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HOUSING PRICES AND MORTGAGE CREDIT IN LUXEMBOURG

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Housing Prices and Mortgage Credit in Luxembourg

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Abstract

This paper investigates the interaction between residential housing prices and mortgage credit in Luxembourg over the period 1980Q1-2017Q1. We use a vector error correction framework to model this interaction and allow for feedback effects between the two variables. In the long-run, higher housing prices lead to a mortgage credit expansion, which in turn puts upward pressure on prices. The growing demand for mortgage credit is also sustained by positive net migration to Luxembourg. Construction activity is another important determinant of housing prices, in line with existing supply-side limitations on dwelling availability. These dynamics lead to a structural imbalance between housing supply and demand, with the latter being fueled by demographic factors, tax incentives and fiscal subsidies, as well as the low interest rate environment. While price dynamics are partially explained by these structural factors, our results suggest that over the last few years residential housing prices have been characterized by a moderate, but persistent, overvaluation with respect to market fundamentals. Between 2012Q1 and 2017Q1, the average overvaluation is estimated at 6.85% but its trend is decreasing in the last quarters. Results also show that housing prices have a slow rate of adjustment to deviations from fundamentals (only 2.2% of the misalignment is corrected each quarter) and they do not directly adjust to disequilibria in the mortgage market. These findings are supported by impulse response analysis, which suggests that shocks to the endogenous variables lead to permanent increases in housing prices.

Keywords: residential real estate, housing market, VECM, property price valuation

JEL classification: C58, G12, G18, R31

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Résumé non technique

La crise financière de 2008 a révélé l'importance de la dynamique du marché immobilier pour la stabilité financière et l'économie réelle. Bien que les prix immobiliers soient le fruit de facteurs structurels et de dynamiques complexes, l'association d'une croissance excessive des prêts à un important allégement des conditions d'octroi de crédits semble avoir été la cause fondamentale de la bulle immobilière aux Etats-Unis. Ce constat a placé les interactions entre le crédit hypothécaire et les prix de l'immobilier résidentiel au centre des débats de politique économique et de la recherche académique. En effet, une littérature scientifique croissante documente l'importance du crédit dans la dynamique du marché immobilier, notamment à travers les rétroactions entre les prix et le crédit.

Dans la lignée d'études antérieures, ayant privilégié l'analyse d'un seul pays (Hong Kong, Finlande, Grèce, Espagne, Irlande, Norvège, France, Suède), ce travail propose d'évaluer les rétroactions entre les prix résidentiels et les prêts hypothécaires au Luxembourg entre le début de 1980 et le premier trimestre de 2017. Afin de modéliser ces interdépendances dynamiques et de tenir compte de la possible endogénéité des variables, le choix d'une approche vectorielle à correction d'erreur est fait. Bien que les variables d'intérêt soient l'indice des prix immobiliers et le flux réel de crédits immobiliers, la base de données inclut également un proxy de l'activité de construction, le taux d'intérêt réel des prêts hypothécaires, le produit intérieur brut, ainsi qu'un ensemble de variables démographiques.

Les résultats révèlent que, sur le long terme, des prix immobiliers élevés entrainent une expansion du crédit hypothécaire qui, à son tour, enclenche une nouvelle augmentation des prix. Néanmoins, l'analyse confirme également le caractère fondamental des facteurs structurels pour le marché immobilier luxembourgeois. Premièrement, le niveau d'activité de construction, déterminant important sur le long terme, reflète les contraintes de l'offre en termes de disponibilité de logements. Ensuite, l'analyse souligne la nécessité d'une prise en compte de facteurs démographiques et insiste sur la contribution significative d'un solde positif migratoire sur le caractère soutenu de la demande de prêts hypothécaires. Ces dynamiques engendrent un déséquilibre structurel entre une offre limitée et une demande soutenue, nourrie à la fois par des facteurs démographiques, des incitations et des subventions fiscales, mais aussi par un environnement de taux d'intérêt bas. Toutefois, cet ensemble de facteurs « structurels » n'explique que partiellement la dynamique des prix du marché de l'immobilier résidentiel au Luxembourg. Ainsi, une mesure de surévaluation des biens immobiliers résidentiels, construite à partir de l'écart entre les prix observés et ceux prédits par le modèle, révèle que le marché des biens immobiliers résidentiels luxembourgeois est caractérisé depuis les dernières années par une surévaluation modérée, mais persistante, des

prix par rapport à leurs fondamentaux. Celle-ci s'explique bien sûr par l'importance des rigidités de marché induites par les facteurs sous-jacents à la limitation de l'offre et de l'excès de la demande. La surévaluation est estimée à 6,85% en moyenne depuis le début de 2012 mais avec une tendance décroissante sur les derniers trimestres. Toutes choses égales par ailleurs, la non considération de telles rigidités dans le modèle se traduirait par de plus importantes déviations des prix par rapport au prix d'équilibre estimé. En d'autres termes, les résultats des modèles convergeraient vers ceux déterminés par les ratios statistiques.

Sur le court terme, l'analyse montre que la correction de la déviation des prix immobiliers par rapport à leurs fondamentaux s'effectue plus lentement que dans d'autres pays, à un rythme moyen de 2,2% de la surévaluation chaque trimestre. Cela implique que la mesure de la demi-vie (le temps nécessaire pour éliminer 50% du désalignement) est de 31,5 trimestres pour les prix résidentiels. En comparaison, la correction de la déviation du crédit hypothécaire par rapport à ses propres fondamentaux ne prend qu'environ un trimestre. Cette déviation entre également dans l'équation de court terme pour les prix du logement. Cependant, son coefficient est statistiquement non significatif, ce qui suggère que les prix immobiliers ne s'ajustent pas immédiatement à un déséquilibre sur le marché des prêts hypothécaires. Sans ce mécanisme de correction, une augmentation des crédits, qui ne s'expliquerait pas par les fondamentaux, peut alimenter une demande soutenue pour l'immobilier et contribuer de fait, à court terme, à accroitre davantage les prix. En somme, les résultats suggèrent qu'un déséquilibre sur le marché des prêts hypothécaires est corrigé plus rapidement que sur le marché immobilier. Ces résultats sont également corroborés par l'analyse des réponses impulsionnelles, qui montre que les chocs sur les variables endogènes entraînent des hausses permanentes des prix des logements.

1 Introduction

The recent financial crisis has demonstrated that developments in the residential real estate market may have severe repercussions on the financial system and the real economy.[1] The association of excessive credit growth with deteriorating credit standards was the primary cause for the U.S. housing bubble and subsequent international crash. In general, it is also known that more credit-intensive expansions tend to be followed by deeper recessions (Jordà, Schularick, and Taylor (2013)). This understanding has brought the interaction between housing prices and mortgage credit into the center of the economic policy debate. A growing literature documents the importance of credit growth to housing market dynamics and, in particular, the existence of feedback effects between housing prices and credit. Along these lines, Gerlach and Peng (2005) study the relationship between residential property prices and bank lending in Hong Kong. Oikarinen (2009) shows that there has been a significant two-way interaction between housing prices and mortgage credit in Finland. Brissimis and Vlassopoulos (2009) and Gimeno and Martinez-Carrascal (2010) look at a similar relationship in Greece and Spain, respectively. This interaction has also been investigated for Ireland (see e.g. Fitzpatrick and McQuinn (2007); Lyons and Muellbauer (2013)). Anundsen and Jansen (2013) examine the nexus of housing prices and credit in Norway within a structural vector error correction model (VECM). Avouyi-Dovi, Labonne, and Lecat (2014) and Avouyi-Dovi et al. (2015) focus on the case of housing and credit markets in France. Turk (2015) finds similar results for the case of Sweden.

Our paper contributes to this branch of the literature by focusing on the interaction between residential housing prices and mortgage loans in Luxembourg over the period 1980Q1–2017Q1. Our main variables of interest are therefore the real housing price index and flows of real mortgage loans. The set of fundamentals used in the analysis also includes proxies for construction activity (namely building permits and real construction cost index), the real mortgage rate, demographic variables (such as net migration to Luxembourg) and gross domestic product (GDP) as a proxy for income. Standard unit root tests reveal that the variables are integrated of order one, and results from Johansen's cointegration test suggest the existence of two cointegrating relations. We therefore follow the VECM approach and interpret the two cointegrating relations as long-run equations for housing prices and credit. Following a first estimation based on initial identification restrictions, we find support for the weak exogeneity of the real construction cost index and building permits. Therefore, we use a restricted VECM to investigate the interaction between housing prices and mortgages,

[1] See Reinhart and Rogoff (2009) for a global overview, or ESRB (2015) for a discussion on the EU historical experience with financial stability risks related to the housing sector.

and allow for feedback effects between the two variables. In the long-run, we find that higher housing prices lead to an expansion of mortgage credit, which in turn puts upward pressure on prices. Our analysis also confirms the importance of structural factors in the Luxembourg housing market: first, construction activity is an important long-run determinant of property prices, reflecting supply-side limitations on dwelling availability; second, demographic factors should be taken into account, as positive net migration to Luxembourg helps sustain the demand for mortgage credit. These dynamics lead to a structural imbalance between supply and housing demand, with the latter being fueled by demographic factors, tax incentives and fiscal subsidies, as well as the low interest rate environment.

While price dynamics are partially explained by these structural factors, we estimate that over the last few years residential housing prices have been characterized by a moderate, but persistent, overvaluation with respect to market fundamentals. This overvaluation is explained by the importance of market rigidities caused by the factors underlying the dwelling supply limitation and the strong demand. *Ceteris paribus*, without taking into account such rigidities in the model, the estimated overvaluation would be more substantial and the model results would converge toward those of statistical ratios.[2] To investigate this issue, we follow the literature and calculate a valuation measure based on the misalignment of the actual price series from the fundamental long-run fitted values. Since the beginning of 2012, the average overvaluation in the Luxembourg residential real estate market is estimated to be 6.85% but its trend is decreasing in the last quarters. For comparison purposes, Turk (2015) estimates that housing prices were between 5.5% and 12% above the long-run equilibrium in Sweden (in 2015Q2). Our methodology and conclusions therefore differ from other studies that use econometric techniques designed to test for rational bubbles and to detect explosive behavior in prices (e.g. see Garino and Sarno (2004), Tan and Xiao (2007), Phillips, Wu, and Yu (2011), Anundsen (2015) and Phillips, Shi, and Yu (2015a,b)).[3] As an example, Pavlidis et al. (2015) apply these econometric tests to 22 countries (including Luxembourg) and they detect a pattern of synchronized explosive behavior during the last international house boom-bust episode not seen before.

In terms of short-term dynamics of housing prices, we estimate the coefficient of the corresponding error correction term to be -0.022. This implies that the direct rate of adjustment is 2.2% per quarter, suggesting that price deviations from fundamentals are corrected at a slow pace when comparing to other countries. Caldera Sánchez and Johansson (2011) show that there are wide differences across countries in the implied speed of price adjust-

[2] For example, the gap of the price-to-disposable income ratio to its historical average is close to 30%.

[3] More recently, Maggiori, Giglio, and Stroebel (2016) analyze the existence of housing bubbles associated with a failure of the transversality condition in the U.K. and Singapore, which they test using a unique dataset on leaseholds and freeholds.

ment and calculate quarterly corrections to be between 2.7% (for Japan and Denmark) and 77.6% (for Poland). These estimates, however, do not consider the inclusion of a long-run equation for mortgage credit. Similarly, the speed of adjustment estimated here is considerably lower than the value of 7.7% documented for Luxembourg by Di Filippo (2015a). Again, this is most likely due to the inclusion of mortgage credit in the analysis. Indeed, in the short-term equation of housing prices, the coefficient on the mortgage error correction term represents the rate of adjustment of prices to mortgage credit disequilibria (i.e. the deviations of mortgage credit from its own fundamentals). However, we find that property prices do not directly adjust to disequilibria in mortgage credit, i.e. the coefficient on the mortgage error correction term is statistically insignificant. On the contrary, regarding the short-term dynamics for mortgages, both error correction terms are statistically significant and negative. First, we estimate the coefficient of the corresponding error correction term to be -0.560, which implies that the direct rate of adjustment of mortgage loans is fast, at 56.0% per quarter. Second, the coefficient on the housing price error correction term is estimated to be -0.259; thus, a positive deviation of housing prices from their long-run equilibrium leads to a decrease of 25.9% in new mortgage loans over the next period. The findings therefore suggest that the (quantity) equilibrium in the mortgage market is restored faster than is the case for housing prices. Another way to see this result is through the half-life measure (i.e. the time needed in order to eliminate 50% of the deviation), which is calculated as the ratio of ln(2) to the (absolute) value of the coefficient on the error correction term. Given the values indicated above for the direct rate of adjustments, the half-life is 31.5 quarters for housing prices and only around one quarter for mortgages. These results are also supported by impulse response analysis, which shows that shocks to the endogenous variables lead to permanent increases in housing prices.

In general, our work is related to the long literature that analyzes housing market dynamics. Several studies use data on a large set of countries in order to characterize housing cycles and identify statistical regularities - for some examples, see Bracke (2011), Agnello and Schuknecht (2011), Igan and Loungani (2012), or Borio and McGuire (2014). Another branch of the literature focuses on the identification of leading indicators and the development of early-warning tools.[4] The work by Ferrari, Pirovano, and Cornacchia (2015) highlights the important role of both housing price variables and credit developments in predicting real

[4] In related work, Burnside, Eichenbaum, and Rebelo (2015) argue that it is generally difficult to find observable fundamentals that are useful for predicting whether a boom will turn into a bust. Consistent with this observation, they develop a model where agents have heterogeneous expectations about long-run fundamentals but change their views because of social dynamics. The role of households expectations and beliefs about the housing market has been empirically confirmed in the literature (e.g. see Piazzesi and Schneider (2009), Huang (2014), or Gomes and Mendicino (2015)).

estate-related banking crises.[5] Similarly, Anundsen et al. (2016) use a panel data for 20 OECD countries to explore the importance of house prices and credit in the likelihood of a financial crisis; they find that a combination of exuberance in house prices and high household leverage substantially increases the vulnerability of the financial system. Crowe et al. (2013) provide a summary and discussion of options available to policymakers in dealing with real estate booms and busts.

