surprises into quarterly weighted sums following [Ottonello and Winberry \(2020\)](#). Doing so gives more weight to events that occur early in the quarter and allows events occurring later in the month to have an effect in both

¹¹Specifically, the asset prices include federal funds futures (the current-month and each of the next six months contract rates), Eurodollar futures (the current-quarter and each of the next eight quarters contract rates), Treasury bond yields (3-month, 6-month, and 2-, 5-, 10-, and 30-year maturities), the S&P 500, and yen- and eurodollar exchange rates.

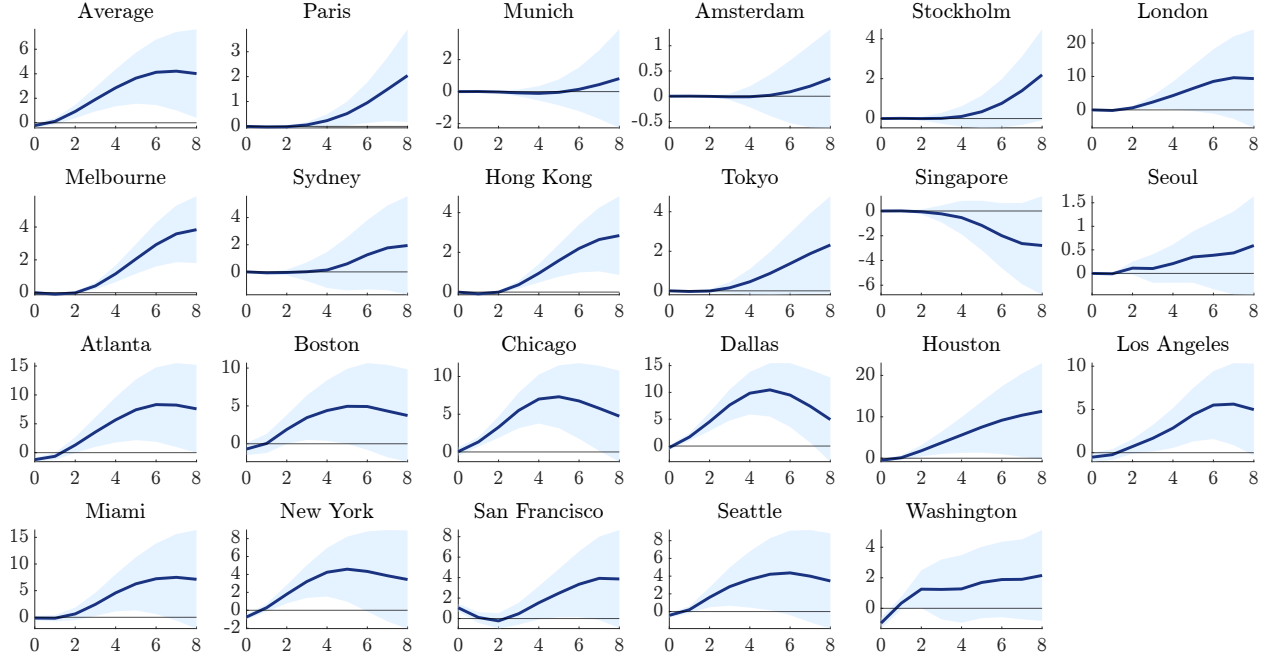
the current and subsequent month.

Finally, we use five country-level macroeconomic variables in the country block of our VAR. As a measure for the long-term interest rate, we use the 10-year government bond yield from the IMF World Economic Outlook. Data for the Consumer Price Index (CPI) and the (CPI-based) real effective exchange rate (REER) are obtained from the IMF International Financial Statistics database. Credit, measured as domestic and foreign credit to non-financial sectors as a percent of GDP, is obtained from the BIS. GDP at constant prices and local currency is obtained from national statistical offices. Real GDP, the credit-to-GDP ratio, the REER and the CPI enter the GVAR-X model in logs, while the interest rate enters the model in percentage levels. Finally, bilateral portfolio investments for country-level weights are extracted from the IMF’s Coordinated Portfolio Investment Survey.

3 Empirical results

We start by discussing our main empirical result: a US quantitative easing shock raises CRE prices, not only in the US, but also in CRE markets outside the US. Figure 2 plots the cumulative responses of CRE prices to a US QE shock in each of the 22 cities in our sample, as well as the (trading-volume weighted) average response across these cities. Here, and in what follows, we calibrate the size of the shock such that it delivers a 10 basis points decline in the 10-year US Treasury yield on impact, unless stated otherwise. On average, the QE shock has a positive, statistically significant and highly persistent effect on CRE prices. The response of CRE prices builds up over time, reaching a peak of about 4% after 2 years following the shock. Zooming in on the individual cities, we find that this pattern is common to the majority of cities in our sample. Not surprisingly, the strongest responses of CRE prices are found in US cities, particularly in Houston (with a peak response of more than 11%), Dallas and Atlanta (with peak responses exceeding 8%). However, not all US cities behave alike. The impact of QE on CRE prices is less pronounced in Seattle

Figure 2: Response of CRE prices to a US quantitative easing shock

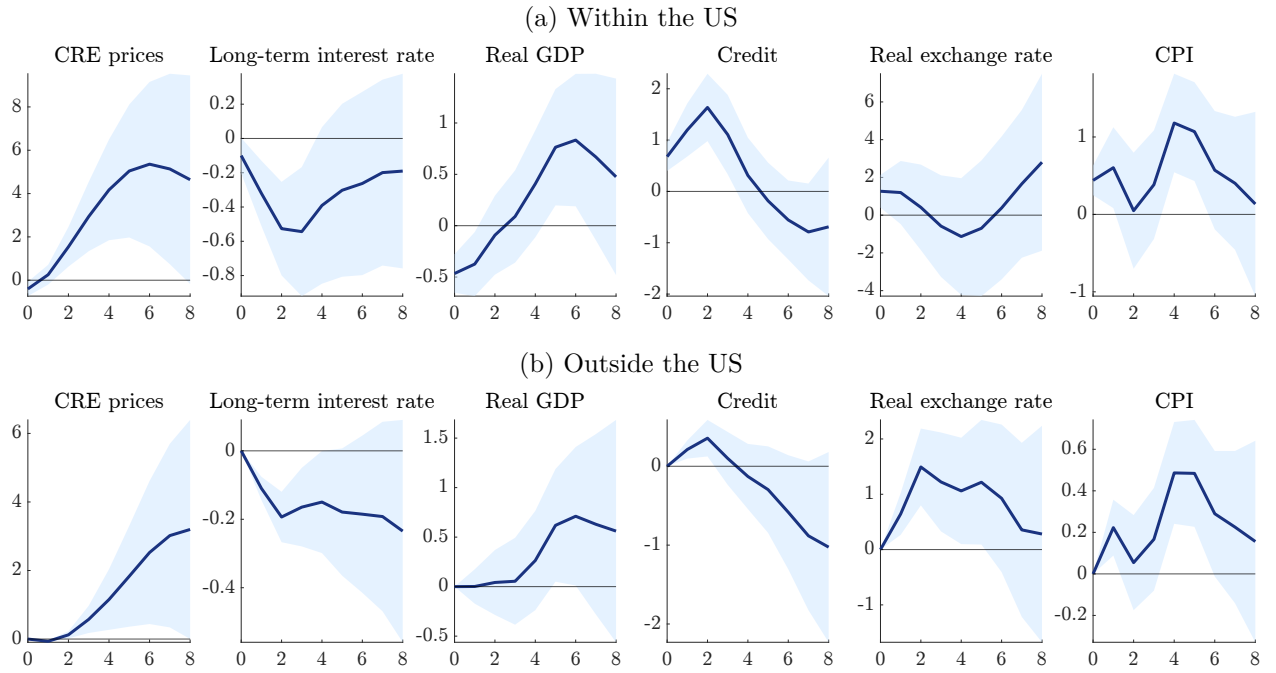


Notes: The figure shows cumulative IRFs to represent variables in levels. The US quantitative easing shock is calibrated to deliver a 10 basis points decline in the 10-year US Treasury yield on impact. The average response across the 22 cities in our sample is trading-volume weighted. Shaded areas denote the upper and lower bound of the 90% confidence interval. Units are expressed in percentage points. Horizontal axes

and New York, while in San Francisco and Washington the impact is insignificant. We also observe a gradual and persistent rise in CRE prices in Paris, Melbourne and Hong Kong. These cross-border spillover effects are, however, not uniform across non-US markets, as we find insignificant responses in Munich, Amsterdam, Seoul and Sydney, and a negative (but insignificant) response in Singapore.

Figure 3 plots the responses of the aggregate variables, distinguishing between the responses in the US (panel *a*) and those in other countries (panel *b*). Examining these responses helps us identify the underlying drivers of the (spillover) effects of US quantitative easing on CRE prices. The figure confirms that, on average, the response of CRE prices is larger in the US (about 5%) than in other countries (around 3%). Furthermore, the figure shows that QE persistently lowers the long-term interest rate in the US. This persistent response suggests a sizable stock effect of QE that arises when assets bought during QE events remain on investors' balance sheets until maturity, in line with evidence from [D'Amico and King](#)

Figure 3: Response to a US quantitative easing shock, within and outside the US



Notes: The figure shows cumulative IRFs to represent variables in levels. The US quantitative easing shock is calibrated to deliver a 10 basis points decline in the 10-year US Treasury yield on impact. Countries outside the US include France, Germany, the Netherlands, Sweden, the United Kingdom, Australia, China, Japan, Singapore and South-Korea. Shaded areas denote the upper and lower bound of the 90% confidence interval. Units are expressed in percentage points. Horizontal axes measure quarters. IRFs are averaged across all cities (volume-weighted).

(2013). The easing in financing conditions, in turn, is expansionary and has a significant, positive and persistent effect on both GDP and inflation through an expansion of credit. The US real exchange rate appreciates slightly and briefly, due to the rise in inflation. Outside the US, long-term yields also decline, consistent with an immediate ‘global portfolio rebalancing’ channel, as reported in Georgiadis and Jarociński (2025), through which QE forces down long-term yields globally. However, the positive impact of QE on credit is much more persistent in the US than it is in the other countries in our sample. Moreover, the real exchange rate appreciates as well, and by more so than in the US, likely reflecting a widening of interest rate differentials vis-à-vis the US.

These findings confirm those from existing work on the positive and expansionary cross-border spillover effects from US monetary policy (Chen et al., 2016; Georgiadis, 2016; Albagli et al., 2019), yet also suggest that these effects work through more peculiar and narrower channels than previously thought. In particular, a positive response to a US-based QE shock of CRE prices across all countries is accompanied by a positive and strong expansion of credit in the US up to 4 quarters, but only a mild expansion of credit outside the US. This suggests that the rise in CRE prices in non-US markets is more likely driven by demand from US investors than from non-US investors. The relatively strong appreciation of non-US currencies further supports the notion that a US quantitative easing shock triggers an outflow of credit from the US to other countries. Hence, what seems key in understanding the spillover effects of QE are the international *financial* linkages that arise from global CRE portfolios. We discuss this mechanism in greater depth in Section 5. Before we do so, we first turn to a set of robustness checks on our empirical analysis.

4 Robustness exercises

We performed a number of exercises to assess the robustness of our empirical results. Sections 4.1 and 4.2 show that the effects of US quantitative easing on CRE prices globally do

not depend on the specific assumption about the cross-city or cross-country weights that were used in our global VAR. Other robustness exercises are relegated to the Appendix. In Appendix C.2 and C.3, we further show that our empirical results are robust to relaxing the assumption that only US variables are allowed to respond contemporaneously to US monetary policy shocks, and also to using an alternative QE shock series that is purged from possible ‘information effects’, as suggested by Jarociński and Karadi (2020). Appendix C.4 highlights that the results are virtually unaffected when expanding the information set with euro area QE surprises from Altavilla et al. (2019) to control for the effects of asset purchases by the ECB. Finally, using these shocks, Appendix C.5 reports similar, albeit somewhat smaller, spillover effects of euro area QE on global CRE prices.

