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

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Abstract

We propose a new housing portfolio channel of quantitative easing (QE) transmission. QE induces regional households to rebalance portfolios from bonds to houses, lowering bond and housing expected future returns, possibly stimulating consumption and output. We study this channel in a panel of all German administrative regions during a housing boom without a credit boom. Identification exploits regional variation in land scarcity. We estimate that a one-standard-deviation increase in QE raises GDP growth in the most exposed regions by 2-3 percentage points more than in the least exposed ones, cumulatively, during 2010-2017. Our channel accounts for at least 60% of the total QE impact on this growth differential, with other channels accounting for the remainder. To guide our empirical analysis and identification, we also set up a simple portfolio model with preferred habitat investing in local housing markets.

Keywords: Asset Market Segmentation, Buy-to-let, Germany, Housing Returns, Portfolio Rebalancing, Quantitative Easing, Rental Yields.
JEL Classification: E3, E4, E5, R3

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1 Introduction

During and after the global financial crisis (GFC), the Fed and other advanced-economy central banks expanded their policy toolkit by adopting unconventional monetary policies. To support the economy with the policy rate near the zero lower bound, they started to purchase long-term bonds and other risky assets—the so-called quantitative easing policy (QE). The European Central Bank (ECB) also continued to use the interest rate policy by setting a negative rate on its deposit facility. Not surprisingly, a large literature quickly developed investigating the financial and real effects of QE on firm and bank behavior and on the macroeconomy as a whole.

In this paper, we propose a new housing portfolio channel of QE transmission, and evaluate its quantitative importance for output growth differences across all 401 German administrative regions exploiting regional variation in land scarcity. We estimate that, in regions in which land is scarcer, real GDP grows at least 2 percentage points more than in regions in which land is more abundant, on average, cumulatively, during the 2010-2017 period. We also find that this channel is more important than the traditional credit, collateral and wealth channels, explaining at least 60% the total QE impact on regional growth differentials through local residential real estate markets.

To illustrate the working of the housing portfolio channel that we propose and to discipline our empirical analysis, we set up a simple housing portfolio model with asset market segmentation and preferred habitat investors. In the model, local real estate investors and national bond investors specialize in holding houses and bonds, respectively. Local households arbitrage among cash, bonds and local houses. In response to QE, as the bond supply declines, preferred habitat investors and local households lower their bond holdings, and the bond price increases. Provided that the bond and house payoffs are positively correlated, local households increase their demand for houses and bid up house prices. Meanwhile, preferred habitat real estate holders sell houses to regional households. Expected future returns on both assets decline, driving down the aggregate portfolio return. In turn, lower expected total and housing portfolio returns can stimulate the local economy by boosting current consumption and output.

In this channel, therefore, QE works through a reduction in expected future housing returns, rather than bank portfolio rebalancing, higher credit supply, equity extraction from mortgage refinancing, or pure wealth effects from capital gains on housing and other risky assets, as extensively documented in the US data. At the core of our new mechanism is portfolio rebalancing by households. House sales and purchases are cash transactions in our model. As a result, QE can affect the economy also in a creditless environment, as during the German post-GFC period of bank deleveraging. Nevertheless, the paper's contention is not that other channels are not in the data in Germany, but that the housing portfolio channel we propose is present and conspicuous alongside the other traditional channels.

Table 1 Aggregate Household Balance Sheet

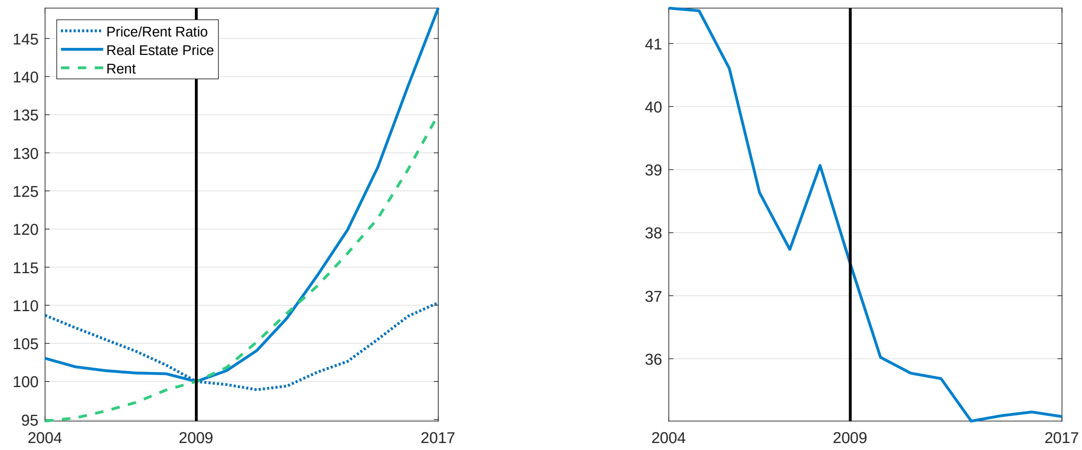
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Real Estate/Total Assets	0.55	0.55	0.56	0.56	0.55	0.55	0.55	0.55	0.56	0.57	0.56
Bonds/Total Assets	0.026	0.024	0.023	0.021	0.019	0.017	0.014	0.012	0.011	0.010	0.010
Real Estate/Bonds	21.17	22.68	24.26	26.11	29.34	33.53	40.18	45.51	49.74	54.35	57.40
Loans/Total Assets	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12
Homeownership (in %)	-	53.2	53.4	53.3	52.6	52.5	51.9	51.7	51.4	51.5	51.1
Homeownership (With loans, in %)	-	27.8	28.1	28.0	27.6	26.6	26.2	26.2	25.7	25.6	25.8

Note. The table reports selected variables on the composition of the German household balance sheet based on aggregate flow of funds data from the Federal Statistical Office (Destatis), as well as German home ownership rates from the OECD. Real estate assets are the sum of buildings, structures and land; bonds include all short-term and long-term debt securities; loans are equal to all liabilities; and total assets are all financial and non-financial assets. The household sector includes households and non-profit institutions serving households.

Real estate represents the lion share of households' total assets in Germany, increasing by two percentage points during our sample period, from 55% in 2009-2010 to 57% in 2018 (Table 1). Changes in housing returns, therefore, can have sizable effects on the total return to wealth. The transmission implied by our model is also consistent with the declining homeownership rate by about two percentage points during this period (from an already very low level by international standard) that implies an increasing share of renters and landlords. Table 1 shows an increasing ratio of real estate assets to bonds during the 2010-

Figure 1 Germany: A Housing Boom without Credit Boom

Panel A: Residential house price and rent indexes (2009=100) B: Mortgage credit to households (% GDP)



Note. Panel A plots national residential house price and rent indexes, and their ratio (equal to 100 in 2009). Panel B plots the stock of mortgage credit to households as a share of GDP. The vertical line marks the beginning of the German recovery in 2009. See the Data Appendix for variable definitions and data sources.

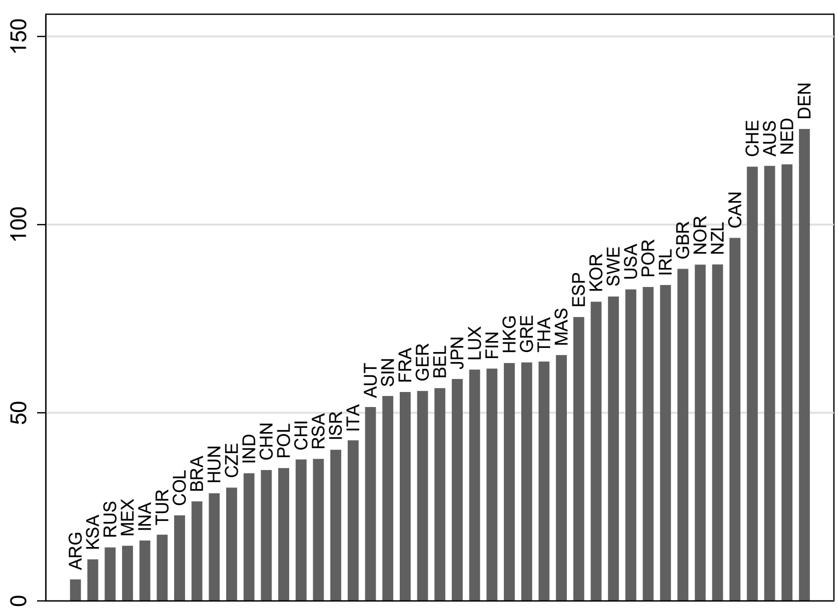
2019 period.[1] Table 1 also shows that household leverage is low and on a declining trend in Germany during this period, consistent with an even lower (and equally declining) share of home owners with housing credit. Indeed, anecdotal evidence suggests that many residential real estate transactions are cash purchases during our sample period.

We investigate this housing portfolio channel by studying the impact of the ECB's QE policy in Germany. Germany is an ideal laboratory for our empirical analysis because it went through a housing boom without credit boom since 2009. Figure 1 plots national aggregate residential rent and price indexes and households' mortgage credit. The figure shows a stark negative correlation between housing and credit market dynamics since the beginning of the recovery in 2009. This stylized fact not only is consistent with the evidence of declining household leverage in Table 1, but is also a striking example of a housing boom without a credit boom.

[1] Equity to Total Assets and Deposits to Total Assets are not reported but are slightly increasing and constant, respectively, over this period. However, the share of equity assets in total assets is quite low in Germany, averaging 8.5% during our sample period.

The German post-GFC housing boom is not the only one that differs from the intensively studied US boom-bust cycle of the 2000s. The household demand side of China's housing boom has been largely creditless. Historically, emerging markets have long experienced boom-bust cycles in housing and consumption, despite chronic domestic financial underdevelopment (Cesa-Bianchi, Cespedes and Rebucci 2015 and Cesa-Bianchi, Ferrero and Rebucci 2018). At slightly more than 50% of GDP, even during the 2010-2017 period, the level of household credit in Germany is close to the median of the main advanced and emerging economies in the BIS data (Figure 2). More generally, Cerutti, Dagher and Dell'Ariccia (2017) estimate that 19 of 83 housing booms that they identify are not associated with a credit boom. Even in the US case, the importance of credit for the boom-bust cycle of the 2000s remains a hotly debated issue—see, for instance, Favara and Imbs (2015), Favilukis, Ludvigson and Van Nieuwerburgh (2017), Kaplan, Mitman and Violante (2020), and Greenwald and Guren (2021).

Figure 2 Household Credit as a Share of GDP: International Comparison



Note. The figure plots average household credit as a share of GDP during 2010-2017. Data source: BIS.

To assess and quantify this channel empirically, we assemble a rich matched region-level database that we describe in detail in the paper. Total assets of the Eurosystem of Central Banks (or its debt security component) is our proxy variable for QE. The EONIA rate controls for the ECB's traditional interest rate policy. As an empirical measure of the expected future housing return, we use the regional rent to price ratio (or rental yield). As Appendix B documents, the rental yield predicts a large portion of expected future housing returns at medium-to-long run horizons in historical German data, as in the case of the United States (e.g., Cochrane 2011). Ideally, one would like to use regional consumption data to investigate empirically the real effects of our housing portfolio channel. Unfortunately, there are no regional consumption data in Germany, and available survey data cover only about 12,000 (mostly non-repeat) households observed at only three points in time over our sample period. We use real per capita GDP growth instead, ruling out potential QE effects through residential and corporate investments by using regional data on building permits and other controls. We match regional output data with a proprietary database on apartment prices and rents from Bulwiengesa AG (a reputable German real estate data provider that supplies also the ECB and Deutsche Bundesbank), and detailed land-use and land-cover data from a German granular database.[2]

To establish causality, we rely on identification by geographic variation. In particular, we interact the aggregate monetary policy indicators (QE and the EONIA rate as well as all mediating variables used in the paper) with an indicator of land scarcity based on detailed land-use and land-cover data and kept constant over time at its 2008 pre-sample value. This measure of land supply scarcity is the share of land covered by water bodies and urban open space—a housing supply elasticity measure in the spirit of Saiz (2010). As in several previous studies, we assume that natural and man-made land use restrictions drive this proxy for housing supply elasticity and vary across regions quasi-randomly at business cycle frequency. We show that the interaction of this exposure with QE explains regional rental

[2] The segment of the residential housing market on which we focus on is the most prevalent housing solution, especially in the rental market.

yields, and hence expected future housing returns, across German regions. Moreover, in our theoretical analysis, we also derive mild conditions under which the housing portfolio channel that we posit is stronger the tighter is the regional housing supply, in line with the empirical evidence of relevance of our instrument that we report.

To dispel concerns about reverse causality when using land scarcity as an instrument for output growth as an outcome variable, we document that all results in the paper are robust, and in some cases even stronger, when we employ an alternative instrument based on political affiliation—namely, the average regional voting share for the German Green party in the national elections of 2002, 2005 and 2009. As we discuss in the paper, the Green party has a long-standing tradition of supporting policies geared toward removing access barriers to rental markets, thus likely more popular in regions in which demand in these markets is structurally higher.

The main finding of the paper is that QE leads to a larger impact on output growth in regions with more land scarcity, and our housing portfolio channel can account for more than half of the total QE impact. We reach this conclusion by estimating both reduced-form and instrumental-variable specifications. In the reduced-form analysis, we regress output growth on QE interacted with land scarcity. We estimate that on average, during the 2010-2017 period, in response to a one-standard-deviation increase in QE, regions at the 75 percentile of the land scarcity distribution grow 2-3 percentage points more than regions at the 25th percentile, cumulatively. In the instrumental-variable setup, we regress regional output growth on *regional* rental yields, instrumenting the latter by the interaction between QE and exposure, as for instance in Chaney, Sraer and Thesmar (2012) and Aladangady (2017). We find that our instrument is relevant and that QE affects the growth differentials through regional rental yield variation, consistent with the implications of our model.

These results are quite robust along several dimensions. They always hold after controlling for the EONIA interest rate, which has no differential effect on regional output growth given QE. They are robust to controlling for observable region characteristics possibly correlated with land scarcity and for housing supply dynamics—and hence for the direct impact of residential investment on regional output growth. In Appendix D, we also document robustness with respect to (i) controlling for a host of common shocks possibly confounding with QE, including national fiscal policy, a measure of financial uncertainty, aggregate capital and migration inflows; (iii) using alternative measures of QE, including the monetary policy surprises identified in Altavilla, Brugnolini, Gürkaynak, Motto and Ragusa (2019) and alternative components of the ECB's total assets; (iv) estimating the main specification over the 2014-2017 sub-sample period of formal ECB QE policy and over a pre-sample placebo period. Finally, in Appendix D, we also split the sample in rich and poor regions, or West and East German regions, providing corroborating evidence consistent with the housing portfolio channel posited in our model.

In order to quantify the importance of our housing portfolio channel relative to other QE transmission channels that are salient in US data, including the credit, collateral, and wealth channels, we run a battery of horse-races between alternative mediating variables. In addition to the rental yield, we consider the term spread that can mediate multiple channels, the price and volume of mortgage credit, the level of house prices, as in typical collateral and wealth channel specifications, and the dividend-to-price ratio to control for household portfolio rebalancing toward equities. We find that the statistical significance of the QE impact disappears once we control for the rental yield. In contrast, all other mediating variables that we consider do not have the same "absorbing" effect.

Even in the case of the term spread, which can absorb the reduced-form QE impact as the rental yield, we find that the share of the total QE impact that this critical mediating variable can explain is significantly smaller than the portion we can attribute to the rental yield. Equally important, we show that an increase in banks' mortgage credit does not reduce the statistical or economic significance of QE. This implies that the classical bank lending channel of monetary policy cannot explain our reduced-form results. A similar result holds when we control for the level of house prices, suggesting that wealth and/or collateral channels too cannot explain our empirical findings.[3] We also find that household portfolio rebalancing toward equities cannot explain our reduced-form results. Nonetheless, when we include all mediating variables in one specification, we run into multicollinearity, forcing us to horse-race only two channels at the time. Here, we estimate that the quantitative importance of our housing portfolio channel ranges between 60% and 100% of the total QE effect on the regional growth differential depending on the alternative mediating variable that we consider. The second most important contributor is the term spread, accounting for about 20% of the total QE effect.