More closely related to our methodology, the error correction framework is widely employed to model housing price dynamics: Gattini and Hiebert (2010) estimate a quarterly VECM for the Euro area over 1970-2009, Caldera Sánchez and Johansson (2011) use the ECM framework and estimate long- and short-run housing dynamics for 21 OECD countries, and Arestis and Gonzalez (2013) employ the VECM technique using a panel dataset of 18 OECD countries with annual data from 1970 to 2011. Given the importance of country-specific factors in the evolution of the housing market, many authors also opt for focusing on a single country.[6] For example, Steiner (2010) focus on the Swiss housing market, Meulen, Micheli, and Schmidt (2011) measure and forecast housing price movements in Germany, Nobili and Zollino (2012) estimate a structural system for Italy, Anundsen (2015) estimates a recursive VECM for the U.S. and Panagiotidis and Printzis (2016) use a VECM framework to assess the interdependence between housing prices and macroeconomic determinants in Greece. For the case of Luxembourg, however, the existing evidence is scarce. The housing market in Luxembourg is discussed in IMF (2014, 2015, and 2017). In terms of valuation of housing prices, the analysis in Di Filippo (2015a) and Di Filippo (2015b) relies on univariate ratios and multivariate models. The ratios of price-to-income, price-to-rent and price-to-construction cost are benchmarked against their (recursive) historical averages. The modeling strategy includes the ECM framework and a Markov-Switching model (based on Corradin and Fontana (2013)), treating as fundamentals the disposable income per household, the user cost of owning a dwelling,[7] the number of households and the stock of dwellings. Both ratios and model results suggest that, over recent years, prices evolved in line with fundamentals within a moderate-growth regime. Although credit variables are not directly included in the modeling framework, Di Filippo (2015b) provides an overview of the risks stemming from the

[5] Luxembourg is included in their sample of 25 EU countries, which covers the period from 1970Q1 to 2013Q1. However, as the country experienced no real estate-related banking crisis according to the definition used, many results are not easily extended for the case of Luxembourg. This may suggest that preference should be given to country-specific modeling.

[6] Where data is available, there are also papers focusing on housing sub-markets across different regions of a single country. For example, Meen (2011) studies housing sub-markets across regions in the U.K., and Damianov and Escobari (2016) use data on U.S. statistical areas to examine the interdependence between high and low price tiers during the latest housing market boom and bust.

[7] The user cost of owning a dwelling is defined as the costs inherent to holding a residential property by the occupying owner.

mortgage market (both for households and lenders). Overall the analysis suggests that the structural imbalance between a growing housing demand and a constrained supply underlines the sustained growth in Luxembourg housing prices. The limited supply of dwellings, insufficient to meet demographic pressures brought by increasing population and positive net migration to Luxembourg, has been highlighted by other studies.[8] While our analysis confirms the importance of structural factors for housing market dynamics, our paper is, to the best of our knowledge, the first to also model feedback effects between housing prices and mortgages in Luxembourg using a VECM approach. As the results suggest the existence of a significant two-way interaction between the two variables, the modeling choice employed here is particularly suitable to address possible endogeneity concerns.

The rest of the paper is organized as follows. Section 2 describes the data. Section 3 discusses the methodology. Section 4 presents the initial VECM estimation and the main results. Section 5 considers possible robustness checks. Section 6 concludes.

2 Data and Variables

2.1 Data Sources

We gather data from different sources on residential real estate prices, construction activity and housing supply, mortgage loans and interest rates, as well as demographic measures and GDP. Whereas the historical information for Luxembourg dates back to early 1970s for some variables, this is not the case for most series. Moreover, the frequency availability also differs across variables. Therefore, our final quarterly sample is constrained by data availability and covers the period between 1980Q1 and 2017Q1.

The data on housing price indices for Luxembourg is made available at a quarterly frequency by STATEC. We use the index for new and existing dwellings that has been published online since 2007Q1.[9] Given the short time span, we complete the time-series using historical data compiled from the Central Bank of Luxembourg (BCL) and the *Observatoire de l'Habitat*.[10] The resulting housing price index covers the period between 1980Q1 and 2017Q1, it is seasonally adjusted and rebased to 2010.

[8] According to STATEC, the number of completed dwellings per year was on average 2,483 between 2010 and 2013. However, in order to meet the increasing housing demand, it is estimated that 6.500 new dwellings should be built each year between 2010 and 2030 (see Observatoire de l'Habitat (2015) and Peltier (2011)).

[9] The data, denominated Series C of *Indicateurs Rapides*, is not seasonally adjusted. It can be found at http://www.statistiques.public.lu/fr/publications/series/indicateur-rapides/.

[10] Historical data is also made available by the International House Price Database from the Federal Reserve Bank of Dallas. The Dallas Database is described in Mack and Martinez-Garcia (2011) and available at http://www.dallasfed.org/institute/houseprice/.

Regarding construction activity and housing supply, we use STATEC information on dwelling permits, housing stock values, and construction cost. The number of dwelling permits includes only residential buildings (with one, two, or more dwellings) and it is available at a monthly frequency since 1979M01 (please refer to STATEC *Indicateurs Rapides* – Series G). Monthly permits are summed over each quarter to obtain a quarterly series. As permits proxy the construction activity, we calculate their moving average over eight quarters to account for construction delays and the volatility in the series.[11] We also calculate a housing stock series, using lagged permits and available housing stock values. Although information on the number of existing dwellings is not regularly published by STATEC, this number was estimated to be 135,760 at the end of 1979 and amounts to 227,326 in 2015Q1.[12] We use these initial and end values, combined with the construction activity proxied by lagged permits, to calculate an average depreciation rate and fit a series for the housing stock. Moreover, we include in the analysis a construction cost index. Originally published by STATEC every semester since early 1970, we interpolate the series to obtain a quarterly variable and then rebase it to 2010. All the resulting series for permits, housing stock, and construction cost are also seasonally adjusted.

With respect to mortgage credit, we use data on new mortgage loans granted to domestic households, published by the BCL.[13] The data is available quarterly from 1992Q1 onwards, and annually for the period 1978–1991. We therefore start by interpolating the annual series to a quarterly frequency (using a quadratic match sum approach) and extend the current series backwards using the implied quarterly growth rates. The resulting series of mortgage loans is then seasonally adjusted. Section 5.3 discusses the implications of using mortgage stocks as opposed to mortgage flows in the VECM estimation. For data on mortgage interest rates, we use information from the ECB's Statistical Data Warehouse (SDW). As mortgage rates in Luxembourg are available at a monthly frequency starting in 2003M01, we use quarter averages. Moreover, we extend the data backwards by using a close proxy, i.e. the growth rates of the quarterly three-month interbank lending rate for Belgium.[14]

[11] Internal BCL calculations using cross-correlation analysis find that building completions lag building permits by two years. Using 8Q lagged permits in the estimation yields similar results in terms of the VECM coefficients but makes the fitted value for housing prices substantially more volatile. In a previous version of this paper, we have also used a moving average over four quarters with similar conclusions. All results are available upon request.

[12] The former estimate is referred in STATEC (1982), p. 79, while the latter can be found online at http://www.statistiques.public.lu/en/news/enterprises/construction/2015/05/20150505/index.html.

[13] See Table 11.09, classification *Secteur residentiel – Credits aux non-promoteurs*, available at http://www.bcl.lu/fr/statistiques/series_statistiques_luxembourg/index.html.

[14] The SDW mnemonics for the relevant series are MIR.M.LU.B.A2C.AM.R.A.2250.EUR.N and MEI.Q.BEL.IR3TIB01.ST. We have considered, as a possible alternative to the Belgian interbank rate, the Luxembourg 10Y sovereign bond rate (with SDW mnemonic IRS.Q.LU.L.L40.CI.0000.EUR.N.Z). However, the available time-series starts in 1993Q4 and its correlation with the Luxembourg mortgage rate is

The housing market dynamics in Luxembourg are strongly influenced by demographic pressures, with housing demand being driven by an increasing population and a sustained net migration to Luxembourg. To capture this effect, we collected STATEC data on household size, population, and net migration.[15] The average size of resident households is obtained from census data; the information is available every 10 years since 1970, so we linearly interpolate the data to obtain a quarterly series. Annual population estimates are also available since 1970; we apply a quadratic match average method to obtain a quarterly population variable. The average number of households is calculated as the ratio between total population and average size of resident households. Finally, data on annual net migration to Luxembourg is available since 1980 and it is converted to a quarterly frequency using a quadratic match sum process.

In Luxembourg, long series for households' disposable income are not publicly available. In order to incorporate this information in the housing valuation model, we use as proxy the real GDP *per capita*. Given that quarterly GDP data is available since 1995Q1, we complement this information with annual data from SDW.[16] In particular, we use GDP values at current market prices, convert annual values to quarterly frequency using a quadratic match sum process, and use the implied growth rates to extend backwards the available quarterly series. The resulting GDP series is divided by quarterly population estimates to obtain *per capita* values and is seasonally adjusted.

Where applicable, variables are measured in real terms, i.e. the housing price index, mortgage loans, mortgage rate, construction cost index and GDP *per capita* are deflated by the consumer price index for Luxembourg.[17] Following the literature, all variables are measured in logs, with the exception of the real mortgage rate (which is measured in percent $p.a.$).[18] Therefore, the final variables are: real housing price index ($rhpi_t$), building permits (bp_t), housing stock (h_t), real construction cost index (cc_t), real new mortgage loans granted to domestic households (mg_t), real mortgage rate (r_t), average number of households (hh_t), net migration (mi_t) and real GDP *per capita* (gdp_t).

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lower (76.1%) compared to the corresponding value for the Belgian proxy (98.6%). We have also considered a constant mark-up on the reference rate instead of using growth rates to extend the series. The average mortgage rate mark-up on the Belgian interbank lending rate for the available period (after 2003Q1) is 1.32% but the actual mark-up is volatile. Given this volatility and the high correlation mentioned above, we opt for extending the Luxembourg series using the growth rates as described in the text.

[15] The data can be found at http://www.statistiques.public.lu/fr/population-emploi/index.html.

[16] The SDW mnemonics for the relevant series are AME.A.LUX.1.0.0.0.UVGD and MNA.Q.N.LU.W2.S1.S1.B.B1GQ._Z._Z._Z.EUR.V.N

[17] Available at SDW with mnemonic MEI.Q.LUX.CPALTT01.IXOB.

[18] As net migration equals the number of people migrating to Luxembourg over those who leave, it can in principle be negative. In practice, the only sample year registering a negative value is 1982. Hence, we first linearly interpolate the net migration series between the two adjacent years and then apply the log transformation.

2.2 Unit Root Tests

Table 1 provides summary statistics for the variables indicated above. The order of integration was also analyzed, with the results of Augmented Dickey-Fuller (ADF) unit root tests presented in Table 2. The results suggest that the variables are non-stationary in levels. In first-differences, most variables are stationary but the average number of households and the housing stock are found to be non-stationary as well.[19]

The finding that housing stock and demographic variables are $I(2)$ is common in the literature and often discarded due to data availability constraints (i.e. the variables are treated as stationary in differences, ignoring the possible effects in the estimation). See, for some examples, Gimeno and Martinez-Carrascal (2010), Anundsen and Jansen (2013), and Turk (2015). In our case, we observe that alternative measures seem to be a better option: in terms of construction activity, building permits and construction cost are good proxies for housing supply and are stationary in differences; regarding demographic variables, net migration effectively captures the increase in population in Luxembourg and is also $I(1)$. According to Turk (2015), net migration is preferred over other demographic variables, as immigration typically generates more immediate housing needs compared to the natural increase in population. Therefore, we opt for dropping housing stock (h_t) and the number of households (hh_t) from the analysis. This ensures that all variables included in the econometric modeling are at most integrated of order one. Figure 1 displays their time-series.

3 Model

3.1 Modeling Housing Prices

In general, the relationship between housing prices and fundamentals can be analyzed under the life-cycle model of housing (see e.g. Meen (1990, Muellbauer and Murphy (1997), and Anundsen (2015)). We follow Anundsen and Jansen (2013) and augment this model with a term capturing the presence of credit constraints. In this case, the following condition must hold in equilibrium:

$$MRS_t = RHPI_t \left[(1-\tau_t)i_t - \pi_t + \delta - \frac{R\dot{H}PI}{RHPI} + \frac{\lambda_t}{\mu_c} \right], \quad (1)$$

[19]Results from Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Tests and Phillips-Perron (PP) Tests are similar, with the main difference being that PP results suggest that households and housing stock are $I(1)$, whereas KPSS tests suggest non-stationarity in first-differences as well. Results from Dickey-Fuller Test with GLS Detrending (DFGLS) also support the latter.

where MRS_t is the marginal rate of substitution between housing and consumption, $RHPI_t$ is the real housing price index, τ_t is the marginal tax deduction rate, i_t is the nominal mortgage rate, π_t is the inflation rate, δ is the housing depreciation rate (which is assumed to be constant), $R\dot{H}PI/RHPI$ is the expected real rate of appreciation for housing prices, λ_t is the shadow price of the credit constraint and μ_c is the marginal utility of consumption. The condition in equation (1) follows from the representative household's maximization problem. The term in brackets is commonly referred to as the real user cost of housing, in this case augmented with the credit constraint.