4.1 Alternative cross-city weights

Our baseline approach of incorporating spatial dependencies across CRE markets relies on the ownership overlap ratio, i.e. the share of properties owned by investors that also own properties elsewhere. We use this ratio to determine the city-pair weights that are used to construct, for each CRE market, weighted averages of CRE prices from other markets. Since our main finding on the international spillover effects of US quantitative easing crucially depends on this weighting scheme, it is worth considering other measures of interconnectedness of CRE market pairs which the literature has pointed to as being relevant. We consider (i) geographic distance, (ii) being located in the same country or (iii) currency area, or (iv) having a strong overlap in the location of advanced producer service (APS) firms.¹² Specifically, we extend our baseline model by including additional spatial dependency terms that

¹²Advanced producer service firms operate in sectors such as accountancy, advertising, banking and finance, and law, and serve as conduits for the exchange of capital, knowledge and labor between cities. Spatial dependence can then be measured by the proportion of APS firms shared between cities.

are constructed by one of these alternative measures:

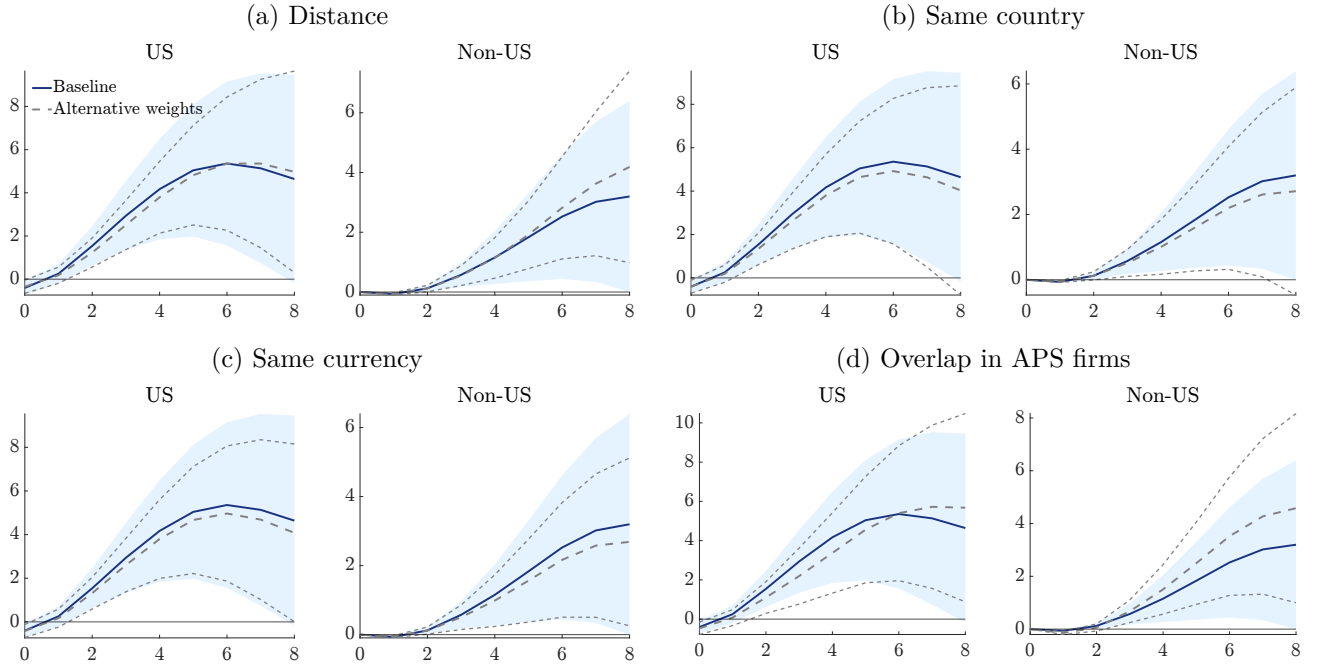
$$\begin{aligned}
\Delta y_{i,t} = & a_i + \iota_i t + \sum_{q=1}^{Q_1} a_{i,q} \Delta y_{i,t-q} + \sum_{q=1}^{Q_2} b_{i,q} \Delta y_{i,t-q}^s + \sum_{q=1}^{Q_3} \lambda_{i,q} \Delta x_{i,t-q} \\
& + \phi_{i,s} (y_{i,t-1} - y_{i,t-1}^s) + \phi_{i,z} \beta'_i z_{i,t-1} \\
& + \phi_i^* (y_{i,t-1} - y_{i,t-1}^*) + \sum_{q=1}^{Q_4} \vartheta_{i,q} \Delta y_{i,t-q}^* + \varepsilon_{i,t}^y.
\end{aligned} \tag{10}$$

The first two rows of Equation (10) are the same as those in our baseline model given by Equation (1). In the third row, we add two additional terms that both rely on the weighted average of CRE prices in cities other than city i , i.e. the variable $y_{i,t}^* = \sum_{j \in \{1, \dots, N\} \setminus \{i\}} s_{i,j}^* y_{j,t}$, and where the calculation of the (time-invariant) weights $s_{i,j}^* \in [0, 1]$ is based on one of the four alternative measures of interconnectedness mentioned above.

Figure 4 plots the effects of a US quantitative easing shock on CRE prices in the US and their spillover effects in other countries. The blue solid lines show the responses from our baseline model, whereas the gray dashed lines show the responses as estimated by the alternative model in Equation (10), with the alternative weighting scheme based on either the geographic distance between cities (panel *a*), whether cities are located in the same country (panel *b*) or in the same currency area (panel *c*), or on the proportion of APS firms shared across cities (panel *d*). In all four cases, our main result holds up remarkably well: QE has a significant and positive effect on CRE prices, both inside and outside the US. Overall, the results are qualitatively very similar across alternative measures of spacial dependency.

It should be noted that we are not claiming that the overlap in property ownership is the most important channel that drives the strong short-term co-movement in CRE prices across cities. As shown in [Zhu and Lizieri \(2021\)](#), a high common property ownership ratio happens to be observed more often in geographically close cities, cities within the same country or currency area, or with a higher proportion of shared APS firms. This positive correlation may thus explain the minor differences between our baseline results and those from the alternative models, as shown in Figure 4. What this robustness exercise merely indicates is

Figure 4: Responses of CRE prices to a US quantitative easing shock under alternative measures of interconnectedness of CRE markets



Notes: The figure compares our baseline results (solid line) with those from an extended model that includes an additional spatial dependency term (dashed lines), see Equation (10). The weights used to construct the additional spatial dependency term are based on either geographic distance between cities (panel a), whether cities are located in the same country (panel b), whether cities belong to the same currency area (panel c), or on the proportion of APS firms shared across cities (panel d). Countries outside the US include France, Germany, the Netherlands, Sweden, the United Kingdom, Australia, China, Japan, Singapore and South-Korea. Dotted lines denote the upper and lower bound of the 90% confidence interval. Units are expressed in percentage points. Horizontal axes measure quarters.

that the ownership overlap ratio adequately captures connectivity between commercial real estate markets.

That said, a potential concern remains that the weights, $s_{i,j,t}$, are endogenous to CRE prices, $y_{i,t}$. Specifically, as investors strategically select which cities to invest in, real estate market performance could affect the ownership overlap ratio. The direction of this effect is ambiguous, as opportunistic funds may find it more attractive to invest in cities with a high indirect return (i.e. a high index price growth) – such as those in emerging economies – whereas risk-averse investors may favor more developed real estate markets with a low indirect return, such as London. In either case, CRE price developments may affect the clustering of investors across cities, which causes an endogeneity issue in our approach to capture spatial interdependencies of CRE markets that, in turn, might bias our results.

To purge the city-pair weights from potential endogenous dependencies of CRE market developments, we take an instrumental variables approach. Specifically, we first regress the ownership overlap ratio on a set of instruments, $D_{i,j,t}$, and year dummy variables, D_t^{year} :

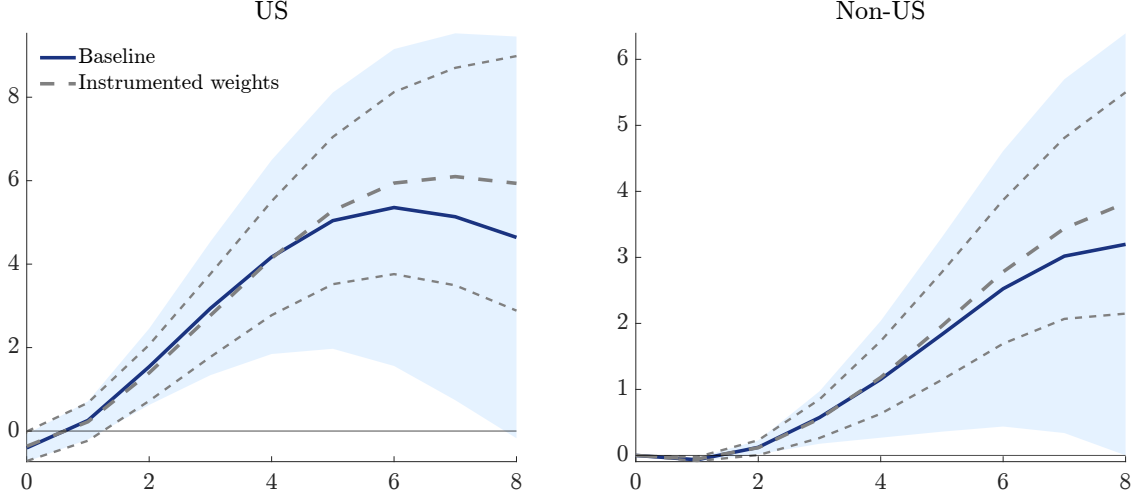
$$s_{i,j,t} = \tau + \varpi \ln(D_{i,j,t}) + \varsigma D_t^{year} + e_{i,j,t}. \quad (11)$$

The instruments include the four alternative measures of interconnectedness discussed earlier and two additional proxies: whether cities have the same legal system and the cultural distance across cities. The latter, which is measured at the country level, is based on [Hofstede \(2011\)](#)’s Cultural Index and is designed to measure affinity across six distinct cultural dimensions.¹³ Intuitively, having the same legal system and a high degree of cultural similarity could impact overlapped ownership, but it is unlikely that these measures impact price returns directly. As argued by [Kelejian and Piras \(2014\)](#), these instruments should all be (largely) exogenous to the performance of the real estate market.¹⁴ We then use the predicted

¹³These factors assess a society’s attitudes and responses with respect to (1) power distance, (2) individualism versus collectivism, (3) masculinity versus femininity, (4) uncertainty avoidance, (5) long-term versus short-term orientation, and (6) indulgence versus restraint. The data is taken from [Geert Hofstede’s homepage](#).

¹⁴Regression results are presented in Table 4 in Appendix C.1. All instruments are significant and have

Figure 5: Responses of CRE prices to a US quantitative easing shock using instrumented weights



Notes: The figure compares our baseline results (black lines) with those from an alternative model in which the spatial dependency terms are based on instrumented, rather than observed, weights (gray lines). IRFs are cumulative to represent variables in levels. Countries outside the US include France, Germany, the Netherlands, Sweden, the United Kingdom, Australia, China, Japan, Singapore and South-Korea. Shaded areas denote the upper and lower bound of the 90% confidence interval. Units are expressed in percentage points. Horizontal axes measure quarters.

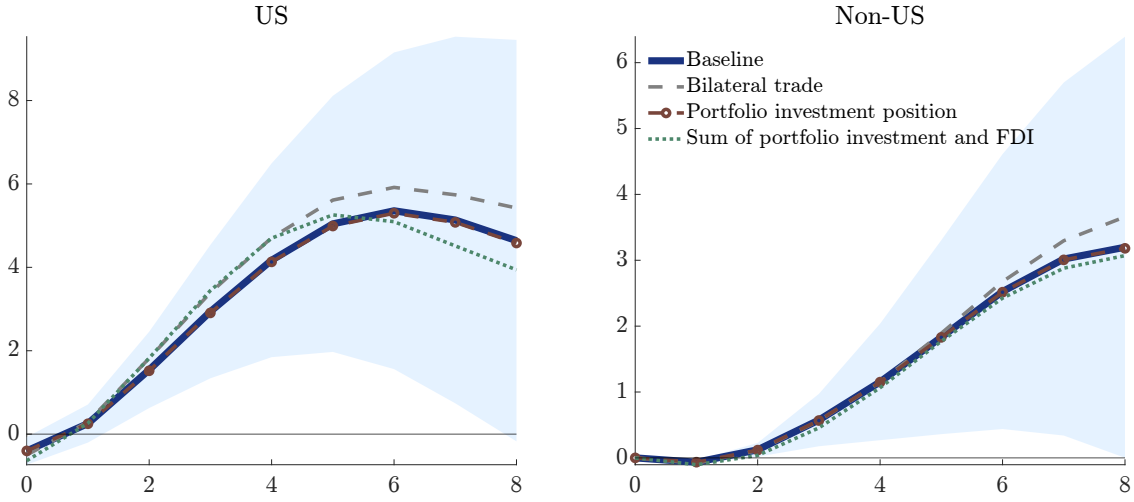
weights from Equation (11) to construct the spatial dependency terms in (1). Figure 5 shows that the difference between our baseline results (blue solid lines) and the alternative model featuring instrumented weights (gray dashed lines) is marginal and insignificant, suggesting that our baseline weighting scheme is unlikely to suffer from endogeneity bias.

