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

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Abstract

We propose a new housing portfolio channel through which a central bank's quantitative easing (QE) can affect local consumption and hence output growth. To illustrate the working of this channel of QE transmission, we set up a simple portfolio model with segmented local housing markets. In our model, a national financial intermediary manages wealth on behalf of local households and responds to QE interventions by rebalancing its portfolio from bonds to houses. As a result, house prices increase, expected future returns fall, and the total household portfolio return declines, boosting the local economy by stimulating current consumption. The more scarce is land supply, the tighter the local housing supply, and the stronger the QE impact on the portfolio return and hence consumption and output growth. We investigate this channel empirically in German region-level data. Identification exploits the exogenous variation in land supply scarcity across regions to construct a measure of exposure to the housing portfolio channel. We estimate that a one-standard-deviation increase in the size of the ECB's balance sheet raises GDP growth in the most exposed regions by 2-3 percentage points more than in the least exposed ones, cumulatively, during the 2010-2017 period. The housing portfolio channel can account for 60-80% of this regional growth differential, with the remaining portion accounted for by the term spread and credit and collateral channels.

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JEL Classification: E3, E4, E5, R3

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1 Introduction

During and after the global financial crisis (GFC), central banks expanded their monetary policy toolkit, adopting unconventional instruments. Several central banks, including the European Central Bank (ECB), started to purchase long-term bonds and other risky assets, the so-called quantitative easing interventions (QE), in order to support the economy. The ECB also continued to use interest rate policy by setting a negative deposit facility rate. The empirical analysis of the transmission mechanism of monetary policy is an important and time-honored area of quantitative research. Not surprisingly, in the aftermath of the GFC, 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 to economic activity and estimate its impact on output growth differences across 401 urban and rural German administrative regions. We find that this channel is quantitatively more important than the traditional credit and collateral channels in German data, and also dominates the term spread, explaining between 60% and 80% of the total QE impact on regional growth differentials. We estimate that, in regions in which land is scarcer, real GDP grows at least 2 percentage points more than in the least exposed ones, cumulatively, for each one-standard deviation increase in QE during the 2010-2017 period. To illustrate the working of the housing portfolio channel that we propose, discipline our empirical analysis, and support the identification assumptions that we make, we also set up a simple housing portfolio model with asset market segmentation and preferred habitat investors.

Empirically, we assess and quantify this new channel by estimating the differential impact of QE on the housing returns and output growth across all German regions, controlling for the European interbank market rate (EONIA), other traditional QE transmission channels, and possible confounding factors. We find supporting evidence for this channel showing that it is conspicuous in our data. Theoretically, we set up a simple housing portfolio model with segmented asset markets in which preferred habitat local real estate investors and national financial intermediaries hold houses and bonds. In response to QE, as the bond supply declines and their price increases, intermediaries rebalance their portfolios. Provided the two asset returns are positively correlated, both house and bond prices increase. Preferred habitat real estate holders lower their demand accommodating the intermediaries' increase. Expected future returns on both assets decline driving down the aggregate portfolio return. A lower return on saving can thus stimulate the local economy by boosting consumption and income. As housing has a large weight in the households wealth (Davis and Van Nieuwerburgh 2015, Piazzesi and Schneider 2016), such a decline in housing returns can affect consumption and hence output.[1] In this channel, therefore, the real effects of QE work through a reduction in expected future housing returns, rather than higher consumption and activity stimulated by credit growth.

Consistent with our model's predictions, to achieve identification, we exploit the differential exposure of German *regions* to local land supply scarcity, and thus the region's sensitivity to this housing portfolio channel. The hypothesis that the tighter a region's land supply is, the less elastic is the housing supply, and the stronger is the QE impact on a region's housing returns, predicates the relevance of our instrument and is supported by the evidence that we report in the paper. The well known argument that man-made and natural land constraints on the house supply are distributed quasi randomly at business cycle frequency underpins the orthogonality condition. In line with our model's predictions, we find that the QE impact on annual real GDP growth is stronger in regions with tighter land supply constraints.

The housing portfolio channel that we focus on is different from the traditional bank lending and collateral channels that work through the credit market (see Chaney, Sraer and Thesmar 2012; Mian, Rao and Sufi 2013 and Greenwald and Guren 2019). The key mechanism relies on the portfolio rebalancing behavior of households, or financial intermediaries in the delegated-investment set up of our simple model that we use to illustrate it. House sales and purchases are cash transactions in our model. A critical difference, therefore, is that credit does not need to increase to stimulate the economy. Therefore, QE can also affect the real economy in a creditless environment, as during the post-GFC period of bank deleveraging. Our evidence and analysis, therefore, provides a mechanism through which QE can still support the macroeconomy even in the absence of credit growth. Note, however, that this paper's contention is not that the credit and collateral channels are not present in the data, but that the housing portfolio channel is important alongside the other traditional channels.

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 has gone through a housing boom without credit boom since 2009. Anecdotal evidence suggests that many residential real estate transactions are cash purchases, by both households and financial intermediaries, including foreign investors. Figure 1 plots national aggregate residential rent and price indexes and households' housing credit from two different sources as a share of GDP. The figure shows a stark negative correlation between housing and credit market dynamics. In the run up to the GFC, house prices (and rents) decline, while credit expands. Since 2009, the two markets moved in opposite direction. A more direct inspection

[1] In Germany, real estate as a share of total household assets or net worth is quite high at more than 55 % and 65 % respectively, as Table C.5 illustrates.

of aggregate balance sheet data confirms that Germans households are not levered, and that leverage declined further after 2009 to only slightly more than 10 %, as Table C.5 illustrates. This is a striking example of a housing boom without a credit boom (see Cerutti, Dagher and Dell'Ariccia 2017).[2]

We start by illustrating the plausibility and the mechanics of the housing portfolio channel in a simple intertemporal consumption model with segmented asset markets. To do so, we connect two strands of literature, one on housing portfolios as for instance in Flavin and Yamashita (2002), and the other on the preferred habitat investor, such as in Vayanos and Vila (2021) and Greenwood, Hanson, Stein and Sunderam (2020), Gabaix and Maggiori (2015) and Maggiori (2021) in the international context. In this set up, QE reduces the total supply of risky long-term bonds to the private sector, which in equilibrium induces financial intermediaries to rebalance from risky bonds to houses and local preferred habitat real estate investors to lower their demand. As a result, both house and bond prices increase, and the aggregate portfolio return falls. Local consumption increases in response to a fall in the return to saving if the intertemporal elasticity of substitution is large enough in our simple set up. Thus, the model predicts that QE simultaneously decreases (increases) risky expected returns (asset prices), including on bonds and houses, and boosts consumption spending through a portfolio rebalancing channel.

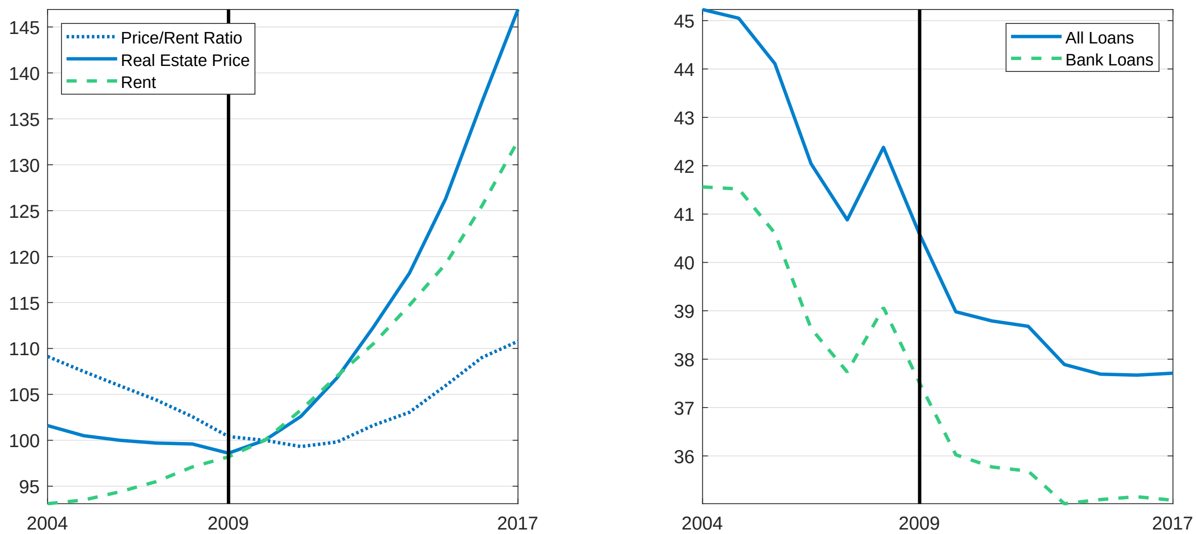
To assess and quantify this channel empirically, we assemble a database that includes aggregate and region-level data described in detail in Section 3. The size of the ECB's total assets as a share of nominal euro area GDP is our proxy for QE. However, our results are robust to a number of alternative proxy variables for QE. The EONIA rate controls for the traditional interest rate policy. As empirical measure of the housing portfolio returns, we use the rental to price ratio (rental yields) at both the national and regional level. As we document in in Appendix B, the rental yield can predict a large portion of the expected future housing returns at medium-to-long run horizons in the data. Next, we construct a new matched region-level data set. Unfortunately, regional consumption data are not available in Germany. We use real per capita GDP growth instead, ruling out QE effects through residential investments by using detailed data on building permits. We match regional output data with a proprietary database on apartments prices and rents from Bulwiengesa AG (a reputable German real estate data provider), and detailed land-use and land-cover data from a German granular database.[3]

[2]Germany is not the only case that markedly differs from the well-know and intensively researched US case. China's housing boom has also been creditless until very recently. Emerging markets have long experienced boom bust cycles in housing and consumption, despite suffering from chronic domestic financial underdevelopment (Cesa-Bianchi, Ferrero and Rebucci, 2018). See Figure C.1 for a cross-country comparison of average household credit to GDP during 2010-2017.

[3]The segment of the residential housing market on which we focus on is the most prevalent housing

Figure 1 Germany: A Housing Boom without Credit Boom

Panel A: Residential house price and rent indexes (2010=100)   B: Domestic housing credit to households (% GDP)



Note. Panel A plots national residential house price and rent indexes, and their ratio. Panel B plots the stock of loans for housing purposes to households as a percentage of GDP. The vertical lines mark the beginning of the German recovery in 2009. See the Data Appendix for variable definitions and data sources.

To establish causation, we rely on identification by geographic variation. In particular, we interact the aggregate monetary policy indicators (QE and the EONIA rate) with an indicator of land scarcity based on detailed land-use and land-cover data that varies across regions quasi-randomly and is kept constant over time at its pre-sample value in 2008. This measure is the share of land covered by water bodies and urban open space – a land supply scarcity measure in the spirit of Saiz (2010). As we show in the paper, this indicator has a very tight association with regional rental yields and hence expected future housing returns across German regions.

The main empirical finding of the paper is that QE leads to a larger impact on output growth in regions with more land scarcity, and the housing portfolio channel can account for the bulk of the total QE impact. We estimate that, during the 2010-2017 period, for each one-standard deviation increase in QE, regions at the 75 percentile of the land scarcity distribution grow 2-3 percentage points more, cumulatively, than regions at the 25th percentile. We also estimate that our housing portfolio channel accounts for between 60% and

solution, especially in the rental market. Recall here that despite the high share of real estate in total household assets and net worth, Germany has one of the lowest home ownership rates among advanced economies with a significant share not occupied real estate in the portfolio (see Cesa-Bianchi, Ferrero and Rebucci 2018).