We interpret this evidence as suggesting that the housing portfolio channel that we propose not only is present in the data but is also conspicuous. The alternative channels, while also likely in the data, are not dominating, consistent with the macroeconomic evidence reported above showing that Germany has been experiencing a housing boom without a credit boom after the GFC. Our evidence and analysis, therefore, illustrates a mechanism through which QE can still support the economy through its impact on the residential real estate markets even in the absence of credit, collateral or wealth effects.

Related Literature Our paper relates to the literature along multiple dimensions. First, several papers document that QE works through the classical credit and bank-lending channel by stimulating credit supply and affecting bank and firm behaviors. Rodnyansky and Darmouni (2017) show that bank exposure to QE increases bank lending to firms. Using loan officer survey data, Kurtzman, Luck and Zimmermann (2017) show that QE softens lending standards and raises bank risk-taking. Chakraborty, Goldstein and MacKinlay (2019) show that banks benefiting from QE increase mortgage origination. Acharya, Eisert, Eufinger and Hirsch (2019) provide evidence that the ECB's OMT program induced banks with greater foreign exposure to expand loan supply, especially so to low-quality (zombie) borrowers. However, Bittner, Rodnyansky, Saidi and Timmer (2021) show that, when implemented to-

[3] Indeed, Bednarek, Kaat, Ma and Rebucci (2021) show that the collateral channel through the *commercial* real estate market has an important role in explaining urban region growth differentials in response to bank portfolio rebalancing from foreign to domestic lending, but not through the *residential* real estate market.

gether with negative interest rate policy, QE can induce deposit-dependent banks to reduce their credit supply to firms. Todorov (2020) finds that the ECB's Corporate Sector Purchase Programme increased prices, liquidity, and firms' issuance in the European corporate bond market. Luck and Zimmermann (2020) show that QE leads firms to increase employment. The housing portfolio channel of QE transmission that we propose does not rely on credit and focuses on household, rather than bank or firm, behavior.

Similar to our paper, Peydró, Polo and Sette (forthcoming) and Koijen, Koulischer, Nguyen and Yogo (2021) focus on bank portfolio rebalancing driven by asset return differentials. Using Italian credit and security data, Peydró et al. (forthcoming) document that less capitalized banks substitute securities with lower yields for riskier credit loans during crises times. Using security-level euro-area investor holdings, Koijen et al. (2021) study portfolio rebalancing during the March 2015—December 2017 QE period. They estimate a system of government bond demands similar to those specified in our model to relate portfolio rebalancing to yield changes and find that bond yields decreased by 65 basis points on average across countries (60 bps in Germany). We also take a portfolio approach, but we focus on local residential real estate markets and household portfolio rebalancing.

Second, our paper relates to the vast literature on the collateral and wealth channels of monetary policy transmission. In particular, several papers study the relationship among interest rates, house prices, and economic activity via collateral or wealth effects. As it is well known, QE lowers the term spread and mortgage rates. Chaney, Sraer and Thesmar (2012) show that a reduction in mortgage rates can increase house prices in regions with a more restricted land supply, raising collateral valuations and boosting firm investment. Aladangady (2017) shows that lower mortgage rates also increase consumption. Adelino, Schoar and Severino (2015) provide evidence of collateral effects on small business employment. Many papers also explore the wealth effect of house or equity price on consumption. Closely related to our work, Mian, Rao and Sufi (2013) show that differences in household leverage drive the geographic distribution of consumption declines during the Great Recession. A critical difference with our setup is that our housing portfolio channel does not depend on higher house prices relaxing binding collateral constraints or raising household wealth. Instead, the transmission works through a decline in expected future housing returns, similar to Drechsler, Savov and Schnabl (2020), but via risky houses rather than safe deposits.

Third, our new transmission channel speaks to the literature that on housing as a risky asset in household portfolios. For example, Flavin and Yamashita (2002) study the impact of housing consumption on the optimal holding of other finacial assets. Similarly, Yao and Zhang (2005) study the importance of housing in shaping the portfolio of other assets in a model in which households can also choose whether to own or rent. Cocco (2005) looks at housing as a determinant of the cross-section variation in stock market participation, relying on a fixed participation cost rather than modeling the housing-tenure decision. In line with these studies, we also stress the importance of housing as a driver of the household portfolio choices. But we study the impact of rebalancing between housing and other risky assets following a QE intervention and its implications for consumption and output, without explaining the cross-section variation in bond or equity holdings. Our model relies on the segmented asset market hypothesis through preferred habitat investors, as for instance proposed by Vayanos and Vila (2021). The novelty of our contribution, here, is to focus on the portfolio implications of preferred habitat investing in the residential real estate market, which can be applied in countries in which housing finance is underdeveloped, or other asset markets are repressed. Our critical assumption that local real estate markets are segmented is consistent with the empirical and quantitative evidence in Gete and Reher (2018) and Greenwald and Guren (2021).

The rest of the paper is organized as follows. Sections 2 presents the model and its empirical implications. Section 3 presents the data. Section 4 discusses the research design and identification. Section 5 reports the estimation results. Sections 6 and 7 explore the transmission mechanism. Section 8 concludes. An appendix not for publication reports model and data details, the robustness analysis, and additional estimation results.

2 Model

In this section, we build a simple two-period model to illustrate the housing portfolio channel that we study empirically.

2.1 Agents and Markets

Consider a regional representative household who solves a portfolio problem including local houses, national bonds, and a transaction technology (or cash). Regional houses and national bonds are risky assets. Their payoffs are $\mu_1+\varepsilon_1$ and $\mu_2+\varepsilon_2$, respectively, with $E[\varepsilon_1] = E[\varepsilon_2] = 0$, $\text{Var}(\varepsilon_1) = \sigma_1^2$, $\text{Var}(\varepsilon_2) = \sigma_2^2$ and $\text{Cov}(\varepsilon_1, \varepsilon_2) = \sigma_{12}$. Here we focus on a one-region economy, but in Appendix A.2 we show that the results extend to two regions.

There are three agents trading: two preferred habitat investors in each risky asset and one regional household who arbitrages between the two markets. Following Vayanos and Vila (2021), we assume that the preferred habitat investor in the local housing market has the following downward sloping demand function

$$\tilde{h} = -\alpha_1(P - \beta_1), \tag{1}$$

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

$$\tilde{b} = -\alpha_2(Q - \beta_2), \tag{2}$$

where $\alpha_2, \beta_2 > 0$ are the parameters, Q is the bond price and $\tilde{b}$ is the quantity demanded.

The preferred habitat investors are passive in our model in the sense that they buy (sell) the excess supply (demand) of the regional households at given market prices. Unlike the regional households, they do not arbitrage across markets and segment the two markets for risky assets. The rationale is that both housing and bond markets have a specialized investor base. In the local housing market, these investors can be interpreted as real estate agents who intermediate among households, absorbing excess demand or supply. They can also represent *poor* (not optimizing) homeowners that transact with *wealthy* (wealth maximizing) regional households, who can either consume more housing themselves or buy-to-let.[4] As the model only illustrates the channel that we study empirically and underpins identification, we abstract from modeling local consumption, employment and residential investment decisions.

One important assumption is that the regional household has a mean-variance utility (or equivalently power utility over end of period wealth), and hence limited risk-bearing capacity. Otherwise, the price of risky assets would only reflect the expected payoffs with no price impact stemming from changes in the quantity of assets supplied. In addition to the two risky assets, the household also has access to a transaction technology, or cash x, that for simplicity pays a zero return.[5] In each period, the local representative household chooses her portfolio of houses, h, bonds, b, and cash, x, solving the following problem:

$$\max_{h,b,x} \quad E[W'] - \frac{\gamma}{2}Var(W') = h\mu_1 + b\mu_2 + x - \frac{\gamma}{2}(h^2\sigma_1^2 + b^2\sigma_2^2 + 2hb\sigma_{12}) \tag{3}$$

$$\text{s.t.} \quad W = Ph + Qb + x, \ (\lambda) \tag{4}$$

$$W' = h(\mu_1 + \varepsilon_1) + b(\mu_2 + \varepsilon_2) + x \tag{5}$$

where γ is the risk aversion parameter and $W(W')$ is initial (end-of-period) wealth. The optimality conditions are:

$$\lambda Q = \mu_2 - \gamma b\sigma_2^2 - \gamma h\sigma_{12} \tag{6}$$

$$\lambda P = \mu_1 - \gamma h\sigma_1^2 - \gamma b\sigma_{12} \tag{7}$$

$$\lambda = 1. \tag{8}$$

[4]Recall that home ownership declined in Germany during the sample period (Table 1).

[5]An alternative, here, is to introduce short-term bonds as a third traded asset, or adding an exogenous process for the short-term interest rate controlled by the central bank. As we will see, empirically, QE absorbs the effect of the monetary policy rate. For this reason, we do not model this channel of monetary policy transmission explicitly. In addition, as we noted earlier, negative rates work through the banking system and the corporate sector from which we abstract in our analysis.

These conditions are intuitive: the regional agent equates the marginal cost of investing one additional unit of wealth in each asset with its marginal benefit, which is the expected risk-adjusted payoff of that asset.

2.2 Market Clearing and Equilibrium

The total supply of risky assets is fixed in the model, while the central bank supplies cash elastically as demanded. In equilibrium, market clearing requires:

$$h + \tilde{h} = \bar{h} \tag{9}$$

$$b + \tilde{b} = \bar{b} \tag{10}$$

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

An equilibrium is an asset allocation—i.e., a set of asset demands by the regional household and preferred habitat investors, $\{h, \tilde{h}, b, \tilde{b}\}$—and a set of asset prices, $\{P, Q\}$, such that (1) the regional households 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 QE and Portfolio Rebalancing

We model QE as a reduction in the bond supply to the market, $\bar{b}$, through central bank purchases. To analyze the impact of QE, consider the following comparative statics with respect to the total bond supply $\bar{b}$:

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

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

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

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

The impact of a reduction in $\bar{b}$ on the bond market is unambiguous, driven by the downward demand of the preferred habitat investor and the fixed supply. QE drives down the total bond supply available to both investors, pushing up the bond price, Q, and reducing the bond holdings of both investors. Other things equal, the regional household lowers her demand of bonds in response to the QE intervention to increase the risk-adjusted payoff as we can see from equation (6). In contrast, the impact of a reduction in $\bar{b}$ on the local housing market is ambiguous and depends on the covariance between bond and house payoffs, σ_{12}, as the following proposition illustrates.

Proposition 1. ***(QE-induced Housing Portfolio Rebalancing)*** *A reduction in the supply of bonds, $\bar{b}$ (a QE intervention), increases the local demand of houses 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 payoffs are positively correlated ($\sigma_{12} \geq 0$).*

Proof. See Appendix A.1. □

Houses and bonds are substitutes in the household's portfolio when their payoffs are positively correlated, as it is also the case in our data. A drop in bond holdings, b, increases the risk-adjusted payoff of housing investment through the last term in equation (7). In equilibrium, for a given supply of houses, the local household increases her exposure to houses (either through more housing consumption herself or buying-to-let), the house price increases to accommodate the higher demand through the sales of the preferred habitat investor—the real estate agent serving the seller or the poor household selling directly.

The transmission channel from QE to the housing market relies on the payoff structure of risky assets and the risk-aversion assumption. The response of the housing component in the household portfolio to QE is zero when the payoff correlation between bonds and houses is zero, i.e., $\sigma_{12} = 0$ or the agent's risk aversion is zero, i.e., $\gamma = 0$. Note here that, while the local agents' risk aversion in the model is exogenous and constant, it can be time-varying in richer set ups and in the data. So one can think about QE working through its impact on risk aversion as well. In our model, both a lower γ and lower $\bar{b}$ imply a higher risk-adjusted housing payoff. However, a decline in γ implies a different transmission mechanism. In our model, lower γ induces portfolio rebalancing from cash to *both* risky assets, bonds and houses.[6] In contrast, a lower $\bar{b}$ implies a portfolio rebalancing from national bonds to local houses. Nonetheless, in the empirical analysis, we control for the impact of QE through this risk channel by holding constant global proxy measures of risk aversion, such as the VIX index or the bond spread of Southern European countries relative to Germany.

As the regional household responds to QE by adjusting her portfolio, the total return on wealth changes. To see this, define the total expected return on wealth, $E[R]$, as

$$
\begin{aligned}
E[R] &= \frac{E[W']}{W} = \frac{h\mu_1 + b\mu_2 + x}{W} && (11)\\
&= 1 + \underbrace{\frac{h(\mu_1 - P)}{W}}_{\equiv E[R^h]} + \underbrace{\frac{b(\mu_2 - Q)}{W}}_{\equiv E[R^b]} && (12)\\
&= 1 + \frac{\gamma}{W}(h^2\sigma_1^2 + b^2\sigma_2^2 + 2hb\sigma_{12}), && (13)
\end{aligned}
$$

where the last expression derives from using the budget constraint and the optimality conditions of the household. In equilibrium, the total expected portfolio return is equal to the zero-return on the safe asset plus a risk premium proportional to the total portfolio risk. As Proposition 1 states, with a positive covariance term $\sigma_{12} > 0$, QE induces a portfolio rebalancing with regional agents holding fewer national bonds, b, and more local houses, h, and both asset prices increasing. The third term in equation (12) shows that the bond component of the total return, $E[R^b]$, always declines since the bond price increases while the holding declines in response to QE for given initial wealth, W. The effect of QE on the expected housing return, $E[R^h]$, is ambiguous and depends on the relative strength of price and quantity responses to QE that push in opposite directions. Thus, the QE impact on the total portfolio return depends on the relative contribution of the two assets to the total

[6] In fact, one can show that $\frac{db}{d\gamma}, \frac{dh}{d\gamma}, \frac{dP}{d\gamma}, \frac{dQ}{d\gamma} < 0$ regardless of the sign of σ_{12}.

portfolio risk, which in turn depends on the model's structural parameters. The following proposition shows that, if $\sigma_{12} > 0$, the decline in $E[R^b]$ is strong enough to guarantee that the total return always declines regardless of $E[R^h]$. Moreover, if the house price response is large enough, $E[R^h]$ also declines.

Proposition 2. ***(QE Impact on Total and Housing Expected Portfolio Returns)*** *If σ_{12} is positive, QE lowers the expected total portfolio return, i.e.,*

$$\frac{dE[R]}{d\bar{b}} > 0.$$

Moreover, if the equilibrium holding of houses is large enough, i.e.,

$$h > \frac{\alpha_1\mu_1 + \bar{h} - \alpha_1\beta_1}{2},$$

where

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

the QE impact on the house price (P) dominates the effect on the quantity (h), and the expected housing return $E[R^h]$ also declines, i.e.,

$$\frac{dE[R^h]}{d\bar{b}} > 0.$$

Proof. See Appendix A.1. □

The intuition is as follows. The relationship between housing returns and the equilibrium house holdings is inverted U-shaped in the model. When the equilibrium holding is large enough, the expected housing return falls with h. Thus, in this case, as QE increases the equilibrium house holdings h, it also lowers the housing return.