Market efficiency requires that, in equilibrium, the cost of owning a given dwelling should be equal to the real imputed rental price for housing services, Q_t (i.e. what it would have cost to rent a dwelling of similar quality). It follows that:

$$RHPI_t = \frac{Q_t}{\left[(1-\tau_t)i_t - \pi_t + \delta - \frac{R\dot{H}PI}{RHPI} + \frac{\lambda_t}{\mu_c}\right]}. \tag{2}$$

Equation (2) can be interpreted as an inverted housing demand function (see Poterba (1984)). As Q_t is unobservable, one common approach in the literature is to assume that it is a function of related variables, e.g. Anundsen and Jansen (2013) use real disposable income for the household sector and the stock of dwellings as proxies for Q_t. A second approach is to assume that Q_t can be proxied by the observed rent. In the case of Luxembourg, long series for households' disposable income and rent index are not publicly available. Therefore, we use instead proxies for Q_t that are related to housing stock, construction activity and demographic variables, and use GDP *per capita* as a proxy for income. In particular, as discussed in Section 2, we use building permits (BP_t), real construction cost (CC_t), net migration (MI_t) and real GDP *per capita* (GDP_t). We can then write the inverted demand function as:

$$RHPI_t = f(BP_t, CC_t, MI_t, GDP_t, r_t, R\dot{H}PI/RHPI, \lambda_t/\mu_c), \tag{3}$$

where r_t is the real after tax interest rate, i.e. $r_t = (1-\tau_t)i_t - \pi_t$. We follow the literature and model price expectations by allowing lagged real price appreciations in the model dynamics. This is similar to Abraham and Hendershott (1996), who consider a "bubble builder" effect, represented by lagged real housing price appreciations, and a "bubble burster" effect through the error correction term. Finally we use mortgage loans (MG_t) as a proxy for the λ_t/μ_c term (see Anundsen and Jansen (2013)). Consequently, equation (3) can be rewritten as:

$$RHPI_t = f(BP_t, CC_t, MI_t, GDP_t, r_t, MG_t). \tag{4}$$

Taking a log-linear approximation of equation (4) yields:

$$rhpi_t \approx \tilde{\beta}_{BP} bp_t + \tilde{\beta}_{CC} cc_t + \tilde{\beta}_{MI} mi_t + \tilde{\beta}_{GDP} gdp_t + \tilde{\beta}_r r_t + \tilde{\beta}_{MG} mg_t, \tag{5}$$

where lower-case letters indicate that the variables are measured in logs, and r_t is expressed as percent *p.a.* Following Anundsen (2015), the equilibrium correction representation of equation (5) can be expressed as:

$$\Delta rhpi_t = \tilde{\gamma} + \tilde{\alpha}_{rhpi}(rhpi_{t-1} - \sum_k \tilde{\beta}_k k_{t-1}) + \sum_{i=1}^{p-1} \tilde{\rho}_{rhpi,i} \Delta rhpi_{t-i} + \sum_k \sum_{i=1}^{p-1} \tilde{\rho}_{k,i} \Delta k_{t-i} + \tilde{\epsilon}_t, \tag{6}$$

where $k = \{bp, cc, mi, r, mg, gdp\}$ denotes the set of housing market fundamentals used in the analysis and we expect $\left(rhpi_t - \sum_k \tilde{\beta}_k k_t\right)$ to be $I(0)$. We also expect the adjustment coefficient $\tilde{\alpha}_{rhpi}$ to be negative and significantly different from zero if housing prices are determined by fundamentals.

3.2 Modeling Mortgage Loans

In the same spirit as Anundsen and Jansen (2013), we supplement our model for housing prices with a relationship that determines new mortgage credit in a long-run equilibrium:

$$MG_t = f(RHPI_t, CC_t, MI_t, GDP_t, r_t). \tag{7}$$

Equation (7) defines new mortgage credit as a function of housing prices, construction cost, net migration, GDP and the interest rate. Regarding building permits, we assume that they do not directly affect the amount of mortgage loans in the long-run. This is in accordance with e.g. Fitzpatrick and McQuinn (2007), where the housing stock variable is excluded from the long-run equation for credit. Indeed, the literature often expresses credit as a function of income, house prices and interest rates (see also Gerlach and Peng (2005)). Here we extend the standard model by considering net migration, which is an important determinant of mortgage demand in Luxembourg. Although we also initially allow for construction cost to enter the long-run equilibrium, results will show that it is not a significant long-run driver of mortgage credit. It should however be noted that construction-related variables still have a second-round long-term effect on mortgages, via their impact on housing prices and the interaction of prices with credit.

As above, taking a log-linear approximation of equation (7), the equilibrium correction representation for mortgages can be represented as:

$$\Delta mg_t = \breve{\gamma} + \breve{\alpha}_{mg}(mg_{t-1} - \sum_v \breve{\beta}_v v_{t-1}) + \sum_{i=1}^{p-1} \breve{\rho}_{mg,i} \Delta mg_{t-i} + \sum_v \sum_{i=1}^{p-1} \breve{\rho}_{v,i} \Delta v_{t-i} + \breve{\epsilon}_t, \tag{8}$$

where $v = \{rhpi, cc, mi, gdp, r, bp\}$ denotes the set of fundamentals used to explain credit and we impose $\breve{\beta}_{bp} = 0$ in accordance with condition (7). We expect $\left(mg_t - \sum_v \breve{\beta}_v v_t\right)$ to be $I(0)$ and the adjustment coefficient $\breve{\alpha}_{mg}$ to be negative and significantly different from zero if new mortgages are determined by fundamentals.

3.3 Vector Error Correction Model

To analyze the relationship between residential property prices, mortgage credit, and their fundamentals, we generalize conditions (6) and (8) above and estimate a multivariate vector error correction model (VECM) of the form:

$$\Delta \mathbf{y}_t = \nu + \Pi \mathbf{y}_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta \mathbf{y}_{t-i} + \epsilon_t, \tag{9}$$

where $\mathbf{y}_t$ is a $K \times 1$ vector of variables, ν is a $K \times 1$ vector of parameters, and ϵ_t is a $K \times 1$ vector of disturbances. ϵ_t has mean $\mathbf{0}$, has covariance matrix Σ, and is $i.i.d.$ normal over time. Engle and Granger (1987) show that, if the variables $\mathbf{y}_t$ are stationary in differences, the matrix Π in equation (9) has rank $0 \leq r < K$, where r is the number of linearly independent cointegrating vectors. If the variables cointegrate, then $0 < r < K$.

The tests for cointegration used to determine the rank r are based on Johansen's method (see Johansen (1991)). If the log likelihood of the unconstrained model that includes the cointegrating equations is significantly different from the log likelihood of the constrained model that does not include the cointegrating equations, we reject the null hypothesis of no cointegration. Given the rank, Π can be expressed as $\Pi = \alpha\beta'$, where α and β are both $K \times r$ matrices of rank r. Without further restrictions, the cointegrating vectors are not identified. In practice, the estimation of the parameters of a VECM requires at least r^2 identification restrictions.

As α is a $K \times r$ matrix of rank r, the deterministic component ν can be expressed as:

$$\nu = \alpha\mu + \gamma, \tag{10}$$

where μ is a $r \times 1$ vector of parameters and γ is a $K \times 1$ vector of parameters. We can rewrite equation (9) as:

$$\Delta \mathbf{y}_t = \alpha \left(\beta' \mathbf{y}_{t-1} + \mu\right) + \sum_{i=1}^{p-1} \Gamma_i \Delta \mathbf{y}_{t-i} + \gamma + \epsilon_t. \tag{11}$$

Equation (11) allows for a linear time trend in the level variables and restricts the cointegration equation(s) to be stationary around constant means.

4 Model Estimation

4.1 Cointegration Tests

Table 3 provides the results of Johansen's cointegration tests, where $K = 7$. As discussed above, the endogenous variables included in vector $\mathbf{y}_t$ are the real housing price index ($rhpi_t$), building permits (bp_t), real construction cost index (cc_t), real mortgages (mg_t), real mortgage rate (r_t), net migration (mi_t) and real GDP *per capita* (gdp_t). Results are shown for the trace test statistic and max-eigenvalue test statistic, including two lags and a linear deterministic trend as in equation (11).[20] As shown in Table 3, results are mixed. At a 5% confidence level, the max-eigenvalue test suggests the existence of two cointegrating relations, whereas the trace test suggests the existence of four cointegrating relations. We analyze the number of cointegrating equations in more detail using recursive cointegration tests. We find that results are time-varying and that, for the recent years, a rank of two is a better representation of the data. Hence, we estimate a model with two cointegrating relationships and, following the literature (see, for example, Gimeno and Martinez-Carrascal (2010)), we identify them as long-run equilibrium relationships for house prices and mortgage loans.

4.2 Initial VECM Estimation

4.2.1 Identifying Restrictions

The estimation of the VECM parameters requires at least r^2 identification restrictions in the cointegrating vectors, where $r = 2$ in our case. As discussed in the previous section, we identify the two cointegrating equations as long-run equilibria for house prices and mortgage loans. This implies that, in the first $rhpi_t$ equation, we impose a normalization restriction

[20] According to the Akaike information criterium, the optimal lag length to include in the test equation is three; according to the Schwarz information criterium, the optimal lag length is one. We choose two lags as a trade-off between avoiding VECM dimensionality and accounting for autocorrelation in the residuals.

on housing prices (so that $\beta_{rhpi,1} = 1$) and, in the second mg_t cointegrating relationship, we impose a normalization restriction on mortgage loans (so that $\beta_{mg,2} = 1$).[21]

For the third identification restriction, in accordance with equation (8), we assume that building permits (bp_t) do not directly affect the amount of mortgage loans in the long-run, i.e. $\beta_{bp,2} = 0$. As discussed above, there is still a second-round effect, via the impact of construction activity on housing prices and their effect on mortgage credit.

Regarding the last identification restriction, we start by restricting the coefficient of the interest rate r_t and imposing $\beta_{r,1} = -0.1$.[22] Empirically, the derivative of real house prices with respect to the interest rate is often found to be statistically insignificant (see, for example, Caldera Sánchez and Johansson (2011)). As argued by Anundsen and Jansen (2013), its sign is theoretically ambiguous when controlling for disposable income and mortgage loans, as the main effects of a change in the interest rate work through these variables, and the remaining substitution effects may be of either sign. The authors start by estimating long-run equations for housing prices and debt without restricting the interest rate coefficient and find $\beta_{r,1} = -0.13$ (although statistically insignificant). Similarly, Gimeno and Martinez-Carrascal (2010) impose a zero coefficient on interest rates, so that aggregate credit is the variable that captures the impact of financing costs on house prices. In our case, when allowing for one cointegrating equation on housing prices (the only identifying restriction in this case is $\beta_{rhpi} = 1$), we obtain a positive relation with the real interest rate. As Fitzpatrick and McQuinn (2007) point out, a possible explanation for the positive sign may be the relatively high correlation with other market interest rates, such as deposit rates. This effect might be particularly important in Luxembourg, where households have high levels of financial assets. Moreover, as shown below, this identifying restriction will be relaxed with very similar results.

4.2.2 Initial VECM Results: Long-Run Analysis

Table 4 displays the results of the exactly identified model. Panel A presents the estimated cointegrating equations for housing prices (CEq1) and mortgage loans (CEq2), which correspond to the long-run equilibria. Most variables are statistically significant at the 10% confidence level and show the expected signs in both equations (the exceptions are the insignificant net migration mi_t and real GDP per capita gdp_t in the first relationship, as well as the insignificant real construction cost index cc_t in the second relationship). Our results

[21] For a more detailed discussion on the identification of the two cointegrating equations as equilibrium relations for house prices and mortgages loans, see also Section 5.1.

[22] The cointegrating vectors are expressed as $CEqi_t = \sum_y \beta_{y,i} y_t + c_i$, where $y = \{rhpi, bp, cc, mi, r, mg, gdp\}$ and $i = \{1, 2\}$. Hence, $\beta_{rhpi,1} = 1$ and $\beta_{r,1} = -0.1$ imply a positive long-run relationship between the interest rate and housing prices.

support the hypothesis that housing prices and mortgage credit are mutually dependent. We find that, in the long-run, increases in mortgage credit are associated with increases in real housing prices, which is consistent with a positive effect on housing demand. The number of building permits, a proxy for construction activity and the supply of dwellings, is negatively related with the price level. Similarly, an increase in the construction cost index translates to lower supply and higher housing prices. For the long-run equation on mortgage loans, we find that the positive effect of housing prices is highly statistically significant, confirming the existence of a two-way interaction between prices and credit. Moreover, the real interest rate is negatively related to credit, so that higher financing costs lead to a lower search for house credit by households. An increase in the number of households caused by net migration to Luxembourg translates to a more significant amount of mortgage loans. Similarly, we estimate a positive long-run relation between real GDP *per capita* and new mortgage credit, with a cointegration coefficient equal to -0.61. This finding is in line with the results of Gerlach and Peng (2005), who document a coefficient very close to 1, implying that real bank loans and real income grow proportionally over time. While this effect may be unexpected, it also seems to indicate that, as the GDP in Luxembourg increases, there is a greater demand for investing in the domestic housing market also in part because higher income attracts migration.[23]

In terms of magnitude, our results also seem to be in line with the literature. We report an elasticity of housing prices with respect to mortgage debt of 1.19, close to the 0.98 documented by Anundsen and Jansen (2013) for Norway. Moreover, the elasticities of prices with respect to housing supply proxies are in line with the literature (respectively, -1.60 for building permits and 7.42 for construction cost). Although not directly comparable, Caldera Sánchez and Johansson (2011) use the stock of dwellings and find high negative elasticity values (i.e. lower than -1) for 15 out of the 21 OECD countries considered. Anundsen and Jansen (2013) estimate an elasticity of housing prices with respect to the stock of dwellings of -3.03 for Norway. Di Filippo (2015a) uses the number of dwellings and estimates a corresponding elasticity value of -4.53 for Luxembourg. Regarding the effect of demographics, we find that the elasticity of housing prices with respect to net migration is 0.09; although insignificant, it is in line with the value of 0.07 documented by Turk (2015) for Sweden. The estimated semi-elasticity of mortgage loans with respect to the real interest rate is -0.02. This implies that a 1 percentage point increase in the real interest rate will decrease mortgage borrowing by 0.02% in the long-run. This is lower (in absolute terms) than the value of -2.74 estimated by Anundsen and Jansen (2013) but is closer to the value of -0.04 documented by

[23]This interpretation seems to be corroborated by the smaller estimated coefficient of net migration here compared to the same coefficient in a model without GDP (around -0.1).

Brissimis and Vlassopoulos (2009) for Greece. In turn, Fitzpatrick and McQuinn (2007) find a positive but very small effect of interest rates on credit in Ireland. Finally, we estimate that a 1% increase in housing prices increases mortgage loans by 1.18% in the long-run.