80% of the total QE effect. The second largest contributor is the term spread, accounting for about 20%. This result holds after controlling for the EONIA (a measure for the traditional interest rate policy), other channels of transmission likely at work and various additional confounding factors. Interest rate policy, in particular, has no differential effect on regional output growth once we control for QE.

Specifically, in order to quantify the relative importance of the housing portfolio channel relative to alternative mechanisms, we run a horse race between rental yields (as predictors of expected housing returns that drive the consumption increase in our theoretical model) and other candidate mediating variables. These include the price and the volume of credit, the level of real house prices, as in typical collateral channel specifications, and the term spread. We find that the statistical significance of the QE effects disappears once our regressions control for the aggregate rental yield. In contrast, proxy variables for the traditional credit and collateral channels do not have the same "absorbing" effect. Importantly, an increase in banks' mortgage origination does not reduce the statistical or economic significance of QE, so that the classical bank lending channel of monetary policy does not seem to explain our results. A similar conclusion applies to all other mediating variables considered, even though, when we consider them all together in one specification, we run into issues of multicollinearity. To deal with this, we resort to regional credit data and, in unreported regressions, we find that there is no impact on credit, consistent with the stylized facts of the German housing boom discussed before. In particular, this holds when we control for housing prices, suggesting that the collateral channel, as in Chaney, Sraer and Thesmar (2012), Mian, Rao and Sufi (2013) and Greenwald and Guren (2019), cannot explain our empirical findings. We interpret this evidence as suggesting that these channels cannot be dominating in the German case, consistent with the macroeconomic evidence reported above showing that Germany has been experiencing a house price boom without a credit boom since 2009.[4]

We complement the reduced form analysis above by an instrumental variable specification at the regional level, i.e., using the interaction of aggregate QE measure and regional land scarcity as an instrument for the regional rental yields, as in Chaney, Sraer and Thesmar (2012) and Aladangady (2017). We find that our instrument is relevant and QE affects the regional output growth differentials through region-level expected future housing returns, as predicted by rental yields.

Finally, we show that there are significant cross-regional differences in the intensity of QE's output growth effects depending on the regions' characteristics. Here, we show that our

[4]Indeed, Bednarek, te Kaat, Ma and Rebucci (forthcoming) show that the collateral channel has an important role in explaining *commercial* real estate market dynamics, but not the residential one, in response to a capital flow shock in the same data.

results are driven by the wealthier and more densely populated regions. In contrast, in the least densely populated areas, the traditional interest rate channel plays a more prominent role than QE.

Literature Review Our paper relates to the literature along multiple dimensions. First, there is a large literature on the financial and real effects of Fed and ECB QE focusing on bank and firm behavior, as well as macroeconomic outcomes.[5] Kurtzman, Luck and Zimmermann (2017); Rodnyansky and Darmouni (2017); Chakraborty, Goldstein and MacKinlay (2019); Acharya, Eisert, Eufinger and Hirsch (2019); Todorov (2020) focus transmission through banks and on effects on bank and firm behavior and macroeconomic outcomes. Altavilla, Burlon, Giannetti and Holton (2019a); Bottero, Minoiu, Peydró, Polo, Presbitero and Sette (2019); Heider, Saidi and Schepens (2019); Bubeck, Maddaloni and Peydró (2020) focused on ECB's NIR policy. Eberly, Stock and Wright (2019); Luck and Zimmermann (2020); Fabo, Jančoková, Kempf and Pástor (2021) focus on the macroeconomic effects. We propose a new channel.

Second, our paper belongs to the very large literature on house prices, credit, and household consumption and firm investment. For example, Iacoviello (2005) and Liu et al. (2013) develop closed-economy DSGE models in which house price increases have real aggregate effects through the collateral channel, either on the household or the firm side. Chaney, Sraer and Thesmar (2012) use US firm-level data to empirically show that an exogenous variation in property prices triggered by aggregate mortgage rate changes can have a sizable impact on corporate investment. Using the same identification strategy, Aladangady (2017) shows that house price increases also raise consumer spending. A critical difference here is that the housing portfolio channel that we study does not depend on higher house prices relaxing a binding collateral constraint. Instead, the transmission mechanism works through expected future housing returns and applies to house price booms without credit booms.

Third, the new portfolio channel that we propose speaks to the literature that views housing as a risky asset in household portfolios. For example, Flavin and Yamashita (2002) study the impact of the constraint imposed by housing demand on optimal holding of financial assets. In other words, they emphasize the importance of real estate holding in determining other asset's shares in the investor portfolio. However, they only consider the optimal portfolio of owner-occupiers and do not explicitly model life-cycle income and saving decisions of the household. Yao and Zhang (2005), however, emphasize the importance of housing choice in shaping the portfolio of financing assets using a life-cycle model and allow

[5]See Carlson, D'Amico, Fuentes-Albero, Schlusche and Wood (2020) for a survey overview of studies examining the financial and real consequences of QE. See Fabo, Jančoková, Kempf and Pástor (2021) for a meta study on the effectiveness of those policies.

households choose whether to own or rent housing in each period. They show that renters and owners have rather different portfolios of financial assets because house prices are uncertain and volatile on the one hand and homeowners can use home equity as a buffer against income shock on the other hand. Consistent with both the previous two studies, we also highlight the importance of housing as one important component in household portfolios. But unlike those papers, we study portfolio rebalancing following a QE intervention and its effects on on consumption. Moreover, we do not differentiate between home owners and renters but solve a problem of delegated investment to financial intermediaries who solve the portfolio problem on behalf of the households. Our model thus relies on the segmented asset market hypothesis through preferred habitat investors, as for instance proposed by Vayanos and Vila (2021) and, in the international context, Greenwood et al. (2020), Maggiori (2021) and Gabaix and Maggiori (2015). The novelty of our contribution, here, is to focus on the portfolio implications of preferred habitat investing in the housing market.

Finally, we also contribute to the emerging literature studying the German post-2009 housing boom. Kindermann, Le Blanc, Piazzesi and Schneider (2020) use household survey data to study expectation formation during this boom. Bednarek, te Kaat, Ma and Rebucci (forthcoming) examine the transmission of a capital flow shock through residential and commercial real estate markets and finds that the collateral channel is at work in the commercial sector but not in the residential one. This paper focuses on monetary policy shocks and investigates an alternative, new channel of transmission through the residential real estate market that don't go through credit.

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 identification. Section 5 reports the main estimation results. Section 6 explores the transmission mechanism. Section 7 concludes. All technical details and selected additional estimation results are in an appendix at the end of the paper. All results not reported are available from the authors on request.

2 Model

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

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

2.1 Households

We consider a representative household that lives for two periods, today and tomorrow. We view this household as a representative citizen of a German city or region.[6] The consumer delegates his/her savings s to a financial intermediary that offers a composite return, r. This return will be determined by the equilibrium in financial markets. In other words, the consumers take the return as given and solve the following consumption/saving problem:

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

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

The optimality condition for this problem is

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

Therefore, the consumption response to return changes is given by

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

As we discuss below, under plausible assumptions on the correlation between the two asset returns, the return to saving falls in the model in response to QE. Thus, here, we seek conditions under which consumption increases in response to a decline in r. The denominator of (3) is negative as the marginal utility is decreasing in consumption. Given CRRA preferences with risk aversion coefficient σ, the numerator is given by $(1-\sigma)\beta c'^{-\sigma}$. Thus, in this two-period set up, consumption increases in response to a reduction in r (i.e., $\frac{dc}{dr} < 0$) when $\sigma < 1$, or the intertemporal elasticity of substitution (EIS) is larger than 1.[7]

[6] There is only one region in the benchmark model. Extending the model to multiple regions is work in progress and does not alters the main results on the QE transmission.

[7] Wealth effects through discounting would arise in a multi-period or infinite-horizon version of the model,

2.2 Intermediaries

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

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

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

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

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

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

The preferred habitat investors are passive in our model. They just absorb the excess demand at given market prices. Moreover, they do not arbitrage across markets. Therefore, they segment the two asset markets. The underlying rationale is that both housing and bond markets have a specialized investor base. In the case of the local housing in our model, these investors are homeowners and they will sell to national home investors (or buyers to let in other regions) through the national arbitragers.

The national arbitragers are market players that hold houses and long-term bonds for financial investment purposes. Specifically, we assume that there exists a national arbitrager, delegated by the representative household to trade a portfolio of both assets. One important assumption here is that the national arbitrager has a mean-variance utility and thus limited risk-bearing capacity. Otherwise, the price of risky assets would only reflect their expected payoffs with no price impact stemming from changes in the quantity of assets supplied. In addition to the two risky assets, the arbitragers also have access to a storage technology, x, that for simplicity, but without loss of generality, pays a zero return. This assumption allows us to derive analytical solutions.[8]

In each period, the arbitragers choose their portfolio of houses, h, and bonds, b, and

allowing us to relax this assumption.

[8]An alternative, here, is to introduce short-term bonds as a third traded assets, or adding an exogenous process for the short-term interest rate controlled by the central bank. As we shall see empirically, however, QE absorbs the effect of the monetary policy rate. For this reason, we do not model this channel of monetary policy transmission explicitly.

storage technology, x, solving the following problem:

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

where γ is the arbitrager's risk aversion coefficient and W is her initial wealth. The optimality conditions are:

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

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

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

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

where $\bar{h}$ and $\bar{b}$ are the total supply of houses and bonds, respectively. Thus, all else equal, cities and regions with lower housing supply have tighter housing markets.

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

2.3 Real Effects of QE via Housing Portfolio Rebalancing

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

To analyze the impact of QE, we consider the following comparative statistics with respect to 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. In particular, QE reduces the bond holding of the financial arbitrager and pushes up the bond price. This is intuitive because QE drives down the total bond supply available to investors. Other things equal, the bond price has to increase to accommodate the excess demand. As a result, the bond return falls in response to the QE intervention. This induces financial arbitragers to reduce their portfolio loading of risky bonds.

The impact of a reduction in $\bar{b}$ on the housing market is ambiguous and depends on the covariance between bond and house returns, σ_{12}, that affects houses' risk-adjusted returns, as the proposition below illustrates.

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

Proof. See Appendix A. □

Houses and bonds are substitutes in the arbitrager's portfolio when their payoffs are positively correlated. A drop in bond holdings, b, reduces the risk contribution of housing in the portfolio through the last term in equation (8). In equilibrium, the arbitragers increase their exposure to houses. As a result, the house holdings of the preferred habitat investors (the home-owners in our model) have to fall to accommodate the increased demand of the arbitragers (the buyer to let in our model) for given supply, which in equilibrium pushes up house prices.

Notice here that this channel relies on the payoff structure of risky assets and the mean-variance utility assumption. The response of housing portfolios and house prices to QE is zero when the payoff correlation between bonds and houses is zero, i.e., $\sigma_{12} = 0$ or the arbitrager's risk aversion is zero, i.e., $\gamma = 0$. Also, note that, while the arbitrager's risk aversion in the model is exogenous and constant, in richer set ups and in practice in the data, it is time-varying. So one could think about QE working through its impact on risk aversion as well. However, in our model, a change in γ has a different transmission from a reduction in $\bar{b}$.[9] For this reason, in the empirical analysis, we control for the impact of QE via risk aversion by holding constant global and regional proxy measures for risk aversion, such as the VIX index or the GIPS bond spread.

As the financial arbitragers respond to QE by adjusting their portfolios, the return that they deliver to the households also changes. For simplicity, we specify the portfolio return omitting capital gains and considering only the expected yields of the two assets, i.e., $r = h\mu_1 + b\mu_2$.[10] Intuitively, QE induces the arbitragers to hold fewer bonds, b, and more houses, h. Therefore, the impact on the total portfolio return depends on the relative strength of these two forces. The following proposition summarizes the results.