In the empirical analysis of our housing portfolio channel of QE transmission, for identification purposes, we exploit regional variation in housing supply scarcity, represented by $\bar{h}$

in our model. The next proposition shows that, under mild conditions on the size of σ_{12}, the impact of QE on the total expected portfolio return and both its components, called return sensitivity to QE, is stronger in regions with scarcer housing supply.[7]

Proposition 3. ***(Return Sensitivity to QE and Housing Supply)*** *With a positive but moderate payoff covariance, σ_{12}, the response to QE of the total expected portfolio return, $E[R]$, and its two components, $E[R^b]$ and $E[R^h]$, is stronger in regions in which housing supply is scarcer. Specifically,*

$$\frac{d}{d\bar{h}}\left(\frac{dE[R]}{d\bar{b}}\right) < 0, \textit{ if } \sigma_{12} < \sqrt{\sigma_1^2\sigma_2^2 - \frac{1}{\gamma^2\alpha_1\alpha_2}}$$

$$\frac{d}{d\bar{h}}\left(\frac{dE[R^h]}{d\bar{b}}\right) < 0, \textit{ if } \sigma_{12} < \sqrt{\sigma_1^2\sigma_2^2 - \frac{1}{\gamma^2\alpha_1\alpha_2} + \frac{\alpha_1\sigma_1^2 - \alpha_2\sigma_2^2}{\gamma\alpha_1\alpha_2}}$$

$$\frac{d}{d\bar{h}}\left(\frac{dE[R^b]}{d\bar{b}}\right) < 0, \textit{ if } \sigma_{12} < \sqrt{\sigma_1^2\sigma_2^2 - \frac{1}{\gamma^2\alpha_1\alpha_2} - \frac{\alpha_1\sigma_1^2 - \alpha_2\sigma_2^2}{\gamma\alpha_1\alpha_2}}.$$

Proof. See Appendix A.1. □

Equipped with these theoretical results, we are now ready to discuss the implications of our simple model for the design and implementation of our empirical analysis. Before proceeding, recall that, thus far, we considered only a one-region economy for sake of exposition. However, Appendix A.2 shows that all three propositions above extend to a two-region economy.

2.4 Empirical Implications

Although simple, our model provides a useful set of priors that inform and guide our empirical analysis. Specifically, following a reduction in the net supply of traded government bonds, our model implies that regional bond holdings decline (both for preferred habitat investors

[7] As the proposition shows, the conditions to obtain identification of our channel not only depend on the moments of the asset payoffs, but also on the demand elasticity of the preferred habitat investors and the degree of risk aversion of *the regional agent*. While we cannot verify them empirically, we will see below that, in the data, $\frac{d}{d\bar{h}}\left(\frac{dE[R^h]}{d\bar{b}}\right) < 0$.

and households) and bond prices increase. Under mild conditions on the covariances of the housing and bond payoffs, the model implies that the regional household holdings of houses increase, accommodated by the sales of the local preferred habitat investors, local house prices increase, and the regional expected total portfolio return and *both* its two components decline. Importantly, the model also implies that the response to QE of the total expected portfolio return and both its asset-specific components is stronger in regions that have scarcer housing supply, which we will exploit for identification purposes.

In our empirical analysis, we explore this housing portfolio channel of QE transmission in an annual panel of all German urban and rural areas (also called regions). Lower expected total and housing portfolio returns can affect the local economy through multiple channels that we do not model theoretically as they are standard. First, a decline in the total portfolio expected return can lead to a consumption boom, and hence a regional output boom.[8] Second, regional investment could also increase in response to QE, indirectly driven by the local consumption boom, by the relaxation of firms' collateral constraints associated with higher commercial real estate valuations (e.g., Chaney et al. 2012, Liu et al. 2013, and Bednarek et al. 2021, among others), wealth effects (Mian et al., 2013) or by bank portfolio rebalancing and credit supply increase as extensively documented in the literature. A local construction response to the house price increase associated with the QE intervention could also directly stimulate residential investment and hence regional output growth. As our channel should be driven by household portfolio rebalancing and consumption, we will control for the investment response with several observable regional characteristics, residential investment dynamics, and variables mediating other channels possibly at work in the data.

While the total regional portfolio return and its two components respond in the same direction to QE, for identification purposes, we will focus on the housing component, controlling for the bond component with the German Bund term spread. The bond component

[8]Without resorting to controversial assumptions on the intertemporal elasticity of substitution, theoretically, it is possible to show that consumption increases in response to a decline in the interest rate as long as agents have an income process that is tilted upward.

of the total portfolio return also depends on characteristics of the local housing market—in particular, the demand elasticity of the local preferred habitat investor. Unfortunately, however, this structural parameter of the model does not have a counterpart in the data that can be reliably quantified. In addition, as we saw earlier, the housing portfolio share dwarfs the bond share (or even the bond and equity shares combined) in the aggregate data. For these reasons, in our empirical analysis, we focus on the housing component of the total regional portfolio return as the critical mediating variable in the transmission of QE through our housing portfolio channel. In Appendix B, we show that the rent-to-price ratio (the so-called rental yield) explains a large fraction of expected future housing return in the medium-to-long term in German historical data, as for instance documented by Cochrane (2011), among others, for the United States. In our empirical analysis, therefore, we will use the rental yields as proxy for regional expected future housing returns.

3 Data

To conduct our empirical analysis, we assemble a unique matched data set covering all 401 German administrative regions at the annual frequency, from 2010 to 2017. In our regressions, the outcome variable is regional real per capita GDP growth. Ideally, one would like to use regional consumption data as the housing portfolio channel that we posit is driven by regional household's decisions. Unfortunately, however, there is no regional consumption data in Germany.[9] As a consequence, in our regression analysis, we will control for the QE impact on investment by using housing supply variables and holding constant other channels of QE transmission through which the housing market can affect corporate investment. As region-level deflators are not available, we subtract from the per capita nominal GDP growth rate the official state-level consumer price index inflation rate.

[9]The Bundesbank's Panel on Household Finances survey (PHF) covers only 12-14,000 and includes only three cross-sections of households in 2011, 2014 and 2017. Regional output data, in contrast, is more representative, strengthening the external validity of our causal inference. Results based on regional employment, which is more closely associated with consumption, are similar but not reported.

As we already discussed, we proxy for future expected housing returns using the rental yields that predict returns well in historical German data at medium-to-long term horizons (see details in Appendix B). We construct regional rental yields based on a proprietary panel of nominal residential property price and rental indexes from Bulwiengesa AG that is a reputable and well-known German proprietary data provider (providing its data also to the ECB). Bulwiengesa AG constructs residential price and rent indexes by region employing both unit-specific valuation and transaction data from building and loan associations, research institutions, realtor associations, as well as the chambers of industry and commerce. These indexes are at the annual frequency and cover owner-occupied existing and newly-constructed apartments. They are calculated as region-wide simple averages of individual unit prices and rents.[10] Again, as regional GDP deflators or CPI indexes are not available, we deflate nominal property price and rent indexes by using state-level official consumer price indexes. To construct regional rental yields, we take the 2009 national rental yield level of 5.38% from the Macrohistory Database of Jordà et al. (2017) and Jordà et al. (2019) and inflate it with the region-specific rent-to-price index ratio from Bulwiengesa AG.

In order to construct the instrumental variable that we use throughout the paper, we employ data from the German Monitor of Settlement and Open Space Development (IOER Monitor). This is a detailed land-cover, 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 land use and hence the residential real estate supply. As an alternative instrument, for robustness, we also use political affiliation with the Green Party, which has a long-standing tradition of supporting policies that can ease supply constraints in housing rental markets. The idea is that political support for easing supply constraints in housing rental market should be stronger in regions in which these constraints are tighter.

As a QE indicator, we use the total assets of the Eurosystem's consolidated balance sheet as a share of euro area GDP, henceforth called the size of the *ECB*'s balance sheet

[10] House price data are also available for town houses and single-family homes. However, Bulwiengesa provides consistent price-rent indexes only for apartments.

for brevity.[11] To control for the ECB's interest rate policy, throughout the paper, we use the EONIA rate, i.e., the weighted average interest rate of all overnight unsecured lending transactions in the European interbank market, even though the results are robust to using other euro area short-term rates.

As we noted in the introduction, although the ECB formally announced its first Asset Purchase Program in mid-2014, expanding it significantly in 2015, it actually started purchasing euro area government debt as early as 2009 in response to the Global Financial Crisis. However, these earlier purchases were much smaller, as Figure A1 in the Appendix shows. In order to assure that our main results are indeed driven by QE and not by banking sector liquidity generated by the ECB via its refinancing operations, we will also use specific components of the ECB's balance sheet, including total debt securities, government debt securities, non-financial private sector debt securities, and debt securities issued by banks. In additional robustness checks, in this regard, we also replace QE and the EONIA by their identified surprise counterparts, based on Altavilla et al. (2019), who extract monetary policy surprises by estimating latent factors from changes in yields of financial assets.

The empirical analysis also relies on several observable region characteristics from official statistics—including population density, the number of building permits, demographic variables, and immigration statistics—and other macroeconomic variables, such as German fiscal policy indicators, global uncertainty measures and aggregate immigration flows. The variables describing regional characteristics are sourced from the INKAR database and the matching is based on a common region identifier. Appendix Tables A2-A3 define all variables that we employ, describe their sources, and also provide summary statistics.

[11] Strictly speaking, the European System of Central Banks (or the Eurosystem for brevity), comprising the ECB as well as the national central banks, and not the ECB alone, is responsible for conducting monetary policy in the euro area. In the paper, we use ECB and Eurosystem interchangeably.

4 Research Design and Identification

In this section, we discuss the econometric specifications that we estimate in the empirical analysis, the exposure measure that we use to identify our housing portfolio channel, and the relevance and orthogonality conditions of this instrumental variable.

Empirically, the critical challenge is to identify exogenous variation in regional rental yields in response to QE. We address this issue by exploiting regional variation in land supply in the spirit of Saiz (2010). The underlying idea is that, the larger is the fraction of a region's reference area that is covered by non-developable land, the more constrained is construction and the lower is the regional housing supply elasticity. Thus, we approximate the regional differences in $\bar{h}$ in our model with differences in land supply scarcity in the data. This provides identification consistent with the model since, according to Proposition 3, the scarcer the house supply, the stronger the response to QE of the total regional expected portfolio return and both its components, and hence also the stronger the potential increase in consumption and output. Equipped with an exogenous regional indicator of housing elasticity, we exploit its variation across regions as a source of "exposure" to housing return shocks. We then interact the exposure measure with QE indicators and other mediating variables to estimate the differential effects of QE on housing returns and GDP growth, both in reduced-form and instrumental-variables specifications.

The reduced-form specification regresses regional output growth on the interaction between a QE variable and the exposure variable, controlling for the corresponding interactions between exposure and the EONIA, other region characteristics, as well possible confounding factors, such as fiscal policy, global and regional investors' risk aversion and aggregate migration flows. Our main hypothesis is that the impact of QE should be stronger in regions with scarcer land supply, consistent with the predictions of the model. While QE can be endogenous to economic conditions in individual German regions, especially in regions in which banking activity is concentrated, its interaction with an exposure measure, whose distribution should be orthogonal to local and aggregate economic conditions, can provide a quasi-random source of variation in the intensity with which QE impacts different regions' economic activity through the residential housing market.

The instrumental-variable specification regresses regional output growth on the fraction of the *regional* rental yield variation explained by the interaction between QE and the exposure variable, yielding an estimate of the causal impact on output growth differences across regions working through the housing component of the expected future portfolio return.

Table 2 reports the correlations between alternative land scarcity indicators that we consider at their pre-sample 2008 values and the average rental yield over the 2010-2017 sample period. The land shares 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—or the city boundary) correlates positively with rental yields, while urban open space (a sub-component of settlement and transportation infrastructure that is reserved for parks and other green spaces as opposed to real estate construction) has a significant and negative correlation with rental yields.

The driver of the positive correlation between open space and the rental yield is the share of land covered by forests, arguably capturing urban sprawl in the sense of Ehrlich, Hilber and Schöni (2018) rather than supply scarcity. Table 2 also illustrates that agricultural land, one major sub-component of open space, is positively correlated with expected housing returns in East Germany, possibly reflecting economic underdevelopment rather than land scarcity. In contrast, both land covered by water bodies and other open space (the residual category) have a negative correlation with yields. However, the correlation is statistically significant only for land covered by water bodies. Based on this evidence, we construct our land scarcity indicator as the share of land covered by water bodies and urban open space in the total reference area of the region.[12]

We present formal econometric evidence on the relevance condition for the instrument

[12] In a set of not reported experiments, we obtain similar results using only the share of urban open space (without water bodies). The inclusion of other open spaces in the calculation also does not affect our results.

Table 2 RENTAL YIELDS AND ALTERNATIVE LAND SCARCITY INDICATORS

	Regional Rental Yields		
	All Regions	West	East
Open Space	0.17 (0.00)	0.14 (0.01)	0.15 (0.19)
of which: Water Bodies	-0.18 (0.00)	-0.22 (0.00)	-0.19 (0.10)
of which: Agriculture	0.01 (0.91)	-0.03 (0.64)	0.02 (0.84)
of which: Forest	0.19 (0.00)	0.20 (0.00)	0.17 (0.14)
of which: Other Open Space	-0.04 (0.48)	-0.04 (0.53)	-0.14 (0.23)
Urban Open Space	-0.15 (0.00)	-0.14 (0.01)	-0.15 (0.19)
Land Scarcity, Exposure	-0.21 (0.00)	-0.22 (0.00)	-0.22 (0.05)

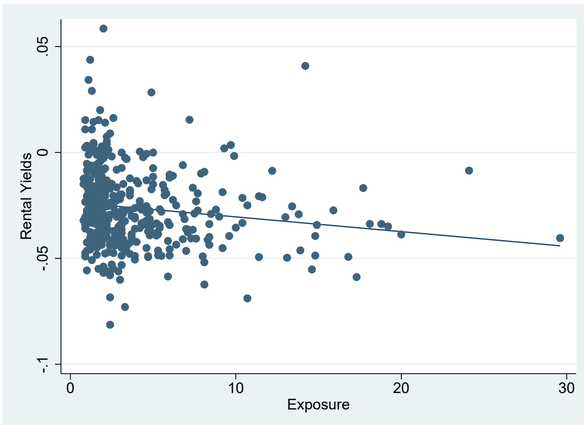
NOTE. The table reports the correlation between the 2008 value of alternative land scarcity indicators and the average regional rental yield over the 2010-2017 sample period. The correlations are reported for the full sample of 401 regions as well as for West and East regions. P-values are in parenthesis. See the Data Appendix for sources and definitions.

together with the results on the first stage of the instrumental-variable specification in Section 6. Nonetheless, Figure 3 provides preliminary evidence consistent with the assumptions underlying both our specifications. The figure reports scatter plots of the conditional correlation between the two critical outcome variables and our main QE indicator against the exposure measure. The correlation between the rental yield and QE is negative in most of the regions in the sample, and the more so the higher is the exposure measure, consistent with the implications of our model. The correlation between output growth and QE is more heterogeneous, but tends to increase with exposure, as we hypothesize in our empirical analysis.

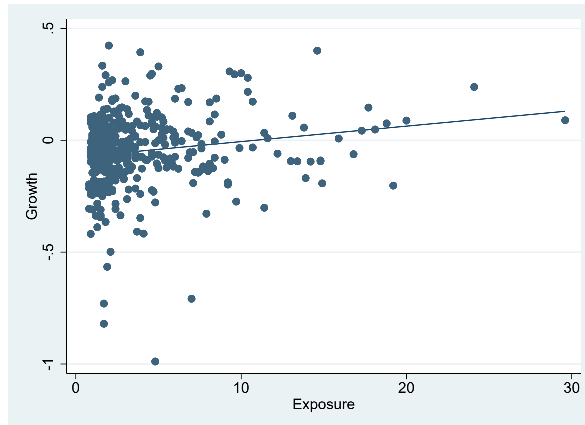
The argument supporting the assumption that land scarcity meets the orthogonality condition for rental yields is that natural and man-made constraints on the housing supply are distributed quasi-randomly at business cycle frequency. Even though this variable has little time variation, we hold it constant at the pre-sample value of 2008 to isolate the time-varying effect of monetary policy.

Figure 3 Exposure Measure and Outcome Variables Correlation with QE

Panel A: Rental Yield



Panel B: Output Growth



Note. The figure reports scatter plots of the conditional correlations between rental yields in Panel A (output growth in Panel B) and QE over the 2010-2017 sample period against 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 slopes of the regression lines are equal to -0.15 and 0.16, respectively, with p-values of 0.