4.2.3 Initial VECM Results: Short-Run Dynamics

Panel B of Table 4 presents the estimation output of the short-term equations for $\Delta rhpi_t$ and Δmg_t, displaying the adjustment coefficients and coefficients statistically significant at a 10% cutoff level. Regarding the $\Delta rhpi_t$ equation, the error correction term (i.e. the lagged residuals of the long-run equation for prices) is close to being statistically significant at 10% but the second error correction term for mortgages is not. Our initial results suggest that, if housing prices deviate from their long-run equilibrium, they will revert back to the fundamental value at a very slow pace (i.e. with a correction of 1.1% of the disequilibrium per period). Caldera Sánchez and Johansson (2011) show that there are wide differences across countries in the implied speed of price adjustment, estimating quarterly corrections to be between 2.7% (for Japan and Denmark) and 77.6% (for Poland). This is also corroborated by the findings in Arestis and Gonzalez (2013), but neither paper considered the inclusion of a long-run equilibrium equation for mortgage credit. Similarly, the speed of adjustment estimated here is considerably lower than the value of 7.7% documented for Luxembourg by Di Filippo (2015a), most likely due to the inclusion of mortgage credit in the analysis. In fact, we find that the coefficient on the mortgage error correction term is insignificant. This finding is in contrast with the results of Gimeno and Martinez-Carrascal (2010) and Anundsen and Jansen (2013), who document a significant negative coefficient for Spain and Norway, respectively. Nonetheless, it is in line with the results of Brissimis and Vlassopoulos (2009), who show that property prices do not adjust to the disequilibrium in the mortgage lending market in Greece. In a similar fashion, Gerlach and Peng (2005) estimate a single long-run relationship for bank lending in Hong Kong and find that its loading coefficient on real property prices is insignificant.

Regarding the Δmg_t equation, both error correction terms are statistically significant and negative. The speed of adjustment of mortgage loans is estimated to be 54.7% per quarter, while a positive deviation of housing prices from their long-run equilibrium leads to a decrease of 13.6% on mortgage loans over the next period. For comparison purposes, the same values estimated by Gimeno and Martinez-Carrascal (2010) for mortgage stocks in Spain are 10.9% and 2.8%, respectively. Anundsen and Jansen (2013) find a lower speed of adjustment for real household debt in Norway (the estimated coefficient is -0.046) and an insignificant effect of the price error correction on the debt equation. With respect to other short-term dynamics, we document a positive effect of lagged house price changes on $\Delta rhpi_t$

in line with the literature.

4.3 Main Results

4.3.1 Weak Exogeneity Tests and Restricted VECM

In this section, we investigate the weak exogeneity of the variables with respect to the long-run coefficients. This amounts to testing if the loadings of both cointegrating vectors with respect to each variable y are zero, i.e. $\alpha_{y,1} = \alpha_{y,2} = 0$ (see Johansen (1992)). The only variables for which we find support for the weak exogeneity hypothesis are the real construction cost index, cc_t, and building permits, bp_t.[24] The test statistic for the binding restrictions on cc_t is $\chi^2(2) = 1.89$ with a p-value of 0.39; the test statistic for the binding restrictions on bp_t is $\chi^2(2) = 3.18$ with a p-value of 0.20. To illustrate what this implies in terms of the VECM estimation, it is convenient to partition the vector $\mathbf{y}_t$ containing the variables into a vector of endogenous variables, $\mathbf{x}_t$, and a vector of weakly exogenous variables, $\mathbf{z}_t$. The VECM representation of equation (11) can then be expressed as:

$$\Delta \mathbf{x}_t = \alpha \left(\beta' \mathbf{y}_{t-1} + \mu\right) + \sum_{i=1}^{p-1} \Gamma_{x,i} \Delta \mathbf{x}_{t-i} + \sum_{i=0}^{p-1} \Gamma_{z,i} \Delta \mathbf{z}_{t-i} + \gamma + \epsilon_t, \qquad (12)$$

where $\mathbf{y}_t = (\mathbf{x}_t', \mathbf{z}_t')$ (see Anundsen (2015) for details and references therein). According to the results above, we consider $\mathbf{z}_t = [cc_t, bp_t]$ and $\mathbf{x}_t = [rhpi_t, mg_t, r_t, mi_t, gdp_t]'$.

As Table 4 shows, the estimated coefficient of cc_t in the long-run mortgage equation of the exactly identified VECM is statistically insignificant. Given this result, we also test the hypothesis $\beta_{cc,2} = 0$ in addition to the weak exogeneity restrictions. Moreover, as the coefficient of net migration in the first cointegrating equation CEq1 is statistically insignificant, we also impose $\beta_{mi,1} = 0$ and instead estimate the coefficient on the real interest rate. Specifically, the second identifying restriction on CEq1 is now given by the zero constraint on the migration coefficient and $\beta_{r,1}$ is estimated freely, allowing us to confirm our conjecture relative to the positive semi-elasticity of housing prices with respect to the real interest rate. Finally, given the weak result for gdp_t in the long-run price equation, we further impose $\beta_{gdp,1} = 0$. We find empirical support for the joint test. The test statistic for the six binding restrictions (i.e. four weak exogeneity restrictions and the two additional restrictions on the cointegrating vectors) is $\chi^2(6) = 6.44$ with a p-value of 0.38.

Therefore, we proceed with the estimation of the restricted VECM described in equation (12), where we drop mi_t and gdp_t from the cointegration vector for housing prices (CEq1)

[24] In a previous version of the paper, where bp_t were constructed using a moving average over four quarters, they were not found to be weakly exogenous. Results were otherwise similar.

and cc_t from the cointegrating vector for mortgage loans (CEq2). Moreover, as several lagged regressors are statistically insignificant in the second part of the VECM estimation output, we estimate a restricted short-run dynamics where only the significant variables are kept (using a 10% level cutoff). In particular, we use the results from the first step Johansen's procedure for the restricted cointegrating vectors and estimate the short-term equations for $\Delta \mathbf{x}_t$ using the Seemingly Unrelated Regressions (SUR) approach.[25] This allows us to find a parsimonious model by using a general-to-specific approach and stepwise elimination of insignificant variables in the system (see, for some examples Brissimis and Vlassopoulos (2009), Anundsen and Jansen (2013), or Turk (2015)), while accounting for heteroskedasticity and contemporaneous serial correlations in the error terms across equations.

4.3.2 Restricted VECM Results

Long-Run Analysis

Table 5 presents our main estimation results, the restricted VECM discussed above. Regarding the cointegrating equations (see Panel A), all variables are highly statistically significant and the results overall confirm the signs and magnitudes of the initial estimation. The elasticity of housing prices with respect to mortgage debt decreased slightly to 0.87. This is also the case for housing supply proxies, where the estimated elasticities are now -0.67 for building permits and 2.44 for construction cost. By construction, net migration and GDP no longer directly affect the long-run equation for housing prices (recall that, in the unrestricted estimation, both variables were statistically insignificant). More importantly, we obtain a positive effect for the real interest rate on housing prices, supporting the initial identifying restriction on $\beta_{r,1}$. As discussed above, a possible explanation for the positive sign may be the relatively high correlation with other market interest rates, such as deposit rates. This effect might be particularly important in Luxembourg, where households have high levels of financial assets. In the same line, Arestis and Gonzalez (2013) find a positive and significant long-run effect of mortgage rates on housing prices for Canada, Sweden, and the United Kingdom. Moreover, the estimated semi-elasticity of mortgage loans with respect to the real interest rate remains similar at -0.03 and in line with the literature. With respect to net migration, we find a positive effect on the volume of new mortgage loans, with an estimated elasticity of 0.07. Finally, the restricted estimation shows that housing prices exercise a

[25] Caldera Sánchez and Johansson (2011) use SUR to jointly estimate both long- and short-run systems of equations for housing prices and residential investment. Unlike our paper, they do not consider the Johansen's procedure for the cointegrating vectors in the long-run, and do not allow the error correction term of residential investment (prices) to enter the short-term equation for housing prices (residential investment). As our focus is to model the mutual dependence between housing prices and mortgage loans, we use the results of the cointegration long-run analysis and employ SUR to jointly estimate the short-run system.

greater impact on mortgage credit than does mortgage credit on prices; this result is the opposite of that found by Anundsen and Jansen (2013) for total household borrowing, but is in line with the findings of Gimeno and Martinez-Carrascal (2010) for house purchase loans. In particular, we estimate that a 1% increase in housing prices increases mortgage loans by 1.24% in the long-run.

Figure 2 plots the actual series $rhpi_t$ and mg_t along their corresponding long-run values, which are estimated from the restricted cointegrating vectors. The long-run values can be interpreted as the *fundamental values* of housing prices and mortgage loans. The deviations of the actual series from the estimated values are the error correction terms CEq1 and CEq2. Model inference depends crucially on the stationarity of these long run-residuals. Figure 3 plots their time-series and indicates that both series are stationary and roughly between -30% and 30%. Table 6 further confirms that the existence of unit roots for both series is strongly rejected (using individual or group unit root tests).

Short-Run Dynamics

Panel B of Table 5 presents the estimation output of the restricted VECM short-term dynamics. As detailed above, we estimate the short-run system using the SUR approach and implement a stepwise elimination of insignificant variables. In terms of specification issues, Table 7 shows that standard Portmanteau tests indicate no serial correlation in the system residuals.

Regarding the $\Delta rhpi_t$ equation, the first error correction term CEq1 (i.e. the lagged residuals of the long-run equation for housing prices) is statistically significant. Whereas the estimated coefficient is higher in comparison to the exactly identified VECM, the adjustment of housing prices in Luxembourg to deviations from fundamentals is considered slow, with an estimated correction of 2.2%. This is similar, for example, to the value of 2.7% estimated by Caldera Sánchez and Johansson (2011) for Denmark, or the value of 3.1% estimated by Panagiotidis and Printzis (2016) for Greece. Furthermore, we find that the coefficient on the mortgage error correction term is insignificant (and therefore CEq2_{t-1} is dropped from the $\Delta rhpi_t$ equation). As discussed above, this finding is in contrast with the results of Gimeno and Martinez-Carrascal (2010) and Anundsen and Jansen (2013), who document a significant negative coefficient for Spain and Norway, respectively, but is in line with the results of Brissimis and Vlassopoulos (2009), who show that property prices do not adjust to the disequilibrium in the mortgage lending market in Greece. With respect to other variables, we document a positive effect of lagged house price changes on $\Delta rhpi_t$ (in line with the literature), a positive (negative) contemporaneous (lagged) effect of changes in construction cost, and a positive coefficient for lagged net migration and GDP changes.

Overall, the estimation fit of the first short-term equation is noticeable, with an adjusted R^2 of 60.1%.

In the Δmg_t equation, both error correction terms are statistically significant and negative. The speed of adjustment of mortgage loans is now estimated to be 56.0% per quarter, while the effect of CEq1_{t-1} is more important in comparison to the unrestricted case. In particular, a positive deviation of housing prices from their long-run equilibrium leads to a decrease of 25.9% on mortgage loans over the next period. It seems therefore that the equilibrium in the mortgage market is restored faster than for the case of housing prices. Regarding other short-term equations, we find for example a positive and significant effect of lagged CEq1 and CEq2 on net migration. This implies that housing price and credit deviations contribute, in the short-run, to an increase in net migration, which may magnify the existing imbalance between housing demand and supply. Finally, following the sequential deletion of insignificant variables, both error correction terms are dropped from the Δgdp_t equation, even though the weak exogeneity hypothesis was not supported for gdp_t; we check this issue further in Section 5.

4.3.3 Valuation Measure of Residential Housing Prices

The results suggest an important role for the interaction between residential housing prices and mortgage credit in Luxembourg. While the adjustment of housing prices to long-term deviations from fundamentals is done at a slow pace, property prices do not directly adjust to disequilibria in the mortgage market. Against this background, an important question refers to the degree of overvaluation or undervaluation of housing prices. To investigate this issue, we follow the literature and calculate a valuation measure based on the misalignment of the actual price series from the fundamental values estimated with the restricted cointegrating vectors.[26] Figure 4 displays the results for the period between 2000Q1 and 2017Q1. The red shaded areas correspond to periods of clear overvaluation of housing prices, when the estimated misalignment is positive and the lower dotted line is above zero. The greed shaded areas correspond to periods of clear undervaluation of housing prices, when the estimated misalignment is negative and the upper dotted line is below zero.

Overall the evidence suggests the existence of an undervaluation period between 2003Q3 and 2005Q3. This is consistent with the observation of a sharp decline in building permits and construction activity in the early 2000's (see Figure 1 and recall that we account for delays in construction activity). The deceleration of construction activity would be reflected

[26] As Figure 2 shows, the estimated long-run equilibrium is more volatile than the actual price series. Therefore, we use smoothed long-run residuals, calculated as a moving average of CEq1 over eight quarters, as our valuation measure. To calculate the (symmetric) confidence bands, the standard deviation is also calculated over an eight quarter horizon.

in a more limited supply of dwellings and, therefore, a jump in the fundamental value of housing. As the actual prices were growing at a steady rate, the dynamics are consistent with the estimated undervaluation. Furthermore it should be noted that, although net migration to Luxembourg also decreased, this drop was less significant and its long-run effect on housing prices is of a second-round nature (as it acts through a positive impact on mortgage credit).

The model also identifies two major overvaluation periods, the first roughly around 2008-2009 and coinciding with a decline in new mortgage loans, and the second between 2013Q2 and 2015Q2. The analysis of the endogenous variables since 2013Q2 reveals a continuous increase in housing prices, an expansion of mortgage credit, a rise in construction cost and real GDP, a stabilization of net migration to Luxembourg and some fluctuation in building permits and mortgage rates. Both the expansion of mortgage credit and the rise in construction cost directly contribute to a higher estimated fundamental value of housing prices. At the same time, $rhpi_t$ is increasing at a steady pace. Overall this evolution translates to a moderate, but persistent, overvaluation of housing prices. Since 2013Q2, the average overvaluation in the Luxembourg residential real estate market is estimated to be 7.78% but its trend is decreasing in the last quarters and, as Figure 4 shows, it is no longer significant (the last observation for 2017Q1 stands at around 1%). For comparison purposes, Turk (2015) estimates that housing prices were between 5.5% and 12% above the long-run equilibrium in Sweden (in 2015Q2). The analysis therefore confirms that the sustained increase in housing prices in Luxembourg is partially explained by structural factors, such as supply-side constraints (reflected in high construction cost and an insufficient level of building permits) and changes in demographics (with mortgage demand being heavily influenced by net migration to Luxembourg). It should be noted that, without taking into consideration such market rigidities in the model, the estimated overvaluation would be more substantial and the model results would converge toward those determined by the statistical ratios.