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

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

Proof. See Appendix A. □

2.4 Empirical Implications

Albeit simple, our model has a rich set of implications for the data that inform our empirical analysis. Assuming a sufficiently high household EIS and a positive but sufficiently low correlation between bond and house price returns, the model has following implications:

- Bond holdings go down, bond prices increase;
- House holdings and prices go up, assuming a positive correlation between housing and bond returns consistent with the data.
- Overall, the household portfolio return decreases, assuming a moderate positive correlation between housing and bond returns;
- Consumption increases, assuming a sufficiently high household EIS.

[9] One can show that $\frac{db}{d\gamma}, \frac{dh}{d\gamma}, \frac{dP}{d\gamma}, \frac{dQ}{d\gamma} < 0$. If QE lowers the risk-aversion parameter γ for financial arbitragers or increases their risk capacity, they are more willing to take more positions on risky assets. Therefore, the portfolio rebalancing for the arbitrager would happen from riskless to risky assets, which would increase risky asset prices and lower expected returns.

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

In our empirical analysis, we will explore this channel of QE transmission in a cross-section of German urban and rural areas. Critically, for identification purposes, we will exploit the fact that regions in which land is scarcer should have a lower house supply, and thus a stronger portfolio return response to a QE intervention. In particular, in Appendix A, we show that the equilibrium portfolio return without capital gains is $r = h\mu_1 + b\mu_2$ and with capital gains is $r' = h\frac{\mu_1}{P} + b\frac{\mu_2}{Q}$. Both have a non-zero derivative with respect to $\bar{h}$, which provides the cross-regional identification. Furthermore, we show that the sensitivity of the portfolio return with capital gains to a QE intervention can also be identified by $\bar{h}$, i.e., $\frac{d}{dh}\left(\frac{dr'}{db}\right) \neq 0$.

The housing portfolio channel that we propose relies on the response of expected housing portfolio returns to the QE intervention. Empirically, we use the rent-to-price ratio (the rental yield) as a proxy for expected housing returns. As we document in Appendix B, the relationship between rental yields and expected future housing returns holds in historical German data, consistent with the evidence of Campbell and Shiller (1988) and Cochrane (2011), among others, in the case of the US. Specifically, we find that the rental yield explains a large fraction of expected future returns variability at medium-to-long term horizons.

3 Data

To conduct the empirical analysis, we assemble a unique region-level data set including all 401 German administrative regions at the annual frequency, from 2010 to 2017. In addition to official region-level statistics, the data set includes a proprietary panel data set of nominal residential property price and rental indexes from Bulwiengesa AG and detailed land-use and land-cover data from the German Monitor of Settlement and Open Space Development (IOER Monitor).[11]

To construct these indexes by region, Bulwiengesa AG uses both valuation and transaction data from building and loan associations, research institutions, realtor associations, as well as the chambers of industry and commerce. Residential price and rent indexes are at the annual frequency and include the price of owner-occupied existing and newly-constructed apartments. They are calculated at the region level as simple averages of the individual unit prices and rents.[12] Thus, they can be seen as common region-level factors for unit-specific prices and rents — see, for instance, Pesaran (2015). As city-level CPI indexes are not

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

[12] In principal, house price data are also available for town houses and single-family detached homes. However, Bulwiengesa only provides rental information for apartments. Our results are essentially unaffected when we also include town houses and single-family homes in the construction of our house price index (result available upon request).

available, we deflate nominal property price and rent indexes by using state-level official consumer price indexes.

In our instrumental variable estimation, we also use Bulwiengesa regional price and rent indexes to calculate regional rental yields as predictors of expected future housing returns as we discussed above. To this end, we initialize the rental yields for all regions to a value of 5.38% in 2009 — the value reported in the Macrohistory Database of Jordà et al. (2017) and Jordà et al. (2019) for Germany. Then, this initial value is inflated by using the rate of growth of the region-specific ratio between the rental and price indexes.

In order to construct our instrument used throughout the paper, described in Section 4, we employ land-use data from the 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 real estate supply. Finally, we also match several other region-level variables to our data set, including population density, the number of building permits as well as demographic variables. These variables are sourced from the INKAR database as detailed in the Data Appendix.[13]

The dependent variable in our main region-level regressions is real per capita GDP growth. Again, as region-level price inflation data are not available, we deflate nominal GDP growth by using the same official state-level consumer price inflation data used to construct real property price indexes. The matching of the region-level data is based on a common region identifier.

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

Although we do not provide the summary statistics separately for regions in the West and East of Germany, some significant differences stand out. Real GDP growth is higher

[13] While the IOER data are based on the 2017 territorial status of German regions and real estate prices are based on the 2018 territorial status, the GDP data are based on the 2019 territorial status. However, only three municipalities have been incorporated into a different administrative region between 2017 and 2019 and, in cases where this happened, only 2-2.7% of the population in the respective administrative region switched borders. The different territorial statuses of the data are therefore highly unlikely to affect our estimations. In fact, our results are unchanged when we drop from the sample those administrative regions where a change in the territorial status happened since 2017.

in the East than in the West of Germany on average (2.7% vs 2.2%, respectively). East Germany is much less densely populated (333 vs 566 people per square kilometer) and land in East Germany is on average more intensively used for or covered by urban open space (2% vs 1.6%), agricultural land (53% vs 47.3%) and water bodies (2.7% vs 1.9%). In contrast, forests cover a larger share of land in the West (30.2% vs 29.4%).

The main proxy of the ECB's quantitative easing policy stance is the size of the Eurosystem's consolidated balance sheet relative to Euro Area nominal GDP, henceforth just called the size of the *ECB*'s balance sheet for brevity.[14] In a robustness check, we also use specific portions of the balance sheet, distinguishing between total debt securities, government debt securities, private sector debt securities and debt securities issued by banks. This, however, does not affect our estimates, which is not surprising given correlations in the range of 85-98% among the different balance sheet components. To control for the ECB's interest rate policy, we use the EONIA rate, which is the weighted average of all overnight unsecured lending transactions in the interbank market of the European Monetary Union. Again, results are robust to using alternative proxy variables for the ECB policy rate.

Additional macroeconomic variables used in the empirical analysis are the following: government consumption over GDP and the share of the government's net lending to GDP, both of which are important to control for the stance of fiscal policy; the average government bond spread of Greece, Italy, Portugal and Spain relative to Germany (the so called GIPS spread) and the CBOE volatility index (VIX),[15] both of which are measures of financial risk and uncertainty that are particularly sensitive to global or regional investors' risk aversion; the German term spread, defined as the difference between the 10-year German government bond yield and the EONIA rate;[16] and four national variables related to the German housing 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 C.2 also reports the summary statistics for all of the macroeconomic variables. During our 2010-2017 sample period, the size of the ECB's balance sheet on average was 28.1% of nominal GDP, with a maximum of 39.9 %. The average value of the EONIA rate was 0.1%, ranging from -0.4% to 0.9%. While government bonds in the South of Europe

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

[15] For both variables, we use annual averages, and not the year-end values, to prevent the annual values to be driven by outliers.

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

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%.

Tables C.3 and C.4 of the Appendix report the correlations between selected regional and aggregate variables, respectively. The correlation coefficients among the regional characteristics that we consider are relatively low. As one might expect, QE and the EONIA rate have a sizable negative correlation of -51%, consistent with the view that QE and interest rate policies may be complement each other rather than substitutes. Further, both monetary policy tools have a tight relation with rental yields, the term spread, the average mortgage interest rate and the national house price index. In contrast, their associations with changes in the volume of mortgage credit are very weak.

4 Identification

Empirically, the critical challenge is to identify exogenous variation in housing returns in response to QE interventions. We address this issue by exploiting regional variation in land supply, and hence house supply elasticity in the spirit of Saiz (2010). Consistent with the model set up, our hypothesis is that the tighter a region's housing supply is, the more significant is the impact of QE on the region's housing returns, and hence consumption and output growth. This is the case because, as we noted earlier, in a given local real estate market, all else equal, a lower housing supply translates into a higher sensitivity of housing returns to changes in QE, as portfolios rebalance from bonds to houses.

In order to proxy for the elasticity of housing supply, we use a measure of land scarcity, as discussed in more detail below. The underlying idea is that if a larger fraction of a region's reference area is covered by non-developable land (e.g., water bodies), new construction is constrained and the regional housing supply should be lower. Equipped with an exogenous region-level indicator of housing elasticity, we use this regional variation as a source of "exposure" to housing shocks. We then interact this exposure measure with QE changes over time to estimate the differential effects of QE on housing returns and GDP growth, both in reduced form and instrumental variables (IV) specifications. As we noted earlier, we proxy for future expected housing returns with rental yields that we show predict returns well in historical German data at medium-to-long term horizons, reporting details in Appendix B.

The reduced form specifications that we report regress regional output growth on the interaction between the aggregate measure of quantitative easing and the region-level exposure variable, controlling for the corresponding interactions between exposure and the EONIA, as well as other potentially confounding factors, such as fiscal policy changes or global and regional investors' risk aversion. Our hypothesis is that the impact of QE is stronger in regions with scarcer land supply, consistent with our model that predicts QE to lower bond returns and to induce households to rebalance their portfolios towards housing, thus reducing expected housing returns and increasing households' current consumption. By showing that, in our reduced form set up, the statistical and economic significance of the QE interaction decreases once we control for the mediating role of national rental yields as a proxy for expected housing returns in Germany, we also provide empirical evidence that households' portfolio rebalancing is the main transmission mechanism from QE to regional economic activity.

The IV specification that we estimate uses the component of the regional rental yields variation predicted by the interaction between QE and our exposure variable, yielding an IV estimate of the differential impact on output growth through the proposed housing portfolio channel. While QE can be endogenous to economic conditions in individual German regions in which banking activity is concentrated, its interaction with this exposure measure, whose city distribution is assumed to be orthogonal to local and aggregate economic conditions, provides a quasi-random source of variation in the intensity with which QE impacts different cities' level of economic activity. Taken together, these two steps can therefore provide a causal estimate of the causal effects of QE on region output growth *through* housing return changes as predicted by our simple model. Thus, our identification strategy is one of identification by geographic variation, grounded on the availability of an indicator of land supply scarcity that varies quasi-randomly across regions.