4.2 Alternative cross-country weights

In our baseline specification, we also use bilateral portfolio investment positions of the financial sector to proxy spatial dependencies across countries, following Lane and Shambaugh (2010) and Abbate et al. (2016), among others. Commonly used alternative measures to determine these weights are the *total* economy's portfolio investment position and the sum of the total portfolio investment and foreign direct investments, as done by Eickmeier and Ng (2015). Moreover, given the importance of global trade in the international transmission

the expected sign. An F -test for the relevance of the instruments is also significant at the 1% level. Ideally, we also test for the exogeneity of the instruments using a Sargen-Hansen test, yet this is not possible given the differences in dimensions in the first and second stages.

Figure 6: Responses of CRE prices to a US quantitative easing shock using alternative country-weights



Notes: The figure compares our baseline results (black lines) with those from an alternative model in which the spatial dependency terms are based on (i) countries' relative trade (dashed lines), (ii) the total economy's portfolio investment position (marked lines), or (iii) the sum of total portfolio investment and foreign direct investments (dotted lines). IRFs are cumulative to represent variables in levels. Countries outside the US include France, Germany, the Netherlands, Sweden, the United Kingdom, Australia, China, Japan, Singapore and South-Korea. Shaded areas denote the upper and lower bound of the 90% confidence interval. Units are expressed in percentage points. Horizontal axes measure quarters.

of shocks, another straightforward measure of spatial dependency is the sum of exports and imports of each country pair over the respective countries' total trade – as done by e.g. [Pesaran et al. \(2004\)](#) and [Chudik and Pesaran \(2016\)](#) – which captures bilateral trade linkages. As shown in Figure 6, using any of these alternative weighting schemes does not change our main results. Arguably, strong economic ties between countries are reflected in both high levels of cross-border financial investment and bilateral trade, which is why we find a strong correlation between the alternative weights.¹⁵

¹⁵The correlation between our baseline cross-country weights – based on the portfolio position of the financial sector – and the total economy's portfolio position, the total economy's portfolio position plus foreign direct investments, and the sum of exports and imports of each country pair over the respective countries' total trade are, respectively, 0.999, 0.726 and 0.85.

5 A New Keynesian model with commercial real estate

5.1 Model description

To interpret our empirical findings, we turn to a medium-scale two-country New Keynesian model. Specifically, we follow closely the model developed by [Wu et al. \(2024\)](#), which features international financial integration that arises through cross-border lending activities by banks. We extend this model by incorporating CRE markets in order to study their role in the international spillover effects of QE. In this section, we discuss the key building blocks of the model. A full description is provided in [Appendix D](#).

The two countries are referred to as ‘Home’ and ‘Foreign’. Each country is populated by eight different types of agents: households, capital producers, CRE producers, wholesale firms, retail firms, financial intermediaries, and a monetary and fiscal authority. International trade arises from households purchasing both Home and Foreign goods. International finance takes the form of financial intermediaries holding both Home and Foreign (private and public) bonds. In what follows, we focus on the Home economy and denote Foreign variables with an asterisk, i.e. x^* for any generic variable x . Foreign is modeled symmetrically, unless stated otherwise.

Commercial real estate producers transform investment goods into new CRE, denoted by $\hat{I}_{h,t}$, which builds up the stock of CRE, H_t , by the law of motion $H_t = (1 - \delta_h) H_{t-1} + \hat{I}_{h,t}$, where $\delta_h \in [0, 1]$ is the depreciation rate of CRE. Similarly, physical capital other than CRE, K_t , is produced by capital producers using new capital, $\hat{I}_{k,t}$. Wholesale firms purchase new CRE and capital, and combine them with land, $\mathcal{L}_t$, and labor, $L_{d,t}$, to produce intermediate goods, $Y_{w,t}$, according to the following production technology:

$$Y_{w,t} = \left[\left(H_t^\xi \mathcal{L}_t^{1-\xi} \right)^{\alpha_h} (u_t K_{t-1})^{1-\alpha_h} \right]^\alpha L_{d,t}^{1-\alpha}, \quad (12)$$

with $\alpha \in (0, 1)$ the output elasticity with respect to total capital and u_t the utilization rate

of capital. The output elasticity with respect to CRE and land, $\alpha_h \in (0, 1)$, as well as the parameter governing the output share of CRE relative to land, $\xi \in (0, 1)$, will be relevant in determining the strength with which CRE markets propagate the macroeconomic effects of QE shocks, both domestically and abroad.

Wholesale firms rely on credit from financial intermediaries due to a loan-in-advance constraint that requires them to finance a fraction $\psi \in (0, 1]$ of their investments with marketable debt in the form of long-term private bonds, B_t^P :

$$\psi \left(P_t^h \hat{I}_{h,t} + P_t^k \hat{I}_{k,t} \right) \leq Q_t^P \left(B_t^P - \kappa_P B_{t-1}^P \right), \quad (13)$$

where P_t^h and P_t^k are the prices of new CRE and capital, Q_t^P denotes the private bond price, and $\kappa_P \geq 0$ governs the average duration of private bonds. This loan-in-advance constraint not only allows QE to have real effects – by raising bond prices and thereby relaxing the constraint – but also ensures that land prices and business investment move in tandem, as we observe in the data (Liu et al., 2013).

CRE markets are linked internationally through financial intermediaries, or ‘banks’, that invest in both Home and Foreign private bonds, $B_{H,t}^P$ and $B_{F,t}^P$. Therefore, different from our empirical framework in which we capture the global nature of CRE markets through the *direct* ownership of commercial real estate across cities and countries, here we take an *indirect* approach in which ownership of CRE is local, but the financing of CRE investment is global. This indirect approach allows us to abstract from international portfolio decisions of the firm, while retaining the international financial linkages that we argue are key in understanding the spillover effects of domestic QE shocks on foreign CRE markets.

In addition to private bonds, the bank also invests in Home and Foreign public bonds, $B_{H,t}^G$ and $B_{F,t}^G$, and holds reserves, RE_t , at the domestic central bank, which offer a gross nominal return of R_t^{re} . The bank’s financing resources consist of net worth, N_t , and deposits from domestic households, D_t , on which the bank pays a gross nominal return, R_t^d . The

balance sheet of the bank is thus given by

$$Q_t^P B_{H,t}^P + Q_t^G B_{H,t}^G + Q_t^{P*} B_{F,t}^P \mathcal{E}_t + Q_t^{G*} B_{F,t}^G \mathcal{E}_t + RE_t = D_t + N_t, \quad (14)$$

with Q_t^G the price of public bonds and $\mathcal{E}_t$ the nominal exchange rate which is used to convert Foreign denominated assets into Home currency. In each period, the bank's beginning balance, $\mathcal{B}_t$, is determined by the excess return on its assets:

$$\begin{aligned} \mathcal{B}_t = & \left(R_t^P - R_{t-1}^d \right) Q_{t-1}^P B_{H,t-1}^P + \left(R_t^G - R_{t-1}^d \right) Q_{t-1}^G B_{H,t-1}^G \\ & + \left[R_t^{P*} \frac{\mathcal{E}_t}{\mathcal{E}_{t-1}} \left(1 - \Gamma_t^P \left(\omega^P \right) \right) - R_{t-1}^d \right] Q_{t-1}^{P*} B_{F,t-1}^P \mathcal{E}_{t-1} \\ & + \left[R_t^{G*} \frac{\mathcal{E}_t}{\mathcal{E}_{t-1}} \left(1 - \Gamma_t^G \left(\omega^G \right) \right) - R_{t-1}^d \right] Q_{t-1}^{G*} B_{F,t-1}^G \mathcal{E}_{t-1} \\ & + \left(R_{t-1}^{re} - R_{t-1}^d \right) RE_{t-1} + R_{t-1}^d N_{t-1}, \end{aligned} \quad (15)$$

where R_t^j , for $j = \{P, G\}$, denotes the nominal yield to maturity on bonds. The term Γ_t^j is a foreign transaction cost (charged by the domestic government) which the bank incurs when it changes its holdings of Foreign bonds. This cost serves as a proxy for the greater uncertainty and risk exposure inherent in overseas lending relative to domestic lending. In each period, a share $1 - \sigma$ of the bank's beginning balance is paid out to the household, who is the owner of the bank, while the bank receives a real transfer, X_t , from the household. Therefore, the bank's net worth evolves according to $N_t = \sigma \mathcal{B}_t + P_t X_t$, where P_t is the consumer price index.

The objective of the bank is to maximize the sum of current and future expected real dividend payouts:

$$V_t = \max (1 - \sigma) E_t \sum_{j=1}^{\infty} \Lambda_{t,t+j} \frac{\mathcal{B}_{t+j}}{P_{t+j}}, \quad (16)$$

with $\Lambda_{t,t+j}$ the household's stochastic discount factor (used to discount, at period t , cash flows that are realized in period $t + j$), subject to an enforcement constraint that prevents

the bank from filing for bankruptcy whilst absconding with a share θ of its assets:

$$V_t \geq \theta \left[Q_t^P \frac{B_{H,t}^P}{P_t} + \Delta Q_t^G \frac{B_{H,t}^G}{P_t} + \left(Q_t^{P*} \frac{B_{F,t}^P}{P_t^*} + \Delta Q_t^{G*} \frac{B_{F,t}^G}{P_t^*} \right) \mathcal{E}_t \right]. \quad (17)$$

Following [Gertler and Karadi \(2011\)](#), the parameter Δ lies between 0 and 1, which implies that it may be more difficult for the bank to abscond public bonds than private bonds (note that reserves are fully recoverable by depositors). When the constraint (17) is binding, holding long-term bonds yields an excess return over the return on deposits which, depending on the size of Δ , may be greater for holding private bonds than public bonds.

The central bank conducts conventional monetary policy according to a standard Taylor rule, that relates the short-term interest rate to inflation and output growth, and may also perform quantitative easing through purchases of Home private bonds, $B_{H,t}^{P,CB}$. Without loss of generality, we assume the central bank's (real) bond purchases to be exogenous and governed by the following AR(1) process:

$$b_{H,t}^{P,CB} - b_H^{P,CB} = \rho_P (b_{H,t-1}^{P,CB} - b_H^{P,CB}) + \varepsilon_t^{P,CB}, \quad (18)$$

in line with [Gertler and Karadi \(2013\)](#), where $b_t^{P,CB} \equiv \frac{B_t^{P,CB}}{P_t}$, $\rho_P \in [0, 1]$ determines the persistence of bond purchases, and variables without a t subscript denote steady-state values. The term $\varepsilon_t^{P,CB}$ is the QE shock. By raising the bond price, Q_t^P , a positive QE shock affects CRE investment both directly – by relaxing the loan-in-advance constraint of the wholesale firm – and indirectly through changes in the relative return on bonds that affect the lending decisions of both Home and Foreign banks (i.e. portfolio rebalancing).

The remaining part of the model is relatively standard. Households consume Home and Foreign goods, pay lump-sum taxes to the Home government and hold deposits at domestic banks. Their income consists of the return on their bank deposits, dividends received from domestic financial and non-financial firms (which they own) and income from supplying labor to domestic firms through labor unions. Furthermore, households own the land used for the

production of intermediate goods. Retail firms assemble the intermediate goods into the final good, which is sold domestically and abroad to households and the fiscal authorities. The latter maintains a balanced budget in each period by equating public consumption with the sum of tax revenue, central bank profits (that may arise from QE) and foreign transaction costs paid by banks. Finally, the economy features several real and nominal rigidities, i.e. consumption habits (faced by households), investment adjustment costs (faced by CRE and capital producers), staggered wage setting (by labor unions) and staggered price setting (by retail firms).

5.2 Calibration

The calibration of the model is fairly standard and largely follows [Wu et al. \(2024\)](#). We assume Home and Foreign economies to be symmetric. A description of all model parameters, and their calibration, is provided in [Appendix E](#). The presence of CRE markets implies a handful of parameters that do not appear in [Wu et al. \(2024\)](#) and whose calibration is worth discussing. We also briefly reflect on some of the parameters governing the financial frictions in our model, as these are key in driving the (spillover) effects of QE.

We set the depreciation rate of CRE equal to $\delta_h = 0.015$, as suggested by [Bokhari and Geltner \(2018\)](#), which is slightly larger than the 0.01 set by [Iacoviello and Neri \(2010\)](#) for residential real estate. The output elasticity with respect to CRE and land is set to $\alpha_h = 0.75$. We obtain this number by taking the share of non-residential real estate assets in total assets of non-financial businesses – which hovered around 30% over the last three decades ([Ghent et al., 2019](#)) – and then divide this share by the share of tangible assets over total assets. [Ewens et al. \(2025\)](#) find this ratio to be on average 0.4 for US firms between 2007-2017 (when QE was conducted) and close to the longer-run average of 0.43 reported in [Peters and Taylor \(2017\)](#). To set the output share of CRE relative to that of land, ξ , we use the residential housing share of output as a proxy, as similar data for CRE does not exist. For the US, [Davis and Heathcote \(2007\)](#) find this share to be 0.54.

