Real Effects of the ECB's Quantitative Easing: A Housing Portfolio Channel*

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Abstract

We propose a new channel of transmission through which central bank quantitative easing (QE) can affect local economic activity. In our model, in response to a QE intervention, a national financial intermediary responds by rebalancing its portfolio from bonds to housing. As a result, house prices increase, and the total portfolio return declines, boosting the economy by stimulating current consumption; the shorter the local housing supply, the stronger the consumption effects. We then investigate this channel empirically by employing German region-level data. Identification exploits the exogenous variation in land supply scarcity across regions to construct a measure of exposure to this housing channel. In line with the transmission in the model, we find that the QE impact on GDP growth is more potent in regions with tighter land supply. We estimate that a one-standard-deviation increase in the size of the ECB's balance sheet raises GDP growth in the most exposed areas by 10-20 basis points more per year than in the least exposed ones. The differential response of residential property prices and rents to QE can account for this regional growth differential. The significance of the QE impact on growth disappears once we control for the government bond term spread, but survives when we condition on mortgage credit.

Keywords: Unconventional Monetary Policy, Housing Portfolio Channel, EONIA, Quantitative Easing, Regional Business Cycles, Germany, Real Estate

JEL Classification: E3, E4, E5, R3

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1 Introduction

During and after the global financial crisis (GFC), central banks expanded their monetary policy toolkit, adopting unconventional instruments. Several central banks, including the European Central Bank (ECB), started to purchase long-term bonds and other risky assets, the so-called quantitative easing interventions (QE), in order to support the economy. The ECB has also continued to use interest rate policies by setting a negative deposit facility rate.

The effects of QE on asset prices, credit, borrowing and lending behavior have been studied intensively. The impact on the final target of monetary policy, however, remains under-researched. What are the economic effects of QE on aggregate investment, consumption and output? What are the channels of transmission?

In this paper, we propose a new channel through which QE can affect the real economy — a housing portfolio channel. On the theoretical side, we set up a simple housing portfolio model with segmented asset market and show that financial intermediaries rebalance their portfolios from bonds to houses in response to QE. As a result, house and bond prices increase and the aggregate portfolio return decreases. A lower return on saving can stimulate the local economy by boosting consumption under certain conditions. We then investigate this new channel empirically by estimating the differential impact of QE on house prices and output growth across German regions, controlling for the European interbank market rate (EONIA) and other confounding factors.

To achieve identification, we exploit the differential exposure of German *regions* to tightness in local land supply. Our hypothesis is that the tighter a region's land supply is, the more significant is the impact of QE on the region's house prices and output growth. In a given local real estate market, all else equal, a tighter land supply should translate into a higher sensitivity of property prices to changes in QE, as wealthy households rebalance their portfolios towards real estate.

We find that the QE impact on annual real GDP growth is stronger in regions that face tighter land supply constraints. Once we control for QE, interest rate policy does not have a significant impact on regions' GDP. The differential impact of QE can be accounted for by residential property price and rent changes. We estimate that, in regions most exposed to land scarcity, real GDP grows 10-20 basis points more per year than in the least exposed ones for each one-standard deviation increase in QE during the 2010-2017 period. We also show that the transmission mechanisms are in line with our model. Specifically, the effects of QE become insignificant once we control for the yield curve or the interest rate on long-term financial assets. In addition, we show that QE reduces long-term interest rates and flattens the yield curve.

We first illustrate the plausibility of the housing portfolio channel in a simple intertemporal consumption model with segmented asset markets. By doing so, we connect two strands of literature, one on housing portfolios a la Flavin and Yamashita (2002), and the other on the preferred habitat investor, such as Vayanos and Vila (2021). In our model, QE reduces the total supply of risky (long-term) bonds to the private sector, which in equilibrium induces financial intermediaries to rebalance from risky bonds to housing. As a result, both house and bond prices increase, and the aggregate portfolio return falls. Local consumption increases in response to a fall in the return to saving if the the intertemporal elasticity of substitution is larger than 1 with CRRA preferences.

Our simple model predicts that QE simultaneously increases risky asset prices, including bonds and houses, and consumption spending through a portfolio rebalancing channel. To test this channel empirically, we assemble a database that includes aggregate and region-level data described in detail in Section 3. The size of the ECB's assets as a share of nominal area GDP is our proxy for QE, while the EONIA is our proxy for the traditional interest rate policy. Next, we construct a new matched region-level data. Although our model predicts an increase in consumption spending following QE, given the lack of regional consumption data, we use output growth instead. We match regional GDP growth data with a proprietary database on residential property prices and rents from Bulwiengesa AG (a reputable German real estate data provider), and detailed land use and land cover data.

To establish causation, we rely on identification by geographic variation. In particular, we interact the aggregate monetary policy indicators with a measure of exposure to land supply scarcity that varies across regions quasi-randomly and is kept constant over time at its pre-sample value in 2008. This measure is the share of land covered by water bodies and urban open space — a land supply scarcity measure in the spirit of Saiz (2010). As we show in the paper, this indicator has a very tight association with housing prices across German regions.

The main empirical finding of the paper is that QE leads to a larger impact on output growth in regions with lower land supply, after controlling for the EONIA interest rate and other confounding factors. In contrast, interest rate policy has no differential effect on region output growth if we control for quantitative easing. Moreover, we find no evidence of complementarity between QE and interest rate changes in our setting. The output growth differential between German regions that we estimate can entirely be accounted for by the different response of residential property prices or rents triggered by QE. We estimate that, during the 2010-2017 period, for one-standard deviation increase in QE, regions at the 75 percentile of the land scarcity distribution grow 10-20 basis points more per year than regions at the 25th percentile.

We also show empirically that the transmission mechanism through which QE affects the real economy is consistent with our model. In particular, the significance of the QE effects disappears once we control for the yield curve in our regressions. An increase in banks' mortgage origination does not have this effect, so that the classical bank lending channel of monetary policy does not seem to explain our results. We also provide direct evidence for our theoretical mechanism by showing that QE reduces long-term rates and flattens the yield curve. Finally, we show that there are significant cross-regional differences in the intensity of QE on output growth depending on the regions' characteristics. Particularly, our main estimates are driven by wealthier and more densely populated regions. In contrast, in the least densely populated areas, the traditional interest rate channel plays a more prominent role than QE. We interpret these findings as consistent with the existence of a housing portfolio channel in wealthier parts of Germany, where households rebalance their portfolios from bonds and other financial assets towards real estate when QE reduces long-term interest rates and flattens the yield curve.

Literature Review Our paper relates to the literature along multiple dimensions. First, we contribute to the literature studying the QE effects on bank and firm behavior, as well as macroeconomic outcomes. For example, Rodnyansky and Darmouni (2017) show that banks' exposure to large-scale asset purchases, as measured by the relative prevalence of mortgage-backed securities on their books, affects lending following unconventional monetary policy shocks. Chakraborty, Goldstein and MacKinlay (2019), using micro-level data, find that banks benefiting from quantitative easing increase mortgage origination, compared to other banks. Using confidential loan officer survey data on lending standards and internal risk ratings on loans, Kurtzman, Luck and Zimmermann (2017) document an effect of large-scale asset purchase programs on lending standards and risk-taking. Acharya, Eisert, Eufinger and Hirsch (2019) provide evidence that the ECB's OMT program induced banks with higher foreign exposure to increase loan supply, especially so to pre-exisitng low-quality (zombie) borrowers by raising asset prices and bank equity. Todorov (2020) find that the ECB's Corporate Sector Purchase Programme announcement increased prices, liquidity and debt issuance in the European corporate bond market, in particular for longer-maturity, lower-rated bonds, and for more credit-constrained, lower-rated firms. While these studies focus on the effects of QE on bank lending and firm behavior, only few papers investigate the effects of QE on macroeconomic outcomes. Particularly, Eberly et al. (2019) and Luck and Zimmermann (2020) find that quantitative easing led to a significant increase in employment in the US. Our paper differs from these two papers by proposing a new transmission channel of QE, focusing on the macroeconomic effects of QE via the real estate market. This new channel is closely related to Peydró, Polo and Sette (forthcoming), who document a portfolio channel for monetary policy using Italian credit and security data. Specifically, they find that less capitalized banks substitute securities with lower yields and haircuts for credit supply during crises time, inducing worse firm-level real effects. Differently, we focus on the portfolio rebalancing from bonds to housing and we find a stimulus effect at the regional level following portfolio rebalancing.

Second, our paper belongs to the large literature on the impact of house prices on consumption and investment. For example, Iacoviello (2005) and Liu et al. (2013) develop closed-economy DSGE models to study the effect of house prices on the real economy through a collateral borrowing channel, either on the household or the firm side. Chaney et al. (2012) use US firm-level data to empirically show that an exogenous variation in property prices triggered by aggregate mortgage rate changes can have a sizable impact on corporate investment. A critical difference here is that the housing portfolio channel we study does not depend on a binding collateral constraint and applies to asset price booms without credit booms.