Table 1 reports the correlations between rental yields, our main predictor of housing returns, for each of the 401 regions averaged over the 2010-2017 period, and alternative pre-sample supply scarcity measures that we consider. These indicators are in percent of the total reference area and capture regional variation in geography and land-use regulations. The table shows that "Open Space", the complement of land available for settlement, transportation and infrastructure (or the city boundary), does not correlate negatively with rental yields. The driver of this positive correlation is the share of land covered by forests that has a strong positive correlation with rental yields, possibly capturing urban sprawl in the sense of Ehrlich, Hilber and Schöni (2018), rather than supply scarcity. Table 1 also shows that agricultural land, one major sub-component of open space, is positively correlated with expected housing returns in East Germany, which may proxy for economic underdevelopment rather than land scarcity. In contrast, both land covered by water bodies and other open space (e.g., marsh land) have a negative correlation with yields. However, this correlation

Table 1 RENTAL YIELDS AND ALTERNATIVE SUPPLY 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	-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)

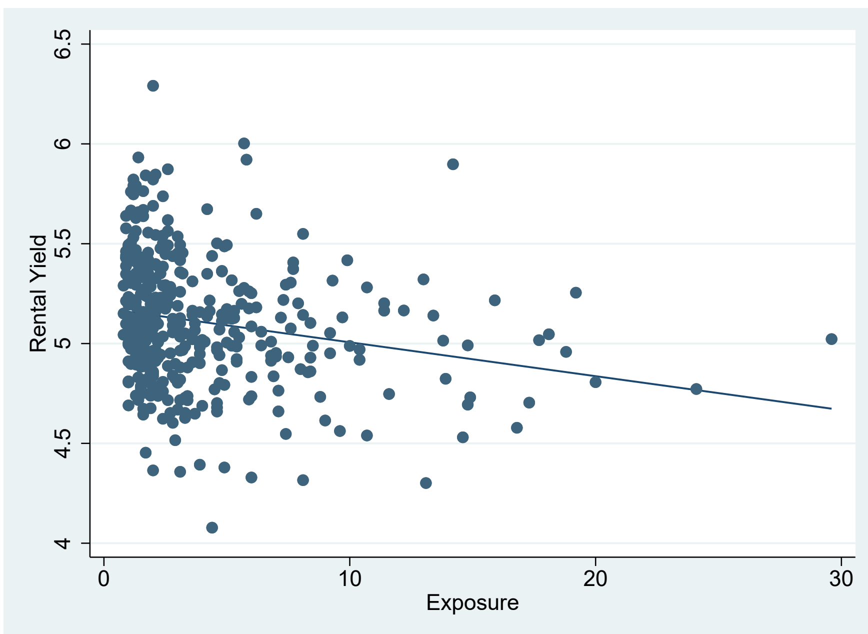
NOTE. This table reports the correlation between the 2008 value of alternative land supply scarcity indicators and the average region-level rental yield (as our proxy for housing returns) during 2010-2017. The correlations are reported for the full sample of 401 regions, for West German and East German only. P-values are in parenthesis. See the Data Appendix for sources and definitions.

is statistically significant only for land covered by water bodies. The table also shows that "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. Based on this evidence, we construct our land supply scarcity indicator as the ratio of land covered by water bodies and urban open space relative to the total reference area of a given region.[17] Even though this exposure measure has little time variation, we hold it constant at the pre-sample value of 2008 to isolate the time-varying effect of monetary policy.

As can be seen from Figure 2, there is a tight negative relation between this exposure measure and rental yields, equal to -21%. Formal econometric evidence on the relevance condition for the instrument will be presented together with the results for the first stage regressions of the econometric specifications that we use in Section 6. So, we can now move on to the presentation of the main reduced form empirical results of the paper, using our "exposure" measure interacted with the two main ECB policy indicators (i.e., the EONIA and the size of the ECB's balance sheet to nominal GDP) to investigate their differential impact on regional output growth through housing portfolio rebalancing.

[17] We obtain similar results when using the share of water bodies or urban open space only, or when including other open spaces in the construction of the exposure measure. The results are available upon request.

Figure 2 Rental Yield and the Exposure Measure



Note. This figure plots the relationship between average region-level rental yields during 2010-2017 and our region-level exposure measure, defined as the 2008 ratio of land covered by water bodies and urban open space to the total reference area of a region. The correlation coefficient is equal to -21% with a p-value of 0.

5 Estimating the Real Effects of QE

In our theoretical model, a QE intervention increases bond prices and lowers its returns, inducing a portfolio rebalancing towards housing. Assuming that housing and bond returns are positively, but not too strongly correlated, house prices also increase, depressing expected housing returns and lowering the overall portfolio return and thereby stimulating consumption and output. The model also implies that the effects should be stronger, the lower a region's housing supply.

In this section, we explore this housing portfolio channel of QE transmission empirically by exploiting the regional quasi-random variation in the measure of land supply scarcity discussed above to achieve identification. Our main "instrument" is the interaction of the GDP share of assets held by the ECB (as a proxy for QE policy) with the regions' exposure to the channel in 2008. As the ECB implements monetary policy using both QE and the policy rate during the sample period, and interest rate policy is transmitted in the same way, throughout the analysis, we always control for the corresponding interaction between exposure and the EONIA interest rate. As we will see, however, QE policy absorbs the effects through the EONIA interest rate. While both indicators of the ECB monetary policy may be endogenous to conditions in individual German regions, their interactions with the exposure measure, whose regional distribution is assumed to be orthogonal to local and aggregate economic conditions, provides an exogenous source of variation in the intensity with which monetary policy impacts economic activity. As there are no regional data on consumption, we focus on output data.[18]

5.1 Reduced Form Estimates

We start by estimating the following region-level reduced form regression:

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

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

[18] Results based on regional employment rates, which may be more closely associated with consumption, are similar and available on request.

and common factors across regions in the German business cycle.

Table 2 Monetary Policy and Regional Output Growth: Reduced Form Estimates

	(1) ΔGDP	(2) ΔGDP	(3) ΔGDP	(4) ΔGDP	(5) ΔGDP	(6) ΔGDP	(7) ΔGDP	(8) ΔGDP
Exposure$_{r,2008}$ × 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)
Exposure$_{r,2008}$ × 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)
Exposure$_{r,2008}$ × QE$_t$ × EONIA$_t$				0.013				
				(0.010)				
Pop. Dens$_{r,2008}$ × EONIA$_t$					0.000			
					(0.000)			
Pop. Dens$_{r,2008}$ × QE$_t$					0.000			
					(0.000)			
Age above 65$_{r,2008}$ × EONIA$_t$						-0.112		
						(0.069)		
Age above 65$_{r,2008}$ × QE$_t$						0.001		
						(0.005)		
Agriculture$_{r,2008}$ × EONIA$_t$							-0.006	
							(0.013)	
Agriculture$_{r,2008}$ × QE$_t$							0.001	
							(0.001)	
Permits$_{r,2008}$ × EONIA$_t$								-0.033
								(0.109)
Permits$_{r,2008}$ × QE$_t$								-0.003
								(0.002)
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3208	3208	3208	3136	3208	3208	3208	3208
R^2	0.264	0.265	0.265	0.266	0.266	0.266	0.266	0.266

Note. The regressions are based on annual region-level data over the period 2010-2017. The dependent variable is real 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 with the exposure measure. Columns (3)-(8) include both interactions at the same time. In Column (4), we also include a triple interaction between our exposure measure, QE and the EONIA. Columns (5)-(8) control for the interactions between the EONIA and QE, respectively, and the following regional 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 2 displays the empirical results. In column (1), we present a specification that includes only the EONIA interaction term. The estimated coefficient indicates that a lower EONIA leads to higher output growth in regions in which land is scarcer as captured by a negative interaction coefficient β, consistent with our theoretical priors. The impact is not only statistically but also economically significant: a one-standard deviation decrease (=0.4 percentage points) in the EONIA rate increases annual output growth of regions at the 75th percentile of the distribution (e.g., Tuebingen) by 9 basis points more than the regions at the 25th percentile (e.g., Bielefeld). Column (2) report the results on the impact of QE without controlling for the policy rate. A QE intervention, as measured by a higher ratio of central bank assets to GDP, also raises the output growth of regions in which land is scarcer. In economic terms, a one-standard deviation increase in ECB assets as a share of GDP (=6.5 percentage points) raises the annual output growth of regions at the 75th percentile by 15 basis points more than of regions at the 25th percentile.

In column (3), our preferred specification, we include both monetary policy instruments at the same time. Critically, the results show that QE absorbs the effects of the EONIA rate — a robust result across all of the specifications that we estimate. The economic growth differential induced by QE decreases only slightly in this regression and is now equal to 12 basis points. Considering the average increase in the share of ECB assets over GDP over our sample period, which was 14 percentage points (from a pre-sample average value of 14% 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 (=14/6.5*12) more on average per year than the least exposed regions during that period, or 2.1 percentage points more cumulatively between 2010 and 2017.

This evidence suggests that QE policy substitutes for interest rate policy via local residential real estate markets. To explore this further, in column (4), we add also a triple interaction between QE, the EONIA and the land scarcity indicator. While the double interaction between QE and exposure remains positive and statistically significant, both the triple interaction and the double interaction between the EONIA and exposure are statistically insignificant. The result suggests that QE and interest rate policy are more likely substitutes than complements in the housing portfolio channel of monetary policy transmission that we are focusing on.

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 control is important because more densely populated cities tend to grow faster due to agglomeration forces. In column (6), we add the interactions with the 2008 share of people aged 65 and older in order to control for demography. Column (7) holds the 2008 share of land covered by agriculture constant, assuming that this variable can proxy for the level of regional economic development, with less developed regions typically having a higher share of agricultural land.[19]

Finally, and most importantly, in column (8), we add the interactions between the two monetary policy tools and the number of building permits per 1,000 inhabitants. More permits means more construction activity, which affects output directly. So, here, the rationale is that our results might be driven by construction investment instead of consumption growth, as predicted by our model, if construction activity was more concentrated in regions with scarcer land supply. On the other hand, construction activity could also be *lower*, because more constrained, in regions in which land is more scarce, i.e., the values of our exposure measure is higher. So omitting to control for the number of new building permits could also result in a downward bias in our coefficient estimates.

The coefficient estimates in columns (5)-(8) show that the baseline results do not change after controlling for these regional characteristics. In particular, while the EONIA interaction remains statistically insignificant throughout, the QE interaction is positive and significant in all alternative specifications. If anything, including the additional interaction terms increases the size of the coefficient to a maximum value of 0.008 in column (7). This implies a QE-induced cumulative growth differential between more and less exposed regions of 2.9 percentage points.

The coefficient on the QE interaction term also increases, relative to the main specification in column (3), when we control for the number of building permits in column (8). This result, therefore, does not support the notion that the identified effects in the baseline reduced form specification are driven by the direct impact of increased construction activity in regions with scarcer land supply. On the contrary, it provides empirical evidence consistent with the mechanism in our model, where QE effects are stronger the tighter is the housing supply. Note also that none of the additional region-level covariates seems to play a separate role in explaining the differential impact of monetary policy on output growth.

5.2 Controlling for Fiscal Policy, Uncertainty and the ECB Balance Sheet Composition

We report additional robustness checks in Section D of the Appendix. Specifically, we saturate the regressions with the interactions between our exposure measure and two potential confounding factors: national fiscal policy as well as global and regional uncertainty measures. National fiscal policy is critical, as it was used actively in Germany during the sample period, and it is thus an aggregate factor correlated with monetary policy, affecting directly

[19] Agricultural intensity might also have a direct impact on GDP growth. At the same time, it has a relatively high and negative correlation of -43% with our exposure measure, as can be seen from Table C.3. As a result, our main estimates could be biased by its omission.

the stock of long-term bonds supplied to the market. Global and regional measures of risk and uncertainty are proxies for investors' risk aversion, and this is a channel through which monetary policy can also be transmitted in practice. Moreover, as we noted earlier, in our theoretical model, a shock to the arbitragers' risk aversion parameter would lead to an observational equivalent transmission in risky asset prices. These checks show that our baseline results are robust to these controls. The results are also robust when we use the QE and interest rate policy surprises identified in Altavilla et al. (2019b), rather than the EONIA and the size of the ECB's balance sheet, as proxies for the two monetary policy tools, even though we lose some statistical significance due to the double layer of instrumentation implicit in the estimation of this specification. We also corroborate the robustness of our main results to using specific portions of the ECB balance sheet, distinguishing between total debt securities, government debt securities, private sector debt securities and debt securities issued by banks.

Finally, 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 the regressors. The interaction between QE and land scarcity remains statistically significant, albeit at a slightly lower level of confidence. Taken together, these results provide strong evidence of a robust and economically sizable QE impact on regional economic activity, consistent with the posited housing portfolio channel embedded in our model.