4.3.4 Impulse Response Functions

As noted above, we report a very slow house price adjustment, with only 2.2% of the misalignment of prices being corrected each quarter. However, from a system perspective, VECM impulse response functions provide a better measure of how fast shocks are eliminated (see, for example, the analysis in Anundsen and Jansen (2013)). This is the case not only for "own shocks" to house prices but also to better understand the full system dynamics. As an example, whereas the real interest rate is positively correlated to house prices in the CEq1 long-run, its relation with mortgage loans in CEq2 is negative; therefore, impulse response analysis provides a convenient way to establish the overall impact of interest rates on housing prices and credit.

To construct the impulse response functions, we take as a starting point the short-term dynamics estimated in Table 5. The error-correction terms CEq1 and CEq2 are written as functions of the variables in levels (with known coefficients from Panel A) and their expressions are substituted in the equations of Panel B. All variables' first-differences are then transformed to log-levels, i.e. $\Delta y_t = y_t - y_{t-1}$. This delivers an (unbalanced) VAR in levels, with known parameters, three lags and five endogenous variables ($rhpi_t$, mg_t, r_t, mi_t and gdp_t, in this order). In addition, there is a constant term and two exogenous variables (i.e. the contemporaneous and lagged building permits and construction cost). The Cholesky decomposition is used to orthogonalize the (known) covariance matrix of the system residuals. Figure 5 presents the orthogonalized impulse responses of housing prices and mortgage loans to one standard deviation innovation shocks of the endogenous variables.

The first plot in Figure 5 shows the orthogonalized impulse responses of housing prices and mortgage loans to a shock to housing prices. This shock has an immediate positive impact on both variables, which instead of dying out, gradually accumulates over time.[27] Given the high responsiveness of mortgage loans to housing prices in the long-run, the cumulative impact is in fact higher for mortgages than for housing prices. Perhaps more interesting is the response to a shock to mg_t, which leads to a permanent increase in $rhpi_t$ (second plot). While mortgages increase on impact, this initial effect starts to dye out as new credit shows a high speed of adjustment to own shocks. However, given the permanent increase of house prices, the positive interaction of credit and prices leads to a new increase in mortgages and a higher permanent value. The third plot shows that a positive shock to interest rates has an unambiguous positive effect on housing prices in the long-run (recall the negative coefficient for r_t in the CEq1 cointegration vector). Interestingly, the initial effect on mortgage loans is also positive, implying that the strong positive effect on housing prices and their direct interaction with credit is stronger than the direct effect of the interest rate (recall the positive coefficient for r_t in CEq2); as the impulse response of $rhpi_t$ starts to decelerate, the effect on mortgages dies out and becomes negative; nonetheless, there is a permanent increase in mg_t. A positive shock to net migration (fourth plot) translates to higher prices and credit, despite the zero coefficient of migration on CEq1. Indeed, an increase in mi_t is associated with more credit, which in turn puts pressure on housing prices (recall that $rhpi_t$ is found to not adjust to disequilibria in the mortgage market). Finally, the fifth plot shows that both prices and mortgages permanently increase in response to a shock to GDP.

[27] In comparison to standard VARs, this approach to a non-zero value reflects the non-stationarity of the system, where a one-time impulse can have permanent effects.

5 Robustness Checks

5.1 Identification of the Cointegration Equations

In the analysis above, only the real construction cost index and building permits are found to be weakly exogenous. Therefore, a possible concern is that CEq1 and CEq2 may be linear combinations of different equilibrium conditions, making it difficult to disentangle the equilibria for interest rates, net migration and real GDP from those for house price and mortgage loans. As weak exogeneity tests may be unreliable in small samples, we investigate this identification issue further. Specifically, we ignore the test results by imposing weak exogeneity also on r_t, mi_t and gdp_t and we re-estimate CEq1 and CEq2. We find that the cointegrating vectors remain identified and are in line with the ones presented in the previous sections. As above, the (two) remaining short-term equations are estimated by SUR and we sequentially drop coefficients that are not statistically significant at the 10% level. Table A1 in the Appendix presents the estimation results and Figure A1 shows the time-series of CEq1 and CEq2.

In comparison to the cointegrating vectors estimated in Section 4.3, the real interest rate is no longer significant at the 10% level (in CEq2) but the coefficients for the other variables retain the same sign and are similar in magnitude (in general, the coefficients are now lower in absolute terms). Interestingly, the two error correction terms are now statistically significant in both short-term equations. The adjustment rate of housing prices is substantially higher than the value estimated before (16.6% compared to 2.2%); results suggest that housing prices also correct for mortgage loans deviations. Moreover, the adjustment speed of mortgage loans is estimated to be around 100% (in fact, the associated coefficient is slightly lower than -1), which would indicate that equilibrium is restored in less than a quarter.

Since the cointegrating vectors remain identified when imposing weak exogeneity on all other variables, we interpret this fact as empirical support for the identification of CEq1 and CEq2 as long-run equilibria for house prices and mortgage loans, respectively. However, the imposed restrictions are clearly rejected in the data, both in terms of individual variables and as a group. In particular, while the test statistic for the binding restrictions underlying the mains results in Table 5 is given by $\chi^2(6) = 6.44$ and a p-value of 0.38, imposing weak exogeneity also in r_t, mi_t and gdp_t leads to a test statistic $\chi^2(12) = 49.72$ with a p-value of 0.00. Therefore, we opt to keep these three variables as endogenous in the main section.

5.2 Imposing Weak Exogeneity on Real GDP

As shown in Section 4.3, although the real construction cost index and building permits are the only variables for which we find support for weak exogeneity, the parsimonious short-term dynamics of gdp_t does not include the long-run residuals. That is, CEq1 and CEq2 are found to be statistically insignificant when applying the stepwise elimination of variables and therefore both error correction terms are dropped from the last equation. As a robustness check, in this section we repeat the estimation imposing weak exogeneity also on gdp_t, i.e. adding to the set of restrictions $\alpha_{gdp,1} = \alpha_{gdp,2} = 0$. We find empirical support for the joint test, with a test statistic given by $\chi^2(8) = 9.96$ and a p-value of 0.27. Results are presented in Table A2 in the Appendix. Overall, results are very similar to the ones presented above, with the exception of the coefficient for gdp_t in CEq2, which is no longer statistically significant at the 10% level.[28]

5.3 Stock of Mortgage Loans as Endogenous Variables

In the previous sections, we have used as a proxy for credit constraints the endogenous variable mg_t, which corresponds to new mortgage loans granted to domestic households. The option of using mortgage or credit flows is also followed in other papers, e.g. Gerlach and Peng (2005) use bank lending to study the relationship between residential property prices and credit in Hong Kong, Fitzpatrick and McQuinn (2007) use the average of new mortgages to examine the interaction between house prices and bank credit in Ireland, and Berki and Szendrei (2017) use average real new housing loans to investigate the position of housing prices in Hungary. Although the flow of new mortgages seems to be a good approximation to the shadow price of the credit constraint at time t, a possible concern is that it ignores information from outward flows, including the volume of existing loans that are being refinanced. Therefore, in this section, we repeat the analysis using as endogenous variable the stock of mortgage loans. The data is available from SDW, with domestic counterpart at a monthly frequency since 1997M09 and with Euro area counterpart at a quarterly frequency since 1980Q1.[29] First, we convert the monthly series to a quarterly frequency by retaining the last observation in each quarter. Second, we use the growth rates of the series with Euro area counterpart to extend backwards the domestic loans. The resulting series is seasonally

[28] This could imply eliminating real GDP *per capita* from the analysis. A previous version of this paper did not include the variable and delivered very similar conclusions for the dynamic interaction of housing prices and mortgages.

[29] The mnemonics for the relevant series are BSI.M.LU.N.A.A22.A.1.U6.2250.Z01.E and BSI.Q.LU.N.A.A22.A.1.U2.2250.Z01.E.

adjusted, measured in log and real terms, and denominated by smg_t.[30] Figure A2 in the Appendix shows the evolution of smg_t.

As unit root tests suggest the series is stationary in first-differences and results of the cointegration tests remain unchanged, we proceed as before and estimate an exactly identified VECM with the same identifying restrictions as in Section 4.2. The results are presented in Table A3 in the Appendix. In comparison to the main results, most of the coefficients of the housing price cointegration equation have the same sign and similar magnitudes. The coefficient of smg_t is (more) negative and strongly significant, while the coefficient of bp_t decreases slightly (from 1.6 to 1.3). Net migration mi_t remains statistically insignificant, whereas the coefficient for cc_t remains negative and increases in absolute terms. The most relevant difference is noted for real GDP *per capita*, which is now statistically significant but negatively related to housing prices in the long-run. Regarding the second cointegration equation, the housing price coefficient remains negative and significant but its importance decreases (from -1.184 to -0.436). The estimated coefficient of the real interest rate is similar in magnitude (0.015 compared to 0.020 in Table 4) but it is no longer statistically significant at the 10% level. Net migration is also insignificant in the second equation, while the coefficient of cc_t is strongly positive. The importance of GDP for the long-run mortgage equilibrium also increases. In terms of short-term dynamics, both adjustment coefficients are estimated to be negative and significant in the $\Delta rhpi_t$ equation but this is not the case for the Δsmg_t equation. Overall the fit for the short-term mortgage dynamics decreases substantially when compared to the main results.

As above, we also investigate the weak exogeneity of the variables with respect to the long-run coefficients. The results suggest that the real construction cost index cc_t, building permits bp_t, and net migration mi_t are weakly exogenous. The test statistic for the binding restrictions on cc_t is $\chi^2(2) = 1.02$ with a p-value of 0.60; for bp_t the test statistic is $\chi^2(2) = 0.59$ with a p-value of 0.74; and finally for mi_t the test statistic is $\chi^2(2) = 3.37$ with a p-value of 0.19. Given the result for net migration and the fact that the variable is insignificant in both long-run equations, we exclude mi_t from the analysis. Therefore, the restricted VECM estimation now entails the same identifying restrictions (i.e. $\beta_{rhpi,1} = 1$, $\beta_{r,1} = -0.1$, $\beta_{mg,2} = 1$ and $\beta_{bp,2} = 0$) in addition to the weak exogeneity restrictions $\alpha_{cc,1} = \alpha_{cc,2} = 0$ and $\alpha_{bp,1} = \alpha_{bp,2} = 0$. We find strong empirical support for the joint test, with a test statistic given by $\chi^2(4) = 1.01$ and a p-value of 0.91.

Table A4 in the Appendix presents the estimation results of the restricted VECM using the stock of mortgage loans. In comparison to the exactly identified case, all variables have

[30] We have also simply used the stock of mortgages with Euro area counterpart as smg_t, with almost identical results to the ones described in this section.

the same sign and are statistically significant (including the real mortgage rate in the second equation). In terms of short-term dynamics, the adjustment coefficients are negative and significant for the case of housing prices. Specifically, the adjustment of housing prices to deviations from fundamentals is estimated to be faster than when considering mortgage flows (i.e. 6.7% compared to 2.2% in Table 5); housing prices are also found to be adjusting to mortgage disequilibria, which was not the case with mortgage flows. However, the adjustment coefficients remain insignificant in the Δsmg_t equation.

Although the long-run residuals are found to be stationary and there is no evidence of residual serial correlation in the estimated system, the poor fit of the smg_t dynamics raises concerns in terms of the ability to model housing prices when using the stock of mortgage loans. Indeed, a replication of the long-run equilibrium (as in Figure 2) shows that deviations from equilibria are larger and more volatile. A closer look at the time-series of smg_t in Figure A2 shows a clear spike in the stock of mortgage loans around 1998, which does not appear consistent with the BCL data for new mortgage loans and might be partially affecting the results. Given these differences and the weaker conclusions, we opt to keep mortgage flows as the endogenous variable in the main section.

6 Conclusion

We investigate the interaction between housing prices and mortgage loans in Luxembourg. To this end, we estimate a restricted VECM that allows for feedback effects between the two variables. In line with the literature results for other countries, we confirm the existence of such interaction. In the long-run, higher housing prices lead to an expansion of mortgage credit, which in turn puts upward pressure on prices. Our analysis also confirms the importance of structural factors in the Luxembourg housing market: first, construction activity is an important long-run determinant of property prices, reflecting supply-side limitations on dwelling availability; second, demographic factors should be taken into account, as positive net migration to Luxembourg helps sustain the demand for mortgage credit. These dynamics lead to a structural imbalance between supply and housing demand, with the latter being fueled by demographic factors, tax incentives and fiscal subsidies, as well as the low interest rate environment.

While price dynamics are partially explained by these structural factors, we estimate that over the last few years residential housing prices have been characterized by a moderate, but persistent, overvaluation with respect to market fundamentals. Our valuation measure is based on the misalignment of the actual price series from the fundamental long-run fitted values. Since the start of the latest identified overvaluation period in 2013Q2, the average overvaluation in the Luxembourg residential real estate market is estimated to be 7.78% but its trend is decreasing in the most recent quarters. Overall the average overvaluation in the last five years is calculated at 6.85%. As noted above, this overvaluation is explained by the importance of market rigidities caused by the factors underlying the supply limitation and the strong demand; without taking into consideration such rigidities in the model, the estimated overvaluation would be more substantial as it would converge toward statistical indicators.

In terms of short-term dynamics of housing prices, we find that the rate of adjustment is 2.2% per quarter, which implies that price deviations from fundamentals are corrected at a slow pace when comparing to other countries. This is most likely due to the inclusion of mortgage credit in the analysis. In fact, we find that property prices do not directly adjust to disequilibria in the mortgage market. On the other hand, the speed of adjustment of mortgage loans is estimated to be 56.0% per quarter, while a positive deviation of housing prices from their long-run equilibrium leads to a decrease of 25.9% in new mortgage loans over the next period. The results therefore suggest that the equilibrium in the mortgage market is restored faster than is the case for housing prices. Given the values indicated above for the direct rate of adjustments, the half-life (i.e. the time needed in order to eliminate 50% of the deviation) is 31.5 quarters for housing prices and only around one quarter for mortgages. These results are also supported by impulse response analysis, which shows that shocks to the endogenous variables lead to permanent increases in housing prices.