One problem of using the share of land covered by water bodies and urban open space to proxy for *supply* tightness in local real estate markets is that, if interpreted as amenities, these characteristic can correlate with the quality of living, and hence with housing demand (Davidoff, 2016). This is concerning in our empirical setting as such amenities may attract more productive workers and therefore affect local output growth through other channels, such as productivity and agglomeration forces. Land scarcity could also be a constraint on productive activities and lead to factor-misallocation and aggregate productivity losses (Hsieh and Moretti, 2019), biasing the estimates in opposite direction.

We address these concerns with a two-prone strategy. First, we control for observable regional characteristics that can be associated with other implications of land scarcity for growth. Second, and more importantly, we also consider an alternative instrument based on political affiliations that is less prone to these criticisms. The indicator of political affiliation that we use does not have a counterpart in the model, but it is unlikely to correlate with housing demand factors over the business cycle. This alternative instrument is the voting share for the German Green party, averaged over the 2002, 2005 and 2009 elections. The

Green party has a long-standing tradition of supporting policies that can ease supply constraints in local housing rental markets. Thus, the idea is that political support for easing supply constraints in rental markets should be stronger in regions in which these constraints are indeed tighter. At the same time, averaging the voting share over these three elections can help controlling for regions' heterogeneous exposure to local economic conditions.

In summary, informed by the implications of our theoretical model, our strategy is one of identification by geographic variation, grounded on the availability of a measure of exposure to the posited housing portfolio channel that varies quasi-randomly across regions. So, we can now move on to the presentation of the empirical results of the paper.

5 Reduced-form Results

We start the empirical analysis by estimating the following reduced-form specification:

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

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 total financial assets held by the ECB over euro area GDP, and $\text{Exposure}_{r,2008}$ is our land scarcity variable evaluated in 2008. The latter is assumed to be uncorrelated with the error term, $\varepsilon_{r,t}$. We also control for time and region fixed effects to capture the direct influence of region-specific factors, such as size and agglomeration, and common factors across regions in the German business cycle.

Table 3 summarizes the results. The specification in column (1) includes only the EONIA interaction, showing that a lower policy rate leads to higher output growth in regions in which land is scarcer. The impact not only is statistically but also economically significant: a one-standard deviation decrease (0.4 percentage points) in the EONIA rate increases the annual output growth of regions on the 75th percentile of the distribution (e.g., Tuebingen) 9 basis points more than the regions on the 25th percentile (e.g., Bielefeld). Column (2) shows that

Table 3 MONETARY POLICY AND REGIONAL OUTPUT GROWTH: REDUCED-FORM RESULTS

	(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)	
$\text{Permits}_{r,t} \times \text{EONIA}_t$								-0.033
								(0.109)
$\text{Permits}_{r,t} \times \text{QE}_t$								-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	3208	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 per capita GDP growth. The main regressor in column (1) is the interaction between the EONIA rate and the 2008 value of our exposure measure. Column (2) interacts the share of central bank assets over GDP (QE) with the exposure measure. Columns (3)-(8) include both interaction terms. In Column (4), we include a triple interaction between our exposure measure, QE and the EONIA. Columns (5)-(8) control for the interactions between the EONIA (QE) and following regional characteristics: population density in 2008, the share of people above age 65 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.

QE also raises the output growth for regions in which land is scarcer. In economic terms, a one-standard deviation increase in the ECB's total assets to GDP (6.5 percentage points) raises the annual output growth for regions on the 75th percentile by 15 basis points more than regions on the 25th percentile of the exposure distribution.[13]

Column (3), our preferred specification, includes both monetary policy instruments at

[13] As we show in Appendix D.3, the reduced-form results are even stronger using the debt component of total assets as a proxy for the ECB's QE policy.

the same time. Critically, the results show that QE absorbs the effects of the EONIA rate—a robust result across all specifications that we estimate. The economic growth differential induced by QE decreases only slightly and is now equal to 12 basis points. Considering the average increase in the share of ECB assets over GDP over our sample period, i.e., 14 percentage points (from a pre-sample average value of 14% of GDP during 2000-2009 to an average of 28% during 2010-2017), this estimate implies that regions most exposed to real estate market tightness might have grown 26 basis points more (=14/6.5*12) on average per year than the least exposed regions during that period, or 2.1 percentage points more cumulatively between 2010 and 2017.[14]

Column (3) suggests that, in the transmission via local residential real estate markets, QE policy substitutes for interest rate policy. To explore this further, in column (4), we add the triple interaction among QE, EONIA, and our exposure measure. While the double interaction between QE and exposure remains positive and statistically significant, both the triple interaction and the EONIA-exposure double interaction are not statistically significant. The result suggests that QE and interest rate policy are more likely to be substitutes than complements in our housing portfolio channel of unconventional monetary policy transmission.

Columns (5)-(8) add to the specification in column (3) the corresponding interactions with other regional characteristics. Specifically, column (5) considers the interactions between the EONIA or QE, respectively, and the 2008 value of population density. This regression controls for the fact that more densely populated regions tend to grow faster due to agglomeration forces. For instance, to the extent to which land scarcity is associated with population density, and thus a more innovation-conducive environment, this variable could be an omitted (demand) factor in our analysis driving the increased growth rates of more exposed regions (Piazzesi and Schneider, 2016). In column (6), we add the interactions with

[14]In unreported regressions, we find that this result is robust to excluding the 10% of the regions with the highest average growth between 2010-2017. The finding is clear evidence that the results are not driven by outliers.

the 2008 share of older people (e.g., aged 65 and older), which controls for the role of demographic drivers of growth.[15] Column (7) controls for the interactions with the 2008 share of land covered by agriculture, as this variable can proxy for the level of regional economic development, with less developed regions typically having a higher share of agricultural land.[16] Finally, and importantly, in column (8), we add the interactions between the two monetary policy instruments and the *time-varying* number of building permits per 1,000 inhabitants to control for housing supply dynamics. More permits means more construction activity, which affects output directly. So, here, the rationale is that our results might be driven by residential investments, rather than consumption growth.

The estimates in columns (5)-(8) show that controlling for observable region characteristics or residential construction dynamics does not undermine the baseline results and, on the contrary, strengthens them. In fact, the coefficient on the interaction between QE and exposure increases to a maximum value of 0.008 in column (7), implying a QE-induced average cumulative growth differential between more and less exposed regions of up to 2.9 percentage points. Moreover, none of these regional characteristics or the permit dynamics play a separate role in explaining output growth differentials, with the corresponding interaction terms being statistically insignificant. While the EONIA interaction remains insignificant throughout, the QE interaction is positive and significant in all specifications. In particular, the estimates in column (3) remain essentially unchanged when we control for permit dynamics in column (8); a result that is inconsistent with the hypotheses that residential investment drives our results.

In unreported regressions, we control for three additional regional characteristics. The first is the distribution of immigrants and refugees in 2008 as in Bednarek et al. (2021). The second is past average regional growth during 2001-2007 (pre-GFC period) that can account for income growth expectations. The third is region-level GDP per capita in 2008, which

[15] Considering other age brackets also does not affect the estimates.

[16] Agricultural intensity might also have a direct impact on GDP growth and has a high and negative correlation of -43% with our exposure measure.

correlates positively with land scarcity (not negatively, as implied by Hsieh and Moretti 2019).[17] In all the three specifications, however, the coefficient on the interaction term between QE and the exposure measure remains statistically significant at the 1% or 5% level. In contrast, the interaction terms with the three additional characteristics do not have a separate role in explaining growth differences across regions.

The reported reduced-form results are quite robust along several dimensions. In Appendix D, we document robustness with respect to (i) employing an alternative exposure measure based on party affiliation and its interaction with land scarcity; (ii) controlling for a host of common shocks possibly confounding with QE, including national fiscal policy, a measure of financial uncertainty, aggregate capital and migration inflows; (iii) using alternative measures of QE, including the monetary policy surprises identified in Altavilla et al. (2019) and alternative components of the ECB's total assets; (iv) estimating the main specification over the 2014-2017 sub-sample period of formal ECB QE policy and over a pre-sample placebo period. Finally, in Appendix D, we also split the sample in rich and poor regions, or West and East German regions, providing corroborating evidence consistent with the posited housing portfolio channel.[18]

Overall, the reported reduced-form evidence suggests a statistically significant and economically sizable QE impact on the growth differentials across regions through the local housing market, consistent with the posited housing portfolio channel of our model, under the assumption that lower expected portfolio and housing returns can lead to higher consumption and output. So we now want to explore whether a reduction in expected future housing returns may indeed drive the reduced-form results.

[17] According to Hsieh and Moretti (2019), growth could be lower in regions with scarcer land supply as this constraint can hamper the efficient allocation of labor and aggregate productivity growth.

[18] In unreported regressions, we also estimate a spatial autoregressive panel data model, applying an inverse distance weighting matrix for the 401 German regions and including spatial lags of the dependent variable, the error terms, and all regressors. The interaction between QE and land scarcity remains statistically significant, albeit at a slightly lower level of confidence.

6 Instrumental Variable Results

Having established that QE raises more the output growth in regions with tighter land supply, we want to investigate the mechanism through which this outcome materializes. Specifically, we examine whether the data support the idea that QE stimulates output through a reduction in expected future housing returns, consistent with the model implication. As we discussed earlier, as a predictor for future expected housing returns, we use regional rental yields, grounded in the evidence in Appendix B on housing return predictability in Germany.

In order to show that QE affects economic activity by reducing regional rental yields, we regress output growth on rental yields, instrumenting them by the interaction of QE and our exposure measure.[19] The first-stage regression is specified as follows:

$$\text{Rental Yield}_{r,t} \;=\; \alpha_r + \alpha_t + \gamma \cdot (\text{QE}_t \times \text{Exposure}_{r,2008}) + \eta_{r,t} \tag{14}$$

where Rental Yield$_{r,t}$ is the rental yield in region r at time t and the regressor is the interaction between the QE indicator at time t and the regional value of land scarcity in 2008. α_r and α_t are region and time fixed effects. Time fixed effects are particularly important, as they control for all aggregate shocks, including the term spread, which in the model also declines with household portfolio rebalancing.

In the second stage, we estimate the impact of rental yield changes triggered by the ECB's quantitative easing on output growth by estimating the following specification:

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

where the instrument for the rental yield is $\text{QE}_t \times \text{Exposure}_{r,2008}$. In the second stage, QE

[19]This is the same approach as in Chaney et al. (2012) and Aladangady (2017). These studies interact the aggregate mortgage interest rate (our QE variable) with the housing supply elasticity of Saiz (2010) and then use the explained component of local real estate prices in the first stage to estimate their mediating effect on firm investment and household consumption in response to the aggregate mortgage interest rate change in the second stage.

can affect regional output growth differences *via* the explained component of the regional rental yield variations, with a strength that depends on the housing supply elasticity, as captured by the land scarcity indicator and also implied by our model.

Table 4 OUTPUT GROWTH AND REGIONAL RENTAL YIELDS: INSTRUMENTAL VARIABLE RESULTS

	1st stage Unweighted	1st stage Weighted	2nd stage Unweighted	2nd stage Weighted
	(1) Rental Yield	(2) Rental Yield	(3) ΔGDP	(4) ΔGDP
$\text{Exposure}_{r,2008} \times \text{QE}_t$	-0.001***	-0.001***		
	(0.000)	(0.000)		
$\text{Rental Yield}_{r,t}$			-9.927**	-7.408**
			(4.474)	(3.480)
Time FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Obs	3208	3208	3208	3208
F-Stat (1st stage)	8.2	13.3	-	-

NOTE. This table reports instrumental variable estimates. The regressions are based on annual regional data from 2010 to 2017. In the first stage, the dependent variable is the regional rental yield 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 rental yield. All regressions include region and time fixed effects. The regressions in columns (2) and (4) are weighted by regional GDP per capita. 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.

Table 4 reports the first- and second-stage results. Column (1) shows that the interaction between QE and our exposure measure has a negative impact on rental yields, as expected. However, the first-stage F-statistic is slightly below the norm of 10. As we show in the robustness analysis in Appendix D, the reduced-form evidence is stronger in wealthier German regions, as captured by GDP per capita, or in West Germany. Based on this evidence, column (2) reports the same first-stage regression but weights observations by regional GDP per capita. Doing so raises the F-statistic to 13.3, so that the second-stage estimates are not contaminated by any weak instrument issues.

Turning to the second-stage results, columns (3)-(4) confirm the important role of rental yields in the transmission of QE to regional output growth via the real estate market. Specifically, lower rental yields driven by QE raise output growth in more exposed regions, with coefficient estimates statistically significant at 5%. Interestingly, weighted and unweighted estimates are equally precise. Moreover, Table A5 in Appendix D shows that, when we use the political affiliation to the Green party as an alternative exposure measure, the first-stage F-statistics increase sharply, and the second-stage estimates become significant at 1%.

In our reduced-form analysis, we saw that QE leads to higher growth rates in regions with scarcer land supply. The IV results in this section show that, as one would expect, the reduced-form impact can entirely be accounted for by a decrease in region-level rental yields triggered by QE. To see this, multiply the first-stage coefficient in column (1) of Table 4, which is -0.0007, by the second-stage estimate in column (3), which is -9.927. The resultant product is 0.007, which is the same as the reduced-form estimate in column (2) of Table 3.

To sum up, the instrumental-variable results in this section establish that, in the German case, QE can affect output growth differences across regions by lowering rental yields, and hence expected future housing returns, consistent with the implications of our model. This evidence, therefore, establishes that housing portfolio rebalancing is a plausible mechanism of QE transmission. Next, we want to quantify its importance relative to alternative channels possibly also at work in the data.

7 Quantifying the Housing Portfolio Channel

The previous section provides strong evidence on the presence of a housing portfolio channel of QE transmission working through the mediating role of the *regional* rental yields as a proxy for regional expected future housing returns. In this section, we want to assess its quantitative relevance relative to other channels of unconventional monetary policy transmission through the housing market, including particularly the credit, collateral, and wealth channels typically emphasized in the exiting literature. Two additional important concerns are controlled for: (i) the bond component of the total expected future portfolio return that in our model moves in the same direction as the housing component; (ii) the possible presence of an equity portfolio channel driven by household rebalancing toward equities rather than houses in response to the bond return decline.

7.1 Horse-racing Alternative Mediating Variables

To quantify the relative importance of alternative QE transmission channels, we re-estimate the baseline reduced-form specification in column (3) of Table 3, considering one mediating variable for each of the alternative channels that we consider. We then compare their ability or lack thereof to absorb the impact of QE on the regional growth differential. This exercise can provide evidence on whether the relation between QE and output growth works through the specific meditating role of the variable under consideration, and thus corroborating or refuting the posited hypothesis. For example, if the mechanism were to work mostly through equity portfolio rebalancing, the credit market, the collateral or the wealth channels, rather than our housing portfolio channel, expected future equity returns, the quantity and price of mortgage credit, or the *level* of the national house price index should absorb the estimated impact of QE on output growth. As some of these variables are national while others can be measured also at the region level, for comparability purposes, we conduct the horse-race with national mediating variables for all channels.

Table 5 summarizes the results. The reported battery of regressions control for one mediating variable at the time and the corresponding bilateral race with the rental yield. Column (1) is our favourite specification considering the national rental yield as a proxy for expected future housing returns. The QE interaction term loses its statistical significance once we control for the rental yield interaction. The interaction term between the rental yield and exposure has a negative sign and it is statistically significant at the 1% level, providing strong evidence that lower housing returns raise output growth in regions with more land scarcity.[20] Note that, in this regression, the interaction term with the EONIA rate is positive and statistically significant. In contrast, in column (1) of Table 3, it was negative

[20]In an unreported regression, we show that in this specification the coefficient on the rental yield turns insignificant in a pre-QE (pre-2010) placebo sample period of the same length.

and significant. These different results suggest that some of the expansionary effects of a lower EONIA are transmitted via housing returns as well.