6 Exploring the Transmission Mechanism

Having established that QE raises the output growth of regions with tighter land and hence housing supply, we now want to explore the mechanisms through which this outcome materializes. Specifically, we delve into the specifics of the portfolio channel of transmission posited in Section 2 by examining whether there is evidence in the data that QE reduces expected housing returns, thereby raising consumption and output. At the same time, we also want to rule out that these effects are driven by other channels of monetary policy transmission, including particularly the classical credit channel (Bernanke and Gertler 1995; Kashyap and Stein 2000) or the collateral channel as for example in Iacoviello (2005), Liu et al. (2013), Chaney et al. (2012) and Cloyne et al. (2019).

To isolate portfolio rebalancing as the main channel of transmission, we estimate four econometric specifications. First, we provide indirect evidence of housing portfolio rebalancing by controlling for the mediating role of an aggregate measure of the rental yield as a proxy for expected housing returns in Germany. The choice of the rental yield as a mediating variable is grounded in the evidence that Appendix B reports, where we show that the current rental yield explains a large fraction of expected future housing returns variability at medium-to-long term horizons. To the extent to which the rental yield absorbs the impact of QE, this is evidence that the relation between QE and regional outpt growth works through portfolio rebalancing towards housing, consistent with our model's implications. On the other hand, if the mechanism were to work through the credit market or the collateral channel, the quantity and price of mortgage credit, or the *level* of the national house price index should absorb the estimated impact of QE. In this part of the analysis, we also conduct a horse race between the QE-absorption capacity of the rental yield with these alternative mediating variables.

Second, to quantify the relative importance of the different channels in the overall QE impact, we exploit the time series variation in the data by predicting the alternative mediating variables that we use with QE. We then combine the coefficients from these time series predictions with the reduced form estimates to quantify the relative importance of the different channels.

Third, we also estimate the main reduced form specification splitting the sample in regions that are arguably more or less exposed to the housing portfolio channel that we contend is driving the results. In particular, we compare regions with a higher and lower share of wealthy households, more and less densely populated regions, as well as West and East German regions. If our results were indeed driven by a housing portfolio rebalancing mechanism, the effects should be stronger in wealthier and more densely populated regions and in West Germany.

Finally, we provide causal evidence on the impact of QE on output growth via a fall in the *regional* rental yields by estimating an instrumental variable specification. Here, we regress regional output growth on *regional* rental yields, instrumenting the latter by the interaction between QE and our regional land scarcity indicator. This last specification is similar to the one used in Chaney et al. (2012), Cloyne et al. (2019), Adelino et al. 2015, and Bednarek et al. forthcoming) among others.

6.1 Portfolio, Credit and Collateral Channels: Controlling for alternative Mediating Variables

The battery of regressions that we report in Table 3 controls for alternative candidate mediating variables, interacted with our regional exposure measure. Each of these mediating variable can potentially absorb the reduced form impact of QE on regional economic activity. Column (1) of Table 3 is the specification with our favourite candidate, the national rental yield as a proxy for expected future housing returns. Consistent with our model's predictions, the QE interaction loses its statistical significance once we control for the rental yield interaction, providing evidence that QE affects the real economy by reducing housing returns and increasing current expenditure. The interaction between the rental yield and the exposure variable has a negative sign and it is statistically significant at the 1% level, providing clear strong evidence that lower housing returns raise output growth in regions with more land scarcity.

Table 3 Reduced Form Estimates: Controlling for Alternative Mediating Variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	ΔGDP	ΔGDP	ΔGDP	ΔGDP	ΔGDP	ΔGDP	ΔGDP	ΔGDP	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)			
$\text{Exposure}_{r,2008} \times \Delta Credit$			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 are saturated with the following potential mediating variables, interacted with our exposure measure: the regional rental yield as a proxy for expected housing returns; the term spread; the log change in mortgage credit volumes; the average mortgage interest rate; and real national cumulative 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.

An alternative channel through which QE can affect both housing markets and output growth is via the term spread. This channel posits that non-conventional monetary policy, by flattening the yield curve, induces banks to rebalance their portfolios from financial assets towards credit, thereby inducing sizable real effects (Altavilla et al. 2019b and Bottero et al. 2019). We control for this channel with the interaction between exposure and the term spread, defined as the difference between German 10-year government bond yields and the EONIA rate.

Column (2) shows that the term spread can also absorb the significance of QE. However, once we include both mediating interaction variables simultaneously in column (6), the rental yield clearly dominates the term spread in terms of magnitude of the impact and its p-value. In fact, although both mechanism interactions are statistically insignificant, arguably due to the high correlation of 93% between both variables that inflates the standard errors, the coefficient estimate on the rental yields in column (6) has a much lower p-value of 13%, compared to 36% for the term spread.[20]

Other important channels through which QE can affect the residential real estate market and economic activity are the traditional credit channel of transmission of monetary policy, as in Bernanke and Gertler (1995), Kashyap and Stein (2000) and Jiménez et al. (2012), and the collateral channel. The credit channel can work through both the price and the quantity of credit. By increasing banking sector liquidity, QE can raise banks' mortgage credit supply to households. In addition, by lowering long-term government bond yields on which mortgage rates are benchmarked, QE can also put downward pressure on mortgage rates. Both effects, in turn, can raise mortgage demand and the equilibrium volume of mortgage credit. Increasing house prices can also boost the value of existing housing collateral and relax borrowing constraints, thereby stimulating credit demand, and household consumption, as shown by Cloyne et al. (2019), among others. To rule out the presence of these alternative channels, we first introduce the interaction with aggregate mortgage credit growth.[21] As column (3) shows, this control 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. Thus, increased availability of mortgage credit origination is unlikely to be the main driver of the impact of the QE impact on the regional output growth differential in our data, consistent with the evidence of aggregate deleveraging discussed in the introduction.

Note here that, in unreported regressions, we also matched bank-level mortgage data to the 401 administrative German regions, making use of a unique feature of the German banking system, which allows cooperative and savings banks to lend within their administrative region only. Including this disaggregated regional proxy for mortgage origination, we continue to find that the interaction between QE and exposure to be statistically significant.

Column (4) of Table 3 controls for the price of mortgage credit by interacting the exposure variable with the average German mortgage interest rate. Adding this control absorbs the statistical significance of the QE impact. However, in contrast to the specification in column

[20]To address the issue of a tight correlation between rental yields and the term spread, in an unreported regression, we replace the term spread with the residual that from a regression of the term spread on rental yields. In this case, while the QE and term spread interactions are statistically insignificant, the rental yield interaction is negative and significant at the 1% level.

[21]In unreported specifications, we show that all results are robust to using the level of mortgage credit scaled by nominal GDP.

(1), the interaction with the mortgage rate in column (4) is not statistically significant. In fact, when we add both variables at the same time, in column (8), only the rental yield interaction retains its statistical significance. The same is true when we control for the national cumulative house price growth, in columns (5) and (9), thus suggesting that the collateral channel is not the main transmission mechanism through which QE impacts the regional growth differential via the residential real estate market in Germany.

In sum, this evidence suggests that QE affects the regional output growth differential through the residential real estate market because it reduces housing returns, not because it flattens the yield curve, leads to higher mortgage supply, reduces mortgage rates, or raises the property prices and collateral values. Therefore, our results do not speak to the credit or collateral channels as the main sources of real effects of QE in Germany, consistent with clear macroeconomic evidence that Germany experienced a house price boom without a credit boom during our sample period.[22] Rather, our results are consistent with the housing portfolio channel that we illustrate in our model.

6.2 Quantifying the Importance of the Housing Portfolio Channel

Thus far, we showed that a decrease in the aggregate rental yield, used as a proxy for the expected future housing returns in our housing portfolio channel model, can explain the differential impact of QE across regions heterogeneous in their exposure to this channel. However, other traditional channels cannot be ruled out definitively as some of their corresponding mediating variables, like the term spread or the mortgage interest rate, are 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 that it is present and likely conspicuous during this sample period in which, at the macroeconomic level, there was a housing boom without a credit boom and even sharp household and bank deleveraging. We now want to quantify the importance of the housing portfolio channel relative to alternative channels, and particularly the collateral and credit channels. To do so, we first regress, in the time series dimension, the alternative mediating variables that we used in Table 3 on our QE measure. As we have only 8 years of data, we run these regressions at the monthly frequency, but the magnitude and the sign of the coefficients are consistent across the two frequencies. We then use these estimated coefficients, which are no causal impacts but rather conditional correlations, together with the estimates from Table 3, which we can interpret causally, to decompose the total impact of QE on the regional growth differential in its constituent parts.

[22]This is also consistent with aggregate data on household balance sheets showing that household leverage is very low and declining over our sample period (see Table C.5).

Table 4 reports the results for the predicting regressions, showing that QE predicts all mediating variables in the reduced form estimating equations in a highly significant manner and with the expected sign. One exception is the change in the aggregate mortgage credit, which is hardly affected by QE and seems to have the wrong sign, consistent with the aggregate evidence of deleveraging in Table C.5 and Figure 1 in the Introduction. The results are robust to running the regressions at the annual frequency, like in our reduced form specification, as can be seen from Table D.3.

Table 4 QE and Alternative Mediating Variables

	(1) Rental Yield	(2) Term Spread	(3) ΔCredit	(4) Mortgage Rate	(5) National HP Index
QE_t	-0.044***	-0.069***	-0.334*	-0.076***	1.076***
	(0.004)	(0.010)	(0.192)	(0.010)	(0.087)
Obs	96	96	96	96	96
R^2	0.546	0.287	0.024	0.306	0.554

Note. All regressions are based on monthly data over the period 2010:M1-2017:M12. The dependent variables are the following: Rental yield, interpolated from the quarterly OECD database on house prices and rents and initialized as the regional rental yields discussed in the Data Section above; the term spread, defined as the difference between 10-year government bond yield and the EONIA rate; the log-change in aggregate mortgage credit volumes; the average German mortgage interest rate; and the cumulative real house price growth rate, interpolated from the same quarterly OECD data above. The regressor is the ratio of financial assets held by the ECB over nominal GDP (QE) used in our baseline reduced-form specification. Heteroskedasticity-robust standard errors are shown in parentheses. *, ** and *** indicate statistical significance at the 10%, 5%, and 1% level, respectively.

Combining the two sets of estimated coefficients, the results of Tables 3 and 4 show that our housing portfolio channel is not only conspicuous, but dominates all other channels in the data. 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 3. The coefficient on the rental yield, -0.307, is the explained component by our channel, while the coefficient on QE, 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 -0.044 percentage point decline in the rental yield, causing an indirect effect on the regional growth differential via the rental yield equal to 0.0135 ($= -0.307 * -0.044$) and a direct effect through other channels of 0.003. The relative importance of the indirect QE impact via the rental yield, therefore, is 0.0135/0.0165 or 82%, where the total effect is $0.0165 = 0.003 + 0.0135$. Thus, only 18% of the total impact remains unexplained after controlling for the portfolio channel.

Obviously, the importance of the portfolio channel declines if we explicitly consider the alternative channels reported in columns (6)-(9) of Table 3 through which QE can affect the growth differentials across German regions. 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 3, the housing portfolio channel can explain 77-100% of the QE-induced growth differentials.

Finally, note that the relative importance of the housing portfolio channel further declines the more mediating variables we consider in the estimating specification. In the limit, when we include all five candidate channels in one (unreported) specification, we find that they are all insignificant. Nonetheless, when we include only those that are 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 QE impact and the corresponding rental yield interaction coefficient has a statistical significance just below the 10% level (p-value=0.13).