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Table 1:

Summary Statistics

This table reports descriptive statistics for real housing price index ($rhpi_t$), building permits (bp_t), housing stock (h_t), real construction cost index (cc_t), real new mortgage loans granted to domestic households (mg_t), real mortgage rate (r_t), average number of households (hh_t), net migration (mi_t) and real GDP per capita (gdp_t). All variables are expressed in logs, except the mortgage rate that is measured in percent *p.a.* Autocorr refers to the first order autocorrelation and * (**) denotes statistical significance at 5% (1%). Panel A shows summary statistics for the log variables in levels, while Panel B displays summary statistics for log variables in first-differences. The sample period is 1980Q1–2017Q1.

Panel A: Variables in Levels

	Obs	Mean	Stdev	Min	Max	Autocorr
$rhpi_t$	149	4.095	0.473	3.291	4.824	0.987**
bp_t	146	6.636	0.324	5.950	7.078	0.986**
h_t	149	12.081	0.164	11.822	12.370	0.981**
cc_t	149	4.552	0.067	4.402	4.630	0.983**
mg_t	149	6.087	0.877	4.511	7.424	0.983**
r_t	149	5.508	4.741	−1.285	17.684	0.952**
hh_t	149	5.134	0.202	4.849	5.532	0.980**
mi_t	149	6.700	1.167	2.970	7.955	0.986**
gdp_t	149	2.626	0.349	2.002	3.063	0.983**

Panel B: Variables in First-differences

	Obs	Mean	Stdev	Min	Max	Autocorr
$rhpi_t$	148	0.009	0.017	−0.045	0.052	0.582**
bp_t	145	0.004	0.041	−0.123	0.119	0.319**
h_t	148	0.004	0.001	0.001	0.011	0.522**
cc_t	148	0.001	0.006	−0.015	0.018	0.162*
mg_t	148	0.017	0.074	−0.245	0.264	−0.035
r_t	148	−0.120	0.976	−4.007	3.513	0.056
hh_t	148	0.005	0.002	0.001	0.011	0.645**
mi_t	148	0.011	0.168	−1.066	0.862	0.567**
gdp_t	148	0.007	0.017	−0.035	0.072	0.013*

Table 2:

Unit Root Tests

This table reports the results of Augmented Dickey-Fuller (ADF) unit root tests for real housing price index ($rhpi_t$), building permits (bp_t), housing stock (h_t), real construction cost index (cc_t), real mortgages (mg_t), real mortgage rate (r_t), average number of households (hh_t), net migration (mi_t) and real GDP per capita (gdp_t). All variables are expressed in logs, except the mortgage rate that is measured in percent *p.a.* Results are shown for variable level and first-differences, in the case where the test equation includes (i) a constant and (ii) a constant and a linear time trend. Lags represent the optimal lag length calculated according to the Schwarz information criterion, allowing for a maximum of 6 lags (the conclusions remain unchanged if the Akaike information criterion is used). The probability is the p-value associated with the ADF null hypothesis of existence of unit root. Numbers in bold represent the cases where we cannot reject the null. The sample period is 1980Q1–2017Q1.

	Constant		Constant and Trend	
	Level	1st Diffs	Level	1st Diffs
Housing Prices, $rhpi_t$				
Lags	2	1	2	1
Test Statistic	-0.229	-3.628	-3.281	-3.656
Probability	**0.931**	0.006	**0.073**	0.029
Building Permits, bp_t				
Lags	3	2	4	2
Test Statistic	-2.123	-3.486	-3.605	-3.447
Probability	**0.236**	0.010	0.033	0.049
Housing Stock, h_t				
Lags	3	2	3	2
Test Statistic	0.808	-2.864	-3.289	-3.042
Probability	**0.994**	**0.052**	**0.072**	**0.125**
Construction Cost, cc_t				
Lags	4	3	4	3
Test Statistic	-1.145	-4.168	-2.099	-4.143
Probability	**0.697**	0.001	**0.542**	0.007
Mortgage Loans, mg_t				
Lags	0	0	0	0
Test Statistic	-0.299	-12.564	-2.450	-12.527
Probability	**0.921**	0.000	**0.353**	0.000
Real Interest Rate, r_t				
Lags	0	0	0	0
Test Statistic	-1.937	-11.451	-3.198	-11.446
Probability	**0.315**	0.000	**0.089**	0.000
Number of Households, hh_t				
Lags	4	3	4	3
Test Statistic	2.345	-1.106	-1.557	-2.917
Probability	**1.000**	**0.713**	**0.805**	**0.160**
Net Migration, mi_t				
Lags	1	0	1	0
Test Statistic	-1.666	-6.370	-2.775	-6.345
Probability	**0.446**	0.000	**0.209**	0.000
Real GDP per capita, gdp_t				
Lags	4	3	4	3
Test Statistic	-1.423	-6.211	-0.786	-6.356
Probability	**0.570**	0.000	**0.964**	0.000

Table 3:

Johansen Cointegration Tests

This table reports the results of the Johansen cointegration tests. The endogenous variables included in the analysis are the real housing price index ($rhpi_t$), building permits (bp_t), real construction cost index (cc_t), real mortgages (mg_t), real mortgage rate (r_t), net migration (mi_t) and real GDP per capita (gdp_t). All variables are expressed in logs, except the mortgage rate that is measured in percent *p.a.* The tests allow for two lags in first-differences and the inclusion of a linear deterministic trend. The columns 5% c.v. (1% c.v.) represent the critical values from surface regressions in MacKinnon, Haug, and Michelis (1999) at the 5% (1%) level. Numbers with * denote the first hypothesis that is not rejected for each significance level and for each test statistic. The sample period is 1980Q4–2017Q1.

		Trace Statistic			Max-Eigenvalue Statistic		
No.CE(s)	Eigenvalue	Test Stat	5% c.v.	1% c.v.	Test Stat	5% c.v.	1% c.v.
r=0	0.356	186.471	125.615	135.973	63.022	46.231	52.308
r≤ 1	0.273	123.449	95.754	104.962	45.624	40.078	45.869*
r≤ 2	0.172	77.825	69.819	77.819	27.033	33.877*	39.370
r≤ 3	0.140	50.792	47.856	54.682*	21.511	27.584	32.715
r≤ 4	0.109	29.281	29.797*	35.458	16.493	21.132	25.861
r≤ 5	0.068	12.788	15.495	19.937	10.021	14.265	18.520
r≤ 6	0.019	2.766	3.841	6.635	2.766	3.841	6.635

Table 4:

Exactly Identified VECM

This table reports the output estimation of the exactly identified VECM, using a lag of two periods and a rank of two. The endogenous variables included in the analysis are the real housing price index ($rhpi_t$), building permits (bp_t), real construction cost index (cc_t), real mortgages (mg_t), real mortgage rate (r_t), net migration (mi_t) and real GDP per capita (gdp_t). All variables are expressed in logs, except the mortgage rate that is measured in percent *p.a.* Panel A displays the estimated cointegrating equations, which correspond to the first part of the estimation output and are expressed as $CEqi_t = \sum_y \beta_{y,i} y_t + c_i$, where $y = \{rhpi, mg, bp, r, mi, cc, gdp\}$ and $i = \{1, 2\}$. Panel B presents the (partial) estimated short-term dynamics for $\Delta rhpi_t$ and Δmg_t (for brevity, we also only display adjustment coefficients and coefficients that are statistically significant at the 10% level. Full estimation results are available upon request). T-statistics are shown in brackets and *(**) represents statistical significance at the 5% (1%) level. The sample period is 1980Q4–2017Q1.

Panel A: Cointegrating Equations

	$rhpi_t$	mg_t	bp_t	r_t	mi_t	cc_t	gdp_t	c
CEq1	1	-1.185**	1.600**	-0.1	-0.088	-7.415**	0.736	25.460
		[-6.067]	[7.210]		[-1.566]	[-4.036]	[1.307]	
CEq2	-1.184**	1	0	0.020**	-0.052**	0.317	-0.613**	-0.835
	[-12.599]			[3.883]	[-2.946]	[0.603]	[-2.911]	

Panel B: Short-term Dynamics

$\Delta rhpi_t$	CEq1_{t-1}	CEq2_{t-1}	$\Delta rhpi_{t-1}$	$\Delta rhpi_{t-2}$	Δmi_{t-1}	Δgdp_{t-1}	c
	-0.011	-0.011	0.229*	0.331**	0.014	0.109	0.003
	[-1.564]	[-0.536]	[2.209]	[3.433]	[1.790]	[1.682]	[1.849]
	$R^2 = 0.535$, Adj.$R^2 = 0.476$						

Δmg_t	CEq1_{t-1}	CEq2_{t-1}	Δbp_{t-1}	Δgdp_{t-2}	c
	-0.136**	-0.547**	0.347*	0.636	0.017*
	[-3.352]	[-4.719]	[1.960]	[1.711]	[2.000]
	$R^2 = 0.229$, Adj.$R^2 = 0.132$				

Table 5:

Main Results: Restricted VECM Estimation

This table reports the output estimation of the restricted VECM. Panel A displays the restricted cointegrating equations. Panel B presents the estimated short-term dynamics, where the equations are estimated by SUR and we sequentially drop coefficients that are not statistically significant at the 10% level. T-statistics are shown in brackets and *(**) represents statistical significance at the 5% (1%) level. In the last column, (1) is R^2, (2) is adjusted R^2 and (3) is the Durbin-Watson statistic. The sample period is 1980Q4–2017Q1.

Panel A: Cointegrating Equations

	$rhpi_t$	mg_t	bp_t	r_t	mi_t	cc_t	gdp_t	c
CEq1	1	-0.865**	0.669**	-0.061**	0	-2.442**	0	8.187
		[-14.313]	[6.442]	[-7.813]		[-3.651]		
CEq2	-1.242**	1	0	0.027**	-0.069**	0	-0.342*	0.208
	[-15.244]			[5.434]	[-5.044]		[-2.314]	

Panel B: Short-term Dynamics

$\Delta rhpi_t$	CEq1_{t-1}	$\Delta rhpi_{t-1}$	$\Delta rhpi_{t-2}$	Δmi_{t-1}	Δcc_t	Δcc_{t-1}	Δgdp_{t-1}	c					(1) 62.1
	-0.022**	0.323**	0.200**	0.016**	0.967**	-0.526**	0.140**	0.003*					(2) 60.1
	[-2.944]	[4.358]	[2.938]	[3.044]	[5.943]	[-2.867]	[2.676]	[2.374]					(3) 2.09
Δmg_t	CEq1_{t-1}	CEq2_{t-1}	Δbp_{t-1}	Δcc_t	c								(1) 20.2
	-0.259**	-0.560**	0.239	1.744	0.015**								(2) 17.9
	[-4.011]	[-5.634]	[1.747]	[1.800]	[2.731]								(3) 1.88
Δr_t	CEq1_{t-1}	$\Delta rhpi_{t-2}$	Δmg_{t-1}	Δmg_{t-2}	Δbp_t	Δbp_{t-2}	Δmi_{t-1}	Δmi_{t-2}	Δcc_t	Δcc_{t-1}	Δcc_{t-2}	c	(1) 43.3
	4.389**	9.650*	2.213*	2.164*	3.677*	4.583**	1.462**	-1.049*	34.803**	20.173	20.283	-0.415**	(2) 38.5
	[7.462]	[2.130]	[2.535]	[2.573]	[2.257]	[2.837]	[3.516]	[-2.563]	[3.322]	[1.906]	[1.765]	[-5.849]	(3) 2.11
Δmi_t	CEq1_{t-1}	CEq2_{t-1}	$\Delta rhpi_{t-2}$	Δbp_{t-2}	Δr_{t-2}	Δmi_{t-1}	Δmi_{t-2}	Δcc_t	Δcc_{t-1}	Δcc_{t-2}	Δgdp_{t-1}		(1) 50.6
	0.581**	0.783**	1.256	-0.462	-0.052**	0.490**	0.153*	-3.860*	4.507*	6.870**	-1.406*		(2) 46.9
	[4.238]	[4.125]	[1.694]	[-1.711]	[-4.832]	[7.078]	[2.181]	[-2.156]	[2.443]	[3.446]	[-2.542]		(3) 1.99
Δgdp_t	Δgdp_{t-2}	Δcc_t	c										(1) 11.6
	0.220**	0.671**	0.005**										(2) 10.4
	[2.919]	[3.016]	[3.169]										(3) 2.00

Table 6:

Stationarity of the Long-Run Residuals

This table reports the results of the stationarity tests on the error correction terms CEq1 and CEq2 (presented in Table 5). Panel A presents the results of individual unit root tests, where ADF refers to the Augmented Dickey-Fuller test and PP refers to the Phillips-Perron test. In both tests, the null hypothesis is the existence of a unit root. Panel B presents the results of group unit root tests, both for the case of a common unit root and individual unit roots. All tests strongly reject the existence of unit roots in the cointegrating equations.

Panel A: Individual Unit Root Tests

	ADF		PP	
	CEq1	CEq2	CEq1	CEq2
Lags / Bandwidth	0	0	2	4
Test Statistic	-3.701	-5.154	-3.751	-5.060
Probability	0.005	0.000	0.004	0.000

Panel B: Group Unit Root Test

Method	Test Stat.	Prob.
Null: Common unit root		
Levin, Lin and Chu	-4.356	0.000
Null: Individual unit roots		
Im, Pesaran and Shin	-4.776	0.000
Fisher-ADF	31.927	0.000
Fisher-PP	31.468	0.000

Table 7:

System Residual Portmanteau Tests

This table reports the results of the multivariate Box-Pierce/Ljung-Box Q-statistics for residual serial correlation up to the specified order. We report both the Q-statistics and the adjusted Q-statistics (with a small sample correction). The null hypothesis is no residual autocorrelation up to lag h. The residuals are estimated from the restricted short-term dynamics presented in Table 5. The test is valid only for lags larger than the system lag order.