Table 5 Controlling for Alternative Mediating Variables

	(1) ΔGDP	(2) ΔGDP	(3) ΔGDP	(4) ΔGDP	(5) ΔGDP	(6) ΔGDP	(7) ΔGDP	(8) ΔGDP	(9) ΔGDP
$\text{Exposure}_{r,2008} \times \text{EONIA}_t$	0.181**	0.109*	0.003	0.006	0.106	0.185**	0.153	0.183**	0.173*
	(0.088)	(0.064)	(0.038)	(0.042)	(0.087)	(0.088)	(0.100)	(0.088)	(0.089)
$\text{Exposure}_{r,2008} \times \text{QE}_t$	0.003	0.004	0.008***	0.003	0.002	0.003	0.004*	0.001	0.004
	(0.002)	(0.002)	(0.002)	(0.005)	(0.003)	(0.002)	(0.002)	(0.004)	(0.003)
$\text{Exposure}_{r,2008} \times \text{Rental Yield}_t$	-0.307***					-0.221	-0.249*	-0.292***	-0.441*
	(0.109)					(0.144)	(0.134)	(0.111)	(0.255)
$\text{Exposure}_{r,2008} \times \text{Term Spread}_t$		-0.097**				-0.046			
		(0.039)				(0.051)			
$\text{Exposure}_{r,2008} \times \Delta\text{Credit}_t$			0.004**				0.002		
			(0.002)				(0.002)		
$\text{Exposure}_{r,2008} \times \text{Mortgage Rate}_t$				-0.052				-0.029	
				(0.057)				(0.057)	
$\text{Exposure}_{r,2008} \times \text{National HP Index}_t$					0.005*				-0.004
					(0.003)				(0.007)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3208	3208	3208	3208	3208	3208	3208	3208	3208
R^2	0.267	0.267	0.266	0.266	0.266	0.267	0.267	0.267	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. The regressions include the following alternative mediating variables (all national aggregate interacted with our exposure measure): the rental yield as a proxy for expected future housing returns; the term spread (defined as the difference between German 10-year government bond yields and the EONIA rate); the log change in mortgage credit volume; the average mortgage interest rate; and cumulative real house price growth. All mediating variables are national, or national aggregate. 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.

Column (2) of Table 5 shows that the term spread can also absorb the significance of QE, consistent with the prediction of our model. However, once we include both mediating variables at the same time in column (6), the rental yield dominates the term spread in terms of magnitude and p-value. In fact, although both interactions are statistically insignificant, due to the 93% correlation between them, the coefficient estimate on the rental yields in column (6) has a p-value of 13%, compared to 36% for the term spread. Moreover, as we can see from Table A6 in the Appendix, when we use the Green party affiliation as exposure measure, the rental yield in column (6) becomes statistically significant at the 10% level.

As we noted already, controlling for the term spread is important because QE directly impacts the bond component of the total expected future return in our housing portfolio model. Therefore, finding that the term spread can also absorb the significance of QE is not inconsistent with our housing portfolio channel. Yet, the sovereign yield curve also provides benchmark pricing for a wide range of household and corporate finance contracts. For example, by flattening the yield curve, QE can induce banks to rebalance portfolios from government bonds to other risky assets and loans, thereby supporting corporate capital expenditure. The term spread should dominate the rental yield in column (6) if its impact on output through banks and corporate investment were to dominate. It is, therefore, reassuring to find that the rental yield is not displaced by the term spread in this specification.

Other channels through which QE can affect local residential real estate market and economic activity are the traditional credit, collateral and wealth channels. The credit channel works through both prices and quantities. By increasing banking sector reserves, QE can raise banks' mortgage supply to households and loan supply to firms. In addition, by lowering long-term government bond yields on which mortgage rates are benchmarked, QE can also put downward pressure on mortgage rates and increase housing demand and mortgage refinancing that can stimulate consumption and output. Higher house prices can also boost the value of housing collateral and relax borrowing constraints for housing and non-housing consumption or giver rise to wealth effects.

Consider first the quantity of credit. Column (3) of Table 5 shows that mortgage credit growth does not absorb the effect of the QE interaction term, even though the mortgage credit interaction itself is positive and statistically significant at the 5% level.[21] Consider now mortgage rates. Column (4) of Table 5 controls for the price of mortgage credit by interacting the exposure variable with the average German mortgage rate. Like the term spread, this control absorbs the statistical significance of the QE impact. However, in contrast to the specification in column (1), the interaction with the mortgage rate in column (4) is not statistically significant. In fact, when we consider both mediating variables together, in

[21] The result is the same if we use the level of mortgage credit to GDP or total rather than mortgage credit.

column (8), only the rental yield interaction retains its significance. The same is true when we control for cumulative house price growth, in columns (5) and (9), thus suggesting that the collateral or wealth channels cannot be the main transmission mechanisms through which QE impacts the regional growth differential *via* the residential real estate market in Germany.

Finally, in an unreported regression we also establish that expected equity returns, as proxied by the current dividend yield, cannot absorb the QE interaction term. This experiment suggests that household portfolio rebalancing toward equities cannot explain our reduced-form results.

In sum, these results establish that QE can affect the output growth differential across German regions through the residential real estate market not only because it flattens the yield curve, leads to higher mortgage supply, reduces mortgage rates, raises property prices and collateral values, as previously established in the literature, but also because it reduces housing returns as implied by our model. Moreover, these results speak to the rental yield and our housing portfolio channel as a salient mechanism in the data. In contrast, the reported evidence does not favor the hypothesis that either the credit, wealth, collateral, or equity portfolio rebalancing channels are dominating, consistent with the fact that Germany experienced a house price boom without a credit boom during our sample period. Indeed, the reported evidence is consistent with the aggregate household balance sheet data discussed earlier showing that leverage is low and declining over this period in Germany, and bonds and equities represent a small share in the aggregate household portfolio.

7.2 Relative Importance of Alternative Channels

Thus far, the reported evidence establishes the presence of our housing portfolio channel in the data. However, at least one traditional channel cannot definitively be ruled out as the corresponding mediating variable—the term spread, which is highly correlated with the rental yield. This is expected, and the paper's contention is not that the proposed housing portfolio channel is the only one in the data, but rather that this new channel is present and likely conspicuous. So, we now want to quantify the importance of the housing portfolio channel relative to the term spread and other channels that we consider.

For this purpose, we exploit the time series variation in the data by means of predicting regressions of QE for all the mediating variables in our analysis. We then combine the coefficients from these predicting regressions with the reduced-form estimates that can be interpreted causally. Specifically, we first regress, in the time series, all mediating variables in Table 5 on our QE indicator. As we have only eight years of data, we run these regressions at the monthly frequency, but the magnitude and the sign of the coefficients are the same as the annual frequency, as Appendix Table A10 shows. We then use the estimated coefficients, which are only conditional correlations, together with the estimates from Table 5, which we can sustain a causal interpretation, to decompose the total impact of QE on the regional growth differential in its constituent parts.

Table 6 reports the predicting regression estimates, showing that QE predicts all mediating variables with expected signs in a statistically significant manner. One exception is the change in aggregate mortgage credit, which is hardly affected by QE and also has the wrong sign, consistent with the aggregate evidence of deleveraging in Table 1 and Figure 1.

Table 6 ALTERNATIVE MEDIATING VARIABLES AND QE
MONTHLY FREQUENCY

	(1) Rental Yield	(2) Term Spread	(3) ΔCredit	(4) Mortgage Rate	(5) Cumulative HP Change
QE_t	-0.043***	-0.069***	-0.328*	-0.075***	1.063***
	(0.003)	(0.010)	(0.189)	(0.009)	(0.085)
Obs	96	96	96	96	96
R^2	0.547	0.289	0.023	0.307	0.554

NOTE. All regressions are based on monthly data over the period 2010:M1-2017:M12. The dependent variables are the following: national rental yield, interpolated from the OECD quarterly database on house prices and rents and initialized the same as the regional rental yields discussed earlier; the term spread, defined as the difference between 10-year government bond yield and the EONIA rate; the log-change in aggregate mortgage credit; the national average mortgage interest rate; and the cumulative national real house price growth rate, interpolated from the same quarterly OECD data above. The regressor is our baseline QE indicator. Heteroskedasticity-robust standard errors are shown in parentheses. *, ** and *** indicate statistical significance at the 10%, 5%, and 1% level, respectively.

Combining the estimated coefficients of Tables 5 and 6 shows that our housing portfolio channel is not only present in the data, but also conspicuous, possibly dominating all other channels. To see this, assume for the sake of exposition that the portfolio channel is the only one at work, as in column (1) of Table 5. The coefficient on the rental yield, -0.307, is the explained component by this channel, while the coefficient on the QE interaction term conditional on the rental yield as a mediating variable, 0.003, is the residual component of the QE impact on the regional growth differential operating through all other channels. Now, a one-percentage point QE increase *predicts* a -0.043 percentage point decline in the rental yield, and hence *causing* an indirect effect on the regional growth differential via the rental yield equal to 0.0132 ($= -0.307 * -0.043$) and a direct effect through other channels of 0.003. Therefore, the relative importance of the indirect QE impact via the rental yield is 0.0132/0.0162, or 81% of the total effect which is $0.0162 (= 0.003 + 0.0132)$. Thus, in this case, only 19% of the total impact remains unexplained after controlling for our portfolio channel.

Of course, the importance of the portfolio channel declines if we explicitly consider the alternative channels reported in columns (6)-(9) of Table 5. As a lower bound, basing the decomposition on column (6) that includes the term spread and provides the smallest estimated impact of the rental yield (-0.221), we find that 61% of the overall QE impact can be accounted for by the proposed housing portfolio channel, and 20% by a flattening of the yield curve, leaving only 19% of the total impact unexplained or attributable to the other channels. In the other specifications in Table 5, the housing portfolio channel can explain between 77% and 100% of the QE-induced growth differentials.

The relative importance of the housing portfolio channel further declines the more mediating variables we consider. In the limit, when we include all channels together, we find that they are all insignificant. Nonetheless, when we include only the ones significant at the 5% level if entered alone (the rental yield, term spread, and credit growth), we find that the rental yield can still explain 67% of the total QE impact. The decomposition, therefore, speaks to a quantitatively important mediating role for expected future housing returns in the transmission of QE to output growth, consistent with the predictions of our theoretical model and the macroeconomic stylized facts that we presented at the beginning of the paper.

8 Conclusions

In this paper, we propose a new channel of QE transmission to real activity through residential housing markets that does not rely on credit, collateral, or wealth effects. From a theoretical perspective, we establish mild conditions under which QE lowers total and housing expected future regional portfolio returns, possibly inducing households to anticipate consumption and hence boosting output. Theoretically, we also show that the QE impact on the total and housing portfolio returns is stronger the lower the housing supply. From an empirical perspective, we study this new channel of QE transmission in a rich matched region-level data set, exploiting geographic variation in land scarcity, proxied by land covered by water bodies and urban open space, as a measure of exposure to the posited channel.

We find that the impact on regional output growth of QE, measured by the ECB's total assets or the debt portion of total assets, is stronger in regions where land is scarcer. The result is robust to a wide range of checks, including particularly using an alternative measure of exposure based on political affiliation, controlling for the ECB policy interest rate, regional characteristics, other common shocks that may confound the estimated causal effects of QE, and a number of placebo experiments. Our estimates imply that regions most exposed to this channel grew 2-3 percentage points more than the least exposed ones, on average, cumulatively, during 2010-2017. Empirically, we also show that the mechanism through which this relationship materializes is consistent with our model. In particular, we show that QE affects output growth across German regions mainly by reducing expected housing returns. Alternative channels, including the term spread, the credit, wealth, collateral, and equity portfolio channels play only a secondary role in explaining our results.

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Appendix

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

(For online publication only)

by D. te Kaat, and C. Ma, and A. Rebucci

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A Model Details

In this Appendix, we provide the proofs of the Propositions 1, 2 and 3 in the main text and present an extension to a two-region economy.

A.1 Proofs of Propositions 1, 2 and 3

The regional household problem is

$$\max_{h,b,x} \quad E[W'] - \frac{\gamma}{2}Var(W') = h\mu_1 + b\mu_2 + x - \frac{\gamma}{2}(h^2\sigma_1^2 + b^2\sigma_2^2 + 2hb\sigma_{12}) \tag{A1}$$

$$\text{s.t.} \quad W = Ph + Qb + x, (\lambda) \tag{A2}$$

$$W' = h(\mu_1 + \varepsilon_1) + b(\mu_2 + \varepsilon_2) + x. \tag{A3}$$

This requires that

$$\lambda Q = \mu_2 - \gamma b\sigma_2^2 - \gamma h\sigma_{12} \tag{A4}$$

$$\lambda P = \mu_1 - \gamma h\sigma_1^2 - \gamma b\sigma_{12} \tag{A5}$$

$$\lambda = 1. \tag{A6}$$

Combining market clearing with the demand functions of two preferred habitat investors, we obtain:

$$\bar{h} - h = -\alpha_1(P - \beta_1) \tag{A7}$$

$$\bar{b} - b = -\alpha_2(Q - \beta_2) \tag{A8}$$

Thus, the equilibrium levels of h and b are

$$h = \frac{(1/\alpha_2 + \gamma\sigma_2^2)(1/\alpha_1\bar{h} + \mu_1 - \beta_1) - \gamma\sigma_{12}(1/\alpha_2\bar{b} + \mu_2 - \beta_2)}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} \tag{A9}$$

$$b = \frac{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2\bar{b} + \mu_2 - \beta_2) - \gamma\sigma_{12}(1/\alpha_1\bar{h} + \mu_1 - \beta_1)}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2}. \tag{A10}$$

The responses of the equilibrium portfolio quantities, b and h, to changes in the fixed supply of the two risky assets, $\bar{b}$ and $\bar{h}$, are

$$\frac{dh}{d\bar{b}} = \frac{-\gamma\sigma_{12}/\alpha_2}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} \tag{A11}$$

$$\frac{db}{d\bar{b}} = \frac{(1/\alpha_1 + \gamma\sigma_1^2)/\alpha_2}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} > 0 \tag{A12}$$

$$\frac{dh}{d\bar{h}} = \frac{(1/\alpha_2 + \gamma\sigma_2^2)/\alpha_1}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} > 0 \tag{A13}$$

$$\frac{db}{d\bar{h}} = \frac{-\gamma\sigma_{12}/\alpha_1}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2}. \tag{A14}$$

As the denominator in the RHS of equation (A11) is strictly positive by Cauchy–Schwarz inequality, the sign of $\frac{dh}{d\bar{b}}$ thus depends on σ_{12}. Moreover, from equation (A7), $\frac{dP}{d\bar{b}} = \frac{1}{\alpha_1}\frac{dh}{d\bar{b}}$. Therefore, $\frac{dh}{d\bar{b}}, \frac{dP}{d\bar{b}} < 0$ iff $\sigma_{12} > 0$. This proves Proposition 1.