Third, the new housing portfolio channel that we propose speaks to the literature that views housing as a risky asset in the portfolio. For example, Flavin and Yamashita (2002) study the impact of the constraint imposed by housing demand on optimal holding of financial assets. We show that this housing portfolio channel can be at work in the transmission of QE interventions. Our model relies on the segmented asset market hypothesis through preferred habitat investors as for instance proposed by Vayanos and Vila (2021) and Ray (2019). The novelty of our contribution, here, is to focus on the portfolio implications of preferred habitat investing in the housing market.

Finally, we also contribute to the strand of the literature studying the German post-2009 housing boom. Kindermann et al. (2020) use new household survey data to study expectation formation during the recent housing boom in Germany. Bednarek et al. (forthcoming) examine the transmission of capital flow shocks during the European sovereign debt crisis on regional GDP growth via the real estate market. We use similar data and identification strategies by geographic variation to look at the transmission of an aggregate shock to local output, but we focus on monetary policy shocks.

The rest of the paper is organized as follows. Sections 2 presents the model and spells out our empirical hypotheses. Section 3 presents the data. Section 4 discusses identification. Section 5 reports all estimation results. Section 6 concludes. All technical details and selected additional estimation results are in an appendix at the end of the paper.

2 Model

In this section, we build a simple model to illustrate the housing portfolio channel that we study empirically. By doing so, we connect two strands of literature, one on housing portfolios a la Flavin and Yamashita (2002) and the other on the preferred-habitat investor as for instance in Vayanos and Vila (2021) and Ray (2019).

Our model features two blocks. One is the real side of the economy where a representative household solves a standard consumption/saving problem. The other is the financial side of the economy where market players solve a portfolio problem and thus pin down asset prices and portfolio shares. In equilibrium, the portfolio choice affects the return to savings (r) to the consumers. Therefore, QE can have a real effect on the economy through its impact on the portfolio choice. Note that, for simplicity, we do not model the impact of QE on output and focus on consumption c. The link from consumption to output can be easily introduced adding endogenous production.

2.1 Households

We consider a representative household that lives for two periods, today and tomorrow. We view this household as a representative citizen of a German city.[1] The consumer delegates his/her savings s to a financial intermediary that offers a composite return, r. This return will be determined by the equilibrium in financial markets. In other words, the consumers take the return as given and solve the following consumption/saving problem:

$$\max_s u(c) + \beta u(c'), \text{s.t. } c + s = w, c' = (1+r)s \tag{1}$$

where $u(\cdot)$ is a standard utility function, β is the discount rate, c and c' are consumption at today and tomorrow, s is saving, w is the initial wealth and r is the composite return on saving.

The optimality condition for this problem is

$$u'(c) - \beta(1+r)u'((1+r)(w-c)) = 0. \tag{2}$$

Therefore, the consumption response to return changes is given by

$$\frac{dc}{dr} = \frac{\beta u'(c') + \beta(1+r)u''(c')(w-c)}{u''(c) + \beta(1+r)^2 u''(c')}. \tag{3}$$

As we discuss below, under plausible assumptions on the correlation between the two asset returns, the return to saving falls in the model in response to QE. Thus, here, we seek conditions under which consumption increases in response to a decline in r. The denominator of (3) is negative as the marginal utility is decreasing in consumption. Given CRRA preferences with risk aversion coefficient σ, the numerator is given by $(1-\sigma)\beta c'^{-\sigma}$. Thus, in this two-period set up, consumption increases in response to a reduction in r (i.e., $\frac{dc}{dr} < 0$) when $\sigma < 1$, or the intertemporal elasticity of substitution (EIS) is larger than 1.[2]

[1] There is only one region in the benchmark model. Extending the model to multiple regions is straightforward.

[2] Wealth effects through discounting would arise in a multi-period or infinite-horizon version of the model, allowing us to relax this assumption.

2.2 Intermediaries

There are two risky assets in the financial markets: houses and bonds. Their payoffs are $\mu_1 + \epsilon_1$ and $\mu_2 + \epsilon_2$, respectively, with $E[\epsilon_1] = E[\epsilon_2] = 0$ $Var(\epsilon_1) = \sigma_1^2$, $Var(\epsilon_2) = \sigma_2^2$ and $Cov(\epsilon_1, \epsilon_2) = \sigma_{12}$.

There are three traders, two preferred habitat investors in each market and one national arbitrager. Following the literature on preferred habitat (Vayanos and Vila, 2021), we assume that the demand of the preferred habitat investor in the housing market is given by

$$\tilde{h} = -\alpha_1(P - \beta_1) \tag{4}$$

where $\alpha_1, \beta_1 > 0$ are the parameters in the demand function, P is the house price and $\tilde{h}$ is the quantity demanded. Similarly, we assume that the demand function of preferred habitat investors in the bond market is

$$\tilde{b} = -\alpha_2(Q - \beta_2) \tag{5}$$

where $\alpha_2, \beta_2 > 0$ are the parameters in the demand function, Q is the bond price and $\tilde{b}$ is the demand of the preferred habitat investor in the bond market.

The preferred habitat investors are passive in our model. They just absorb the excess demand at given market prices. Moreover, they do not arbitrage across markets. Therefore, they segment the two asset markets. The underlying rationale is that both housing and bond investing require specialization and thus attract distinctly different investors.

However, there are market players that can and do arbitrage across markets. Specifically, we assume that there exists national arbitragers, delegated by the representative household to trade a portfolio of both assets. In addition to the two risky assets, the arbitragers also have access to a storage technology, x, which pays zero return. One important assumption here is that the national arbitrager has a mean-variance utility and thus limited risk-bearing capacity. Otherwise, the price of risky assets would only reflect their expected payoffs with no price impact stemming from changes in the quantity of assets supplied. In each period, the arbitragers choose their portfolio of houses, h, and bonds, b, and storage technology solving the following problem:

$$\max_{h,b,x} \quad h\mu_1 + b\mu_2 + x - \frac{\gamma}{2}(h^2\sigma_1^2 + b^2\sigma_2^2 + 2hb\sigma_{12}) \tag{6}$$
$$\text{s.t.} \quad W = Ph + Qb + x \cdots (\lambda) \tag{7}$$

where γ is the risk aversion coefficient for the arbitrager and W is the initial wealth of the national arbitrager.

The optimality conditions are:

$$\lambda P = \mu_1 - \gamma h\sigma_1^2 - \gamma b\sigma_{12} \tag{8}$$
$$\lambda Q = \mu_2 - \gamma b\sigma_2^2 - \gamma h\sigma_{12} \tag{9}$$
$$\lambda = 1 \tag{10}$$

These conditions are intuitive — the arbitrager equates the marginal cost of investing one additional unit of wealth in the asset with the marginal benefit (i.e., expected risk-adjusted payoffs of that asset).

We assume that the total supply of risky assets is fixed in the short run. In equilibrium, market clearing requires:

$$h + \tilde{h} = \bar{h} \tag{11}$$
$$b + \tilde{b} = \bar{b} \tag{12}$$

where $\bar{h}$ and $\bar{b}$ are the total supply of houses and bonds, respectively.

Equilibrium An equilibrium in the financial markets is an asset allocation —i.e., a set of asset demands by arbitragers and preferred habitat investors, $\{h, \tilde{h}, b, \tilde{b}\}$ — and a set of asset prices $\{P, Q\}$ such that (1) the arbitragers solve the mean-variance problem; (2) the demand of the preferred habitat investors is satisfied in both markets; and (3) both asset markets clear.

2.3 The Real Effects of QE via Portfolio Rebalancing

In this simple framework, the link between the real and financial sides of the economy is through the delegated investment by the household to an arbitrager who chooses portfolio shares. Therefore, the real effect of QE is through its impact on the financial arbitrager. We model QE as a reduction in bond supply $\bar{b}$ to the financial markets through central bank purchases of risky long-term bonds that reduce the bond holdings in the private sector.

To analyze the impact of QE, we consider the following comparative statistics with respect to total bond supply $\bar{b}$:

$$
\begin{aligned}
\frac{db}{d\bar{b}} &= \frac{(1/\alpha_1 + \gamma\sigma_1^2)/\alpha_2}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} > 0 \\
\frac{dQ}{d\bar{b}} &= \frac{1}{\alpha_2}\left(\frac{db}{d\bar{b}} - 1\right) = \frac{1}{\alpha_2}\frac{-(1/\alpha_1 + \gamma\sigma_1^2)\gamma\sigma_2^2 + \gamma\sigma_2^2}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} < 0 \\
\frac{dh}{d\bar{b}} &= \frac{-\gamma\sigma_{12}/\alpha_2}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} \\
\frac{dP}{d\bar{b}} &= \frac{1}{\alpha_1}\frac{dh}{d\bar{b}}
\end{aligned}
$$

The impact of a reduction in $\bar{b}$ on the bond market is unambiguous. In particular, QE reduces the bond holding of the financial arbitrager and pushes up the bond price. This is intuitive because QE drives down the total bonds supply available to the investors. Other things equal, the bond price has to increase to accommodate the excess demand. As a result, the bonds return falls in response to the QE intervention. This induces financial arbitragers to reduce their portfolio loading on risky bonds.