On the financial side, we calibrate the coupon decay rate for private debt, κ_P , to match a 10-year duration of long-term bonds. As in [Wu et al. \(2024\)](#), the recoverability parameter for the financial intermediary, θ , is targeted to achieve a 3% annual credit spread. The parameter ψ , which determines the fraction of investment that needs to be financed through long-term debt, is set to 0.81 such that the ratio between outstanding private debt and nominal GDP matches the historical average observed prior to the Great Recession. The survival rate of financial intermediaries is set to $\sigma = 0.95$, while the recoverability parameter of Treasury bonds is fixed at $\Delta = 1/3$, leading to a steady-state term premium of around 100 basis points. Finally, the steady-state fraction of private bonds held domestically is set to 80%, reflecting a strong home bias in financial intermediary’s investment portfolios.¹⁶

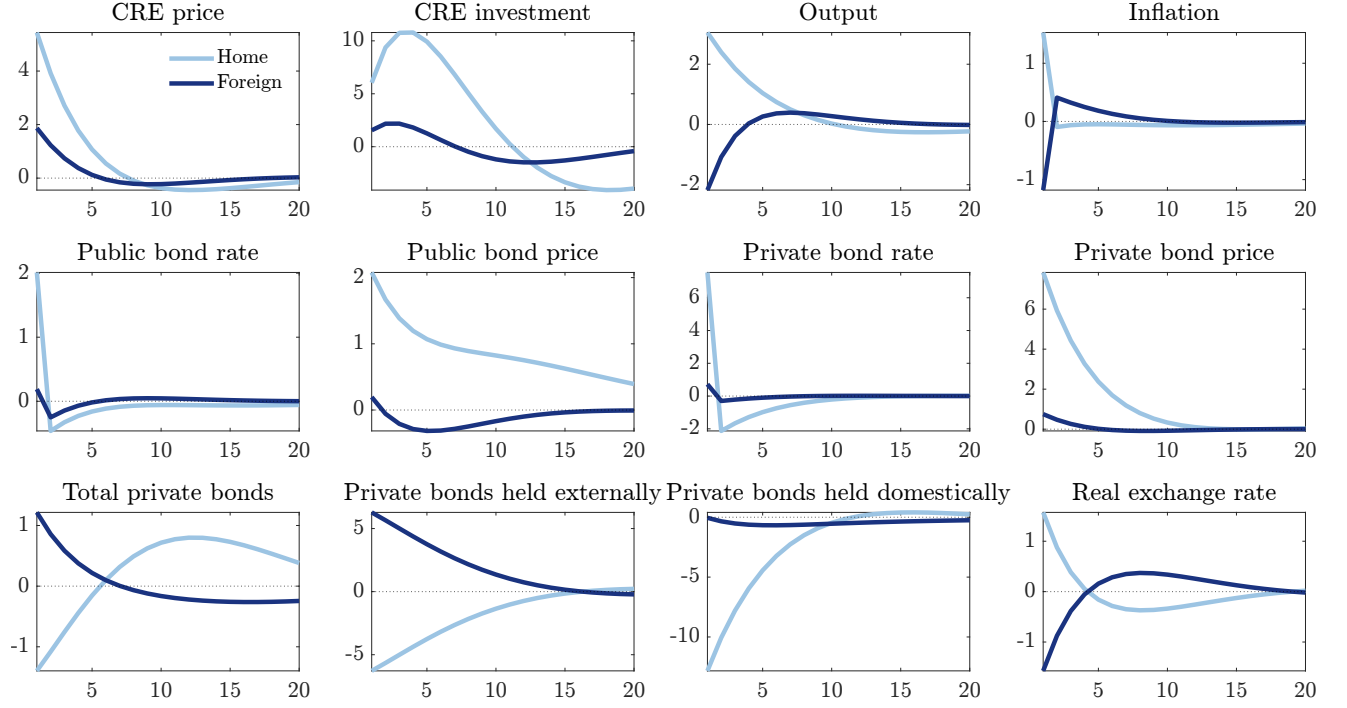
5.3 Understanding the transmission mechanism

We use the model to examine the general equilibrium effects of a quantitative easing shock in the Home economy on both Home and Foreign variables. Figure 7 shows that a QE shock has global spillover effects and is followed by a positive and sustained response of CRE prices in both countries. In line with our empirical results, the response is larger in Home (the ‘US’) than in Foreign (the ‘non-US market’). In Home, the central bank’s purchases of private bonds lead to a persistent increase in bond prices and a concomitant decline in the long-term interest rate on private bonds. The surge in bond prices increases banks’ net worth and relaxes banks’ balance sheet constraint. As a result, banks increase their demand for private bonds (known as the portfolio rebalancing channel, see e.g. [Krishnamurthy and Vissing-Jorgensen, 2011](#)), which in turn eases the loan-in-advance constraint on wholesale firms and raises demand for CRE investments. Consequently, Home output expands and inflation rises.

The effects of QE spill over to Foreign as Home banks raise their demand for Foreign private bonds that have become relatively cheap compared to Home private bonds. This

¹⁶The steady-state share holdings of private bonds by the central bank is set to 0.

Figure 7: Responses to a quantitative easing shock in Home



Notes: Units are in percentage point deviation from steady state. Horizontal axes measure quarters.

portfolio adjustment leads to an increase in the price of Foreign bonds that stimulates CRE investment and pushes up CRE prices in Foreign. The rise in private bond prices is more muted in Foreign than in Home, not only because the QE shock occurs in Home, but also because banks' portfolios are biased towards domestic bonds. Despite the rise in CRE investment, Foreign output falls in the short run due to an appreciation of the real exchange rate, that also results in an immediate drop in inflation. However, in the medium run, the Foreign economy picks up steam and recovers on the back of stronger activity in the CRE market, with both output and inflation moving above their initial steady-state values.

The model underscores the role of cross-border bank lending in transmitting the spillover effects of quantitative easing. As Foreign bond prices rise, Foreign banks *reduce* their demand for these bonds. In contrast, Home banks *increase* their demand, as Home private bonds are relatively more expensive. As a result, CRE prices in Foreign increase – not due to an expansion in credit supplied by domestic lenders, but because of an increase in investment by foreign lenders. This outcome aligns with our empirical findings presented in Figure 3,

which show that a US QE shock raises CRE prices in non-US markets even though credit supply does not respond by much in those markets.

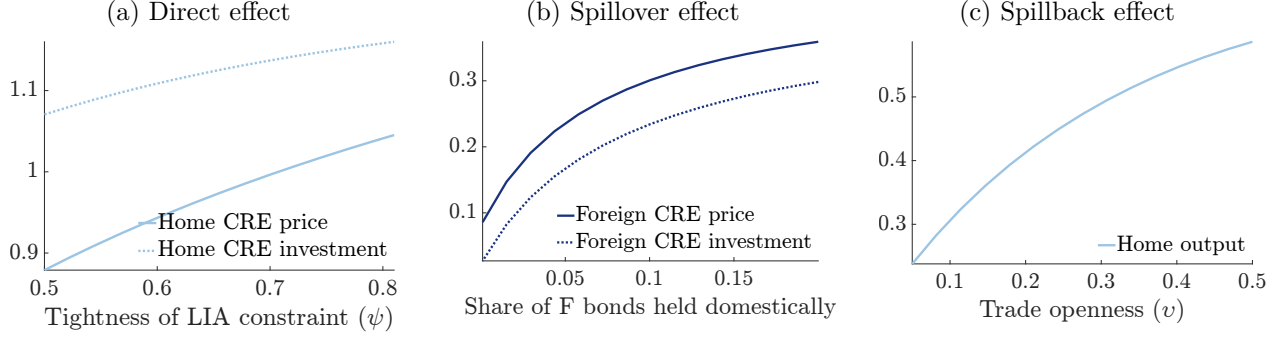
The model also reveals an additional channel through which some of the spillover effects of QE from Home to Foreign ‘spill back’ to Home. Specifically, the depreciation of the Home real exchange rate following the QE shock triggers a consumption-switching effect in Foreign, as households shift away from relatively expensive Foreign goods toward cheaper Home goods. Simultaneously, as conditions in the Foreign CRE market improve and investment demand rises, Foreign imports from Home increase further. These spillback effects amplify the initial output response in Home to the QE shock.

Overall, we identify three novel transmission channels of quantitative easing through global CRE markets: (1) a *direct effect*, which boosts domestic CRE investment by easing domestic financing conditions; (2) a *spillover effect*, whereby foreign bonds become relatively more attractive, increasing domestic demand for them and helping to boost foreign CRE markets; and (3) a *spillback effect*, which arises from an increase in foreign demand for domestic exports due to a depreciation of the domestic real exchange rate and an improvement in foreign CRE activity.

We illustrate the importance of each of these channels using a sensitivity analysis in which we vary a set of key parameters. First, the strength of the direct effect of QE on domestic CRE prices is governed by the parameter ψ , which determines the tightness of the loan-in-advance constraint faced by wholesale firms, given by Equation (13). The greater is ψ , the tighter is the constraint and so the more sensitive will be CRE prices and investment to a marginal loosening of the constraint induced by QE. This is confirmed by Figure 8, panel *a*, which shows that the impact response of Home CRE prices and CRE investment to a Home QE shock is greater for higher values of ψ .

Second, the size of the spillover effect of QE on foreign CRE markets depends on the strength of international financial linkages, which in turn depends on the amount of foreign bonds held by domestic banks as a share of total domestic bond holdings. Panel *b* of Figure 8

Figure 8: Impact responses to a Home QE shock



Notes: The direct effect is measured by varying the tightness of the loan-in-advance constraint ψ (panel a). The spillover effect is measured by varying the share of foreign bonds held domestically (panel b). The spillback effect is measured by varying the degree of trade openness v (panel c). Our baseline calibration for ψ , the share of foreign bonds held domestically and v are, respectively, 0.81, 0.8 and 0.5. Units are in percentage point deviation from steady state.

shows that increasing the steady-state share of foreign private bonds held by domestic banks strengthens the impact response of Foreign CRE prices and CRE investment. Following a QE shock, the increase in demand for Foreign bonds by Home banks leads to a sharper rise in Foreign bond prices, which in turn provides a stronger boost to Foreign CRE investment.

Finally, spillback effects arise from an increase in demand for Home goods by Foreign households and therefore depend on the import share of consumption, which is governed by the parameter v . Panel c of Figure 8 shows that greater trade openness, as captured by higher values of v , is associated with a stronger impact response of Home output to a Home QE shock, as the latter is amplified by a more prominent spillback effect. Note that the spillback effect is conditional on the size of the spillover effect: the larger is the spillover effect (e.g. due to a greater share of foreign bonds held by domestic banks), the greater is the spillback effect.

6 Conclusion

This paper provides novel empirical results on the international transmission of US monetary policy through global CRE markets, and a theoretical framework to interpret these results. Using a global VAR-X model enriched with city-level ownership data, we show that

US quantitative easing shocks lead to a persistent and significant rise in CRE prices both within and outside the US. While credit expands in the US in response to the QE shock, it barely moves in non-US markets, suggesting that the international spillover effects of QE are primarily driven by increased demand from US investors for CRE assets in non-US markets.

To interpret our empirical findings, we develop a two-country New Keynesian model with globally integrated CRE markets and international financial linkages. The model verifies our main empirical result that QE raises both domestic and foreign CRE prices. The framework highlights three key transmission channels of QE: a *direct effect*, that works through an easing of domestic financing conditions, a *spillover effect*, that operates via cross-border portfolio rebalancing, and a *spillback effect* that arises through stronger foreign demand for domestic goods. Combined, these channels underscore the importance of global financial integration in amplifying the transmission and spillover effects of monetary policy.

Our findings suggest that global CRE markets are crucial in understanding how monetary policy shocks propagate across borders. Therefore, as central banks engage in new rounds of quantitative easing or embark on quantitative tightening, policymakers' assessments of the effects of these policies can be improved through continued monitoring of CRE markets. How policymakers should respond to foreign monetary policy shocks in the context of deeply integrated CRE markets is a topic we leave for future research.