Define the expected total portfolio return as

$$E[R] = \frac{E[W']}{W} = \frac{h\mu_1 + b\mu_2 + x}{W} \tag{A15}$$

$$= 1 + \underbrace{\frac{h(\mu_1 - P)}{W}}_{E[R^h]} + \underbrace{\frac{b(\mu_2 - Q)}{W}}_{E[R^b]} \tag{A16}$$

$$= 1 + \frac{\gamma}{W}(h^2\sigma_1^2 + 2hb\sigma_{12} + b^2\sigma_2^2) \tag{A17}$$

To prove Propositions 2 and 3, we need to find conditions under which the following inequalities hold:

$$\frac{dX}{d\bar{b}} > 0 \tag{A18}$$

$$\frac{d}{d\bar{h}}\left(\frac{dX}{d\bar{b}}\right) < 0 \tag{A19}$$

where

$$X \in \{E[R], E[R^b], E[R^h]\}.$$

It is easy to see that

$$\frac{dE[R]}{d\bar{b}} = \frac{2\gamma[(h\sigma_{12} + b\sigma_2^2)/\alpha_1 + \gamma b(\sigma_1^2\sigma_2^2 - \sigma_{12}^2)]}{\alpha_2 W[(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2]} > 0 \tag{A20}$$

$$\frac{dE[R^h]}{d\bar{b}} = \frac{2}{\alpha_1 W}\left(\frac{\alpha_1\mu_1 + \bar{h} - \alpha_1\beta_1}{2} - h\right)\frac{dh}{d\bar{b}} \tag{A21}$$

$$\frac{dE[R^b]}{d\bar{b}} = \frac{\gamma[(h\sigma_{12} + 2b\sigma_2^2)(1/\alpha_1 + \gamma\sigma_1^2) - \gamma b\sigma_{12}^2)]}{\alpha_2 W[(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2]} > 0 \tag{A22}$$

and that

$$\frac{d}{d\bar{h}}\left(\frac{dE[R]}{d\bar{b}}\right) = 2\gamma\sigma_{12}\frac{\frac{1}{\alpha_1\alpha_2} - \gamma^2(\sigma_1^2\sigma_2^2 - \sigma_{12}^2)}{\alpha_1\alpha_2 W[(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2]^2} \tag{A23}$$

$$\frac{d}{d\bar{h}}\left(\frac{dE[R^h]}{d\bar{b}}\right) = \frac{(1/\alpha_2 + \gamma\sigma_2^2)(\gamma\sigma_1^2 - 1/\alpha_1) - \gamma^2\sigma_{12}^2}{\alpha_1 W[(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2]}\frac{dh}{d\bar{b}} \tag{A24}$$

$$\frac{d}{d\bar{h}}\left(\frac{dE[R^b]}{d\bar{b}}\right) = \frac{(1/\alpha_1 + \gamma\sigma_1^2)(\gamma\sigma_2^2 - 1/\alpha_2) - \gamma^2\sigma_{12}^2}{\alpha_2 W[(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2]}\frac{db}{d\bar{h}}. \tag{A25}$$

Therefore, we have

- $\frac{dE[R]}{d\bar{b}} > 0$
- $\frac{dE[R^h]}{d\bar{b}} > 0$ if $h > \frac{\alpha_1\mu_1+\bar{h}-\alpha_1\beta_1}{2}$, or $\frac{(1/\alpha_2+\gamma\sigma_2^2)(1/\alpha_1\bar{h}+\mu_1-\beta_1)-\gamma\sigma_{12}(1/\alpha_2\bar{b}+\mu_2-\beta_2)}{(1/\alpha_1+\gamma\sigma_1^2)(1/\alpha_2+\gamma\sigma_2^2)-\gamma^2\sigma_{12}^2} > \frac{\alpha_1\mu_1+\bar{h}-\alpha_1\beta_1}{2}$
- $\frac{dE[R^b]}{d\bar{b}} > 0$
- $\frac{d}{d\bar{h}}\left(\frac{dE[R]}{d\bar{b}}\right) < 0$ if $\sigma_{12} < \sqrt{\sigma_1^2\sigma_2^2 - \frac{1}{\gamma^2\alpha_1\alpha_2}}$
- $\frac{d}{d\bar{h}}\left(\frac{dE[R^h]}{d\bar{b}}\right) < 0$ if $\sigma_{12} < \sqrt{\sigma_1^2\sigma_2^2 - \frac{1}{\gamma^2\alpha_1\alpha_2} + \frac{\alpha_1\sigma_1^2-\alpha_2\sigma_2^2}{\gamma\alpha_1\alpha_2}}$.
- $\frac{d}{d\bar{h}}\left(\frac{dE[R^b]}{d\bar{b}}\right) < 0$ if $\sigma_{12} < \sqrt{\sigma_1^2\sigma_2^2 - \frac{1}{\gamma^2\alpha_1\alpha_2} - \frac{\alpha_1\sigma_1^2-\alpha_2\sigma_2^2}{\gamma\alpha_1\alpha_2}}$,

which prove Propositions 2 and 3.

A.2 Two-region Extension

Without loss of generality, consider an economy with two regions. Each regional household has access to the local housing market, national bonds, and cash, without cross-region real estate investment.[A1] We denote the second region with a $*$. Like in our benchmark economy, representative regional households with risk-aversion γ (γ^*) choose local housing h (h^*), national bond b (h^*) and cash balances x (x^*) satisfying the following four optimality conditions:

$$P = \mu_1 - \gamma h\sigma_1^2 - \gamma b\sigma_{12} \tag{A26}$$
$$Q = \mu_2 - \gamma b\sigma_2^2 - \gamma h\sigma_{12} \tag{A27}$$
$$P^* = \mu_{1^*} - \gamma^* h^*\sigma_{1^*}^2 - \gamma^* b^*\sigma_{1^*2} \tag{A28}$$
$$Q = \mu_2 - \gamma^* b^*\sigma_2^2 - \gamma^* h^*\sigma_{1^*2}. \tag{A29}$$

There are now three preferred habitat investors. Combining their downward sloping demands with the market clearing condition for each market, we have

$$\bar{h} - h = -\alpha_1(P - \beta_1) \tag{A30}$$
$$\bar{h^*} - h^* = -\alpha_{1^*}(P^* - \beta_{1^*}) \tag{A31}$$
$$\bar{b} - b - b^* = -\alpha_2(Q - \beta_2). \tag{A32}$$

To solve for the model equilibrium, we first obtain the region house holdings using equations (A26), (A28), (A30), and (A31)

$$h = m_1 - m_2 b \tag{A33}$$
$$h^* = m_{1^*} - m_{2^*} b^*, \tag{A34}$$

[A1] Considering a finite number of regions does not alter the main results.

where the m-coefficients are defined as

$$m_1 = \frac{\mu_1 - \beta_1 + \frac{1}{\alpha_1}\bar{h}}{1/\alpha_1 + \gamma\sigma_1^2} \tag{A35}$$

$$m_2 = \frac{\gamma\sigma_{12}}{1/\alpha_1 + \gamma\sigma_1^2} \tag{A36}$$

$$m_{1^*} = \frac{\mu_{1^*} - \beta_{1^*} + \frac{1}{\alpha_{1^*}}\bar{h^*}}{1/\alpha_{1^*} + \gamma^*\sigma_{1^*}^2} \tag{A37}$$

$$m_{2^*} = \frac{\gamma^*\sigma_{1^*2}}{1/\alpha_{1^*} + \gamma^*\sigma_{1^*}^2}. \tag{A38}$$

From the remaining bond holding optimality conditions, we obtain

$$b = \frac{\gamma^*(\sigma_2^2 - \sigma_{1^*2}m_{2^*})(\bar{b}/\alpha_2 - \beta_2 + \mu_2 - \gamma\sigma_{12}m_1) + 1/\alpha_2(\gamma^*\sigma_{1^*2}m_{1^*} - \gamma\sigma_{12}m_1)}{[1/\alpha_2 + \gamma(\sigma_2^2 - \sigma_{12}m_2)]\,[1/\alpha_2 + \gamma^*(\sigma_2^2 - \sigma_{1^*2}m_{2^*})] - 1/\alpha_2^2}$$

$$b^* = \frac{\gamma(\sigma_2^2 - \sigma_{12}m_2)(\bar{b}/\alpha_2 - \beta_2 + \mu_2 - \gamma^*\sigma_{1^*2}m_{1^*}) + 1/\alpha_2(\gamma\sigma_{12}m_1 - \gamma^*\sigma_{1^*2}m_{1^*})}{[1/\alpha_2 + \gamma(\sigma_2^2 - \sigma_{12}m_2)]\,[1/\alpha_2 + \gamma^*(\sigma_2^2 - \sigma_{1^*2}m_{2^*}),] - 1/\alpha_2^2}.$$

Therefore,

$$\frac{db}{d\bar{b}} = \frac{\gamma^*/\alpha_2(\sigma_2^2 - \sigma_{1^*2}m_{2^*})}{[1/\alpha_2 + \gamma(\sigma_2^2 - \sigma_{12}m_2)]\,[1/\alpha_2 + \gamma^*(\sigma_2^2 - \sigma_{1^*2}m_{2^*})] - 1/\alpha_2^2} > 0 \tag{A39}$$

$$\frac{dh}{d\bar{b}} = -m_2\frac{db}{d\bar{b}} < 0 \tag{A40}$$

$$\frac{db}{d\bar{h}} = \frac{-\gamma\sigma_{12}\,[1/\alpha_2 + \gamma^*(\sigma_2^2 - \sigma_{1^*2}m_{2^*})]}{[1/\alpha_2 + \gamma(\sigma_2^2 - \sigma_{12}m_2)]\,[1/\alpha_2 + \gamma^*(\sigma_2^2 - \sigma_{1^*2}m_{2^*})] - 1/\alpha_2^2}\frac{dm_1}{d\bar{h}} < 0 \tag{A41}$$

$$\frac{dh}{d\bar{h}} = \frac{dm_1}{d\bar{h}} - m_2\frac{db}{d\bar{h}} > 0. \tag{A42}$$

Without loss of generality, we can analyze the regional total expected return in the first region. The results equally apply to the second region, as they are symmetric. As before, the regional total expected return is:

$$E[R] = \frac{E[W']}{W} = \frac{h\mu_1 + b\mu_2 + x}{W} \tag{A43}$$

$$= 1 + \underbrace{\frac{h(\mu_1 - P)}{W}}_{E[R^h]} + \underbrace{\frac{b(\mu_2 - Q)}{W}}_{E[R^b]} \tag{A44}$$

$$= 1 + \frac{\gamma}{W}(h^2\sigma_1^2 + 2hb\sigma_{12} + b^2\sigma_2^2). \tag{A45}$$

As in the one-region economy, we want to find conditions under which the following inequalities hold:

$$\frac{dX}{d\bar{b}} > 0 \tag{A46}$$

$$\frac{d}{d\bar{h}}\left(\frac{dX}{d\bar{b}}\right) < 0, \tag{A47}$$

where

$$X \in \{E[R], E[R^b], E[R^h]\}.$$

After some algebra, it is possible to show that

$$\frac{dE[R]}{d\bar{b}} = \frac{2\gamma}{W}\frac{db}{d\bar{b}}\frac{\gamma b(\sigma_1^2\sigma_2^2 - \sigma_{12}^2) + 1/\alpha_1(h\sigma_{12} + b\sigma_2^2)}{1/\alpha_1 + \gamma\sigma_1^2} > 0,$$

$$\frac{dE[R^h]}{d\bar{b}} = \frac{2}{\alpha_1 W}\left(\frac{\alpha_1\mu_1 + \bar{h} - \alpha_1\beta_1}{2} - h\right)\frac{dh}{d\bar{b}}$$

$$\frac{dE[R^b]}{d\bar{b}} = \frac{\gamma}{W}\frac{db}{d\bar{b}}\frac{\gamma b(2\sigma_1^2\sigma_2^2 - \sigma_{12}^2 + h/b\sigma_1^2\sigma_{12}) + 1/\alpha_1(h\sigma_{12} + 2b\sigma_2^2)}{1/\alpha_1 + \gamma\sigma_1^2} > 0$$

and that

$$\frac{d}{d\bar{h}}\left(\frac{dE[R]}{d\bar{b}}\right) = 2\Omega \times \left[\frac{1}{\alpha_1\alpha_2} - \gamma^2(\sigma_1^2\sigma_2^2 - \sigma_{12}^2)\left(1 + \frac{1}{\alpha_2\gamma^*(\sigma_2^2 - \sigma_{1^*2}m_{2^*})}\right)\right]$$

$$\frac{d}{d\bar{h}}\left(\frac{dE[R^h]}{d\bar{b}}\right) = \Omega \times \left[\frac{1}{\alpha_1\alpha_2} - \gamma^2(\sigma_1^2\sigma_2^2 - \sigma_{12}^2)\left(1 + \frac{1}{\alpha_2\gamma^*(\sigma_2^2 - \sigma_{1^*2}m_{2^*})}\right) - \frac{\gamma\left(\alpha_1\sigma_1^2 - \alpha_2\sigma_2^2 - \frac{\sigma_2^2}{\gamma^*(\sigma_2^2 - \sigma_{1^*2}m_{2^*})}\right)}{\alpha_1\alpha_2}\right]$$

$$\frac{d}{d\bar{h}}\left(\frac{dE[R^b]}{d\bar{b}}\right) = \Omega \times \left[\frac{1}{\alpha_1\alpha_2} - \gamma^2(\sigma_1^2\sigma_2^2 - \sigma_{12}^2)\left(1 + \frac{1}{\alpha_2\gamma^*(\sigma_2^2 - \sigma_{1^*2}m_{2^*})}\right) + \frac{\gamma\left(\alpha_1\sigma_1^2 - \alpha_2\sigma_2^2 - \frac{\sigma_2^2}{\gamma^*(\sigma_2^2 - \sigma_{1^*2}m_{2^*})}\right)}{\alpha_1\alpha_2}\right]$$

where $\Omega \equiv \frac{\gamma\sigma_{12}}{W(1/\alpha_1+\gamma\sigma_1^2)}\frac{\gamma^*(\sigma_2^2-\sigma_{1^*2}m_{2^*})}{\left[1/\alpha_2+\gamma(\sigma_2^2-\sigma_{12}m_2)\right]\left[1/\alpha_2+\gamma^*(\sigma_2^2-\sigma_{1^*2}m_{2^*})\right]-1/\alpha_2^2}\frac{db}{d\bar{b}}\frac{dm_1}{d\bar{h}} > 0.$

Therefore, we have

- $\frac{dE[R]}{d\bar{b}} > 0$
- $\frac{dE[R^h]}{d\bar{b}} > 0$ if $h > \frac{\alpha_1\mu_1+\bar{h}-\alpha_1\beta_1}{2}$, or $m_1 - m_2\frac{\gamma^*(\sigma_2^2-\sigma_{1^*2}m_{2^*})(\bar{b}/\alpha_2-\beta_2+\mu_2-\gamma\sigma_{12}m_1)+1/\alpha_2(\gamma^*\sigma_{1^*2}m_{1^*}-\gamma\sigma_{12}m_1)}{\left[1/\alpha_2+\gamma(\sigma_2^2-\sigma_{12}m_2)\right]\left[1/\alpha_2+\gamma^*(\sigma_2^2-\sigma_{1^*2}m_{2^*})\right]-1/\alpha_2^2} > \frac{\alpha_1\mu_1+\bar{h}-\alpha_1\beta_1}{2}$

- $\frac{dE[R^b]}{d\bar{b}} > 0$
- $\frac{d}{d\bar{h}}\left(\frac{dE[R]}{d\bar{b}}\right) < 0$ if $\sigma_{12} < \sqrt{\sigma_1^2\sigma_2^2 - \frac{1}{\gamma^2\alpha_1\alpha_2}\frac{1}{1+\frac{1}{\alpha_2\gamma^*(\sigma_2^2-\sigma_{1*2}m_{2*})}}}$
- $\frac{d}{d\bar{h}}\left(\frac{dE[R^h]}{d\bar{b}}\right) < 0$ if $\sigma_{12} < \sqrt{\sigma_1^2\sigma_2^2 - \frac{1}{\gamma^2\alpha_1\alpha_2}\frac{1}{1+\frac{1}{\alpha_2\gamma^*(\sigma_2^2-\sigma_{1*2}m_{2*})}} + \frac{\left(\alpha_1\sigma_1^2-\alpha_2\sigma_2^2-\frac{\sigma_2^2}{\gamma^*(\sigma_2^2-\sigma_{1*2}m_{2*})}\right)}{\gamma\alpha_1\alpha_2\left(1+\frac{1}{\alpha_2\gamma^*(\sigma_2^2-\sigma_{1*2}m_{2*})}\right)}}$
- $\frac{d}{d\bar{h}}\left(\frac{dE[R^b]}{d\bar{b}}\right) < 0$ if $\sigma_{12} < \sqrt{\sigma_1^2\sigma_2^2 - \frac{1}{\gamma^2\alpha_1\alpha_2}\frac{1}{1+\frac{1}{\alpha_2\gamma^*(\sigma_2^2-\sigma_{1*2}m_{2*})}} - \frac{\left(\alpha_1\sigma_1^2-\alpha_2\sigma_2^2-\frac{\sigma_2^2}{\gamma^*(\sigma_2^2-\sigma_{1*2}m_{2*})}\right)}{\gamma\alpha_1\alpha_2\left(1+\frac{1}{\alpha_2\gamma^*(\sigma_2^2-\sigma_{1*2}m_{2*})}\right)}}$.