The impact of a reduction in $\bar{b}$ on the housing market is ambiguous and depends on the covariance between bond and house returns, σ_{12}. In particular, houses and bonds are substitutes in the arbitrager's portfolio when their payoffs are positively correlated. A drop in bond holdings, b, reduces the risk contribution of housing in the overall portfolio. In equilibrium, the arbitragers want to increase their portfolio exposure to houses. As a result, the housing demand of preferred habitat investors has to fall to accommodate the decision of financial arbitragers for given supply, which in equilibrium pushes up house prices. Notice that this channel relies on the payoff structure of risky assets and the mean-variance utility assumption. The response of housing portfolio and house prices to QE is zero when the payoff correlation between bonds and houses is zero, i.e., $\sigma_{12} = 0$ or the risk aversion is zero, i.e., $\gamma = 0$. We therefore have the following proposition.

Proposition 1. *A reduction in the net supply of bonds, $\bar{b}$ (a QE intervention), increases demand for housing and house prices (i.e., $\frac{dh}{d\bar{b}} \leq 0$ and $\frac{dP}{d\bar{b}} \leq 0$) if and only if housing and bond returns are positively correlated ($\sigma_{12} \geq 0$).*

Proof. See Appendix A. □

As the financial arbitragers respond to QE by adjusting their portfolios, the return that they deliver to the household also changes. For simplicity, we specify the portfolio return omitting capital gains and considering only the expected yields of the two assets, i.e., $r = h\mu_1 + b\mu_2$.[3] Intuitively, QE induces the arbitragers to hold fewer bonds b and more houses h. Therefore, the impact on the total portfolio return depends on the relative strength of these two forces. The following proposition summarizes the results.

Proposition 2. *As long as σ_{12} is sufficiently low, QE lowers household portfolio returns:*

$$\frac{dr}{d\bar{b}} > 0 \;\; \textit{iff} \;\; \sigma_{12} < \frac{\mu_2}{\mu_1}\left(\frac{1}{\gamma\alpha_1} + \sigma_1^2\right),$$

Proof. See Appendix A. □

2.4 Empirical Implications

Albeit simple, our model has a rich set of implications for the data that inform our empirical analysis. Assuming a sufficiently high EIS, or $\frac{1}{\sigma} > 1$, and a positive but sufficiently low correlation between bond and house price returns, the model above implies that, following a QE intervention:

- Bond holdings go down, bond prices increase, and the overall portfolio return falls;
- House holdings and prices go up, assuming a positive correlation between housing and bond returns consistent with the data;
- Overall, household portfolio returns decrease, assuming a moderate correlation between housing and bond returns;
- Consumption increases, assuming a lower risk aversion $\sigma < 1$.

In our empirical analysis, we explore this channel of QE transmission in a cross-section of German urban and rural areas (regions or cities). Moreover, we expect a stronger response to QE interventions in regions in which land supply, and hence house supply, elasticity is lower.

[3] Alternatively, we can factor capital gains into the portfolio return definition by assuming $r' = h\frac{\mu_1}{P} + b\frac{\mu_2}{Q}$. The results would be unchanged, but the derivations would be more complex. See Appendix A for details.

3 Data

To conduct the empirical analysis, we assembled a unique region-level data set including all 401 German administrative regions at the annual frequency, from 2010 to 2017. In addition to official region-level statistics, the data set includes a proprietary panel data set of nominal residential property price and rental indexes from Bulwiengesa AG.[4]

To construct these indexes by region, Bulwiengesa AG uses both valuation and transaction data from building and loan associations, research institutions, realtor associations, as well as the chambers of industry and commerce. As region-level CPI indexes are not available, we deflate *nominal* property price and rental indexes with *state-level* official consumer price indexes.[5]

Residential price indexes are at the annual frequency and include the price of owner-occupied existing and newly-constructed apartments. They are calculated at the region level as simple averages of the individual unit prices. Thus, they can be seen as common region-level factors for unit-specific prices and rents — see, for instance, Pesaran (2015). In principal, house price data are also available for town houses and single-family detached homes. However, Bulwiengesa only provides rental information for apartments. However our results are largely unaffected when we also include town houses and single-family homes in the construction of our house price index (result available upon request).

In order to construct our instrumental variable described in Section 4, and to conduct various robustness exercises, we employ land use data from the German Monitor of Settlement and Open Space Development (IOER Monitor). This is a detailed land use database that combines information from satellite imaging with geo expert data and other statistical sources, capturing both man-made and geographical limits on real estate supply. Finally, we also match several other region-level variables to our data set, including population density, the number of building permits as well as demographic variables. These variables are sourced from the INKAR database.

The dependent variable in our main region-level regressions is real per capita GDP growth. Again, as region-level GDP deflators are not available, we deflate nominal GDP by using the same official state-level consumer price indexes used

[4]Appendix Table B.2 defines all regional variables we employ and describes their sources.

[5]Germany is a diversified large economy and inflation was low and stable during the period we consider. Hence, it does not make a difference whether we use real or nominal indexes.

to construct real property price indexes. The matching of the region-level data is based on a common region identifier. Table B.2 reports summary statistics for the aforementioned variables.

Average real GDP growth per capita is equal to 2.3%. The average region has a population density of about 520 people per square kilometer and the average share of people aged 65 or above is equal to 20.8%. Permits, on average, amount to 2.9 per 1,000 inhabitants. In terms of land use, water bodies cover 2% of the total reference area, on average; agricultural land covers 48%, forests 30%, and other open space (marsh land etc.) 1%. Urban open space (parks, small gardens, cemeteries, etc.) represents 1% of the total reference area. The complement of these open spaces, which is on average 17%, is made up of built-up land and transport and, therefore, most of this land is in principle available for the construction of residential real estate.

Although we do not provide the summary statistics separately for regions in the West and East of Germany, some significant differences stand out. Real GDP growth is higher in the East than in the West of Germany on average (2.7% vs 2.2%, respectively). East Germany is much less densely populated (333 vs 566 people per square kilometer) and land in East Germany is on average more intensively used for or covered by urban open space (2% vs 1.6%), agricultural land (53% vs 47.3%) and water bodies (2.7% vs 1.9%). In contrast, forests cover a larger share of land in the West (30.2% vs 29.4%).

The main proxy of the ECB's quantitative easing policy stance is the size of the Eurosystem's consolidated balance sheet relative to Euro Area nominal GDP, henceforth just called the size of the *ECB*'s balance sheet for brevity.[6] In unreported specifications, we also used the size of the unconsolidated Eurosystem's balance sheet or specific portions of the the balance sheet, distinguishing between total debt securities, government debt securities, private sector debt securities and debt securities issued by banks. Changing the ECB QE indicator, however, does not affect our estimates. This is not surprising given a correlations in the range of 85-98% among different balance sheet components. To control for the ECB's interest rate policy, we use the EONIA rate, which is the weighted average of all overnight

[6] Strictly speaking, the Eurosystem, which comprises the ECB as well as the national central banks, and not the ECB only, is responsible for conducting monetary policy in the euro area. In this paper, we use ECB as a synonym for the Eurosystem to avoid confusions with the term European System of Central Banks. So, when we refer to the size of the ECB balance sheet, we refer to the size of the Eurosystem balance sheet.

unsecured lending transactions in the interbank market of the European Monetary Union. Again, results are robust to using alternative proxy variables for the ECB policy rate.

Additional macroeconomic variables used in the empirical analysis are the following: government consumption over GDP and the share of the government's net lending to GDP, both of which are important to control for the stance of fiscal policy; the average government bond spread of Greece, Italy, Portugal and Spain relative to Germany (the so called GIPS spread), which is a measure of uncertainty in South Europe and has been shown to be tightly associated with capital flows into Germany (Bednarek et al. (forthcoming)); the VIX as a proxy for global uncertainty; the German term spread, defined as the difference between the 10-year German government bond yield and the the EONIA rate; the average German mortgage interest rate and the average change in the logarithm of mortgage credit.[7]

Table B.2 also reports the summary statistics for all of the macroeconomic variables. During our 2010-2017 sample period, the size of the ECB's balance sheet on average was 28.1% of nominal GDP, with a maximum of 39.9 %. The average value of the EONIA rate was 0.1%, ranging from -0.4% to 0.9%. While government bonds in the South of Europe traded at a spread equal to 4.2% relative to Germany on average, the VIX was equal to 17.1%, the average spread of German 10-year government bonds relative to the EONIA was equal to 1.2% and the growth in mortgage credit volumes was about 2% per year in Germany.

Tables B.3 and B.4 of the Appendix report the correlations between selected variables. While the correlation coefficients between the region-level variables (Table B.3) are rather small, two key facts emerge from Table B.4 that reports the correlations between the macroeconomic variables. First, as one might expect, QE and the EONIA rate have a sizable negative correlation of -51%. This correlation suggests that quantitative easing and the ECB's interest rate policies are complements rather than substitutes. Second, both monetary policy tools have a tight relation with the term spread and the average mortgage interest rates. However, their association with changes in the volume of mortgage credit is weak.