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A Details on the global VAR

Our global VAR is given by

$$\Delta z_t = \mathbf{H}_0 z_{t-1} + a + \sum_{q=1}^Q \mathbf{A}_q \Delta z_{t-q} + \mathbf{C}_0 \Delta z_t + \varepsilon_t, \quad (19)$$

with

$$z_t = \begin{pmatrix} y_t \\ x_t \end{pmatrix}, \quad (20)$$

$$\mathbf{H}_0 = \begin{pmatrix} \Phi^S \odot (I_N - S_{N,t}) & -\Phi^{\mathbf{X}} \mathbf{B}' \odot I_{N \times (K \times M)} \\ -\mathbf{K} \mathbf{H}'_{\mathbf{Y}} \odot I_{(K \times M) \times N} & \mathbf{K} \mathbf{H}'_{\mathbf{X}} \odot I_{(K \times M)} - \mathbf{K} \mathbf{H}'_{\mathbf{W}} \odot (\mathbf{1}_{K \times K} \otimes W_{M,t}) \end{pmatrix}, \quad (21)$$

$$a = \begin{pmatrix} a_{N \times 1} + \iota_{N \times 1} t \\ \alpha_{(K \times M) \times 1} + \iota_{(K \times M) \times 1}^x t \end{pmatrix}, \quad (22)$$

$$\mathbf{A}_q = \begin{pmatrix} \Psi_q \odot I_N + \Psi_q^S \odot S_{N,t} & \Lambda_q^X \odot I_{N \times (K \times M)} \\ \Lambda_q^Y \odot I_{MK \times N} & \Delta_q \odot I_{(K \times M)} + \Delta_q^W \odot (\mathbf{1}_{K \times K} \otimes W_{M,t}) \end{pmatrix}, \quad (23)$$

$$\mathbf{C}_0 = \begin{pmatrix} \mathbf{0}_N & \mathbf{0}_{N \times (K \times M)} \\ \mathbf{0}_{(K \times M) \times N} & \Delta_0^W \odot (\mathbf{1}_{K \times K} \otimes W_{M,t}) \end{pmatrix}, \quad (24)$$

$$\varepsilon_t = \begin{pmatrix} \varepsilon_t^y \\ \varepsilon_t^x \end{pmatrix}, \quad (25)$$

and where Φ , $\mathbf{B}$, Ψ , $\mathbf{K}$, $\mathbf{H}$, Λ , and Δ are coefficient matrices that correspond to their lowercase counterparts in Equations (1) and (2).¹⁷ $\Phi^{\mathbf{X}} \mathbf{B}'$ is an N by $K \times M$ matrix where the element in row i and column $(M-1) \times (k-1) + g$ corresponds to $\phi_{i,g,k} \times \beta_{i,g,k}$, with i , g , k the city, country and variable indices, and where other elements are zero. Additionally, $\mathbf{K} \mathbf{H}'_{\mathbf{Y}}$ is a $K \times M$ by N matrix with the element in row $(M-1) \times (k-1) + m$ and column

¹⁷For example, $\Phi^S = [\phi_1^S, \phi_2^S, \dots, \phi_N^S] \otimes \mathbf{1}_{1 \times N}$.

i corresponding to $\kappa_{i,m,k} \times \eta_{i,m,k}^y$, and with other elements being zero. $\mathbf{KH}'_{\mathbf{X}}$ and $\mathbf{KH}'_{\mathbf{W}}$ are $K \times M$ by $K \times M$ coefficient matrices, corresponding to the long-term cointegration relationship ($\kappa_{i,m,k} \times \eta_{i,m,k}^x$, $\kappa_{i,m,k} \times \eta_{i,m,k}^W$) in Equation (2).

Furthermore, $\mathbf{\Psi}_q^S = [\psi_{1,q}^S, \psi_{2,q}^S, \dots, \psi_{3,q}^S] \otimes 1_{1 \times N}$ and $\mathbf{\Psi}_q = [\psi_{1,q}, \psi_{2,q}, \dots, \psi_{N,q}] \otimes 1_{1 \times N}$. Moreover, $\mathbf{\Lambda}_q^X$ is an N by $K \times M$ matrix where the non-zero element in row i and column $(M-1) \times (k-1) + g$ corresponds to the respective coefficient in $\lambda_{i,q}^x$ in Equation (1) for city i in country g regarding variable k . $\mathbf{\Lambda}_p^Y$ is a $K \times M$ by N matrix where the non-zero element in row $(M-1) \times (k-1) + g$ and column i corresponds to the respective coefficient in $\lambda_{i,p}^y$ in Equation (2) for city i in country g regarding variable k . $\mathbf{\Delta}_p$, $\mathbf{\Delta}_p^W$, and $\mathbf{\Delta}_0^W$ are all $K \times M$ by $K \times M$ matrices where the non-zero element in row $(M-1) \times (k-1) + g$ and column $(M-1) \times (k-1) + g$ corresponds to the respective coefficient in $\delta_{g,p}$, $\delta_{g,p}^W$, and $\delta_{g,0}^W$, respectively, for country g regarding variable k in Equation (2).

B Additional statistics

Below, we present the summary statistics in Table 1. For CRE prices, we show the average statistics across cities – for the macroeconomic variables, we show the average across countries. Tables 2 and 3 further show that almost all city-level CRE prices are non-stationary in log levels, as well as most of the macroeconomic variables.

Table 1: Summary statistics

	Mean	Std Deviation	Max	Min	75%	50%	25%
City Level Data							
Log CRE price index	4.675	0.335	5.804	3.897	4.849	4.63	4.451
Ownership Overlap Ratio	0.164	0.152	0.812	0.002	0.223	0.106	0.054
Country Level Data							
Long-term rate (in %)	3.24%	1.37%	7.46%	0.61%	4.2%	3.13%	2.26%
Log GDP	12.860	1.164	15.432	13.573	12.749	11.764	11.011
Credit to GDP (in %)	194.56	40.22	324	206.3	183.75	168.7	110.1
Log Real Exchange Rate Index	4.607	0.108	4.910	4.670	4.602	4.562	4.223
Log CPI	4.662	0.071	4.913	4.702	4.658	4.606	4.501

Table 2: Dickey-Fuller test for the commercial real estate price variables.

	Log Price	Δ Log Price		Log Price	Δ Log Price
Paris	0.0005	-0.1021	Atlanta	0.0002	-0.0787
Munich	0.0007	-0.1615**	Boston	0.0004	-0.3422***
Amsterdam	0.0002	-0.1659***	Chicago	0.0002	-0.1957***
Stockholm	0.0006	-0.1755**	Dallas	0.0004	-0.2687***
London	0.0006	-0.2152***	Houston	0.0001	-0.2153***
Melbourne	0.0011	-0.4283***	Los Angeles	0.0006	-0.2156**
Sydney	0.0009	-0.2099**	Miami	0.0006	-0.1927**
Hong Kong	0.0010	-0.3808***	New York	0.0004	-0.2002***
Tokyo	0.0001	-0.1927***	San Francisco	0.0004	-0.1229*
Singapore	0.0003	-0.2348***	Seattle	0.0002	-0.1660**
Seoul	0.0007	-0.2157***	Washington	0.0002	-0.1341*

Notes: This table report the Dickey-Fuller tests for the time series' level and first differences, without a deterministic part. The null-hypothesis is non-stationarity. ***, ** and * signifies that the test rejects the null at the 1%, 5% and 10% level, respectively.

Table 3: Dickey-Fuller test for the macroeconomic variables.

	Log GDP	Δ Log GDP	IR	Δ IR	Log (Credit)	Δ Log(Credit)	Log (Ex)	Δ Log(Ex)	Log (CPI)	Δ Log(CPI)
Australia	-0.016	-0.6688***	0.0006	-0.139	0.0012	-1.1134***	-0.0005	-0.9561***	0.0009	-0.2791**
France	-0.0132**	-0.6450***	0.0001	-0.2883**	0.0006	-1.2108***	-0.0004	-0.7802***	0.0006	-0.7130***
Germany	-0.0220**	-0.8993***	0.0001	-0.5529***	-0.0002	-1.0181***	-0.0004	-0.7884***	0.0007	-0.8322***
Hong Kong	0.0119	-1.1705***	0.0003	-0.4671***	0.0035	-0.2620**	0.0008	-0.9102***	0.0019	-0.8403***
Japan	0.0119	-0.7040***	0.0001	-0.7752***	0.0004	-0.3521**	-0.0006	-0.9779***	0.0002	-0.9454***
Netherlands	-0.0054	-1.1730***	0.0001	-0.5525***	-0.0001	-1.0659***	-0.0002	-0.8443***	0.0008	-0.8235***
Singapore	-0.0152*	-0.7077***	0.0008	-0.5358***	0.0031	-0.6671***	0.0004	-0.7559***	0.001	-0.7257***
South Korea	-0.0266**	-1.0731***	0.0005	-0.3533**	0.0018	-0.8876***	-0.0004	-0.8642***	0.0009	-0.3833***
Sweden	-0.0484*	-0.7756***	0.0002	-0.4129***	0.0005	-1.0304***	-0.0008	-0.7284***	0.0006	-0.5542***
United Kingdom	-0.0038	-1.0756***	0.0001	-0.2252**	0.0001	-1.1305***	-0.0004	-0.7942***	0.0011	-0.2436**
United States	-0.0213*	-0.9958***	0.0003	-0.1779*	0.0008	-0.2279**	0.0005	-0.8865***	0.0007	-0.9441***

Notes: This table report the Dickey-Fuller tests for the time series' level and first differences, without a deterministic part. The null-hypothesis is non-stationarity. ***, ** and * signifies that the test rejects the null at the 1%, 5% and 10% level, respectively.

C Additional robustness of the empirical results

This section presents further robustness checks of our empirical results. Section C.1 presents the first-stage results of the instrumental variable approach discussed in Section 4.1, in which we purged city-pair weights from potential endogenous dependencies on CRE market developments. Section C.2 relaxes the assumption that only US variables are allowed to respond within the quarter to the US monetary policy shock. Section C.3 shows the IRFs of macroeconomic variables in the US and non-US countries to a QE shock cleaned from informational effects as suggested by Jarociński and Karadi (2020). Section C.4 highlights that the results are unaffected if we additionally control for the ECB’s asset purchases by adding the QE surprises from Altavilla et al. (2019) as control variables. Finally, using the same shocks, Section C.5 reports similar, albeit somewhat smaller, spillover effects of euro area QE on global CRE prices.

C.1 First-stage results of the IV regression

Section 4.1 shows the robustness of our main results to alternative weighting schemes. One possible concern is in regards to the endogeneity of the weights $s_{i,j,t}$ to CRE prices. We follow an instrumental variable approach to purge city-pair weights from potential endogenous dependencies on CRE market developments. Table 4 reports the first-stage regression results for the instrumented weights, based on Equation (11).

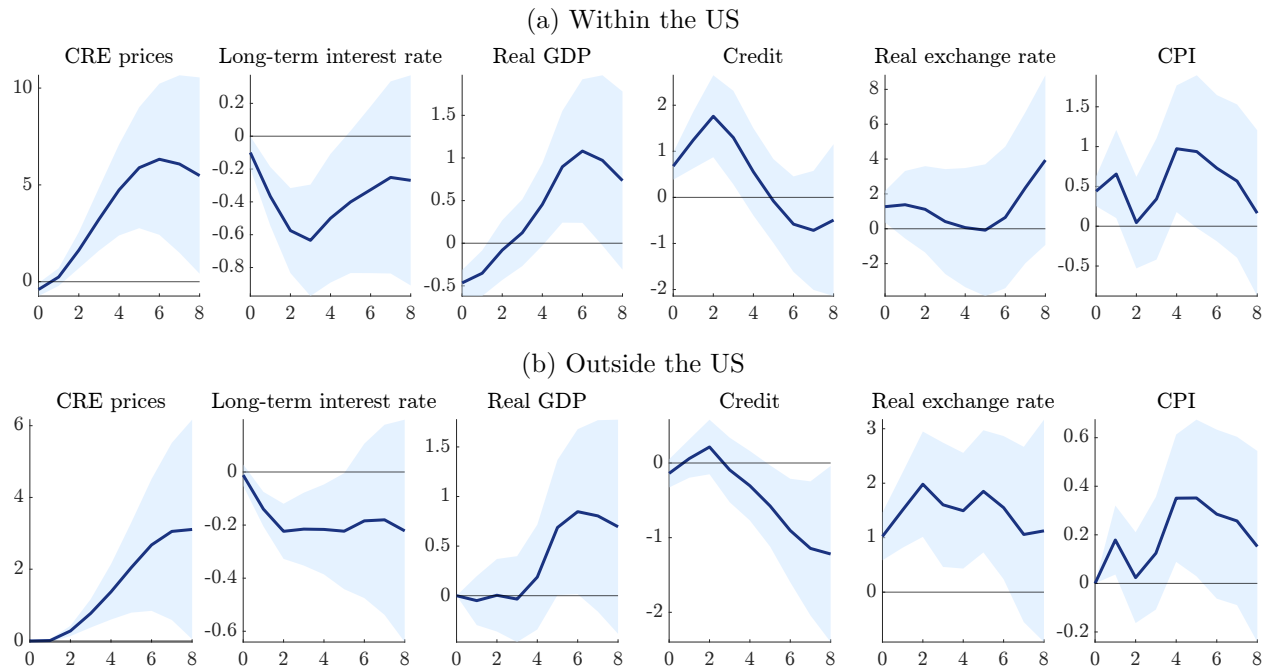
Table 4: First-stage results for instrumented regression

	Overlap in Ownership
Const.	0.1848*** (0.0388)
Geographic distance	-0.0253*** (0.0029)
Same country	0.0175* (0.009)
Same currency	0.1805*** (0.0101)
Same legal system	0.0081* (0.0045)
Overlap in APS firms	0.0302*** (0.004)
Year dummies	Yes
No of obs.	4620
Adjusted R^2	0.4345
F -test	694.52***

Notes: This table reports first-stage regression results for the instrumented weights based on Equation (11). The dependent variable is the overlap ownership ratio. Standard errors are shown in parentheses. ***, ** and * indicate significance at the 1%, 5% and 10% level, respectively.