B Housing Return Predictability in Germany

Cochrane (2011) shows that the current rental yield can predict future housing returns in the case of the United States. In this Appendix, we show that this is also the case for Germany. To do so, we start from the present value identity (Campbell and Shiller, 1988) given by:

$$dp_t \approx \sum_{j=1}^{k} \rho^{j-1} r_{t+j} - \sum_{j=1}^{k} \rho^{j-1} \Delta d_{t+j} + \rho^k dp_{t+k} \tag{A48}$$

where $dp_t \equiv d_t - p_t = \log(D_t/P_t)$ is the log current rental yield, $r_t \equiv \log R_t$ is the log housing return, Δd_t is the log rent growth and ρ is a constant of approximation.

As customary, we then run the following three regressions:

$$\sum_{j=1}^{k} \rho^{j-1} r_{t+j} = a_r + b_r^k \times dp_t + \varepsilon_{t+k}^r \tag{A49}$$

$$\sum_{j=1}^{k} \rho^{j-1} \Delta d_{t+j} = a_d + b_{\Delta d}^k \times dp_t + \varepsilon_{t+k}^{\Delta d} \tag{A50}$$

$$dp_{t+k} = a_{dp} + b_{dp}^k \times dp_t + \varepsilon_{t+k}^{dp}, \tag{A51}$$

estimating them using the Macro History Database of Jordà et al. (2017) and Jordà et al. (2019), which reports reports capital gains and rental yields separately.[A2] To update their German series to 2017, we take the 2009 rental yield and update it with our national house price and rent indexes as follows: Rental yield$_t$ = Rental yield$_{2009}$ $*$ $\frac{\text{Rent index}_t}{\text{House price index}_t}$.

Equipped with these times series, we run regressions of for the weighted excess long-run return, the rent growth, and the future rent-to-price ratio on the current rental yield, as shown in equations (A49)-(A51), for the pre-sample period of 1963-2009, using a value for ρ equal 0.96. The present value identity implies that the long-run coefficients in the regressions

[A2]Note here that the database calculates housing returns based on population-weighted average sales prices for urban areas in West Germany.

above should be equal to 1:

$$1 \approx b_r^k - b_{\Delta d}^k + \rho^k b_{dp}^k. \tag{A52}$$

Table A1 Present Value Identity Regressions

	Future Housing Returns				Future Div. Growth				Future Rent/Price Ratio			
	Obs.	b_r^k	SE	R^2	Obs.	$b_{\Delta d}^k$	SE	R^2	Obs.	$\rho^k\ b_{dp}^k$	SE	R^2
k=1	47	0.04	0.04	0.03	47	-0.09	0.02	0.36	47	1.00	0.03	0.95
k=5	43	0.32	0.16	0.09	43	-0.31	0.09	0.23	43	0.78	0.13	0.58
k=10	38	0.84	0.25	0.23	38	-0.29	0.17	0.07	38	0.56	0.23	0.28
k=15	33	1.82	0.28	0.57	33	0.13	0.21	0.01	33	0.00	0.35	0.00

Note. The table reports the long-run coefficients of regressing cumulative future returns, cumulative future rent growth, and the future rent-to-price ratio on current rent-to-price ratios. The time horizons are 1, 5, 10 and 15 years.

Table A1 shows that the identity also holds in Germany, like in the US case (Cochrane, 2011).[A3] These estimates can further be seen as the share of rental yield variation that can be explained by each source. They show that, in the long run, a large fraction of the price-rent ratio volatility can be attributed to variation in expected returns, with a significantly smaller fraction explained by the other two factors. This evidence suggests that the current rental yield is a good long-run predictor of expected future housing returns, as we use it in our empirical analysis. In our regressions, we will use the in-sample rental yields without pre-multiplying it by the corresponding coefficient estimate since, from an econometric standpoint, multiplying a variable (the rental yield in our case) by a constant does not affect its statistical properties.

C Data Sources, Definitions and Summary Statistics

This appendix defines all variables that we use in the empirical analysis and provides their sources as well as summary statistics.

Table A2 summarizes variable definitions and sources. We described the main variables of interest in the main text. The macroeconomic variables that we use are: 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) and the CBOE volatility index (VIX), both of which are measures of financial risk and uncertainty that are particularly sensitive to global or regional investors' risk aversion;[A4] the German term spread, defined as the difference between the 10-year German government bond yield and the EONIA rate;[A5] and four national variables related to the German housing

[A3] Cochrane (2011) uses the implied rent growth by the return identity. We use actual rent growth in the regressions instead. Due to the approximation error, the identity does not need to hold exactly.

[A4] For both variables, as in the case of the EONIA, we use annual averages rather than year-end values, to prevent the annual values to be driven by outliers.

[A5] We obtain similar results when we calculate the term spread as the difference between 10-year and 1-year German government bonds.

and mortgage market, namely the average German mortgage interest rate, the change in the logarithm of total mortgage credit, the national real house price index and the national rent-to-price ratio (rental yield).

Table A3 reports summary statistics for all variables. Average real GDP growth per capita is 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 mostly of built-up land and also transportation.

Although we do not provide separate summary statistics for West and East Germany, some significant differences stand out. 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 on average land is less intensively covered by urban open space (1.6% vs 2%), but more intensively used for or covered by agricultural land (53% vs 47.3%) and water bodies (2.7% vs 1.9%). Forests cover about the same share of land in the West and the East (30.2% vs 29.4%).

Turning to the the national aggregate variables that we use, during our 2010-2017 sample period, the size of the ECB's balance sheet was 28.1% of nominal GDP on average, 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. The rental yield ranged from 4.4% to 5.3% with an average of 4.9%.

Table A2 Variable Definitions and Sources

Variable	Definition	Unit	Source
Prices	Regional real residential house price index (new and existing apartments)[a]	2009=100	Bulwiengesa
Rents	Regional real residential rent index (new and existing apartments)[b]	2009=100	Bulwiengesa
Rental Yield$_{r,t}$	The initial rental yield reported in Jordà et al. (2019), inflated by Rents/Prices	2009=5.38%	Macrohistory and Bulwiengesa
ΔGDP$_{r,t}$	The difference between region r's growth in nominal GDP per capita and state-level inflation	%	INKAR[c]
Water	Regional share of land covered by water bodies in 2008	%	IOER Monitor
Agriculture	Regional share of land covered by agricultural land in 2008	%	IOER Monitor
Forest	Regional share of land covered by forests in 2008	%	IOER Monitor
Other Open Space	Regional share of land covered by other open space in 2008	%	IOER Monitor
Urban Open Space	Regional share of land covered by urban open space in 2008	%	IOER Monitor
Exposure	Regional share of land covered by water bodies and urban open space in 2008	%	IOER Monitor
Exposure (alternative)	Previous exposure measure multiplied by regional average voting share for the green party in 2002, 2005 and 2009	%	IOER Monitor
Pop. Density	Regional number of inhabitants per square kilometer of land in 2008	-	INKAR
Age above 65	Regional share of people aged at least 65 in 2008	%	INKAR
Permits	Regional building permits per 1,000 inhabitants	-	INKAR
QE	The Eurosystem's total assets (consolidated) over nominal GDP	%	ECB
QE(TOTAL DEBT)	The Eurosystem's total debt securities over nominal GDP	Standardized[d]	ECB
QE(GOV. DEBT)	The Eurosystem's government debt securities over nominal GDP	Standardized	ECB
QE(FIN. DEBT)	The Eurosystem's financial sector debt securities over nominal GDP	Standardized	ECB
QE(PRIVATE DEBT)	The Eurosystem's private sector debt securities over nominal GDP	Standardized	ECB
REFINANCING	The Eurosystem's main and long-term refinancing operations over nominal GDP	%	ECB
EONIA	The weighted average rate of transactions in the European interbank market	%	ECB
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)
GIPS 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
Net Immigration	The net flow of immigrants	-	German Statistical Office
Rental Yield$_{\text{aggr}}$	The initial rental yield reported in Jordà et al. (2019), inflated by a national population-weighted rent-to-price ratio[e]	2009=5.38%	Macrohistory and Bulwiengesa
Term Spread	The difference between German 10-year government bond yields and the EONIA	%	FRED
Mortgage Rate	The German average mortgage interest rate	%	Bundesbank
ΔCredit	Log-difference in the volume of aggregate mortgage credit in Germany	%	FRED
National HP Index	National house price index, based on average house price growth across German regions	2009=100	Bulwiengesa

[a] We inflate the initial value of 100 in 2009 by the difference between nominal house price growth and state-level CPI inflation.
[b] We inflate the initial value of 100 in 2009 by the difference between nominal rent growth and state-level CPI inflation.
[c] The INKAR database is hosted by BBSR Bonn. All data from BBSR Bonn are subject to Data licence Germany – BBSR Bonn – Version 2.0
[d] We standardize the variables by subtracting the mean and dividing by the standard deviation.
[e] This rent-to-price ratio is based on West German cities only, following Jordà et al. (2019).

Table A3 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
Rental Yield$_{r,t}$	3208	5.1	0.4	4.0	5.2	6.1
ΔGDP$_{r,t}$	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
Exposure(alternative)	3208	36.1	46.5	4.0	17.5	252.2
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
QE(TOTAL DEBT)	8	0.0	1.0	-0.8	-0.6	2.0
QE(GOV. DEBT)	8	0.0	1.0	-0.9	-0.6	2.0
QE(FIN. DEBT)	8	0.0	1.0	-0.7	-0.6	2.2
QE(PRIVATE DEBT)	8	0.0	1.0	-1.0	-0.6	1.8
REFINANCING	8	6.5	2.0	4.9	5.9	11.4
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
GIPS 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
Net Immigration	8	476309	298455	127677	422344	1139402
Rental Yield$_{aggr}$	8	4.9	0.3	4.4	4.9	5.3
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
ΔCredit	8	2.1	7.9	-6.7	1.9	19.6
National HP Index	8	113.2	13.8	99.8	109.1	136.0

NOTE. The table reports the summary statistics for all the variables used in our analysis. See Table A2 for data definitions and sources.

D Robustness Analysis

This appendix reports all the robustness checks that we conduct, as well as additional estimation results providing corroborating evidence consistent with the housing portfolio channel of QE transmission in our model.

D.1 Alternative Exposure Measure

The most important robustness check that we conduct is to consider an alternative instrumental variable capturing exposure to our housing portfolio channel of QE transmission. As we discuss in the main text, for this purpose, we use a measure of political party affiliation, i.e., the average voting share for the German Green party in the 2002, 2005, and 2009 national elections. When we use this party affiliation indicator alone, by and large, all results are the same as in the baseline in the text. These results are not reported, but are available on request. Instead, in Tables (A4)-(A5) below, we report the results for party affiliation interacted with our land scarcity indicator, as they yield even stronger results.

Specifically, in Table A4, we continue to find that QE raises the growth differentials of more exposed regions relative to the less exposed ones—an effect that dominates the traditional interest rate channel of monetary policy via the EONIA rate. In economic terms, these estimates imply a growth differential between more and less exposed regions of 9 basis points (for each one-standard deviation increase in QE), only slightly smaller than the 12 basis points in our baseline analysis.

Table A5 indicates that our instrumental variable results are stronger, and this also holds when we use party affiliation alone (not reported). The values of the first-stage F-statistics are much higher, and the second-stage estimates are statistically significant at the 1% level.

Table A6 also confirms that the reduced-form impact of QE is absorbed by a drop in expected housing returns, rather than faster credit growth or increased collateral values. In particular, column (6) of Table A6 that includes both the rental yield and the term spread, now shows that the rental yield is statistically significant at the 10%. This is a critical result, which is strongest when we use the interaction of land scarcity and party affiliation, but improves also with party affiliation alone relative to the baseline specification.

Table A4 Alternative Exposure Measure: Reduced-Form Reuslts

	(1) ΔGDP	(2) ΔGDP	(3) ΔGDP	(4) ΔGDP	(5) ΔGDP	(6) ΔGDP	(7) ΔGDP	(8) ΔGDP
$\text{Exposure}_{r,2008} \times \text{EONIA}_t$	-0.006***		-0.002	-0.052**	-0.008	-0.003	-0.003	-0.002
	(0.002)		(0.003)	(0.023)	(0.005)	(0.003)	(0.004)	(0.003)
$\text{Exposure}_{r,2008} \times \text{QE}_t$		0.0006***	0.0005**	0.0007***	0.0006*	0.0005***	0.0007***	0.0005**
		(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0002)	(0.0002)	(0.0002)
$\text{Exposure}_{r,2008} \times \text{QE}_t \times \text{EONIA}_t$				0.002**				
				(0.000)				
$\text{Pop. Dens}_{r,2008} \times \text{EONIA}_t$					0.000			
					(0.000)			
$\text{Pop. Dens}_{r,2008} \times \text{QE}_t$					-0.000			
					(0.000)			
$\text{Age above } 65_{r,2008} \times \text{EONIA}_t$						-0.119*		
						(0.069)		
$\text{Age above } 65_{r,2008} \times \text{QE}_t$						0.003		
						(0.005)		
$\text{Agriculture}_{r,2008} \times \text{EONIA}_t$							-0.009	
							(0.013)	
$\text{Agriculture}_{r,2008} \times \text{QE}_t$							0.001	
							(0.001)	
$\text{Permits}_{r,2008} \times \text{EONIA}_t$								-0.020
								(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	3208	3208	3208	3208	3208
R^2	0.264	0.265	0.266	0.267	0.266	0.267	0.267	0.266

Note. The regressions are based on annual region-level data over the period 2010-2017. The dependent variable is real per capita GDP growth. The main regressor in column (1) is the interaction between the EONIA rate and an alternative region-level exposure measure, namely the product of the 2008 share of land covered by water bodies and urban open space and the average voting share for the green party during 2002-2009. Column (2) interacts the share of central bank assets over GDP with the alternative exposure measure. Columns (3)-(8) include both interactions at the same time. In Column (4), we also include a triple interaction among the alternative exposure measure, QE and the EONIA. Columns (5)-(8) control for the interactions between the EONIA and QE, respectively, and the following regional characteristics: 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.

Table A5 Alternative Exposure Measure:
Instrumental Variable Results

	1st stage	1st stage	2nd stage	2nd stage
	(1)	(2)	(3)	(4)
	Rental Yield	Rental Yield	ΔGDP	ΔGDP
$\text{Exposure}_{r,2008} \times \text{QE}_t$	-0.00007***	-0.00007***		
	(0.00002)	(0.00002)		
$\text{Rental Yield}_{r,t}$			-8.340***	-7.016***
			(3.044)	(2.685)
Time FE	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes
Obs	3208	3208	3208	3208
F-Stat (1st stage)	17.6	24.3	-	-

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 rental yield at the region level and the regressor is the interaction term between QE and an alternative region-level exposure measure, namely the product of the 2008 share of land covered by water bodies and urban open space and the average voting share for the green party during 2002-2009. In the second stage, we regress region-level real per capita growth on the predicted rental yield. All regressions include region and time fixed effects. The regressions in columns (2) and (4) are weighted by regional GDP per capita. 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.

D.2 Other Common Shocks

In this section, we control for other common shocks possibly confounding the QE transmission in our setup, interacting them with land scarcity, as we do for QE and the EONIA rate. Columns (1)-(5) in Table A7 summarize the estimation results.

First, we consider measures of financial risk and uncertainty that are particularly sensitive to global or regional investors' risk aversion. This control is important because, as the model illustrates, a change in households' risk aversion triggered by QE implies a portfolio adjustment from riskless to risky assets (toward both bonds and housing), rather than a substitution of housing for bonds, but might lead to an observationally equivalent decrease in expected future housing returns. In order to capture risk aversion and financial uncertainty empirically, we use the CBOE volatility index (VIX Index) and the spread of Southern European government bonds of Grece, Italy, Spain and Portugal (GIPS Spread) over the German Bund. The GIPS spread can also proxy for capital flows driven by bank portfolio rebalancing, as illustrated in Bednarek et al. (2021). The attendant results in columns (1) and (2) show that QE continues to affect the output growth differences across regions, even after controlling for the VIX Index or the GIPS spread, as in our baseline results.