[7] We obtain similar results when we calculate the term spread as the difference between 10-year and 1-year German government bonds.

4 Identification

Empirically, a critical challenge in estimating the real effects of QE through the portfolio channel of transmission that we spelled out earlier, is to identify exogenous variation in house prices (and returns) in response to QE interventions. We address this issue by exploiting regional variation in land supply, and hence house supply elasticity in the spirit of Saiz (2010). Our hypothesis is that the tighter a region's land supply is, the more significant is the impact of QE on the region's house prices and returns, and hence consumption and output growth. This is the case because, as we noted earlier, in a given local real estate market, all else equal, a lower land supply should translate into a higher sensitivity of property prices to changes in QE, as portfolios rebalance towards real estate in local markets in which house supply is tighter.

Table 1 House Prices and Alternative Supply Scarcity Indicators

	Residential House Price Growth		
	All regions	West	East
Open Space	-0.28 (0.00)	-0.22 (0.00)	-0.41 (0.00)
of which: Water	0.25 (0.00)	0.27 (0.00)	0.31 (0.00)
of which: Agriculture	-0.08 (0.13)	0.03 (0.65)	-0.31 (0.01)
of which: Forest	-0.24 (0.00)	-0.29 (0.00)	-0.10 (0.41)
of which: Other Open Space	0.01 (0.81)	0.00 (1.00)	0.16 (0.17)
Urban Open Space	0.25 (0.00)	0.20 (0.00)	0.43 (0.00)
Exposure	0.31 (0.00)	0.29 (0.00)	0.44 (0.00)

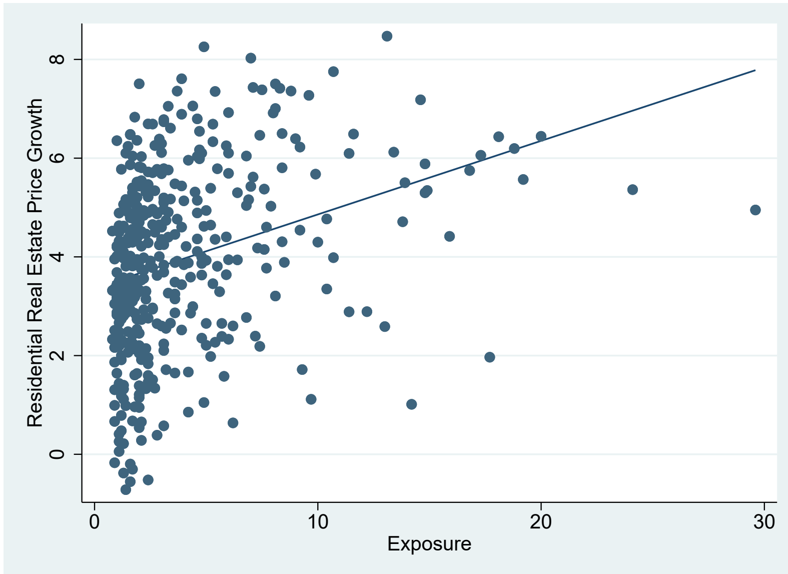
Note. This table reports the correlation between the 2008 value of alternative land supply scarcity indicators and the values of residential house price average growth during 2010-2017. The correlations are reported for the full sample of 401 regions, for West German and East German only. P-values are in parenthesis. Sources and definitions: see Data Appendix.

Equipped with an exogenous region-level indicator of land supply scarcity, we use the regional variation in such "exposure" measure interacted with QE changes over time to estimate the differential effects of QE on house prices. We then use the predicted component of house price variation across regions to estimate differential output growth effects. While QE is likely endogenous to economic conditions in individual German regions in which banking activity is concentrated, its interaction with the exposure measure, whose city distribution is assumed to be orthogonal to local and aggregate economic conditions, provides an exogenous source of variation in the intensity with which QE impacts different cities' level of economic activity. Taken together, these two steps can therefore provide an estimate of causal effects of QE on region output growth *through* property price changes. Thus, our identification strategy is one of identification by geographic variation, grounded on the availability of an indicator of land supply or house supply elasticity that varies randomly across regions.

Table 1 reports the correlations between residential house price growth, for each of the 401 regions averaged over the 2010-2017 period, and alternative pre-sample supply scarcity measures in the spirit of Saiz (2010). These indicators are in percent of the total reference area and capture regional variation in geography and land use regulations. The table shows that open space, the complement of land available for settlement, transportation and infrastructure (the city boundary), does not correlate positively with house price growth. The driver of this negative correlation is the share of land covered by forests that has a strong negative correlation with house price growth, possibly capturing urban sprawl in the sense of Ehrlich et al. (2018), rather than supply scarcity. Table 1 also shows that agricultural land, one major sub-component of open space, is negatively correlated with housing prices in East Germany, which may proxy for economic underdevelopment rather than land scarcity. In contrast, both land covered by water bodies and other open space (marsh land etc.) have a positive correlation with residential house prices. However, this correlation is statistically significant only for land covered by water bodies. It also becomes apparent that urban open space, a sub-component of settlement and transportation infrastructure but which is reserved for parks and other green spaces as opposed to real estate construction, has a significant and positive correlation with house price growth. Based on this preliminary evidence, we construct our land supply scarcity indicator as the ratio of land covered by water bodies and urban open space relative to the total reference area of a region.[8] Even though our exposure measure has little time variation, we hold it constant at the pre-sample value of 2008 to isolate the time-varying effect of monetary policy, and we choose 2008 instead of

[8]Note, however, that we obtain similar results when using the share of water bodies or urban open space only, or when including other open spaces in the construction of our exposure measure. The results are available upon request.

Figure 1 Residential Property Price Changes Exposure Measure



Note. This figure plots the relationship between average region-level real estate price growth during 2010-2017 and our region-level exposure measure, defined as the 2008 ratio of land covered by water bodies and urban open space to the total reference area of a region. The correlation coefficient is equal to 31% with a p-value of 0.

2009 in order to avoid potential effects of the global financial crisis on this variable.

As can be seen from Figure 1, there is a tight positive relation between our exposure measure and residential housing prices, which is equal to 31%. More formal econometric evidence on the relevance condition will be presented with the first stage regressions of the econometric specifications that we use in the next section. As will become apparent later, the F-statistics on our instrument exceed the rule-of-thumb threshold of 10 in all of the specifications. So, we now move to the presentation of the main empirical results of the paper, where we use this "exposure" measure interacted with two indicators of ECB policy during the sample period (i.e., the EONIA and the size of the ECB's balance sheet to nominal GDP) to investigate their transmission to region output growth through real estate markets, and property price changes more specifically.

5 Estimating the Real Effects of QE

In our theoretical model, we propose a new channel through which quantitative easing can affect the real economy, namely by inducing financial intermediaries, on behalf of households, to rebalance their portfolios towards real estate, thereby driving up house prices and consumption. In this section, we explore this hypothesis empirically by exploiting the quasi-random variation across German region in the measure of land supply scarcity discussed above to achieve identification. Our main "instrument" is the interaction of the GDP share of assets held by the ECB (as a proxy for QE policy) with the region-level measure of exposure in 2008, controlling for the corresponding interaction between this exposure measure and the EONIA interest rate, as a proxy for the traditional interest rate channel of monetary policy. While these proxies for the ECB monetary policy may be endogenous to economic conditions in individual German regions, its interaction with the exposure measure, whose region distribution is assumed to be orthogonal to local and aggregate economic conditions, provides an exogenous source of variation in the intensity to monetary policy shocks that can be related to regional differences in economic performance. As we don't have regional data on consumption, we focus on output data.

5.1 Reduced Form Estimates

Equipped with our indicator of land scarcity, we start by estimating the following region-level reduced form regression:

$$\begin{aligned}\Delta GDP_{r,t} = \alpha_r + \alpha_t + \beta \cdot (\text{EONIA}_t \times \text{Exposure}_{r,2008}) \\ +\gamma \cdot (\text{QE}_t \times \text{Exposure}_{r,2008}) + \varepsilon_{r,t}\end{aligned} \tag{13}$$

where $GDP_{r,t}$ is log real GDP per capita in region r at time t, EONIA_t is the overnight interbank market rate at time t, QE_t is the share of financial assets held by the ECB over nominal area-wide GDP, and $\text{Exposure}_{r,2008}$ is the value of our exposure measure in 2008. The latter is assumed to be uncorrelated with the error term, $\varepsilon_{r,t}$. We also add time and region fixed effects to control for the direct influence of region-specific factors, such as size and agglomeration, and common factors across regions in the German business cycle.