In sum, this analysis speaks to a substantial role of rental yields in the transmission of QE in explaining growth differentials across German regions, indicating that the bulk of the QE's real effects can be explained by the housing portfolio channel, consistent with the predictions of our theoretical model.

6.3 Regional Sub-samples

We now want to explore possible cross-regional differences in the reduced form coefficient estimates to cross-check the conclusions reached to this point. We expect that, if our empirical findings are indeed driven by the housing portfolio rebalancing that we postulated, the effect on the interaction between QE and exposure should be stronger in wealthier regions, in West Germany, and in more densely populated regions. To verify this conjecture, we split the regions in two sub-samples, for each of these three characteristics. First, in columns (1)-(2) of Table 5, we examine whether the relation between QE and the real economy differs in West and East German regions. The estimated coefficients show that QE interacted with land scarcity affects growth only in West Germany, whereas both QE and the EONIA are insignificant in the East. This is 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.

Further supporting this conclusion, columns (3)-(4) report results in which we split the sample in richer and poorer regions, finding that the interaction between QE and exposure is only statistically significant in regions with per capita GDP larger than the median of

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

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

NOTE. The regressions are based on annual region-level data over the period 2010-2017. The dependent variable is real GDP per capita growth. The main regressors are the interactions between the EONIA and the 2008 region-level value of our exposure measure and the share of central bank assets over GDP with the exposure measure. All regressions include region and time fixed effects. In columns (1) and (2), we divide the sample into West and East German regions. In columns (3) and (4), we differentiate between regions below and above the median of per capita GDP in the respective year and 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.

the respective year.[23] Finally, we also split the sample into regions with low and high population density, using the 25th percentile of the distribution as the threshold. We expect our baseline estimate to be stronger for more densely populated regions, where presumably a larger number of wealthy households is located. Interestingly, while the QE interaction turns out to be statistically significant only in the high population density sub-sample, as expected, the EONIA interaction is now negatively significant at the 10% level for regions with low population density, even after controlling for QE.[24]

In sum, this evidence consistently indicates that the relation between QE and output growth is detected in richer and more densely populated regions. This result is consistent with a portfolio rebalancing channel, which is more likely at work in regions with higher wealth. In contrast, we find that, in the least densely populated regions, the traditional interest rate channel of monetary policy remains important.

[23]This result is virtually unchanged if we base the sample split on GDP per capita in the year 2008.

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

6.4 IV Estimates of the Housing Portfolio Channel

Previous regressions yield evidence on the importance of QE interventions for output growth working through the mediating role of *national* rent yields. In this sub-section, we exploit *regional* rental yield data. Specifically, in order to show that QE affects regional economic activity by reducing regional rental yields, we regress regional output growth on region-level rental yields, instrumenting the latter with the interaction of QE and our main exposure measure. This approach is similar to Chaney et al. (2012) and Aladangady (2017), who interact the aggregate mortgage interest rate (our QE) with the housing supply elasticity of Saiz (2010) (our exposure measure) and then use the predicted component of local real estate prices to estimate their mediating effect on firm investment and household consumption in response to this common shock.

The first stage regression is specified as follows:

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

where Rental $\text{Yield}_{r,t}$ is the region-level rental yield and the regressor is the interaction between QE and region-level tightness in real estate markets. α_r and α_t are region and time fixed effects.

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

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

where the instrument for the rental yield is ($\text{QE}_t \times \text{Exposure}_{r,2008}$). In this specification, QE can affect regional output growth *via* the predicted component of region-level rent yield variations with a strength that depends on the housing supply elasticity, as captured by the land scarcity indicator.

Table 6 reports the first and second stage results. The first stage result, reported in 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. We thus also present a set of 2SLS regressions where we weight the observations by regional GDP per capita, following the previous evidence of an amplified effect of QE in wealthier parts of Germany. Doing so raises the F-statistic to a value of 13.3 (column 2), so that our second stage estimates are not subject to a potential weak instrument problem. Turning to the second stage results, columns (3)-(4) confirm the important role of rental yields in the transmission of QE to regional economic activity via the real estate market.

Table 6 REGIONAL OUTPUT GROWTH AND PROPERTY PRICES: INSTRUMENTAL VARIABLE RESULTS

	1st stage	1st stage	2nd stage	2nd stage
	(1)	(2)	(3)	(4)
	Rental Yield	Rental Yield	ΔGDP	ΔGDP
Exposure$_{r,2008}$ $\times$ QE$_t$	-0.001***	-0.001***		
	(0.000)	(0.000)		
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 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 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.

Specifically, lower rental yields, predicted by quantitative easing, can raise region-level output growth. The attendant coefficient estimates are statistically significant at the 5% level.

In our reduced form estimations, we show that the ECB's QE leads to higher growth rates in regions with scarcer land supply. The previous IV results show that all of this reduced form impact can 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 6, 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 2. The result that both reduced form and IV results yield equivalent economic magnitudes was to be expected from an econometric point of view. However, the novelty of this sub-section is that it gauges that *region-level* rental yields transmit QE to regional economic activity in Germany.

To sum up, the evidence reported in Section 6 establishes that, consistent with our theoretical model, household portfolio rebalancing, which reduces households' expected housing and total portfolio return and thus raises consumption, seems to be the main transmission mechanism of quantitative easing to economic activity, and quantitatively more important than alternative channels.

7 Conclusions

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

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

We find that the output growth impact of both lower monetary policy rates, as measured by the European overnight interbank market rate, and quantitative easing, as proxied by the ratio of financial assets held by the ECB over nominal GDP, is more significant in regions that are more exposed to land supply scarcity. However, we also find that QE dominates the traditional interest rate effect. Our estimates imply that the regions most exposed to real estate market tightness grow at least 2 percentage points more than the least exposed ones for each one-standard deviation increase in QE, cumulatively, during 2010-2017.

Empirically we also show that the mechanism through which this relationship materializes is consistent with our model. In particular, we find that QE affects output growth across German regions mainly by reducing expected housing returns. Alternative channels, such as credit and collateral channels, only play a secondary role in explaining our empirical results.

References

Acharya, Viral V, Tim Eisert, Christian Eufinger, and Christian Hirsch, "Whatever it takes: The real effects of unconventional monetary policy," *Review of Financial Studies*, 2019, *32* (9), 3366–3411.

Adelino, Manuel, Antoinette Schoar, and Felipe Severino, "House prices, collateral, and self-employment," *Journal of Financial Economics*, 2015, *117* (2), 288–306.

Aladangady, Aditya, "Housing wealth and consumption: Evidence from geographically-linked microdata," *American Economic Review*, 2017, *107* (11), 3415–46.

Altavilla, Carlo, Lorenzo Burlon, Mariassunta Giannetti, and Sarah Holton, "Is there a zero lower bound? The effects of negative policy rates on banks and firms," *ECB Working Paper*, 2019.

_ , Luca Brugnolini, Refet S Gürkaynak, Roberto Motto, and Giuseppe Ragusa, "Measuring euro area monetary policy," *Journal of Monetary Economics*, 2019, *108*, 162–179.

Bednarek, Peter, Daniel Marcel te Kaat, Chang Ma, and Alessandro Rebucci, "Capital flows, real estate, and local cycles: Evidence from German cities, banks, and firms," *Review of Financial Studies*, forthcoming.

Bernanke, Ben S and Mark Gertler, "Inside the black box: The credit channel of monetary policy transmission," *Journal of Economic Perspectives*, 1995, *9* (4), 27–48.

Bottero, Margherita, Ms Camelia Minoiu, José-Luis Peydró, Andrea Polo, Mr Andrea F Presbitero, and Enrico Sette, *Negative monetary policy rates and portfolio rebalancing: evidence from credit register data*, International Monetary Fund, 2019.

Bubeck, Johannes, Angela Maddaloni, and José-Luis Peydró, "Negative monetary policy rates and systemic banks' risk-taking: Evidence from the euro area securities register," *ECB Working Paper*, 2020.

Campbell, John Y and Robert J Shiller, "The dividend-price ratio and expectations of future dividends and discount factors," *Review of Financial Studies*, 1988, *1* (3), 195–228.

Carlson, Mark A, Stefania D'Amico, Cristina Fuentes-Albero, Bernd Schlusche, and Paul R Wood, "Issues in the Use of the Balance Sheet Tool," *FEDS Working Paper*, 2020.

Cerutti, Eugenio, Jihad Dagher, and Giovanni Dell'Ariccia, "Housing finance and real-estate booms: A cross-country perspective," *Journal of Housing Economics*, 2017, *38*, 1–13.

Cesa-Bianchi, Ambrogio, Andrea Ferrero, and Alessandro Rebucci, "International credit supply shocks," *Journal of International Economics*, 2018, *112*, 219–237.

Chakraborty, Indraneel, Itay Goldstein, and Andrew MacKinlay, "Monetary stimulus and bank lending," *Journal of Financial Economics*, 2019.

Chaney, Thomas, David Sraer, and David Thesmar, "The collateral channel: How real estate shocks affect corporate investment," *American Economic Review*, 2012, *102* (6), 2381–2409.

Cloyne, James, Kilian Huber, Ethan Ilzetzki, and Henrik Kleven, "The effect of house prices on household borrowing: A new approach," *American Economic Review*, 2019, *109* (6), 2104–36.

Cochrane, John H, "Presidential address: Discount rates," *Journal of Finance*, 2011, *66* (4), 1047–1108.

Davis, Morris A and Stijn Van Nieuwerburgh, "Housing, finance, and the macroeconomy," *Handbook of Regional and Urban Economics*, 2015.

Eberly, Janice, James H Stock, and Jonathan H Wright, "The Federal Reserve's current framework for monetary policy: A review and assessment," *NBER Working Paper No. 26002*, 2019.

Ehrlich, Maximilian V., Christian A.L. Hilber, and Olivier Schöni, "Institutional settings and urban sprawl: Evidence from Europe," *Journal of Housing Economics*, 2018, *42*, 4–18.

Fabo, Brian, Martina Jančoková, Elisabeth Kempf, and L'uboš Pástor, "Fifty shades of QE: Comparing findings of central bankers and academics," *Journal of Monetary Economics*, 2021.

Flavin, Marjorie and Takashi Yamashita, "Owner-occupied housing and the composition of the household portfolio," *American Economic Review*, 2002, *92* (1), 345–362.

Gabaix, Xavier and Matteo Maggiori, "International liquidity and exchange rate dynamics," *Quarterly Journal of Economics*, 2015, *130* (3), 1369–1420.

Greenwald, Daniel L and Adam Guren, "Do credit conditions move house prices?," *Working Paper*, 2019.

Greenwood, Robin, Samuel G Hanson, Jeremy C Stein, and Adi Sunderam, "A quantity-driven theory of term premia and exchange rates," *NBER Working Paper No. 27615*, 2020.

Heider, Florian, Farzad Saidi, and Glenn Schepens, "Life below zero: Bank lending under negative policy rates," *The Review of Financial Studies*, 2019, *32* (10), 3728–3761.

Iacoviello, Matteo, "House prices, borrowing constraints, and monetary policy in the business cycle," *American Economic Review*, 2005, *95* (3), 739–764.

Jiménez, Gabriel, Steven Ongena, José-Luis Peydró, and Jesús Saurina, "Credit supply and monetary policy: Identifying the bank balance-sheet channel with loan applications," *American Economic Review*, 2012, *102* (5), 2301–26.

Jordà, Òscar, Katharina Knoll, Dmitry Kuvshinov, Moritz Schularick, and Alan M Taylor, "The rate of return on everything, 1870–2015," *Quarterly Journal of Economics*, 2019, *134* (3), 1225–1298.