Second, in columns (3) and (4), we control for the stance of fiscal policy. This might be important because, especially at the beginning of our sample period, both monetary and fiscal policy were deployed to fight the GFC. To the extent that new bond issuance from the national treasury accompanies (or offsets) higher ECB purchases of financial assets (more

Table A6 ALTERNATIVE EXPOSURE MEASURE: CONTROLLING FOR MEDIATING VARIABLES

	(1) ΔGDP	(2) ΔGDP	(3) ΔGDP	(4) ΔGDP	(5) ΔGDP	(6) ΔGDP	(7) ΔGDP	(8) ΔGDP	(9) ΔGDP
$\text{Exposure}_{r,2008} \times \text{EONIA}_t$	0.019**	0.012**	0.000	0.001	0.010	0.019***	0.014*	0.019***	0.018**
	(0.007)	(0.005)	(0.003)	(0.003)	(0.007)	(0.007)	(0.008)	(0.007)	(0.089)
$\text{Exposure}_{r,2008} \times \text{QE}_t$	0.0001	0.0003	0.0007***	-0.0000	0.0001	0.0001	0.0003*	-0.0002	0.0004
	(0.0002)	(0.0002)	(0.0002)	(0.0004)	(0.0002)	(0.0001)	(0.0002)	(0.0004)	(0.0003)
$\text{Exposure}_{r,2008} \times \text{Rental Yield}_t$	-0.033***					-0.023*	-0.024**	-0.030***	-0.053***
	(0.009)					(0.012)	(0.011)	(0.010)	(0.018)
$\text{Exposure}_{r,2008} \times \text{Term Spread}_t$		-0.011***				-0.006			
		(0.003)				(0.004)			
$\text{Exposure}_{r,2008} \times \Delta\text{Credit}_t$			0.0005***				0.0003*		
			(0.0001)				(0.0002)		
$\text{Exposure}_{r,2008} \times \text{Mortgage Rate}_t$				-0.008*				-0.006	
				(0.004)				(0.004)	
$\text{Exposure}_{r,2008} \times \text{National HP Index}_t$					0.0005**				-0.0006
					(0.0003)				(0.0005)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3208	3208	3208	3208	3208	3208	3208	3208	3208
R^2	0.268	0.268	0.268	0.266	0.266	0.268	0.269	0.268	0.268

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 an alternative region-level exposure measure, namely the product of the 2008 share of land covered by water bodies and urban open space and the average voting share for the green party during 2002-2009. The regressions include the following potential mediating variables, all national aggregates, interacted with the alternative exposure measure: the regional rental yield as a proxy for expected future housing returns; the term spread; the log change in mortgage credit volume; the average mortgage interest rate; and cumulative real house price growth. 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.

QE), this confounding factor may bias our results. To rule out this concern, we add in the regression the interactions between exposure and the German share of government net lending in GDP (column 3), or between exposure and government consumption over GDP (column 4). The QE interaction remains positive and statistically significant although the magnitude of the estimated coefficient decreases and the coefficients are less precisely estimated. Moreover, and interestingly, the results show that fiscal policy does not seem to transmit through the housing portfolio channel we are focusing on. In fact, higher government consumption or borrowing (i.e., lower values on government net lending) reduces the growth rates of regions with tighter real estate markets relative to regions with less tight markets.[A6]

Third, in column (5), we control for the significant increase in immigration that took place in Germany during 2010-2017. In fact, immigration can drive up housing rents and prices. To this end, we augment our specification with the interaction between aggregate *net* immigration flows into Germany and the exposure measure.[A7] Column (5) shows that the

[A6] German households can and do invest also in pan-European government bonds. It is therefore important to control for the supply of bonds in the euro area as a whole. In unreported specifications, we control for the interaction between regional land scarcity and *euro area* governments' net lending as a share of GDP. The results are similar.

[A7] The results are similar if we use *gross* immigration flows.

Table A7 REDUCED-FORM RESULTS: ROBUSTNESS TO CONFOUNDING COMMON SHOCKS AND MONETARY POLICY INNOVATIONS.

	(1) ΔGDP	(2) ΔGDP	(3) ΔGDP	(4) ΔGDP	(5) ΔGDP	(6) ΔGDP
Exposure$_{r,2008}$ $\times$ EONIA$_t$	0.005	0.035	0.042	0.028	0.041	
	(0.064)	(0.080)	(0.048)	(0.044)	(0.044)	
Exposure$_{r,2008}$ $\times$ QE$_t$	0.007**	0.007***	0.004*	0.005*	0.008***	
	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)	
Exposure$_{r,2008}$ $\times$ GIPS Spread$_t$	-0.004					
	(0.009)					
Exposure$_{r,2008}$ $\times$ VIX$_t$		-0.007				
		(0.005)				
Exposure$_{r,2008}$ $\times$ Gov. Lending$_t$			0.025**			
			(0.012)			
Exposure$_{r,2008}$ $\times$ Gov. Cons.$_t$				-0.032**		
				(0.015)		
Exposure$_{r,2008}$ $\times$ Net Immigration$_t$					0.000**	
					(0.000)	
Exposure$_{r,2008}$ $\times$ EONIA Shock$_t$						0.008*
						(0.004)
Exposure$_{r,2008}$ $\times$ QE Shock$_t$						0.003*
						(0.002)
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	0.265	0.266	0.267	0.267	0.266	0.264

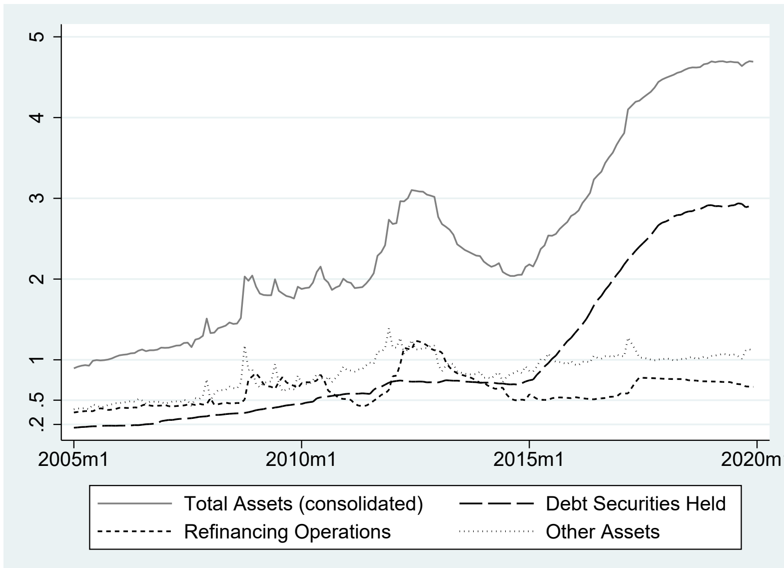
NOTE. The regressions are based on annual region-level data over the period 2010-2017. The dependent variable is real GDP per capita growth. The main regressors are the interactions between the EONIA and the 2008 regional value of our exposure measure, as well as between the share of central bank assets over GDP and the exposure measure. Columns (1)-(5) control for the corresponding interactions between the spread of 10-year government bonds in Greece, Italy, Portugal and Spain relative to Germany (GIPS Spread), the CBOE volatility index (VIX), the share of government lending over GDP, the share of government consumption over GDP, and net immigration flows. 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.

coefficient on the QE interaction remains highly statistically significant and even increases in size relative to the baseline specification. The immigration interaction coefficient itself is positive and statistically significant at the 5% level, indicating that immigration also has a growth-enhancing effect on more exposed regions. Note finally that, in all these specifications, in columns (1)-(5), the EONIA interaction term is statistically insignificant, in line with our main results in Table 3.

D.3 Alternative QE Measures

In a next set of robustness checks, we consider alternative QE measures. First, in column (6) of Table A7, we replace QE and the EONIA by their identified surprise counterparts, based on Altavilla et al. (2019), who extract monetary policy surprises by estimating latent factors from changes in yields of financial assets. The coefficient on the interaction with the QE surprise increases in size, but is less precisely estimated, arguably due to the constructed nature of this variable. In addition, the interaction coefficient between the EONIA surprise and our land scarcity measure has the “wrong” sign.

Figure A1 The Eurosystem's Balance Sheet



Note. This figure plots (in trillion euros) the Eurosystem's consolidated total assets and its main components: total refinancing operations, i.e., main (short-term) and long-term; the total amount of debt securities held, and other assets. Source: ECB.

Second, we consider alternative components of the ECB balance sheet. This is important because, as can be seen from Figure A1, debt securities held by the ECB started to increase steadily during the GFC along with total assets, but became the main driver of total assets (our baseline QE proxy for QE) only after 2015. In contrast, total refinancing operations drive total assets till 2010, but their importance declines thereafter, except for the 2012-2013 period—see also Tristani (2021).

The reported specifications in Table A8 consider the share of total debt securities held by the ECB over nominal euro area GDP, splitting them also into government debt, financial sector debt and non-financial private sector debt.[A8] For ease of comparison, column (1) also reports our baseline results with the same QE proxy as in column (3) of Table 3 in the text. The results show that our baseline results are robust. The reason is that, as Figure A1 illustrates, all components of the ECB balance sheet closely correlate, except the refinancing operations that have a 26% correlation with total assets over the sample period, compared to 92% for debt securities. Not surprisingly, therefore, we obtain statistically insignificant results when we employ the share of the ECB's total refinancing operations as the main regressor in column (6). This is strong evidence that our benchmark results are indeed driven by central bank bond purchases, and not by liquidity provision to banks via refinancing operations.

[A8] In this table, all QE proxies are standardized in order to compare the coefficient magnitude.

Table A8 REDUCED-FORM RESULTS:
ROBUSTNESS TO DIFFERENT ECB BALANCE SHEET COMPONENTS

	(1) ΔGDP	(2) ΔGDP	(3) ΔGDP	(4) ΔGDP	(5) ΔGDP	(6) ΔGDP
$\text{Exposure}_{r,2008} \times \text{EONIA}_t$	-0.015	0.035	0.037	0.021	0.023	-0.067**
	(0.039)	(0.059)	(0.059)	(0.057)	(0.055)	(0.031)
$\text{Exposure}_{r,2008} \times \text{QE}_t$	0.039***					
	(0.015)					
$\text{Exposure}_{r,2008} \times \text{QE(TOTAL DEBT)}_t$		0.051**				
		(0.023)				
$\text{Exposure}_{r,2008} \times \text{QE(GOV. DEBT)}_t$			0.052**			
			(0.023)			
$\text{Exposure}_{r,2008} \times \text{QE(FIN. DEBT)}_t$				0.044**		
				(0.022)		
$\text{Exposure}_{r,2008} \times \text{QE(PRIVATE DEBT)}_t$					0.047**	
					(0.022)	
$\text{Exposure}_{r,2008} \times \text{REFINANCING}_t$						-0.001
						(0.006)
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	0.265	0.265	0.265	0.265	0.265	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 (alternative QE proxies) and the exposure measure. Specifically, column (1) uses our baseline QE indicator. Column (2) uses total debt securities. Columns (3)-(5) break this variable down into government debt securities, financial sector debt securities and non-financial private sector debt securities, all expressed as a share of nominal GDP. All QE proxies are standardized in order to compare the coefficient across specifications by subtracting the mean and dividing by the standard deviation. In column (6), we use the share of the ECB's main and long-term refinancing operations over nominal GDP. The 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.

Interestingly, the estimated coefficient on the interaction term with QE measured by total debt securities in columns (2) is larger than in the baseline in column (1). The result is driven by the share of government debt securities, which itself has the largest estimated interaction coefficient in Table A8. The finding is intuitive when interpreted through the lens of our model, given that government debt typically represents the largest fraction of households' *bond* holdings. In our model, ECB purchases of *government* securities increase bond prices and induce portfolio rebalancing towards housing, reducing total and housing expected future returns, and can increase local consumption.

For the same reasons, in unreported specifications, we also consider two sub-sample periods. The first is the one over which the ECB formally adopted QE, namely 2014-2017 (Tristani, 2021). The second is a placebo pre-sample period of the same length as the 2010-2017 treatment period. When we estimate all reduced-from specifications over the 2014-2017 sub-period, the main results are robust, albeit estimated imprecisely due to the rather short time dimension of the panel. In contrast, when we estimate all reduced-form specifications over the pre-2010 placebo sample period, we find that QE does not have impact on the growth differentials across regions.

D.4 Additional Results and Corroborating Evidence

In this section, we re-estimate the main reduced-form specification splitting the sample in regions that are arguably more or less exposed to our housing portfolio channel of QE transmission. In particular, we compare West and East German regions, regions with a higher and lower share of wealthy households, and more and less densely populated regions. If our results were indeed driven by housing portfolio rebalancing, the effects should be stronger in West Germany, in wealthier regions, and more densely populated regions where housing portfolio rebalancing, buying-to-let, and intertemporal substitution in consumption are more likely.

Table A9 Monetary Policy and Output Growth: Cross-Regional Differences

	West	East	Rich	Poor	High Pop. Den.	Low Pop. Dens.
	(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 percapita growth. The main regressors are the interactions between the EONIA rate and the QE variable and the 2008 value of our 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 percapita GDP in the respective year. In columns (5) and (6), we split the sample along the 25th percentile of 2008 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.

Table A9 reports the results. Columns (1)-(2) show that QE interacted with land scarcity affects growth only in West Germany, whereas both QE and the EONIA rate interactions are insignificant in the East. This is in line with the fact that, in West Germany, on average, households are significantly richer than in the East, and hence more likely to respond to changes in their portfolio returns, substituting aggregate consumption intertemporally. Further supporting this conclusion, columns (3)-(4) show that the interaction between QE and exposure is only statistically significant in regions with per capita GDP above the yearly median.[A9] Finally, we also split the sample into regions with high and low population density, using the 25th percentile of the distribution as the threshold. We expect the effects to be stronger for more densely populated regions, arguably where a larger number of wealthy households is located. Interestingly, while the QE interaction is statistically significant only in the high population density sub-sample, the EONIA interaction term is now negative

[A9]The result is virtually unchanged if we split the sample based on per capita GDP in 2008.

and significant at the 10% for regions with low population density, even after controlling for QE.[A10]

In sum, this evidence indicates that the relation between QE and output growth is detected in richer and more densely populated regions. This result is consistent with our housing portfolio channel that is more likely at work in richer regions and in West Germany. In contrast, we find that, in less densely populated regions, interest rate policy seems more important.

E Annual QE Predicting Regressions

For robustness, in this section, we report the predictive impact of QE on all alternative mediating variables at annual, rather than monthly, frequency, as reported in Section 7. Table A10 shows that the the results in the text estimated at monthly frequency are robust, with two major differences. First, the relationship between QE and credit growth, which is significant at the 10% level when using monthly data, now turns statistically insignificant. Second, the statistical significance of the term spread as dependent variable drops from the 1% to the 10% level. Most importantly, however, the link between QE and the rental yield—our main mediating variable—remains statistically significant at the 5% level and the estimate is only slightly smaller than in Table 6.

Table A10 Alternative Mediating Variables and QE: Annual Frequency

	(1) Rental Yield	(2) Term Spread	(3) ΔCredit	(4) Mortgage Rate	(5) National HP Index
QE_t	-0.033**	-0.066*	-0.208	-0.081***	1.571***
	(0.011)	(0.028)	(0.327)	(0.020)	(0.359)
Obs	8	8	8	8	8
R^2	0.414	0.369	0.029	0.708	0.548

Note. All regressions are based on annual data over the period 2010-2017. The dependent variables are the German rental yield, the German term spread, defined as the yield difference between 10-year government bonds and the EONIA, the log-change in aggregate German mortgage credit volumes, the average German mortgage interest rate and the cumulative real German house price growth. 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.

[A10]Note that the EONIA interaction is only negative and significant for regions with very low population density. In unreported regressions, we also split the sample along the median of the population density distribution and the EONIA interaction was insignificant throughout.