Table 2 displays the empirical results. In Column (1), we investigate the trans-

Table 2 MONETARY POLICY AND REGIONAL OUTPUT GROWTH: REDUCED FORM ESTIMATES

	(1) ΔGDP	(2) ΔGDP	(3) ΔGDP	(4) ΔGDP	(5) ΔGDP	(6) ΔGDP	(7) ΔGDP	(8) ΔGDP
$\text{Exposure}_{r,2008} \times \text{EONIA}_t$	-0.068**		-0.015	-0.406	-0.050	-0.010	-0.026	-0.016
	(0.030)		(0.039)	(0.301)	(0.054)	(0.039)	(0.045)	(0.039)
$\text{Exposure}_{r,2008} \times \text{QE}_t$		0.007***	0.006***	0.008***	0.006*	0.006***	0.008***	0.007***
		(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)
$\text{Exposure}_{r,2008} \times \text{QE}_t \times \text{EONIA}_t$				0.013				
				(0.010)				
$\text{Pop. Dens}_{r,2008} \times \text{EONIA}_t$					0.000			
					(0.000)			
$\text{Pop. Dens}_{r,2008} \times \text{QE}_t$					0.000			
					(0.000)			
$\text{Age above 65}_{r,2008} \times \text{EONIA}_t$						-0.112		
						(0.069)		
$\text{Age above 65}_{r,2008} \times \text{QE}_t$						0.001		
						(0.005)		
$\text{Agriculture}_{r,2008} \times \text{EONIA}_t$							-0.006	
							(0.013)	
$\text{Agriculture}_{r,2008} \times \text{QE}_t$							0.001	
							(0.001)	
$\text{Permits}_{r,2008} \times \text{EONIA}_t$								-0.033
								(0.109)
$\text{Permits}_{r,2008} \times \text{QE}_t$								-0.003
								(0.002)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3208	3208	3208	3136	3208	3208	3208	3208
R^2	0.264	0.265	0.265	0.266	0.266	0.266	0.266	0.266

NOTE. The regressions are based on annual region-level data over the period 2010-2017. The dependent variable is real GDP per capita growth. The main regressor in Column (1) is the interaction between the EONIA and the 2008 region-level value of our exposure measure. Column (2) interacts the share of central bank assets over GDP with the exposure measure and Columns (3)-(8) include both interactions at the same time. In Column (4), we also include a triple interaction between our exposure measure, QE and the EONIA. Columns (5)-(8) control for the interactions between the EONIA and QE, respectively, and the following regional variables: population density in 2008, the share of people aged 65 or more in 2008, the share of land covered by agriculture in 2008 and the time-varying number of building permits per 1,000 inhabitants. All regressions include region and time fixed effects. Heteroskedasticity-robust standard errors clustered at the region level are shown in parentheses. *, ** and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

mission of the traditional interest rate policy by reporting the results of a specification with the EONIA interaction only. The estimated coefficient indicates that a lower EONIA leads to higher output growth in regions in which land is scarcer as captured by a negative interaction coefficient β. This is consistent with several transmission channels. The impact is not only statistically but also economically significant: a one-standard deviation decrease in the EONIA rate increases annual output growth of regions at the 75th percentile of the distribution (e.g., Tuebingen) by 9 basis points more than the regions at the 25th percentile (e.g., Bielefeld). In Column (2), we investigate the transmission of quantitative easing. Quantitative easing, as measured by a higher ratio of central bank assets to GDP, also raises the output growth of regions in which land is more scarce. In economic terms, a one-standard deviation increase in ECB assets as a share of GDP raises the annual output growth of regions at the 75th percentile by 15 basis points more than of regions at the 25th percentile.

In column (3), our preferred specification, we include both monetary policy instruments simultaneously. The estimated coefficients show that QE absorbs the effects of the EONIA rate. The economic growth differential induced by quantitative easing decreases only slightly in this regression and is now equal to 12 basis points. This evidence suggests that the real effects of QE policy dominate those of interest rate policy via local residential real estate markets. In column (4), we further saturate previous specifications by including a triple interaction between QE, the EONIA and region-level exposure. While the double interaction between QE and exposure remains positive and statistically significant, both the triple interaction and the double interaction between the EONIA and exposure are statistically insignificant. This result suggests no complementarity between QE and interest rate changes in our setting.

Columns (5)-(8) add to the specification in Column (3) the corresponding interactions between monetary policy and different controls for other regional characteristics. Specifically, in column (5), we add the interactions between the EONIA and QE, respectively, and the 2008 population density. Population density might be important because more densely populated cities tend to grow more due to agglomeration forces. In column (6), we add the interactions with the 2008 share of people aged 65 and older in order to control for regional demography. Column (7) saturates the regressions with the interactions between monetary policy and the 2008 share of land covered by agriculture, assuming that this variable can proxy for the level of regional economic development, with less developed regions typically having a higher share of agricultural land.[9] Finally, and most importantly, in Column (8), we add the interactions between monetary policy and the number of building permits per 1,000 inhabitants. The rationale, here, is that regions in which land is more scarce

[9] Agricultural intensity might also have a direct impact on GDP growth. At the same time, it also has a relatively high and negative correlation of -43% with our exposure measure, as can be seen from Table B.3. As a result, our main estimates could be biased if that control was not included.

(higher values of our exposure measure) might have lower real estate construction, reducing investment and GDP and therefore biasing our estimates downward.

As can be seen from the coefficient estimates in Columns (5)-(8), the baseline results are not affected by these additional controls. In particular, while the EONIA interaction remains statistically insignificant throughout, the QE interaction is positive and significant in all the alternative specifications. If anything, including the additional interaction terms increases the size of the coefficient to a maximum value of 0.008 in Column (7), implying a QE-induced economic growth differential between exposed and less exposed regions of 18 basis points. In addition, none of the additional region-level covariates seems to play a separate role in explaining the differential impact of monetary policy on economic growth.

As can be seen from Section C of the Online Appendix, this result of the paper is very robust to saturating the regressions with additional macroeconomic variables, like the stance of fiscal policy and the government bond spread of Southern European countries relative to Germany as a proxy for capital flows into the German banking sector (see Bednarek et al. (forthcoming)), and to employing the monetary policy surprises identified in Altavilla et al. (2019) instead of the EONIA and the size of the ECB's balance sheet. Taken together, these results indicate a robust and economically meaningful QE impact on regional growth differentials consistent with the hypothesized housing portfolio channels embedded in our model. In the next section, therefore, we delve more into the specifics of the portfolio channel of transmission and we also explore possible alternative interpretations of this empirical system.

5.2 Exploring the Mechanisms

Having established that QE raises the GDP growth rates of regions with tighter land supply, we now want to explore the mechanisms through which this relationship materializes. In particular, we examine whether there is evidence in the data favoring the housing portfolio channel identified in Section 2, i.e., that QE reduces bond yields and flattens the curve, thereby inducing investors to rebalance their portfolios towards real estate and to spend more in response to lower overall portfolio returns.

To identify household rebalancing as the main underlying channel, we present three sets of specifications. First, we control for potential mediating variables, such as the yield curve, in their interactions with our exposure variable. To the extent to which the relation between QE and regional growth via the real estate market is driven by specific mediating variables, controlling for these variables should reduce the statistical and economic significance of the QE*exposure interaction term. Second, we complement this analysis with more direct evidence, regressing alternative mediating variables on QE. Finally, we perform a sub-sample analysis, splitting the sample into regions that are arguably more or less susceptible to the housing portfolio channel we contend is driving the results. In particular, we compare regions with a higher and lower share of wealthy households, more and less densely populated regions, as well as West and East Germany. If our results were indeed driven by a portfolio rebalancing mechanism, the effects should be stronger in wealthier regions.

5.2.1 Controlling for Alternative Mediating Variables

In this battery of regressions, we control for potential mediating variables, interacted with our exposure measure, that could drive the relationship between QE, real estate markets and regional GDP growth. In column (1) of Table 3, we start with a candidate that is consistent with our theoretical model – the yield curve, defined as the difference between German 10-year government bond yields and the EONIA rate. As expected and consistent with the model predictions, the QE interaction loses its statistical significance once we control for the term spread interaction, providing direct evidence that QE is affecting the real economy by flattening the yield curve and reducing long-term interest rates. The interaction between the term spread itself and our exposure variable is negative and statistically significant at the 5% level, indicating that a flatter yield curve raises economic growth in regions with tighter real estate markets.