_ **, Moritz Schularick, and Alan M Taylor**, "Macrofinancial history and the new business cycle facts," *NBER Macroeconomics Annual*, 2017, *31* (1), 213–263.

Kashyap, Anil K and Jeremy C Stein, "What do a million observations on banks say about the transmission of monetary policy?," *American Economic Review*, 2000, *90* (3), 407–428.

Kindermann, Fabian, Julia Le Blanc, Monika Piazzesi, and Martin Schneider, "Learning about housing cost: Survey evidence from the German house price boom," *Working Paper*, 2020.

Kurtzman, Robert J, Stephan Luck, and Tom Zimmermann, "Did QE lead to lax bank lending standards? Evidence from the Federal Reserve's LSAPs," *Working Paper*, 2017.

Liu, Zheng, Pengfei Wang, and Tao Zha, "Land-price dynamics and macroeconomic fluctuations," *Econometrica*, 2013, *81* (3), 1147–1184.

Luck, Stephan and Tom Zimmermann, "Employment effects of unconventional monetary policy: Evidence from QE," *Journal of Financial Economics*, 2020, *135* (3), 678–703.

Maggiori, Matteo, "International macroeconomics with imperfect financial markets," *Working Paper*, 2021.

Mian, Atif, Kamalesh Rao, and Amir Sufi, "Household balance sheets, consumption, and the economic slump," *Quarterly Journal of Economics*, 2013, *128* (4), 1687–1726.

Pesaran, M Hashem, *Time series and panel data econometrics*, Oxford University Press, 2015.

Piazzesi, Monika and Martin Schneider, "Housing and macroeconomics," *Handbook of Macroeconomics*, 2016, *2*, 1547–1640.

Ray, Walker, "Monetary policy and the limits to arbitrage: Insights from a New Keynesian preferred habitat model," *Working Paper*, 2019.

Rodnyansky, Alexander and Olivier M Darmouni, "The effects of quantitative easing on bank lending behavior," *Review of Financial Studies*, 2017, *30* (11), 3858–3887.

Saiz, Albert, "The geographic determinants of housing supply," *Quarterly Journal of Economics*, 2010, *125* (3), 1253–1296.

Todorov, Karamfil, "Quantify the quantitative easing: Impact on bonds and corporate debt issuance," *Journal of Financial Economics*, 2020, *135* (2), 340–358.

Vayanos, Dimitri and Jean-Luc Vila, "A preferred-habitat model of the term structure of interest rates," *Econometrica*, 2021, *89* (1), 77–112.

Yao, Rui and Harold H Zhang, "Optimal consumption and portfolio choices with risky housing and borrowing constraints," *Review of Financial Studies*, 2005, *18* (1), 197–239.

A Model Derivations and Proofs

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

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

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

The comparative statistics with respect to $\bar{b}$ is given by

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

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

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

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

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

To summarize, a QE intervention leads to a decrease in b, an increase in h (portfolio rebalancing), which in the end results in a higher house price P and bond price Q.

We consider two specifications for the total portfolio return: one without capital gains,

$$r = h\mu_1 + b\mu_2,$$

and the other including capital gains,

$$r' = h\frac{\mu_1}{P} + b\frac{\mu_2}{Q}.$$

The following relationship holds:

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

$$\begin{aligned}
\frac{dr'}{d\bar{b}} &= \frac{\mu_1}{P}\left(\frac{dh}{d\bar{b}} - \frac{h}{P}\frac{dP}{d\bar{b}}\right) + \frac{\mu_2}{Q}\left(\frac{db}{d\bar{b}} - \frac{b}{Q}\frac{dQ}{d\bar{b}}\right) \\
&= \frac{\mu_1}{P}\left(1 - \frac{h}{\alpha_1 P}\right)\frac{dh}{d\bar{b}} + \frac{\mu_2}{Q}\left(1 - \frac{b}{\alpha_2 Q}\right)\frac{db}{d\bar{b}} + \frac{\mu_2 b}{\alpha_2 Q^2} \\
&= \frac{\mu_1}{\alpha_1 P^2}\left(\alpha_1\beta_1 - \bar{h}\right)\frac{dh}{d\bar{b}} + \frac{\mu_2}{\alpha_2 Q^2}\left(\alpha_2\beta_2 - \bar{b}\right)\frac{db}{d\bar{b}} + \frac{\mu_2 b}{\alpha_2 Q^2}
\end{aligned} \tag{A8}$$

Therefore, the impact of QE (i.e., $\bar{b}$) on the portfolio return depends on parameters. Specifically, we have that

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

and $\frac{dr'}{d\bar{b}} > 0$ iff

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

In other words, as long as the covariance term is low enough, the portfolio return declines following a QE intervention.

We also explore the connection between land scarcity and the portfolio returns. We model $\bar{h}$ as the regional land scarcity. In equilibrium, we have

$$\frac{dh}{d\bar{h}} = \frac{(1/\alpha_2 + \gamma\sigma_2^2)/\alpha_1}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} > 0 \tag{A9}$$

$$\frac{db}{d\bar{h}} = \frac{-\gamma\sigma_{12}/\alpha_1}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} < 0 \tag{A10}$$

$$\frac{dP}{d\bar{h}} = \frac{1}{\alpha_1}\left(\frac{dh}{d\bar{h}} - 1\right) \tag{A11}$$

$$\frac{dQ}{d\bar{h}} = \frac{1}{\alpha_2}\frac{db}{d\bar{h}} \tag{A12}$$

$$\frac{d}{d\bar{h}}\left(\frac{dh}{d\bar{b}}\right) = \frac{d}{d\bar{h}}\left(\frac{db}{d\bar{b}}\right) = \frac{d}{d\bar{h}}\left(\frac{dP}{d\bar{b}}\right) = \frac{d}{d\bar{h}}\left(\frac{dQ}{d\bar{b}}\right) = 0 \tag{A13}$$

Therefore, we have

$$\frac{dr}{d\bar{h}} = \frac{\mu_1(1/\alpha_2 + \gamma\sigma_2^2)/\alpha_1 - \mu_2\gamma\sigma_{12}/\alpha_1}{(1/\alpha_1 + \gamma\sigma_1^2)(1/\alpha_2 + \gamma\sigma_2^2) - \gamma^2\sigma_{12}^2} \neq 0$$

$$\frac{d}{d\bar{h}}\left(\frac{dr}{d\bar{b}}\right) = 0$$

$$\frac{dr'}{d\bar{h}} = \frac{\mu_1}{P}\left(1 - \frac{h}{\alpha_1 P}\right)\frac{dh}{d\bar{h}} + \frac{\mu_1 h}{\alpha_1 P^2} + \frac{\mu_2}{Q}\left(1 - \frac{b}{\alpha_2 Q}\right)\frac{db}{d\bar{h}} \neq 0$$

$$\frac{d}{d\bar{h}}\left(\frac{dr'}{d\bar{b}}\right) = -\left[\frac{2\mu_1(\alpha_1\beta_1 - \bar{h})}{\alpha_1 P^3} + \frac{\mu_1}{\alpha_1 P^2}\right]\frac{dh}{d\bar{b}} - \frac{2\mu_2(\alpha_2\beta_2 - \bar{b})}{\alpha_2 Q^3}\frac{db}{d\bar{b}} + \frac{\mu_2(\alpha_2 Q - 2b)}{\alpha_2^2 Q^3}\frac{db}{d\bar{h}} \neq 0$$

In this case, regions with different land scarcity $\bar{h}$ have different returns and return sensitivities to QE interventions. On exception is that the return without capital gains does not vary with $\bar{h}$ in its sensitivity to QE interventions. The return with capital gains, however, does.

B Return Predictability

Cochrane (2011) shows that current rental yields can predict future housing returns in the case of the United States. In this Online Appendix, we gauge that this is also true for Germany. To do so, we start from the present value identity, following Campbell and Shiller (1988) and Cochrane (2011), which is given as follows:

$$dp_t \approx \sum_{j=1}^{k} \rho^{j-1} r_{t+j} - \sum_{j=1}^{k} \rho^{j-1} \Delta d_{t+j} + \rho^k dp_{t+k} \tag{A1}$$

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

Then, we decompose this identity into three distinct regressions, again following Cochrane (2011), as follows:

$$\sum_{j=1}^{k} \rho^{j-1} r_{t+j} = a_r + b_r^k \times dp_t + \varepsilon_{t+k}^r \tag{A2}$$

$$\sum_{j=1}^{k} \rho^{j-1} \Delta d_{t+j} = a_d + b_{\Delta d}^k \times dp_t + \varepsilon_{t+k}^{\Delta d} \tag{A3}$$

$$dp_{t+k} = a_{dp} + b_{dp}^k \times dp_t + \varepsilon_{t+k}^{dp}. \tag{A4}$$

We estimate these regressions, using the Macrohistory Database of Jordà et al. (2017) and Jordà et al. (2019) that contains comprehensive data on housing returns in Germany, including the breakdown into capital gains and rental yields. In this respect, note that the Macrohistory Database calculates housing returns based on population-weighted average sales prices for urban areas in West Germany. When updating the database to the year 2017, we follow this strategy.[25]

Equipped with these data, we then run regressions of weighted excess long-run returns, rent growth and the future rent-to-price ratio on the current rental yield, as shown in equations (A2)-(A4), for the pre-sample period of 1963-2009 and using a ρ parameter of 0.96. The present value identity of Campbell and Shiller (1988) implies that these long-run coefficients should add up to 1:

$$1 \approx b_r^k - b_{\Delta d}^k + \rho^k b_{dp}^k. \tag{A5}$$

As can be seen from Table B.1, in most circumstances, this is indeed the case for Germany.[26] The regression coefficients can further be interpreted as the fractions of rental yield variation attributed to each source. They show that, for the 10-year and 15-year horizon,

[25] In particular, we use the rental yield from the Macrohistory Database for the year 2009 and allow this yield to change according to changes in our house price and rent index as follows: rental yield (t) = rental yield (2009)*(rent index/price index).

[26] Note that Cochrane (2011) uses rent growth implied by a standard return identity. We use actual rent growth in the regressions instead, which implies that the Cambpell–Shiller identity does not hold exactly, as approximation errors can show up.

Table B.1 LONG-RUN RETURN 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 regression 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 studied are 1, 5, 10 and 15 years.

a large fraction (if not all) of price-rent ratio volatility corresponds to variation in expected returns. A significantly smaller fraction corresponds to variation in expected rent growth or future price-to-rent ratios. This is evidence that, also in the case of Germany, current rental yields can predict future housing returns.

Based on this evidence, we could use the pre-sample coefficient estimates from Table B.1 and our in-sample values of rental yields to construct expected housing returns for our sample. However, for two reasons, we only use in-sample rental yields as a proxy for expected housing returns. First, the long-run coefficient estimates of a regression of future housing returns on current rental yields is close to 1, as shown in Table B.1. Second, from an econometric point of view, multiplying a variable (rental yields in our case) by a constant does not affect its statistical properties.

Taken together, and following the evidence of our theoretical model, this Appendix justifies our choice of the rental yield as the measure of expected housing returns, which is used as the main transmission variable of QE in our empirical analysis (see in particular Section 6).