C.2 Contemporaneous effect of US QE on non-US variables

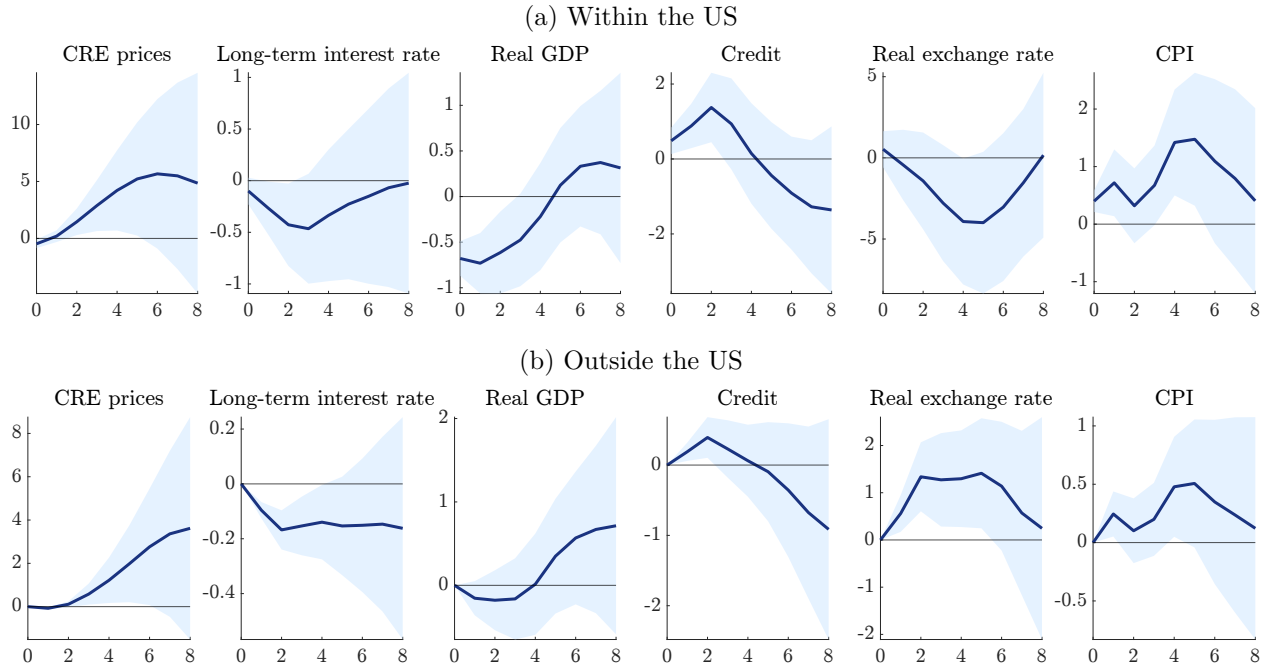
Figure C.1: Response to a US quantitative easing shock when allowing for contemporaneous response to shock



Notes: The figure shows cumulative IRFs to represent variables in levels. The US quantitative easing shock is calibrated to deliver a 10 basis points decline in the 10-year US Treasury yield on impact. Countries outside the US include France, Germany, the Netherlands, Sweden, the United Kingdom, Australia, China, Japan, Singapore and South-Korea. Shaded areas denote the upper and lower bound of the 90% confidence interval. Units are expressed in percentage points. Horizontal axes measure quarters.

C.3 Purging the QE shock of information effects

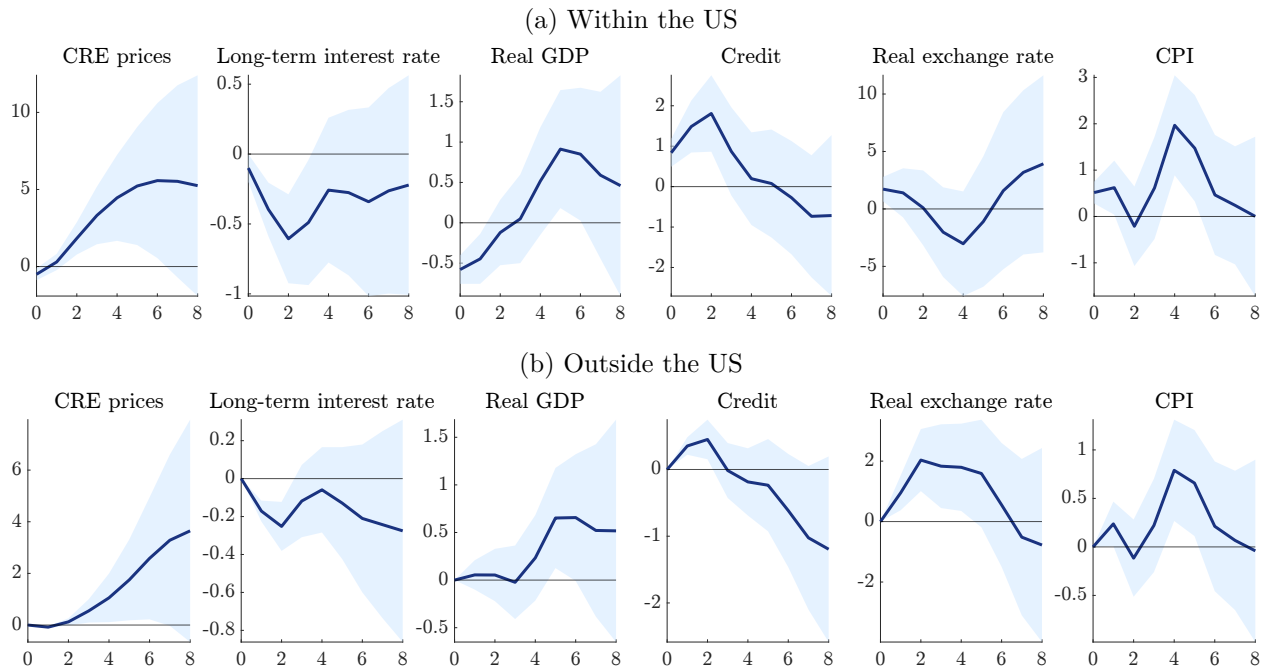
Figure C.2: Response to a US quantitative easing shock when using purged shock



Notes: The figure shows cumulative IRFs to represent variables in levels. The US quantitative easing shock is calibrated to deliver a 10 basis points decline in the 10-year US Treasury yield on impact. Countries outside the US include France, Germany, the Netherlands, Sweden, the United Kingdom, Australia, China, Japan, Singapore and South-Korea. Shaded areas denote the upper and lower bound of the 90% confidence interval. Units are expressed in percentage points. Horizontal axes measure quarters.

C.4 Controlling for quantitative easing by the ECB

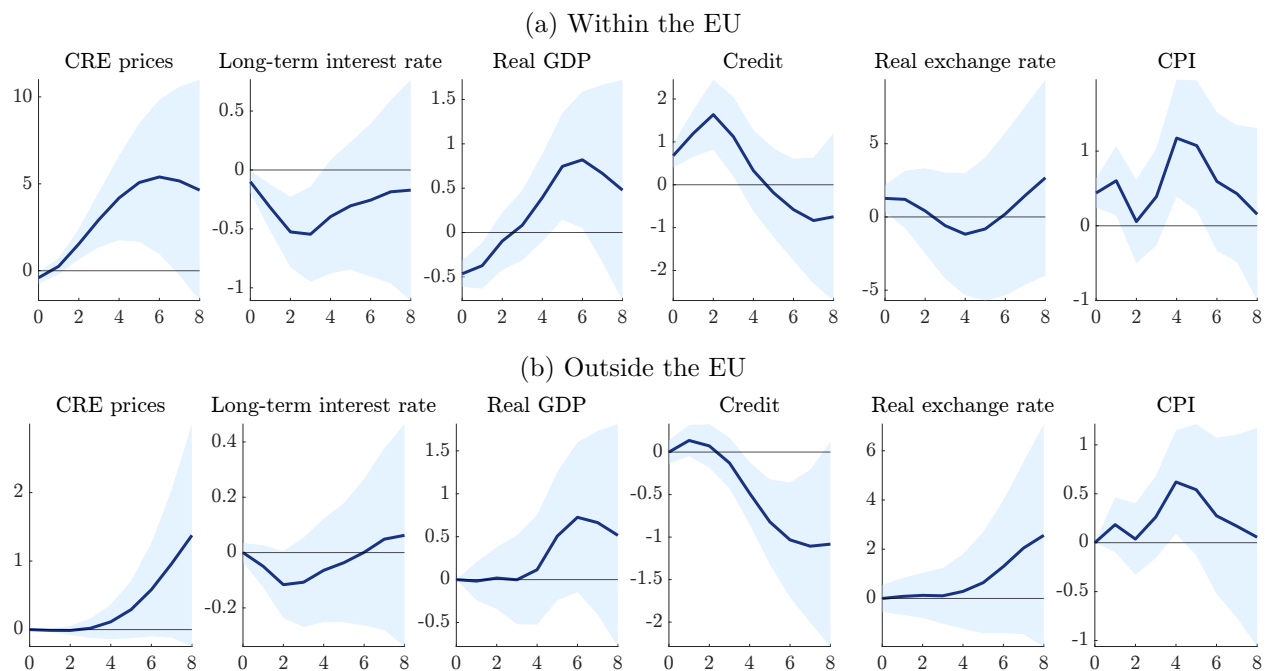
Figure C.3: Response to a US quantitative easing shock when controlling for quantitative easing by the ECB



Notes: The figure shows cumulative IRFs to represent variables in levels. The ECB quantitative easing shock is calibrated to deliver a 10 basis points decline in the 10-year US Treasury yield on impact. Countries outside the US include France, Germany, the Netherlands, Sweden, the United Kingdom, Australia, China, Japan, Singapore and South-Korea. Shaded areas denote the upper and lower bound of the 90% confidence interval. Units are expressed in percentage points. Horizontal axes measure quarters.

C.5 Spillover effects from quantitative easing by the ECB

Figure C.4: Response to an ECB quantitative easing shock



Notes: The figure shows cumulative IRFs to represent variables in levels. The ECB quantitative easing shock is calibrated to deliver a 10 basis points decline in the 10-year German Bund yield on impact. Countries inside the EU include France, Germany and the Netherlands. Countries outside the EU include the US, Sweden, the United Kingdom, Australia, China, Japan, Singapore and South-Korea. Shaded areas denote the upper and lower bound of the 90% confidence interval. Units are expressed in percentage points. Horizontal axes measure quarters.

D Full description of the New Keynesian model

D.1 Households

A representative household in Home consumes both Home and Foreign goods, $C_{H,t}$ and $C_{F,t}$, supplies labor, L_t , and saves by holding one-period deposits at domestic banks, D_t . The household receives lump-sum profits, DIV_t , from all domestic (financial and non-financial) firms, which it owns. The household also owns the land that is available for the production of CRE, $\mathcal{L}$, and which is in fixed supply.