An alternative channel through which QE can affect both house prices and economic growth is via the traditional bank lending or borrowing channels of monetary policy. The former postulates that QE could, by increasing banking sector liquidity, raise banks' mortgage credit supply. The latter hypothesizes that QE reduces long-term government bond yields on which mortgage rates are benchmarked. This in turn can raise mortgage demand and the equilibrium volume of mortgage credit. To evaluate the presence of these alternative channels in our data, we introduce the growth in aggregate mortgage credit interacted with the 2008 region-level exposure value. However, as can be seen from column (2), introducing this additional interaction term does not reduce the economic or statistical significance of the QE

Table 3 Reduced Form Estimates: Controlling for Potential Mediating Variables

	(1)	(2)	(3)	(4)
	ΔGDP	ΔGDP	ΔGDP	ΔGDP
$\text{Exposure}_{r,2008} \times \text{EONIA}_t$	0.109*	0.003	0.006	0.109*
	(0.064)	(0.038)	(0.042)	(0.064)
$\text{Exposure}_{r,2008} \times \text{QE}_t$	0.004	0.008***	0.003	0.003
	(0.002)	(0.002)	(0.005)	(0.005)
$\text{Exposure}_{r,2008} \times \text{Term Spread}_t$	-0.097**			-0.092**
	(0.039)			(0.037)
$\text{Exposure}_{r,2008} \times \Delta Credit$		0.004**		
		(0.002)		
$\text{Exposure}_{r,2008} \times \text{Mortgage Rate}_t$			-0.052	-0.018
			(0.056)	(0.055)
Time FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Obs	3208	3208	3208	3208
R^2	0.267	0.266	0.266	0.267

Note. The regressions are based on annual region-level data over the period 2010-2017. The dependent variable is real GDP per capita growth. The main regressors are the interactions between the EONIA or QE, respectively, and the 2008 region-level value of our exposure measure. Column (1) includes the interaction between the exposure measure and the term spread, column (2) between exposure and the log change in mortgage credit volumes, column (3) between exposure and the average mortgage interest rate and column (4) adds the mortgage rate and term spread interactions at the same time. All regressions include region and time fixed effects. Heteroskedasticity-robust standard errors clustered at the region level are shown in parentheses. *, ** and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

interaction, although the mortgage credit interaction itself is positive and statistically significant at the 5% level.[10] While this specification controls for the volume of mortgage credit, in column (3) of Table 3, we control for the price of mortgage credit, introducing the interaction between the exposure measure and the average German mortgage interest rate, which is tightly correlated with the term spread as well. As is apparent, adding this additional interaction also reduces the statistical significance of the QE interaction; however, in contrast to the specification of

[10]Note here as well that, in unreported specifications, we matched bank-level mortgage data to the 401 administrative German regions, making use of a unique feature of the German banking system, which allows cooperative and savings banks to lend within their administrative region only. Including this more granular cross-regional proxy for mortgage origination, we still find the interaction between QE and region-level tightness in real estate markets to remain statistically significant. Therefore, an increase in mortgage origination is unlikely to be the main transmission mechanism of quantitative easing to economic growth via the real estate market.

column (1) where we added the term spread interaction, the additional interaction term in column (3) itself is not statistically significant. In fact, when we add both additional interaction at the same time (column 4), only the term spread interaction exhibits statistical significance.

In sum, these results suggest that QE affects region-level output growth through the real estate market because it reduces long-term interest rates and flattens the yield curve, not because it leads to higher mortgage origination. The yield curve effect also dominates the mortgage interest rate effect. Therefore, our results do not speak to increased mortgage supply at more favorable terms being the main transmission channel of QE in Germany, but the empirical results are instead more consistent with the housing portfolio channel that we propose in our theoretical model.

5.2.2 Direct Evidence

This result is corroborated by more direct evidence, where we regress the potential mediating variables of Table 3 at monthly frequency on our proxy for quantitative easing. The attendant results, reported in Table 4, show that QE reduces the term spread in a highly statistically significant manner. Although QE is also negatively related to mortgage interest rates (column 2), it hardly affects the change in the log-volume of mortgage credit (column 3). In contrast, the relation between QE and mortgage credit changes is even *negative* and weakly statistically significant at the 10% level.

Table 4 The Impact of QE on Different Mediating Variables

	(1) Term Spread	(2) Mortgage Rate	(3) ΔCredit
QE_t	-0.069***	-0.076***	-0.334*
	(0.010)	(0.010)	(0.192)
Obs	96	96	96
R^2	0.287	0.306	0.024

Note. All regressions are based on monthly data over the period 2010:M1-2017:M12. The dependent variables are the German term spread, defined as the yield difference between 10-year government bonds and the EONIA, the average German mortgage interest rate and the log-change in aggregate German mortgage credit volumes. The regressor is the ratio of financial assets held by the ECB over nominal GDP (QE). Heteroskedasticity-robust standard errors are shown in parentheses. *, ** and *** indicate statistical significance at the 10%, 5%, and 1% level, respectively.

5.2.3 Cross-Regional Differences

Table 5 MONETARY POLICY AND REGIONAL OUTPUT GROWTH: CROSS-REGIONAL DIFFERENCES

	West	East	Rich	Poor	High pop. density	Low pop. density
	(1)	(2)	(3)	(4)	(5)	(6)
	ΔGDP	ΔGDP	ΔGDP	ΔGDP	ΔGDP	ΔGDP
$\text{Exposure}_{r,2008} \times \text{EONIA}_t$	0.010	-0.068	-0.031	-0.017	-0.013	-0.451*
	(0.046)	(0.084)	(0.045)	(0.114)	(0.040)	(0.264)
$\text{Exposure}_{r,2008} \times \text{QE}_t$	0.008***	0.003	0.008***	0.006	0.006**	0.002
	(0.003)	(0.004)	(0.003)	(0.007)	(0.003)	(0.012)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	2592	616	1581	1610	2400	808
R^2	0.264	0.283	0.282	0.290	0.268	0.253

NOTE. The regressions are based on annual region-level data over the period 2010-2017. The dependent variable is real GDP per capita growth. The main regressors are the interactions between the EONIA and the 2008 region-level value of our exposure measure and the share of central bank assets over GDP with the exposure measure. All regressions include region and time fixed effects. In Columns (1) and (2), we divide the sample into West and East German regions. In Columns (3) and (4), we differentiate between regions below and above the median of per capita GDP in the sample and in Columns (5) and (6), we split the sample along the 25th percentile of population density. Heteroskedasticity-robust standard errors clustered at the region level are shown in parentheses. *, ** and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

We now want to explore possible cross-regional differences in the reduced form coefficient estimates. We expect that, if our findings are indeed driven by household portfolio rebalancing, the effect on the interaction between QE and land scarcity should be stronger in wealthier regions, in West Germany, and in more densely populated regions. To verify this conjecture, we split the data in two sub-samples, for each of these three characteristics. First, in columns (1)-(2) of Table 5, we examine whether the relation between QE and the real economy differs in West and East German regions. The estimated coefficients show that QE interacted with land scarcity affects growth only in West Germany, whereas both QE and the EONIA are insignificant in the East. This is line with the fact that in the West, on average, households are richer and hence more likely to be responsive to changes in their portfolio returns. To confirm this result, columns (3)-(4) reports results in which we explicitly divide the full sample in richer and poorer regions finding that the interaction between QE and exposure is only statistically significant in regions with above-median per capita GDP. Finally, we also split the sample into regions with low and high population density, using the 25th percentile of the distribution as the threshold. Consistent with the previous evidence, we expect our baseline estimate to be stronger for more densely populated regions, where presumably a larger number of wealthy households is located. Interestingly, while the QE interaction turns out to be statistically significant only in the high population density sub-sample, as expected, the EONIA interaction is now negatively significant at the 10% level for regions with low population density.[11]

In sum, the evidence reported in this section indicates that the relation between quantitative easing, real estate markets and the real economy is detected in richer and more densely populated regions. This result is consistent with a portfolio rebalancing channel, which is more likely at work in regions with higher wealth. In contrast, we find that, in the least densely populated regions, the traditional interest rate channel of monetary policy remains important.

5.3 Instrumental Variable Estimates

The reduced form estimates in Table 2 yield evidence on the importance of QE interventions for output growth working through the real estate market, but they are silent on the specific role that property prices may play in the transmission mechanism. To shed light on the role of property prices in the transmission of non-conventional monetary policy, similar to Chaney et al. (2012), we now regress regional output growth on property prices and rents, instrumenting the latter with the interaction of QE and our main exposure measure.[12] We next present the first and second stage econometric specifications and corresponding results in turn.

The first stage regression specification is:

$$\text{REP}_{r,t} \quad = \quad \alpha_r + \alpha_t + \gamma \cdot INSTRUMENT_{r,t} + \eta_{r,t}, \tag{14}$$

where $\text{REP}_{r,t}$ is the residential house price index, rental index or price-to-rent index and the instrument ($\text{INSTRUMENT}_{r,t}$) is the interaction between QE and region-

[11] Note that the EONIA interaction is only negative and statistically significant for regions with very low population density. In unreported specifications, we also split along the median of the population density distribution and the EONIA interaction was insignificant throughout.

[12] Chaney et al. (2012) interact the aggregate mortgage interest rate (our QE) with the housing supply elasticity of Saiz (2010) (our exposure measure) and then use the predicted component of local real estate prices to estimate their mediating effect on firm investments in response to this common shock.

level tightness in real estate markets. All regressions are saturated with time and region fixed effects. The results, reported in Columns (1)-(3) of Table 6, show that the interaction between QE and our exposure measure is a strong instrument for residential property prices, rental prices and the price-to-rent ratio with first-stage F-statistics well above the norm. However, the first stage is stronger for real estate prices than for rents or the price-to-rent ratio. Equipped with these first stage results, we proceed to report our instrumental variable second-stage results.