Lags	Q-Stat	Prob.	Adj Q-Stat	Prob.
1	-	-	-	-
2	-	-	-	-
3	44.881	0.998	45.613	0.997
4	78.973	0.940	80.685	0.922
5	114.534	0.739	117.534	0.670
6	135.190	0.801	139.096	0.728
7	154.932	0.860	159.854	0.788
8	169.025	0.946	174.781	0.901
9	193.265	0.938	200.649	0.877
10	212.735	0.958	221.583	0.902
11	234.658	0.963	245.334	0.901
12	261.898	0.945	275.069	0.846

Figure 1:

Evolution of Main Variables

This figure displays the time-series of the variables used in the analysis: real housing price index ($rhpi_t$), real mortgages (mg_t), building permits (bp_t), real mortgage rate (r_t), net migration (mi_t), real construction cost index (cc_t) and real GDP per capita (gdp_t). All variables are expressed in logs, except the mortgage rate that is measured in percent *p.a.* The sample period is 1980Q1–2017Q1.

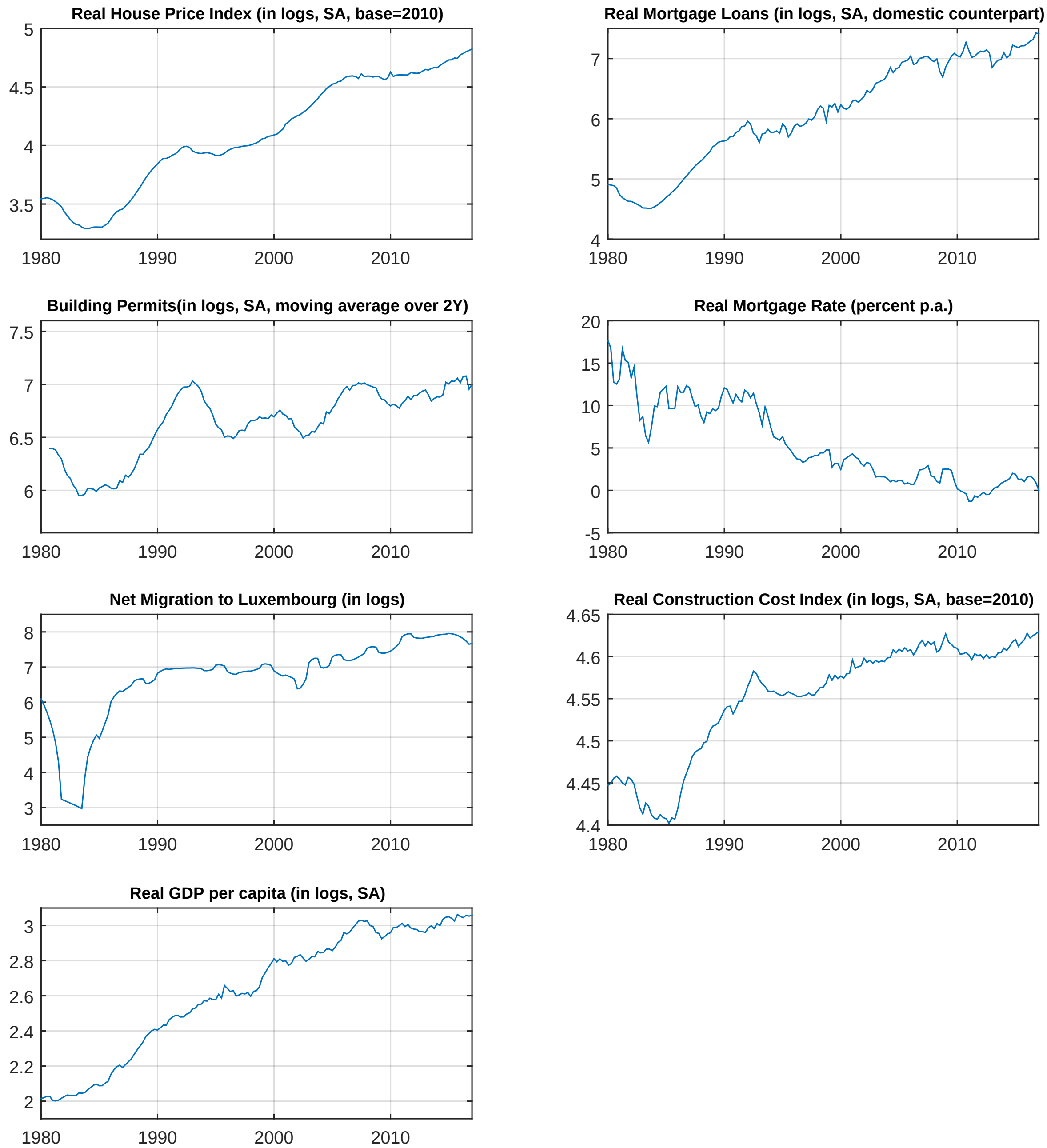
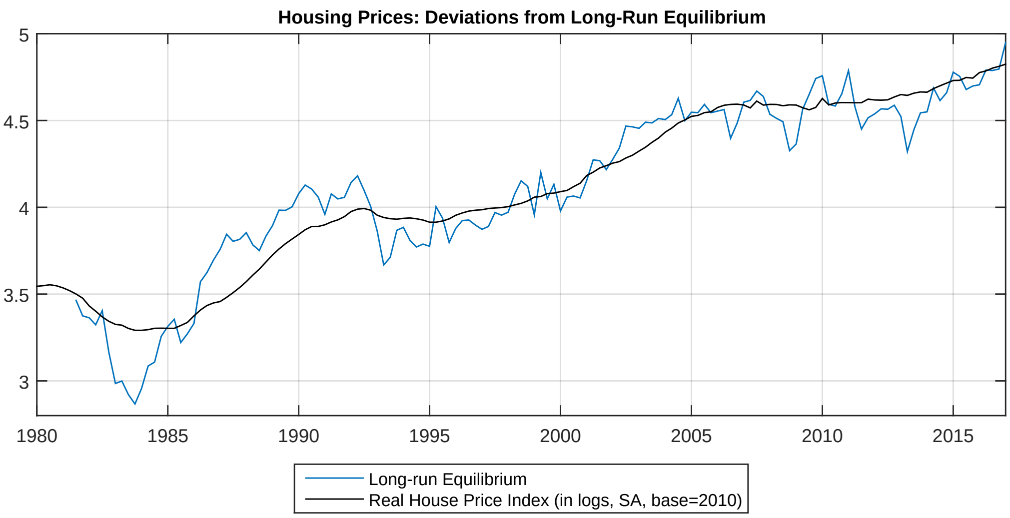


Figure 2:

Long-Run Equilibrium

This figure displays the actual $rhpi_t$ and mg_t series and their long-run equilibria, as determined by the Cointegrating Equations (presented in Table 5). The first plot shows the time-series of the real house price index and the long-run value for this variable. Similarly, the second plot shows the time-series of mortgage loans and their estimated fundamental value. The sample period is 1980Q4–2017Q1.



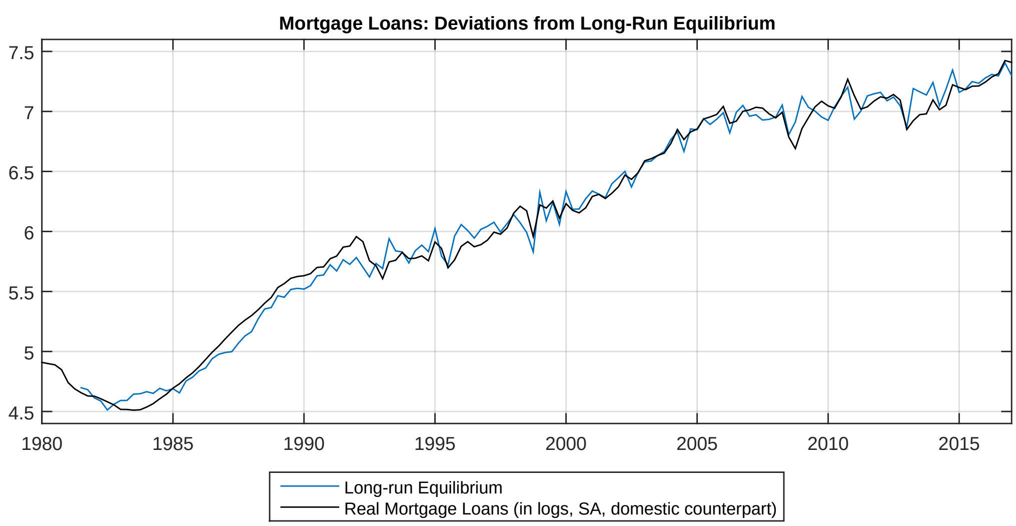
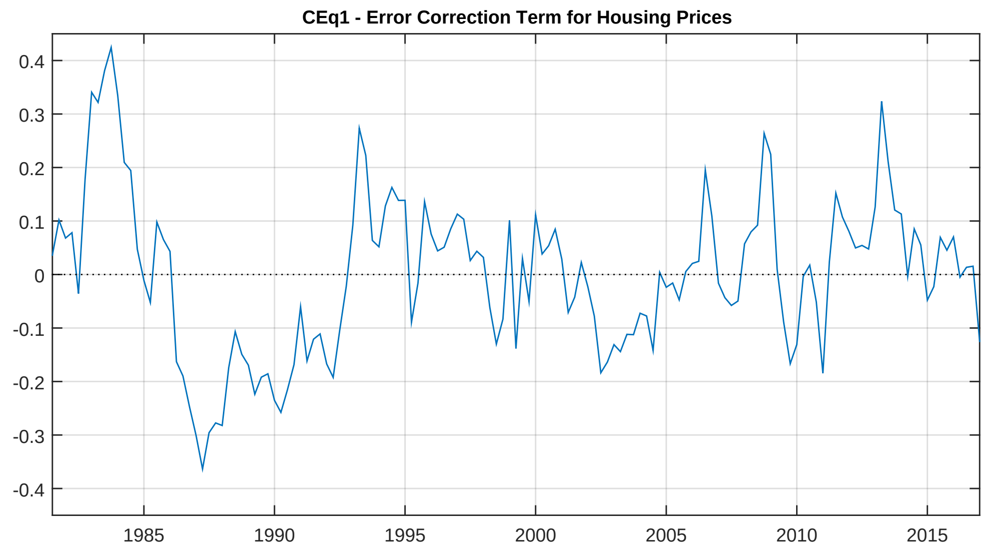


Figure 3:

Long-Run Residuals

This figure displays the time-series of the two error correction terms (used in Panel B of Table 5). These are the long-run residuals, i.e. the differences between the actual series and the estimated fundamental values. CEq1 and CEq2 are estimated using the first step Johansen's procedure for the restricted cointegrating vectors, and they represent the result for housing prices ($rhpi_t$) and mortgage loans (mg_t), respectively. The sample period is 1980Q4–2017Q1.



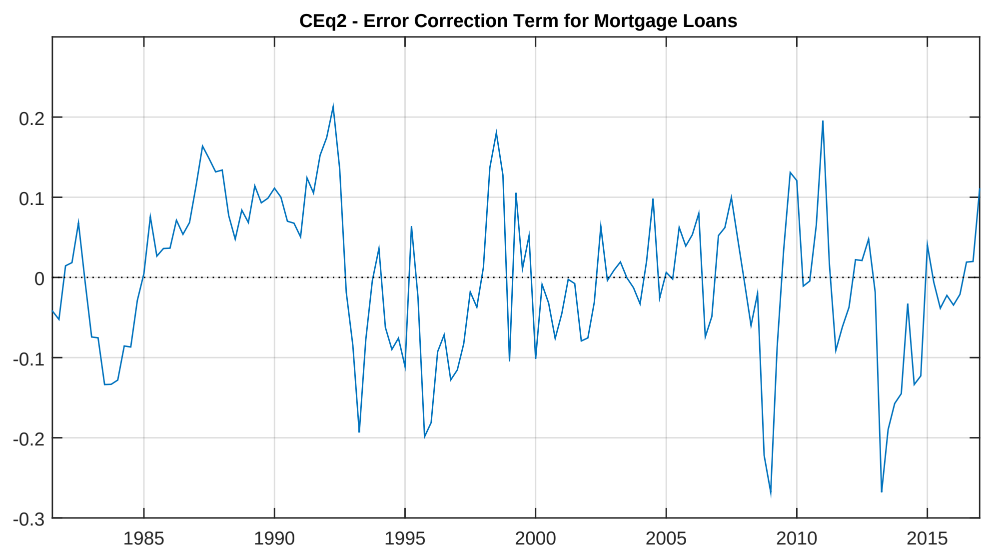


Figure 4:

Housing Prices - Overvaluation and Undervaluation Periods

This figure displays the valuation measure of real housing prices ($rhpi_t$) in Luxembourg. The black line represents the smoothed deviations of actual housing prices from fundamentals (i.e. a moving average of CEq1 calculated over eight quarters). The dotted lines represent a confidence band around the estimated misalignment (where the standard deviation is also computed over the past eight quarters). The red shaded areas correspond to periods of clear overvaluation of housing prices, when the estimated misalignment is positive and the lower dotted line is above zero. The greed shaded areas correspond to periods of clear undervaluation of housing prices, when the estimated misalignment is negative and the upper dotted line is below zero. The sample is 2000Q1–2017Q1.