The objective of the household is to maximize its lifetime utility, given by

$$E_t \sum_{j=0}^{\infty} \beta^j \left(\frac{(C_{t+j} - bC_{t+j-1})^{1-\zeta} - 1}{1-\zeta} - \chi \frac{L_{t+j}^{1+\eta}}{1+\eta} \right), \quad (26)$$

where total consumption is given by $C_t = \left[\nu^{\frac{1}{\vartheta}} (C_{H,t})^{\frac{\vartheta-1}{\vartheta}} + \nu^{\frac{1}{\vartheta}} (C_{F,t})^{\frac{\vartheta-1}{\vartheta}} \right]^{\frac{\vartheta}{\vartheta-1}}$, with $\nu \in (0, 1)$ a measure of trade openness and $\vartheta > 1$ the trade elasticity. The parameter $\beta \in (0, 1)$ denotes the discount factor, b measures the degree of consumption habits, $\zeta > 0$ the elasticity of intertemporal substitution, $\eta > 0$ the inverse Frisch elasticity of labor supply and χ is a scaling parameter used to pin down steady-state hours worked. The household maximizes (26) subject to its period budget constraint:

$$P_{H,t}C_{H,t} + P_{F,t}C_{F,t} + D_t = MRS_t L_t + R_{t-1}^d D_{t-1} + DIV_t - P_t X_t - P_t T_t + P_t^l \mathcal{L}, \quad (27)$$

where $P_{H,t}$ and $P_{F,t}$ are the Home and Foreign producer price indices, MRS_t denotes the earnings from supplying labor, R_t^d the gross nominal deposit rate, P_t the consumer price index and P_t^l the (nominal) price of land. X_t are real transfers paid by the household to the domestic financial intermediary (described below), while T_t are lump-sum taxes paid to the domestic government.

The household's first-order conditions are given by

$$\mu_t = (C_t - bC_{t-1})^{-\zeta} - b\beta E_t (C_{t+1} - bC_t)^{-\zeta}, \quad (28)$$

$$1 = R_t^d E_t \left(\Lambda_{t,t+1} \frac{1}{\Pi_{t+1}} \right), \quad (29)$$

$$\chi L_t^\eta = \mu_t mrs_t, \quad (30)$$

with $\Lambda_{t,t+1} \equiv \beta \frac{\mu_{t+1}}{\mu_t}$ the stochastic discount factor and μ_t the Lagrange multiplier on (27), $\Pi_t \equiv \frac{P_t}{P_{t-1}}$ gross inflation and $mrs_t \equiv \frac{MRS_t}{P_t}$.

A continuum of monopolistically competitive labor unions, indexed by $f \in [0, 1]$, collect labor services from households at MRS_t and sell these services to firms at the wage rate $W_t(f)$, subject to the labor demand schedule $L_{d,t}(f) = \left(\frac{W_t(f)}{W_t} \right)^{-\epsilon_w} L_{d,t}$, with W_t the aggregate wage, $\epsilon_w > 1$ the elasticity of substitution between wage varieties, and $L_{d,t}$ the total demand for labor by firms. While unions can set $W_t(f)$ at a markup $\frac{\epsilon_w}{\epsilon_w - 1}$ over MRS_t , they face a wage-setting constraint that prohibits a fraction $\phi_w \in (0, 1)$ of unions from changing their wage in a given period. The labor union aims to set an optimal real wage, w_t^o , to maximize the discounted sum of expected profits, taking into account the probability of non-wage adjustment:

$$E_t \sum_{j=0}^{\infty} \phi_w^j \Lambda_{t,t+j} DIV_{L,t+j}(f),$$

where profit flows $DIV_{L,t}(f)$ are given by

$$DIV_{L,t}(f) = W_t(f) L_{d,t}(f) - MRS_t L_t(f).$$

The corresponding first-order conditions of the labor union are given by

$$w_t^o = \frac{\epsilon_w}{\epsilon_w - 1} \frac{f_{1,t}}{f_{2,t}}, \quad (31)$$

$$f_{1,t} = w_t^{\epsilon_w} L_{d,t} mrs_t + \phi_w E_t \Lambda_{t,t+1} f_{1,t+1} \Pi_{t+1}^{\epsilon_w}, \quad (32)$$

$$f_{2,t} = w_t^{\epsilon_w} L_{d,t} + \phi_w E_t \Lambda_{t,t+1} f_{2,t+1} \Pi_{t+1}^{\epsilon_w - 1}, \quad (33)$$

where $w_t \equiv \frac{W_t}{P_t}$ is the real wage. Note that the aggregate real wage evolves according to

$$w_t^{1-\epsilon_w} = \phi_w \Pi_t^{-(1-\epsilon_w)} w_{t-1}^{1-\epsilon_w} + (1 - \phi_w) (w_t^o)^{1-\epsilon_w}. \quad (34)$$

D.2 Production

The production of goods consists of three stages. In the first stage, perfectly competitive capital and CRE producers transform investment goods, I_t and $I_{h,t}$, into new capital and CRE, $\hat{I}_t$ and $\hat{I}_{h,t}$, according to the following technology:

$$\hat{I}_t = \left[1 - \frac{\kappa_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right], \quad (35)$$

$$\hat{I}_{h,t} = \left[1 - \frac{\kappa_h}{2} \left(\frac{I_{h,t}}{I_{h,t-1}} - 1 \right)^2 \right] I_{h,t}, \quad (36)$$

where $\kappa_I \geq 0$ and $\kappa_h \geq 0$ govern the size of investment adjustment costs. Let p_t^k and p_t^h denote the real price of new capital and CRE. Maximizing the expected discounted sum of profits, given by

$$E_t \sum_{j=0}^{\infty} \Lambda_{t,t+j} \left\{ p_{t+j}^k \left[1 - S \left(\frac{I_{t+j}}{I_{t+j-1}} \right) \right] I_{t+j} - I_{t+j} \right\}, \quad (37)$$

$$E_t \sum_{j=0}^{\infty} \Lambda_{t,t+j} \left\{ p_{t+j}^h \left[1 - S \left(\frac{I_{h,t+j}}{I_{h,t+j-1}} \right) \right] I_{h,t+j} - I_{h,t+j} \right\}, \quad (38)$$

delivers the first-order conditions of the capital and CRE producers:

$$1 = p_t^k \left\{ 1 - \frac{\kappa_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \kappa_I \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right\} \quad (39)$$

$$+ \Lambda_{t,t+1} p_{t+1}^k \kappa_I \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2,$$

$$1 = p_t^h \left\{ 1 - \frac{\kappa_h}{2} \left(\frac{I_{h,t}}{I_{h,t-1}} - 1 \right)^2 - \kappa_h \left(\frac{I_{h,t}}{I_{h,t-1}} - 1 \right) \frac{I_{h,t}}{I_{h,t-1}} \right\} \quad (40)$$

$$+ \Lambda_{t,t+1} p_{t+1}^h \kappa_h \left(\frac{I_{h,t+1}}{I_{h,t}} - 1 \right) \left(\frac{I_{h,t+1}}{I_{h,t}} \right)^2.$$

In the second stage, perfectly competitive wholesale firms purchase the new capital and CRE from the capital and CRE producers, and hire labor to produce intermediate goods, $Y_{w,t}$, using the following production function:

$$Y_{w,t} = A_t \left[CRE_{t-1}^{\alpha_h} (u_t K_{t-1})^{1-\alpha_h} \right]^\alpha L_{d,t}^{1-\alpha}, \quad (41)$$

with $\{\alpha, \alpha_h, \xi\} \in (0, 1)$, A_t an exogenous TFP shock, whose dynamics are governed by a stationary AR(1) process, and where CRE_t is a composite of CRE and land:

$$CRE_{t-1} = H_t^\xi \mathcal{L}^{1-\xi}. \quad (42)$$

The stock of CRE, H_t , evolves according to:

$$H_t = (1 - \delta_h) H_{t-1} + \hat{I}_{h,t}, \quad (43)$$

with $\delta_h \in [0, 1]$ the depreciation rate of CRE. Similarly, capital, K_t , evolves according to:

$$K_t = (1 - \delta(u_t)) K_{t-1} + \hat{I}_t, \quad (44)$$

where the depreciation rate of capital is a function of the utilization rate, u_t , i.e. $\delta(u_t) = \delta_0 +$

$\delta_1 (u_t - 1) + \frac{\delta_2}{2} (u_t - 1)^2$. Importantly, the wholesale firm faces a loan-in-advance constraint that requires the firm to finance a fraction $\psi \in (0, 1]$ of its newly purchased capital and CRE with long-term bonds, B_t^P :

$$\psi \left(p_t^k \hat{I}_t + p_t^h \hat{I}_{h,t} \right) \leq Q_t^P \left(b_t^P - \kappa_P \frac{b_{t-1}^P}{\Pi_t} \right), \quad (45)$$

with Q_t^P the bond price, $b_t^P \equiv \frac{B_t^P}{P_t}$ real bonds and where $\kappa_P \geq 0$ governs the average duration of the bonds. The objective of the wholesale firm is to maximize the expected discounted sum of real profits, given by

$$\sum_{j=0}^{\infty} \Lambda_{t,t+j} \frac{DIV_{m,t+j}}{P_{t+j}}, \quad (46)$$

where dividends $DIV_{m,t}$ are given by

$$\begin{aligned} DIV_{m,t} = & P_{w,t} A_t \left(\left(H_{t-1}^\xi \mathcal{L}^{1-\xi} \right)^{\alpha_h} (u_t K_{t-1})^{1-\alpha_h} \right)^\alpha L_{d,t}^{1-\alpha} - W_t L_{d,t} - P_t^k \hat{I}_t \\ & - P_t^h \hat{I}_{h,t} - P_t^l \mathcal{L} - B_{t-1}^P + Q_t^P \left(B_t^P - \kappa_P B_{t-1}^P \right), \end{aligned} \quad (47)$$

subject to (41)–(45). Denoting ϑ_t the Lagrange multiplier on (45) and the real wholesale

price by $p_{w,t}$, the corresponding first-order conditions are given by

$$w_t = (1 - \alpha) p_{w,t} \frac{Y_{w,t}}{L_{d,t}}, \quad (48)$$

$$p_t^k M_{1,t} (\delta_1 + \delta_2 (u_t - 1)) = (1 - \alpha_h) \alpha p_{w,t} \frac{Y_{w,t}}{u_t K_{t-1}}, \quad (49)$$

$$p_t^k M_{1,t} = E_t \Lambda_{t,t+1} \left[(1 - \alpha_h) \alpha p_{w,t+1} \frac{Y_{w,t+1}}{K_t} + p_{t+1}^k M_{1,t+1} (1 - \delta (u_{t+1})) \right] \quad (50)$$

$$M_{2,t} Q_t^P = E_t \Lambda_{t,t+1} \frac{1}{\Pi_{t+1}} \left(1 + \kappa_P Q_{t+1}^P M_{2,t+1} \right), \quad (51)$$

$$\frac{M_{1,t} - 1}{M_{2,t} - 1} = \psi, \quad (52)$$

$$p_t^h M_{1,t} = E_t \Lambda_{t,t+1} \left[\xi \alpha_h \alpha p_{w,t+1} \frac{Y_{w,t+1}}{H_t} + p_{t+1}^h M_{1,t+1} (1 - \delta_h) \right], \quad (53)$$

$$p_t^l = (1 - \xi) \alpha_h \alpha p_{w,t} \frac{Y_{w,t}}{\mathcal{L}}, \quad (54)$$

with $M_{1,t} \equiv 1 + \vartheta_t \psi$ and $M_{2,t} \equiv 1 + \vartheta_t$.