Table 6 Regional Output Growth and Property Prices: Instrumental Variable Results

	1st stage	1st stage	1st stage	2nd stage	2nd stage	2nd stage
	(1)	(2)	(3)	(4)	(5)	(6)
	Prices	Rents	Price/Rent	ΔGDP	ΔGDP	ΔGDP
$\text{Exposure}_{r,2008} \times \text{QE}_t$	0.049***	0.017***	0.021***			
	(0.009)	(0.005)	(0.006)			
$\text{Prices}_{r,t}$				0.142***		
				(0.046)		
$\text{Rents}_{r,t}$					0.398**	
					(0.164)	
$\text{Price/Rent}_{r,t}$						0.328**
						(0.132)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3208	3208	3208	3208	3208	3208
R^2	0.867	0.864	0.777	0.202	0.102	0.094
F-Stat (1st stage)	30.3	10.8	11.4	-	-	-

Note. This table reports instrumental variable estimates. The regressions are based on annual region-level data from 2010 to 2017. In the first stage, the dependent variable is the residential property price index, rental index and price-to-rent index at the region level and the regressor is the interaction term between QE and the 2008 value of our exposure measure. In the second stage, we regress region-level real per capita growth on the predicted residential property price index, rental index and price-to-rent index. All regressions include region and time fixed effects. The heteroskedasticity-robust standard errors clustered at the region level are shown in parentheses. *, ** and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

In the second stage, we estimate the impact of property price or rent changes, triggered by quantitative easing, on output growth, estimating the following equation:

$$\Delta GDP_{r,t} \quad = \quad \alpha_r + \alpha_t + \delta \cdot \text{REP}_{r,t} + \varepsilon_{r,t}, \tag{15}$$

where the instrument for residential real estate prices, rents and the price-to-rent ratio, $\text{REP}_{r,t}$, is $(\text{QE}_t \times \text{Exposure}_{r,2008})$. In this specification, QE can affect regional output growth *via* the predicted component of region-level property price and rent variations with a strength that depends on the tightness of the local real estate market, as captured by our exposure measure. Table 6 reports the estimation results. They show that residential property prices, rents and price-to-rent ratios, predicted by quantitative easing, can affect region-level output growth.

In sum, the evidence reported in this section establishes that (i) tighter land supply is associated with a stronger impact of both the EONIA and QE on local economic activity, but the impact of QE dominates the traditional interest rate channel of monetary policy; (ii) residential property price and rent differences across regions, triggered by quantitative easing, can account for this differential impact; and (iii) consistent with our theoretical model, household portfolio rebalancing seems to be the main transmission mechanism of quantitative easing, and qualitatively more important than an expansion of bank loan supply.

6 Conclusions

In this paper, we propose a new channel through which quantitative easing can affect the real economy. On the theoretical side, we establish mild conditions under which QE can stimulate the real economy in a model with segmented asset markets. QE lowers bond yields and increases housing demand, lowering the overall household portfolio return that ultimately boosts consumption.

On the empirical side, we study this channel of transmission empirically by using a matched region-level data set and exploiting the quasi-random geographic variation in a region-level measure of land scarcity. This measure is the share of land covered by water bodies and urban open space — land that cannot be developed for residential purposes — which is determined by geography and land use regulations.

We find that the output growth impact of both lower monetary policy rates, as measured by the European overnight interbank market rate, and quantitative easing, as proxied by the ratio of financial assets held by the ECB over nominal GDP, is more significant in regions that are more exposed to land supply scarcity. However, we also found that QE dominates the traditional interest rate effect. The output growth differential can be accounted for by the differential response of residential property prices and rents across regions. Our estimates imply that the regions most exposed to real estate market tightness, on average, grow 10-20 basis points more per year than the least exposed ones for each one-standard deviation increase in QE.

Empirically we also show that the mechanisms through which this relationship materializes is consistent with our model. Particularly, we gauge that, once we control for the yield curve or the interest rate on financial assets, our quantitative easing estimates turn insignificant. At the same time, we provide evidence that QE flattens the yield curve and that our results are driven by regions with a presumably higher share of wealthy households.

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A Model Derivations and Proofs

We first solve the equilibrium in the financial markets using equations (4), (5), (7)–(12). The optimal holdings are given by

$$h = \frac{(1/\alpha_2 + \gamma\sigma_2^2)(1/\alpha_1\bar{h} + \mu_1 - \beta_1) - \gamma\sigma_{12}(1/\alpha_2\bar{b} + \mu_2 - \beta_2)}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} \tag{A1}$$

$$b = \frac{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2\bar{b} + \mu_2 - \beta_2) - \gamma\sigma_{12}(1/\alpha_1\bar{h} + \mu_1 - \beta_1)}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} \tag{A2}$$

We think QE as a fall in $\bar{b}$. The comparative statistics with respect to $\bar{b}$ is given by

$$\frac{dh}{d\bar{b}} = \frac{-\gamma\sigma_{12}/\alpha_2}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} \tag{A3}$$

$$\frac{db}{d\bar{b}} = \frac{(1/\alpha_1 + \gamma\sigma_1^2)/\alpha_2}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} > 0 \tag{A4}$$

The denominator is positive due to Cauchy–Schwarz inequality, i.e. $\sigma_{12} < \sigma_1\sigma_2$. Therefore, $\frac{dh}{d\bar{b}} \leq 0$ if $\sigma_{12} \geq 0$.

Moreover, we have

$$\frac{dP}{d\bar{b}} = \frac{1}{\alpha_1}\frac{dh}{d\bar{b}} \tag{A5}$$

$$\frac{dQ}{d\bar{b}} = \frac{1}{\alpha_2}\left(\frac{db}{d\bar{b}} - 1\right) = \frac{1}{\alpha_2}\frac{-(1/\alpha_1 + \gamma\sigma_1^2)\gamma\sigma_2^2 + \gamma\sigma_2^2}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} < 0 \tag{A6}$$

To summarize, the effect of QE on asset prices is consistent with intuition, i.e. QE leads to a decrease in b, an increase in h (portfolio re-balance), which in the end results in a higher house price P and bond price Q. What about return? Define two specifications for the return. One is only with dividend payoff, $r = h\mu_1 + b\mu_2$ and the other also includes capital gains, $r' = h\frac{\mu_1}{P} + b\frac{\mu_2}{Q}$. The following relationship holds.

$$\frac{dr}{d\bar{b}} = \mu_1\frac{dh}{d\bar{b}} + \mu_2\frac{db}{d\bar{b}} = \frac{-\mu_1\gamma\sigma_{12}/\alpha_2 + \mu_2(1/\alpha_1 + \gamma\sigma_1^2)/\alpha_2}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} \tag{A7}$$

$$\frac{dr'}{d\bar{b}} = \frac{\mu_1}{P}\left(\frac{dh}{d\bar{b}} - \frac{h}{P}\frac{dP}{d\bar{b}}\right) + \frac{\mu_2}{Q}\left(\frac{db}{d\bar{b}} - \frac{b}{Q}\frac{dQ}{d\bar{b}}\right) \tag{A8}$$

$$= \frac{\mu_1}{P}\left(1 - \frac{h}{\alpha_1 P}\right)\frac{dh}{d\bar{b}} + \frac{\mu_2}{Q}\left(1 - \frac{b}{\alpha_2 Q}\right)\frac{db}{d\bar{b}} + \frac{\mu_2 b}{\alpha_2 Q^2} \tag{A9}$$

$$= \frac{\mu_1}{\alpha_1 P^2}\left(\alpha_1\beta_1 - \bar{h}\right)\frac{dh}{d\bar{b}} + \frac{\mu_2}{\alpha_2 Q^2}\left(\alpha_2\beta_2 - \bar{b}\right)\frac{db}{d\bar{b}} + \frac{\mu_2 b}{\alpha_2 Q^2} \tag{A10}$$

Therefore, the impact of QE on return depends on parameters. Specifically, we have

$\frac{dr}{d\bar{b}} > 0$ iff $\sigma_{12} < \frac{\mu_2}{\mu_1}\left(\frac{1}{\gamma\alpha_1} + \sigma_1^2\right)$ and $\frac{dr'}{d\bar{b}} > 0$ iff

$$\sigma_{12} < \frac{\mu_2}{\mu_1}\left(\frac{1}{\gamma\alpha_1} + \sigma_1^2\right)\frac{\alpha_2\beta_2 - \bar{b}}{\alpha_1\beta_1 - \bar{h}}\frac{\alpha_1 P^2}{\alpha_2 Q^2} + \frac{\mu_2 b}{Q^2}\frac{\alpha_1 P^2}{\gamma\mu_1(\alpha_1\beta_1 - \bar{h})}[(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2]$$

.

In other words, as long as the covariance term is positive and low enough, we have a decline in returns following QE, which ultimately boosts consumption when $\sigma < 1$.