C Data

Table C.1 Variable Definitions and Sources

Variable	Definition	Unit	Source
Prices	region r's residential house price index (new and existing apartments), deflated by state-level CPI	2009=100	Bulwiengesa
Rents	region r's residential rent index (new and existing apartments), deflated by state-level CPI	2009=100	Bulwiengesa
$RentalYield_r$	The initial rental yield reported in Jordà et al. (2019), inflated by Rents/Prices	2009=5.38%	Macrohistory and Bulwiengesa
ΔGDP	region r's growth in GDP per capita, deflated by state-level CPI	%	INKAR
Water	region r's share of land covered by water bodies in 2008	%	IOER Monitor
Agriculture	region r's share of land covered by agricultural land in 2008	%	IOER Monitor
Forest	region r's share of land covered by forests in 2008	%	IOER Monitor
Other Open Space	region r's share of land covered by other open space in 2008	%	IOER Monitor
Urban Open Space	region r's share of land covered by urban open space in 2008	%	IOER Monitor
Exposure	region r's share of land covered by water bodies and urban open space in 2008	%	IOER Monitor
Pop. Density	region r's number of inhabitants per square kilometer of land in 2008	-	INKAR
Age above 65	region r's share of people aged at least 65 in 2008	%	INKAR
Permits	region r's building permits per 1,000 inhabitants	-	INKAR
QE	The Eurosystem's total assets (consolidated) over nominal GDP	%	ECB
EONIA	The European interbank market rate	%	ECB
QE Shock	QE surprises identified in Altavilla et al. (2019b)	-	Altavilla et al. (2019b)
EONIA Shock	Interest rate surprises identified in Altavilla et al. (2019b)	-	Altavilla et al. (2019b)
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
$RentalYield_{aggr}$	The initial rental yield reported in Jordà et al. (2019), inflated by a national population-weighted rent-to-price ratio[a]	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
$\Delta Credit$	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] This rent-to-price ratio is based on West German cities only, following Jordà et al. (2019).

Table C.2 VARIABLE 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
$RentalYield_r$	3208	5.1	0.4	4.0	5.2	6.1
ΔGDP	3208	2.3	3.5	-6.6	2.2	11.9
Water	3208	2.0	2.6	0.3	1.3	13.3
Agriculture	3208	48.4	15.9	14.1	48.1	80.8
Forest	3208	30.1	15.1	2.2	29.4	63.6
Other Open Space	3208	1.0	1.6	0.0	0.4	6.3
Urban Open Space	3208	1.9	2.3	0.3	0.9	10.7
Exposure	3208	3.9	3.9	0.9	2.4	18.8
Pop. Density	3208	521.8	674.7	43.2	199.4	2797.6
Age above 65	3208	20.8	2.2	15.9	20.6	26.1
Permits	3208	2.9	1.8	0.5	2.5	8.4
QE	8	28.1	6.5	21.1	27.2	39.9
EONIA	8	0.1	0.4	-0.4	0.1	0.9
QE Shock	8	0.6	6.9	-9.4	0.1	11.3
EONIA Shock	8	-0.2	3.7	-7.9	-0.3	4.4
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
$RentalYield_{aggr}$	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
$\Delta Credit$	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 C.1 for data definitions and sources.

Table C.3 Regional Variable Correlations

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

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

Table C.4 Macroeconomic Variable Correlations Between

	QE	EONIA	Rental Yield	Term Spread	Mortgage Rate	$\Delta Credit$	National HP Index
QE	100.0						
EONIA	-51.4	100.0					
Rental Yield	-64.4	90.8	100.0				
Term Spread	-60.8	85.0	92.9	100.0			
Mortgage Rate	-84.2	62.2	72.6	72.8	100.0		
$\Delta Credit$	-17.0	-8.4	-20.2	-37.0	-11.7	100.0	
National HP Index	74.0	-87.6	-97.0	-85.8	-70.1	6.8	100.0

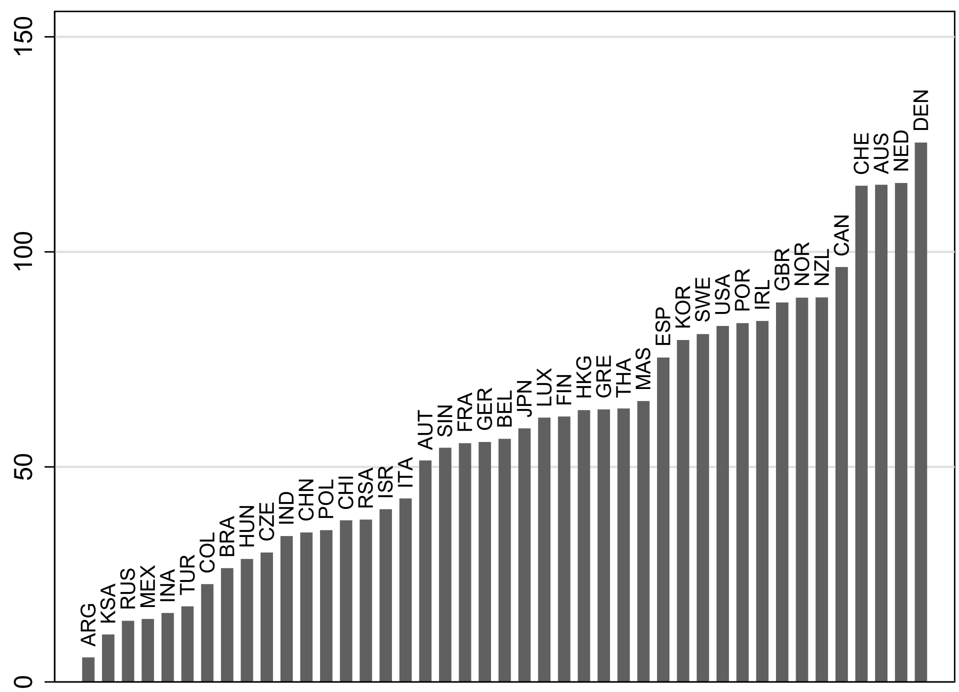
Note. The table reports the correlations between our main macroeconomic variables. The variable definitions and data sources are in Table C.1.

Table C.5 Household Balance Sheet Data

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Real Estate/Total Assets	0.55	0.55	0.55	0.55	0.54	0.53	0.54	0.54	0.56	0.55	0.55	0.56	0.56	0.55	0.55	0.55	0.55	0.56	0.57	0.56
Real Estate/Non-Financial Assets	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Real Estate/Liquid Assets	1.27	1.26	1.30	1.25	1.22	1.18	1.22	1.21	1.31	1.29	1.27	1.31	1.29	1.28	1.28	1.28	1.28	1.28	1.34	1.31
Real Estate/Net Worth	0.67	0.67	0.68	0.67	0.66	0.64	0.65	0.64	0.66	0.65	0.65	0.65	0.65	0.64	0.64	0.64	0.63	0.63	0.65	0.64
Leverage (Loans/Total Assets)	0.19	0.18	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.15	0.15	0.14	0.14	0.14	0.13	0.13	0.13	0.12	0.12	0.12

Note. The data are from the Federal Statistical Office (Destatis). Real estate assets are the sum of buildings, structures and land in the balance sheet of households and non-profit institutions serving households.

Figure C.1 HOUSEHOLD CREDIT AS A SHARE OF GDP: 2010-2017 AVERAGE



NOTE. The figure plots the average of household credit as a share of GDP during 2010-2017. The is from BIS.

D Robustness

This section reports several robustness checks. We start corroborating the robustness of our reduced form results to various alternative model specifications.

In columns (1)-(4) of Table D.1, we control for the interactions between land scarcity (our exposure measure) and other macroeconomic factors. 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 a shock to the arbitrager's risk aversion, in our model, implies a similar transmission via lower housing returns as a QE intervention. In order to capture risk aversion and financial uncertainty empirically, we use the spread of Southern European government bonds over the German Bund, which has also been employed in Bednarek et al. (forthcoming), and the CBOE volatility index (VIX). The attendant results show that QE affects the GDP growth distribution across regions, even after controlling for the GIPS spread or the VIX. If anything, the coefficient estimates increase in size relative to our main results in Table 2.

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 Global Financial Crisis. To the extent that new bond issuance from the national treasury accompanies (or offsets) higher ECB purchases of financial assets (more QE), this confounding factor will bias our results. To rule out this concern and control for German fiscal policy, we add in the regression the interactions between exposure and the share of government net lending over 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) reduce the growth rates of regions with tighter real estate markets relative to regions with less tight markets. Note also that, in all specifications of columns (1)-(4), the EONIA interaction is statistically insignificant, in line with our main results in Table 2.

As the next robustness check, we replace QE and the EONIA by their identified surprise counterparts, based on Altavilla et al. (2019b), who extract monetary policy surprises by estimating latent factors from changes in yields of financial assets. Again, as can be seen from column (5), our main results are robust, with the coefficient on the interaction with the QE surprise increasing in size, but being less precisely estimated, presumably due to the constructed nature of this variable. In addition, the interaction coefficient between the EONIA surprise and our scarcity indicator has the "wrong" sign.

Table D.1 Reduced Form Estimates: Robustness to Confounding Factors and Alternative Measures of QE

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

Note. The regressions are based on annual region-level data over the period 2010-2017. The dependent variable is real GDP per capita growth. The main regressors are the interactions between the EONIA and the 2008 regional value of our exposure measure, as well as between the share of central bank assets over GDP with the exposure measure. Columns (1)-(4) control for the corresponding interactions between the spread of 10-year government bonds in Greece, Italy, Portugal and Spin relative to Germany (GIPS Spread), the CBOE volatility index (VIX), the share of government lending over GDP and the share of government consumption over GDP. Column (5) replaces QE and the EONIA by the QE and interest rate surprises based on Altavilla et al. (2019b). 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.

In a next set of robustness exercises, we employ alternative QE measures. Specifically, we use the share of total debt securities held by the ECB over nominal euro area GDP and we also partition debt securities into government debt, financial sector debt and private sector debt. For reference, we also report our baseline QE proxy in column (1) of Table D.2. Note that, in this table, all QE proxies are standardized in order to make the coefficient estimates comparable across specifications. Given the substantial correlation between all of these QE measures in the range of 85-98%, our main results should be robust to employing these alternative measures. As becomes apparent, this is indeed the case. However, the estimate for QE approximated by debt securities (column 2) is larger than our baseline estimate (column 1). This larger coefficient size is driven by government debt securities, which themselves have the highest estimate in Table D.2, followed by private sector debt and financial debt. This result makes sense through the lens of our model. Given that government debt typically represents the largest fraction of households' bond holdings, especially higher ECB purchases of government bonds should depress households' total bond returns and induce them to rebalance their portfolio towards real estate, which reduces households' overall portfolio returns and increases consumption.

Table D.2 REDUCED FORM ESTIMATES:
ROBUSTNESS TO DIFFERENT ECB BALANCE SHEET COMPONENTS

	(1)	(2)	(3)	(4)	(5)
	ΔGDP	ΔGDP	ΔGDP	ΔGDP	ΔGDP
$\text{Exposure}_{r,2008} \times \text{EONIA}_t$	-0.015	0.035	0.037	0.021	0.023
	(0.039)	(0.059)	(0.059)	(0.057)	(0.055)
$\text{Exposure}_{r,2008} \times \text{QE}_t$	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)
Time FE	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes
Obs	3208	3208	3208	3208	3208
R^2	0.265	0.265	0.265	0.265	0.265

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 different QE proxies, standardized by subtracting the mean and dividing by the standard deviation, with the exposure measure. Specifically, column (1) uses our baseline QE variable for reference, which here is standardized as well. Column (2) uses the share of central bank bond securities over GDP. Columns (3)-(5) break this variable down into government debt securities, financial sector debt securities and private sector debt securities, all expressed as ratios 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.

As the final robustness check, we report the direct effects of QE on the candidate mediating variables, as initially done in Section 6 at monthly frequency, employing annual data. As can be seen from Table D.3, all of the previous results 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 mechanism variable — still features statistical significance at the 5% level and the estimate is only slightly smaller than in Table 4.

Table D.3 The Impact of QE on the Mediating Variables: 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.