Finally, a continuum of monopolistically competitive retail firms, indexed by $h \in [0, 1]$, assemble the intermediate goods into a (differentiated) final good in the third stage, which is sold to the Home and Foreign household by the demand schedule $Y_t(h) = \left(\frac{P_{H,t}(h)}{P_{H,t}} \right)^{-\epsilon_p} Y_t$. Each retail firm can set its price, $P_{H,t}(h)$, at a markup $\frac{\epsilon_p}{\epsilon_p - 1}$ over its marginal costs, yet faces a constant probability $\phi_p \in (0, 1)$ of not being able to change its price in a given period. The objective of the retail firm is to optimally set its price so as to maximize its expected discounted real profits:

$$\sum_{j=0}^{\infty} \phi_p^j \Lambda_{t,t+j} \frac{DIV_{R,t+j}(h)}{P_{t+j}}, \quad (55)$$

where dividend payouts are given by

$$DIV_{R,t}(h) = P_{H,t}(h) Y_t(h) - P_{w,t} Y_{w,t}(h). \quad (56)$$

D.3 Financial intermediaries

A representative financial intermediary, or ‘bank’, holds deposits from domestic households and invests in four types of (long-term) bonds: Home and Foreign private bonds (issued by wholesale firms), $B_{H,t}^{P,FI}$ and $B_{F,t}^{P,FI}$, and Home and Foreign public bonds (issued by fiscal authorities), $B_{H,t}^{G,FI}$ and $B_{F,t}^{G,FI}$. The bank’s resources consist of deposits held by households, D_t , that pay a gross nominal return R_t^d , and net worth, N_t . The balance sheet of the bank is given by:

$$Q_t^P B_{H,t}^{P,FI} + Q_t^G B_{H,t}^{G,FI} + Q_t^{P*} B_{F,t}^{P,FI} \mathcal{E}_t + Q_t^{G*} B_{F,t}^{G,FI} \mathcal{E}_t + RE_t = D_t + N_t, \quad (57)$$

with RE_t reserves held at the domestic central bank, and Q_t^j and Q_t^{j*} , $j = \{P, G\}$, the price of Home and Foreign bonds. As Foreign bonds are issued in Foreign currency, they are converted to Home currency using the nominal exchange rate $\mathcal{E}_t$. In each period, the bank’s beginning balance, $\mathcal{B}_t$, is determined by the excess return on its assets:

$$\begin{aligned} \mathcal{B}_t = & \left(R_t^P - R_{t-1}^d \right) Q_{t-1}^P B_{H,t-1}^{P,FI} + \left(R_t^G - R_{t-1}^d \right) Q_{t-1}^G B_{H,t-1}^{G,FI} \\ & + \left(R_t^{P*} \frac{\mathcal{E}_t}{\mathcal{E}_{t-1}} \left(1 - \Gamma_t^P \right) - R_{t-1}^d \right) Q_{t-1}^{P*} B_{F,t-1}^{P,FI} \mathcal{E}_{t-1} \\ & + \left(R_t^{G*} \frac{\mathcal{E}_t}{\mathcal{E}_{t-1}} \left(1 - \Gamma_t^G \right) - R_{t-1}^d \right) Q_{t-1}^{G*} B_{F,t-1}^{G,FI} \mathcal{E}_{t-1} \\ & + \left(R_{t-1}^{re} - R_{t-1}^d \right) RE_{t-1} + R_{t-1}^d N_{t-1}, \end{aligned} \quad (58)$$

where R_t^j and R_t^{j*} , $j = \{P, G\}$, denote the Home and Foreign nominal yields to maturity and R_t^{re} the gross nominal return on reserves. Holdings of Foreign bonds are subject to a portfolio adjustment cost, $\Gamma_t^j = \frac{\omega}{2} \left(\frac{b_{F,t-1}^{j,FI}}{b_F^{j,FI}} - 1 \right)^2$, where $b_{F,t}^{j,FI} \equiv \frac{B_{F,t}^{j,FI}}{P_t^*}$. In each period, a share $1 - \sigma$ of the bank’s beginning balance is paid out to the household, who is the owner of the bank, while the bank receives a real transfer, X_t , from the household. Therefore, the bank’s net worth, N_t , evolves according to $N_t = \sigma \mathcal{B}_t + P_t X_t$.

The objective of the bank is to maximize the sum of current and future expected real

dividend payouts:

$$V_t = \max (1 - \sigma) E_t \sum_{j=1}^{\infty} \Lambda_{t,t+j} \frac{\mathcal{B}_{t+j}}{P_{t+j}}, \quad (59)$$

subject to an enforcement constraint that prevents the bank from filing for bankruptcy while absconding with a share θ of its assets:

$$V_t \geq \theta \left\{ Q_t^P b_{H,t}^{P,FI} + \Delta Q_t^G b_{H,t}^{G,FI} + \left(Q_t^{P*} b_{F,t}^{P,FI} + \Delta Q_t^{G*} b_{F,t}^{G,FI} \right) \mathcal{Q}_t \right\}, \quad (60)$$

where $\Delta \in [0, 1]$ such that it may be more difficult for the bank to abscond public bonds (note that reserves are fully recoverable by depositors). The first-order conditions of the bank are given by

$$\frac{\lambda_t}{1 + \lambda_t} \theta = \Lambda_{t,t+1} \Pi_{t+1}^{-1} \left(R_{t+1}^P - R_t^d \right) \Omega_{t+1}, \quad (61)$$

$$\frac{\lambda_t}{1 + \lambda_t} \theta \Delta = \Lambda_{t,t+1} \Pi_{t+1}^{-1} \left(R_{t+1}^G - R_t^d \right) \Omega_{t+1}, \quad (62)$$

$$\frac{\lambda_t}{1 + \lambda_t} \theta = \Lambda_{t,t+1} \Pi_{t+1}^{-1} \left\{ R_{t+1}^{P*} \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \left[1 - \frac{1}{2} \omega \left(\frac{b_{F,t}^{P,FI}}{b_F^{P,FI}} - 1 \right) \left(3 \frac{b_{F,t}^{P,FI}}{b_F^{P,FI}} - 1 \right) \right] - R_t^d \right\} \Omega_{t+1}, \quad (63)$$

$$\frac{\lambda_t}{1 + \lambda_t} \theta \Delta = \Lambda_{t,t+1} \Pi_{t+1}^{-1} \left\{ R_{t+1}^{G*} \frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \left[1 - \frac{1}{2} \omega \left(\frac{b_{F,t}^{G,FI}}{b_F^{G,FI}} - 1 \right) \left(3 \frac{b_{F,t}^{G,FI}}{b_F^{G,FI}} - 1 \right) \right] - R_t^d \right\} \Omega_{t+1}, \quad (64)$$

$$-\frac{\omega_t}{1 + \lambda_t} = \Lambda_{t,t+1} \Pi_{t+1}^{-1} \left(R_t^e - R_t^d \right) \Omega_{t+1}, \quad (65)$$

where, using $\mathbf{b}_t \equiv \frac{\mathcal{B}_t}{P_t}$, we defined

$$\Omega_{t+1} = (1 - \sigma) + \frac{\partial V_{t+1}}{\partial \mathbf{b}_{t+1}}.$$

For more details on the derivation of these first-order conditions, we refer the reader to [Wu et al. \(2024\)](#).

D.4 Monetary and fiscal policy

A monetary authority, or ‘central bank’, sets the short-term policy rate, R_t^e , to stabilize domestic producer price inflation, $\Pi_{H,t} \equiv \frac{P_{H,t}}{P_{H,t-1}}$, and output growth, $\frac{Y_t}{Y_{t-1}}$, according to a standard Taylor rule:

$$\frac{R_t^e}{R^e} = \left(\frac{R_{t-1}^e}{R^e} \right)^{\rho_r} \left[\left(\frac{\Pi_{H,t}}{\Pi_H} \right)^{\phi_\pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{\phi_y} \right]^{(1-\rho_r)}, \quad (66)$$

with $\rho_r \in [0, 1]$, $\phi_\pi > 1$ and $\phi_y \geq 0$, and where variables without a subscript t refer to steady-state values. The central bank issues reserves to banks and may purchase domestic private and public bonds, $B_t^{P,CB}$ and $B_t^{G,CB}$. Its balance sheet is given by $Q_t^P B_t^{P,CB} + Q_t^G B_t^{G,CB} = RE_t$. Bond purchases by the central bank, which we refer to as QE, are governed by the following AR(1) process:

$$b_t^{j,CB} - b^{j,CB} = \rho_j (b_{t-1}^{j,CB} - b^{j,CB}) + \varepsilon_t^{j,CB}, \quad (67)$$

with $b_t^{j,CB} \equiv \frac{B_t^{j,CB}}{P_t}$, for $j = \{P, G\}$, $\rho_j \in [0, 1]$, and where $\varepsilon_t^{j,CB} \sim \mathcal{N}(0, \sigma_{j,CB}^2)$ is a QE shock.

The fiscal authority, or ‘government’, issues government bonds, B_t^G , and levies lump-sum taxes, T_t , to finance its (exogenous) consumption expenditures, G_t , and service outstanding debt. The government further receives central bank profits, $T_t^{CB} = \sum_{j=\{P,G\}} (1 + \kappa_j Q_t^j) \frac{B_{t-1}^{j,CB}}{P_t} - R_{t-1}^{re} \frac{RE_{t-1}}{P_t}$, and the portfolio adjustment costs (i.e. transaction fees) paid by the domestic banks. Its period budget constraint is then given by

$$\begin{aligned} P_t G_t + B_{t-1}^G &= P_t T_t + P_t T_t^{CB} + Q_t^G (B_t^G - \kappa_G B_{t-1}^G) \\ &\quad + R_t^{P*} (1 - \Gamma_t^P) Q_{t-1}^{P*} B_{F,t-1}^{P,FI} \mathcal{E}_t \\ &\quad + R_t^{G*} (1 - \Gamma_t^G) Q_{t-1}^{G*} b_{F,t-1}^{G,FI} \mathcal{E}_t. \end{aligned} \quad (68)$$

Following [Wu et al. \(2024\)](#), we assume that public bond supply is kept constant at B^G .

D.5 Market clearing

Goods market clearing implies

$$Y_t = C_{H,t} + \frac{1-\gamma}{\gamma} C_{H,t}^* + I_t + I_{h,t} + G_t, \quad (69)$$

where $\gamma \in (0, 1)$ denotes the population size of Home relative to that of Foreign. Note that there is full home bias in public consumption and capital and CRE investment.

Finally, bonds market clearing implies, with $j = \{P, G\}$:

$$b_t^j = b_{H,t}^{j,FI} + \frac{1-\gamma}{\gamma} b_{H,t}^{j,FI*} + b_t^{j,CB}, \quad (70)$$

$$b_t^{j*} = b_{F,t}^{j,FI*} + \frac{\gamma}{1-\gamma} b_{F,t}^{j,FI} + b_t^{j,CB*}. \quad (71)$$

E Model calibration

Table 5: Calibration of structural parameters

Parameter	Value / Target	Description	Source
<i>Open economy</i>			
γ	0.5	Relative size Home country	Wu et al. (2024)
v	0.5	Home bias (i.e. trade openness)	Wu et al. (2024)
<i>Household preferences</i>			
β	0.995	Discount factor	Wu et al. (2024)
b	0.7	Habit formation	Wu et al. (2024)
η	1	Inverse Frisch elasticity	Wu et al. (2024)
ζ	1	Inverse elasticity of intertemporal substitution	Wu et al. (2024)
ϑ	3	Elasticity of substitution between H and F goods	Wu et al. (2024)
χ	$L = 1$	Labor disutility	Wu et al. (2024)
<i>Supply side</i>			
α	0.33	Output elasticity of capital	Wu et al. (2024)
ϵ_p, ϵ_w	11	Goods and labor elasticity of substitution	Wu et al. (2024)
ϕ_p, ϕ_w	0.75	Price and wage stickiness	Wu et al. (2024)
Π	1	Steady-state gross inflation	Wu et al. (2024)
κ_I	2	Investment adjustment cost	Wu et al. (2024)
δ_0	0.025	Steady-state depreciation rate	Wu et al. (2024)
δ_1	$u = 1$	Capital utilization rate, linear term	Wu et al. (2024)
δ_2	0.01	Capital utilization rate, squared term	Wu et al. (2024)
ψ	0.81	Loan-in-advance constraint	Wu et al. (2024)
<i>Commercial real estate</i>			
ξ	0.54	Output share of CRE compared to land	Davis and Heathcote (2007)
α_h	0.75	CRE share in production	Ghent et al. (2019); Ewens et al. (2025)
δ_h	0.015	CRE depreciation rate	Bokhari and Geltner (2018)
κ_h	2	CRE adjustment cost	
<i>Financial intermediaries</i>			
Δ	1/3	Recoverability of government bonds	Wu et al. (2024)
lev	4	Steady state leverage	Gertler and Karadi (2011)
σ	0.95	Survival probability	Wu et al. (2024)
ω	0.1	Foreign transaction cost	Wu et al. (2024)
θ	$4(R^P - R^d) = 3\%$	Recovery parameter	Wu et al. (2024)
κ_P, κ_b	$1 - 40^{-1}$	Coupon decay rate	Wu et al. (2024)
<i>Government and central bank</i>			
$\frac{G}{Y}$	0.2	Government spending share	Wu et al. (2024)
$\frac{b_g}{y}$	0.41*4	Steady-state debt-to-GDP ratio	Wu et al. (2024)
ρ_r	0.8	Taylor rule, smoothing parameter	Wu et al. (2024)
ϕ_π	1.5	Taylor rule, inflation response	Wu et al. (2024)
ϕ_y	0.25	Taylor rule, output growth response	Wu et al. (2024)
$\bar{\tau}, \bar{\tau}^*$	0	Steady-state lump-sum taxes	
<i>Steady state bond holdings</i>			
$b^{G,CB}$	0.06*4	Share of public bonds held by CB	Wu et al. (2024)
$b^{P,CB}$	0	Share of private bonds held by CB	Wu et al. (2024)
$b^{G,FI}, b^{P,FI}$	0.8	Share of public and private bonds held by domestic banks	Wu et al. (2024)
<i>Shock parameters</i>			
ρ_b	0.8	AR(1) coefficient QE shock	Wu et al. (2024)
σ_b	0.0005	Standard deviation QE shock	

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