B Data Appendix

Table B.1 DEFINITIONS AND SOURCES OF THE VARIABLES

Variable	Definition	Unit	Source
Prices	region r's residential house price index (new and existing apartments), deflated by state-level CPI	2009=100	Bulwiengesa
Rents	region r's residential rent index (new and existing apartments), deflated by state-level CPI	2009=100	Bulwiengesa
Price/Rent	Real estate prices divided by rents (multiplied by 100)	2009=100	Bulwiengesa
ΔGDP	region r's growth in GDP per capita, deflated by state-level CPI	%	INKAR
Water	region r's share of land covered by water bodies in 2008	%	IOER Monitor
Agriculture	region r's share of land covered by agricultural land in 2008	%	IOER Monitor
Forest	region r's share of land covered by forests in 2008	%	IOER Monitor
Other Open Space	region r's share of land covered by other open space in 2008	%	IOER Monitor
Urban Open Space	region r's share of land covered by urban open space in 2008	%	IOER Monitor
Exposure	region r's share of land covered by water bodies and urban open space in 2008	%	IOER Monitor
Pop. Density	region r's number of inhabitants per square kilometer of land in 2008	-	INKAR
Age above 65	region r's share of people aged at least 65 in 2008	%	INKAR
Permits	region r's building permits per 1,000 inhabitants	-	INKAR
QE	The Eurosystem's total assets (consolidated) over nominal GDP	%	ECB
EONIA	The European interbank market rate	%	FRED
QE Shock	QE surprises identified in Altavilla et al. (2019)	-	Altavilla et al. (2019)
EONIA Shock	Interest rate surprises identified in Altavilla et al. (2019)	-	Altavilla et al. (2019)
Spread	The average of the 10-year government bond spread of Greece, Italy, Portugal, and Spain over Germany	%	FRED
VIX	The CBOE volatility index	%	FRED
Gov. Cons.	Government expenditure to GDP	%	WEO October 2020
Gov. Lending	Government net lending to GDP	%	WEO October 2020
Term Spread	The difference between German 10-year government bond yields and the EONIA	%	FRED
Mortgage Rate	The German average mortgage interest rate	%	Bundesbank
$\Delta Credit$	Log-difference in the volume of aggregate mortgage credit in Germany	%	FRED

Table B.2 Summary Statistics

Variable	Observations	Mean	St. Dev.	1st	Median	99th
Prices	3208	113.5	17.8	89.1	107.9	165.5
Rents	3208	106.5	9.6	92.9	103.5	135.3
Price/Rent	3208	106.1	9.8	88.7	104.2	136.0
ΔGDP	3208	2.3	3.5	-6.6	2.2	11.9
Water	3208	2.0	2.6	0.3	1.3	13.3
Agriculture	3208	48.4	15.9	14.1	48.1	80.8
Forest	3208	30.1	15.1	2.2	29.4	63.6
Other Open Space	3208	1.0	1.6	0.0	0.4	6.3
Urban Open Space	3208	1.9	2.3	0.3	0.9	10.7
Exposure	3208	3.9	3.9	0.9	2.4	18.8
Pop. Density	3208	521.8	674.7	43.2	199.4	2797.6
Age above 65	3208	20.8	2.2	15.9	20.6	26.1
Permits	3208	2.9	1.8	0.5	2.5	8.4
QE	8	28.1	6.5	21.1	27.2	39.9
EONIA	8	0.1	0.4	-0.4	0.1	0.9
QE Shock	8	0.6	6.9	-9.4	0.1	11.3
EONIA Shock	8	-0.2	3.7	-7.9	-0.3	4.4
Spread	8	4.2	2.3	2.4	3.0	8.6
VIX	8	17.1	4.4	11.1	16.3	24.2
Gov. Cons.	8	45.0	1.3	44.1	44.6	48.1
Gov. Lending	8	-0.1	0.9	-4.4	0.3	1.4
Term Spread	8	1.2	0.6	0.4	1.2	2.4
Mortgage Rate	8	1.3	0.6	0.3	1.3	2.4
$\Delta Credit$	8	2.1	7.9	-6.7	1.9	19.6

Note. The table reports the summary statistics of the variables employed in our analysis. Data definitions and sources can be found in Table B.1.

Table B.3 Correlations Between Selected Regional Variables

	ΔGDP	Exposure	Pop. Dens.	Share above 65	Agriculture	Permits
ΔGDP	100.0					
Exposure	-11.0	100.0				
Pop. Dens.	-12.5	68.7	100.0			
Share above 65	0.2	6.6	-9.6	100.0		
Agriculture	8.4	-42.7	-57.9	-7.8	100.0	
Permits	-5.1	6.4	2.8	-48.3	12.6	100.0

Note. The table reports the correlations between our main region-level variables. The variable definitions and data sources are in Table B.1.

Table B.4 Correlations Between Selected Macroeconomic Variables

	QE	EONIA	Term Spread	Mortgage Rate	$\Delta Credit$
QE	100.0				
EONIA	-51.4	100.0			
Term Spread	-60.8	85.0	100.0		
Mortgage Rate	-84.2	62.2	72.8	100.0	
$\Delta Credit$	-17.0	-8.4	-37.0	-11.7	100.0

Note. The table reports the correlations between our main macroeconomic variables. The variable definitions and data sources are in Table B.1.

C Robustness Appendix

In this section, we show the robustness of our reduced form results to various alternative model specifications.

In columns (1)-(4) of Table C.1, we control for the interactions between other macro controls and our region-level exposure variable. Specifically, in column (1), we add the relevant interaction of exposure with the spread of Southern European government bonds over the German Bund, which can serve as a measure of capital flows into Germany (see Bednarek et al. (forthcoming)). The attendant results show that quantitative easing still raises the GDP growth rates of regions with tighter real estate markets disproportionately more, even after controlling for capital flow shocks as an alternative source of liquidity in the financial sector. In column (2), we control for the interaction with the CBOE volatility index (VIX) as a proxy for global financial uncertainty and, again, our baseline results are robust.

In columns (3) and (4), we control for the stance of fiscal policy. This might be important because, during the period considered in our paper, not only has monetary policy been expansionary, but also fiscal policy. To the extent that higher central bank purchases of financial assets (more QE) are offset or confounded by new bond issuance from the treasury, this will bias our results. To rule out this concern and to capture the potential growth effects of fiscal policy, we control for the interactions between exposure and the share of government lending over GDP (column 3), as well as between exposure and government consumption over GDP (column 4). As becomes apparent, our QE interaction remains positive and statistically significant. However, the economic significance decreases and the coefficients are less precisely estimated. In addition, fiscal policy does not seem to have a growth-increasing impact via the real estate market. In contrast, higher government consumption and higher government borrowing (i.e., lower values on government lending) reduce the growth rates of regions with tighter real estate markets relative to regions with less tight markets. Taken together, these robustness checks suggest that QE increases the growth rates of regions with tighter real estate markets, even after controlling for other macroeconomic variables interacted with exposure. Moreover, in all of the specifications of columns (1)-(4), the EONIA interaction is statistically insignificant, in line with our main results in Table 2.

As the final robustness check, we replace QE and the EONIA by their identified surprises, based on Altavilla et al. (2019), who extract monetary policy surprises by estimating latent factors from changes in yields on financial assets. While, consistent with our baseline results, QE surprises increase the growth rates of regions with tighter markets disproportionately more, the EONIA surprise interaction has the "wrong" sign, i.e., contractionary interest rate shocks increase the growth rates of regions with tighter real estate markets.

Table C.1 Reduced Form Estimates: Robustness

	(1) ΔGDP	(2) ΔGDP	(3) ΔGDP	(4) ΔGDP	(5) ΔGDP
$\text{Exposure}_{r,2008} \times \text{EONIA}_t$	0.005	0.035	0.042	0.028	
	(0.064)	(0.080)	(0.048)	(0.044)	
$\text{Exposure}_{r,2008} \times \text{QE}_t$	0.007**	0.007***	0.004*	0.005*	
	(0.003)	(0.002)	(0.002)	(0.002)	
$\text{Exposure}_{r,2008} \times \text{Spread}_t$	-0.004				
	(0.009)				
$\text{Exposure}_{r,2008} \times \text{VIX}_t$		-0.007			
		(0.005)			
$\text{Exposure}_{r,2008} \times \text{Gov. Lending}_t$			0.025**		
			(0.012)		
$\text{Exposure}_{r,2008} \times \text{Gov. Cons.}_t$				-0.032**	
				(0.015)	
$\text{Exposure}_{r,2008} \times \text{EONIA Shock}_t$					0.008*
					(0.004)
$\text{Exposure}_{r,2008} \times \text{QE Shock}_t$					0.003*
					(0.002)
Time FE	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes
Obs	3208	3208	3208	3136	3208
R^2	0.265	0.266	0.267	0.267	0.264

Note. The regressions are based on annual region-level data over the period 2010-2017. The dependent variable is real GDP per capita growth. The main regressors are the interactions between the EONIA and the 2008 region-level value of our exposure measure, as well as between the share of central bank assets over GDP with the exposure measure. Columns (1)-(4) control for the corresponding interactions between the spread of 10-year government bonds in Greece, Ireland, Italy, Portugal and Spin relative to Germany, the CBOE volatility index (VIX), the share of government lending over GDP and the share of government consumption over GDP. Column (5) replaces QE and the EONIA by the QE and interest rate surprises based on Altavilla et al. (2019). All regressions include region and time fixed effects. Heteroskedasticity-robust standard errors clustered at the region level are shown in parentheses. *, ** and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.