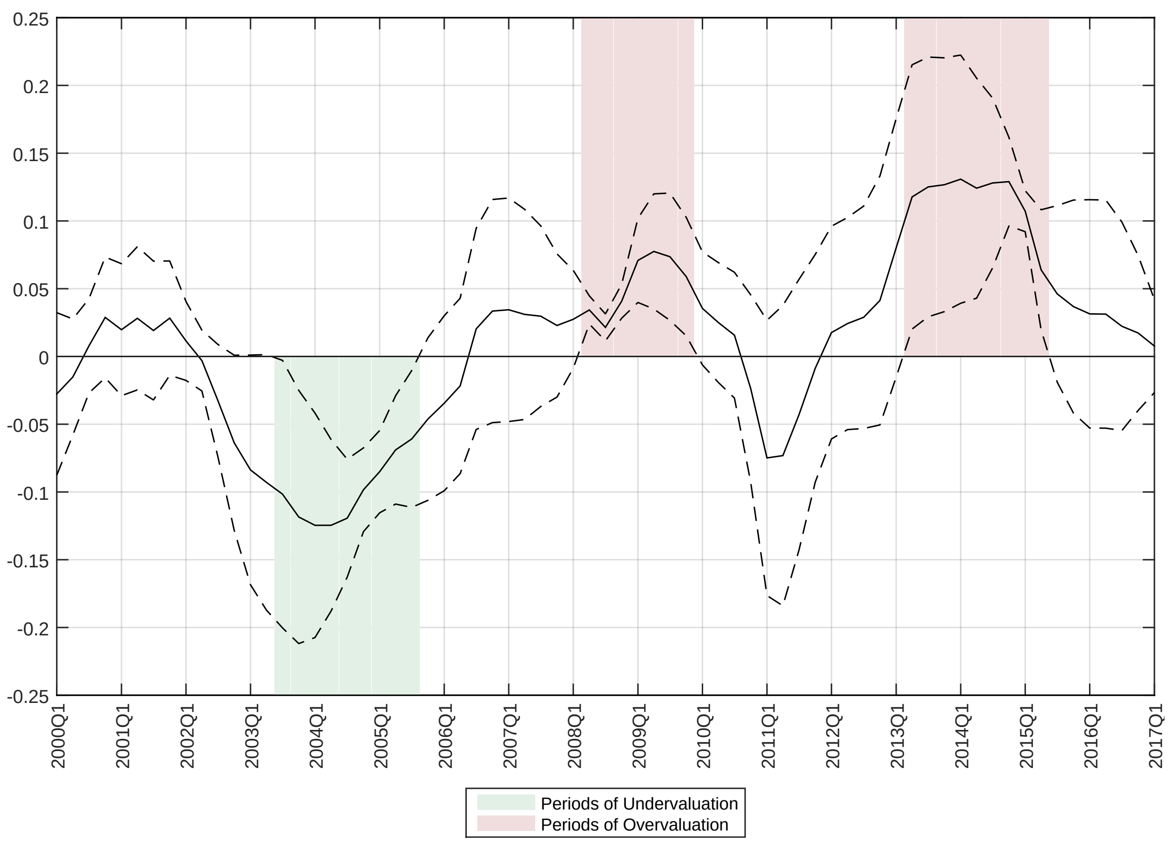
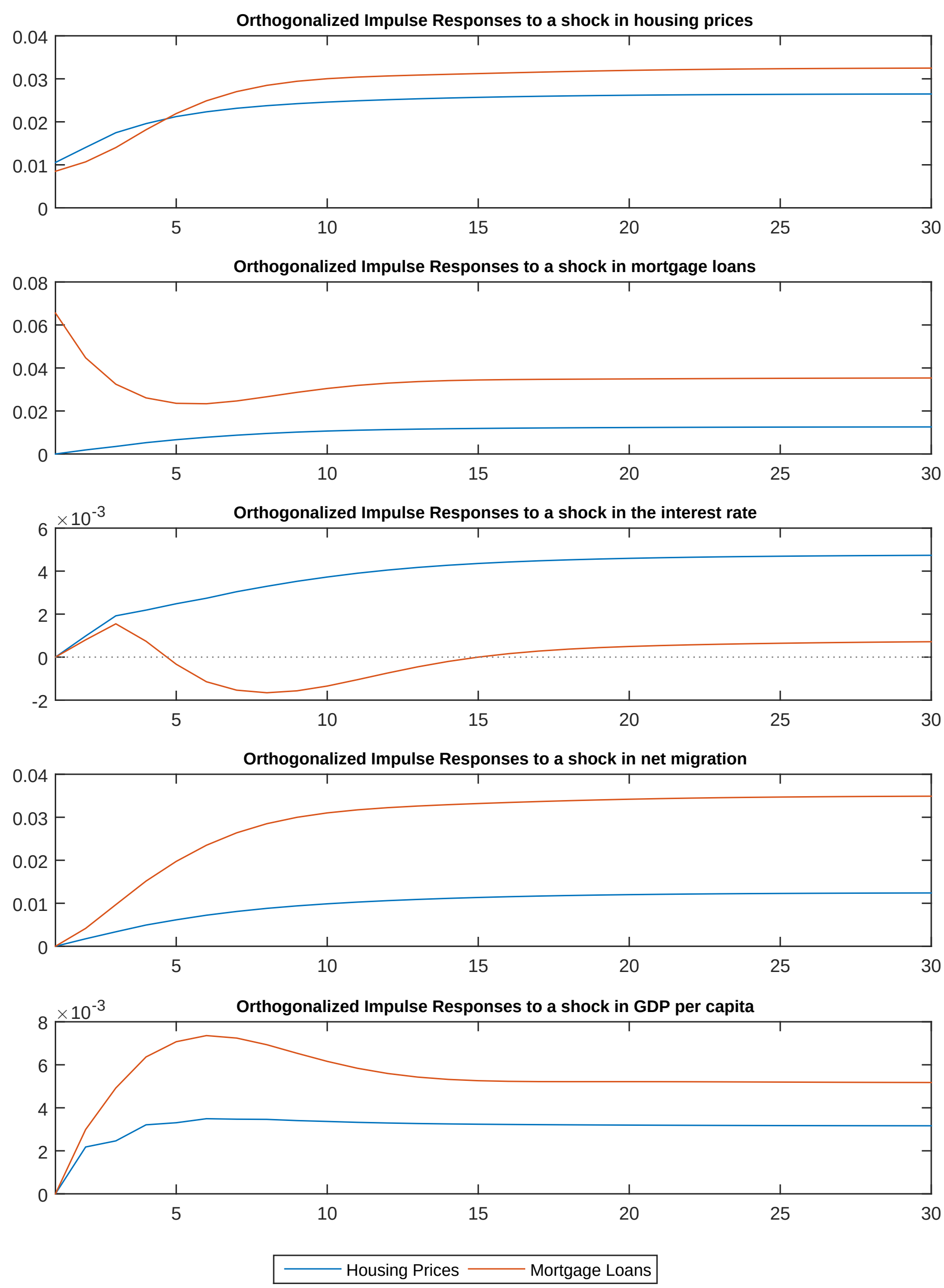


Figure 5:

Impulse Response Functions of Housing Prices and Mortgage Loans

This figure shows the orthogonalized impulse response functions of real housing prices and mortgage loans to one standard deviation innovation shocks of all the five endogenous variables (i.e. $rhpi_t$, mg_t, r_t, mi_t and gdp_t). The Cholesky factorization of the covariance matrix of the system residuals is used for orthogonalization.



Appendix

Table A1:

Identification of Housing Prices and Mortgage Cointegration Vectors

This table reports the output when imposing weak exogeneity on building permits (bp_t), real construction cost index (cc_t), real mortgage rate (r_t), net migration (mi_t) and real GDP *per capita* (gdp_t). Panel A displays the restricted cointegrating equations. Panel B presents the estimated short-term dynamics, where the equations are estimated by SUR and we sequentially drop coefficients that are not statistically significant at the 10% level. T-statistics are shown in brackets and *(**) represents statistical significance at the 5% (1%) level. The sample period is 1980Q4–2017Q1.

Panel A: Cointegrating Equations

	$rhpi_t$	mg_t	bp_t	r_t	mi_t	cc_t	gdp_t	c
CEq1	1	-0.626**	0.211**	-0.010	0	-0.698**	0	1.552
		[-19.658]	[5.304]	[-1.878]		[-2.667]		
CEq2	-1.506**	1	0	0.008	-0.037**	0	-0.218*	0.849
	[-22.312]			[1.326]	[-3.937]		[-2.046]	

Panel B: Short-term Dynamics

$\Delta rhpi_t$	CEq1$_{t-1}$	CEq2$_{t-1}$	$\Delta rhpi_{t-1}$	Δbp_{t-1}	Δcc_t	Δcc_{t-1}	Δgdp_{t-1}	c
	-0.166**	-0.076**	0.258**	0.059**	1.033**	-0.517**	0.135**	0.005**
	[-4.511]	[-2.678]	[3.558]	[2.670]	[7.059]	[-3.053]	[2.699]	[4.522]
	$R^2 = 0.658$, Adj.$R^2 = 0.640$							
Δmg_t	CEq1$_{t-1}$	CEq2$_{t-1}$	Δmg_{t-1}	Δbp_{t-1}	Δgdp_t			
	-1.004**	-1.070**	0.176*	0.394**	1.111**			
	[-5.070]	[-6.290]	[2.133]	[2.820]	[3.849]			
	$R^2 = 0.245$, Adj.$R^2 = 0.224$							

Table A2:

Restricted VECM Estimation with Weakly Exogenous GDP

This table reports the output estimation of the restricted VECM. Panel A displays the restricted cointegrating equations. Panel B presents the estimated short-term dynamics, where the equations are estimated by SUR and we sequentially drop coefficients that are not statistically significant at the 10% level. T-statistics are shown in brackets and *(**) represents statistical significance at the 5% (1%) level. In the last column, (1) is R^2, (2) is adjusted R^2 and (3) is the Durbin-Watson statistic. The sample period is 1980Q4–2017Q1.

Panel A: Cointegrating Equations

	$rhpi_t$	mg_t	bp_t	r_t	mi_t	cc_t	gdp_t	c
CEq1	1	-0.858**	0.689**	-0.061**	0	-2.710**	0	9.233
		[-13.727]	[6.381]	[-7.648]		[-3.901]		
CEq2	-1.298**	1	0	0.029**	-0.078**	0	-0.206	0.131
	[-15.400]			[5.640]	[-5.506]		[-1.341]	

Panel B: Short-term Dynamics

$\Delta rhpi_t$	CEq1_{t-1}	$\Delta rhpi_{t-1}$	$\Delta rhpi_{t-2}$	Δmi_{t-1}	Δcc_t	Δcc_{t-1}	Δgdp_{t-1}	c					(1) 62.1
	-0.022**	0.322**	0.189**	0.016**	0.956**	-0.511**	0.141**	0.003*					(2) 60.2
	[-2.999]	[4.323]	[2.761]	[2.950]	[5.927]	[-2.769]	[2.698]	[2.299]					(3) 2.08
Δmg_t	CEq1_{t-1}	CEq2_{t-1}	Δmg_{t-1}	Δbp_{t-1}	Δgdp_t								(1) 22.1
	-0.248**	-0.617**	0.153	0.298*	1.070**								(2) 19.9
	[-4.026]	[-6.065]	[1.871]	[2.168]	[3.688]								(3) 2.03
Δr_t	CEq1_{t-1}	$\Delta rhpi_{t-2}$	Δmg_{t-1}	Δmg_{t-2}	Δbp_t	Δbp_{t-2}	Δmi_{t-1}	Δmi_{t-2}	Δcc_t	Δcc_{t-1}	Δcc_{t-2}	c	(1) 43.0
	4.269**	9.195*	2.123*	2.143*	3.605*	4.785**	1.428**	-1.053**	34.763**	20.473	20.369	-0.411**	(2) 38.2
	[7.342]	[2.024]	[2.428]	[2.548]	[2.205]	[2.966]	[3.419]	[-2.564]	[3.318]	[1.926]	[1.770]	[-5.774]	(3) 2.11
Δmi_t	CEq1_{t-1}	CEq2_{t-1}	Δr_{t-2}	Δmi_{t-1}	Δmi_{t-2}	Δcc_t	Δcc_{t-1}	Δcc_{t-2}	Δgdp_{t-1}				(1) 47.0
	0.452**	0.689**	-0.043**	0.511**	0.165*	-3.399	3.687	6.945**	-1.136*				(2) 43.9
	[3.413]	[3.681]	[-4.104]	[7.035]	[2.233]	[-1.947]	[1.901]	[3.757]	[-1.992]				(3) 1.84

Table A3:

Exactly Identified VECM using Mortgage Stocks

This table reports the output estimation of the exactly identified VECM, using a lag of two periods and a rank of two. The endogenous variables included in the analysis are the real housing price index ($rhpi_t$), building permits (bp_t), real construction cost index (cc_t), real stock of mortgages (smg_t), real mortgage rate (r_t), net migration (mi_t) and real GDP per capita (gdp_t). All variables are expressed in logs, except the mortgage rate that is measured in percent *p.a.* Panel A displays the estimated cointegrating equations, which correspond to the first part of the estimation output and are expressed as $CEqi_t = \sum_y \beta_{y,i} y_t + c_i$, where $y = \{rhpi, smg, bp, r, mi, cc, gdp\}$ and $i = \{1, 2\}$. Panel B presents the (partial) estimated short-term dynamics for $\Delta rhpi_t$ and Δsmg_t (for brevity, we also only display adjustment coefficients and coefficients that are statistically significant at the 10% level. Full estimation results are available upon request). T-statistics are shown in brackets and *(**) represents statistical significance at the 5% (1%) level. The sample period is 1980Q4–2017Q1.

Panel A: Cointegrating Equations

	$rhpi_t$	smg_t	bp_t	r_t	mi_t	cc_t	gdp_t	c
CEq1	1	-1.693**	1.289**	-0.1	-0.029	-24.207**	5.769**	97.655
		[-10.005]	[5.978]		[-0.286]	[-7.387]	[6.749]	
CEq2	-0.436*	1	0	0.015	-0.024	11.880**	-4.251**	-49.619
	[-2.061]			[1.574]	[-0.379]	[6.534]	[-8.335]	

Panel B: Short-term Dynamics

$\Delta rhpi_t$	CEq1$_{t-1}$	CEq2$_{t-1}$	$\Delta rhpi_{t-1}$	$\Delta rhpi_{t-2}$	Δsmg_{t-2}	Δbp_{t-2}	Δmi_{t-1}	Δgdp_{t-1}	c
	-0.026**	-0.052**	0.221*	0.258**	0.038	0.063*	0.013	0.116	0.003*
	[-3.097]	[-3.468]	[2.237]	[2.708]	[1.758]	[2.074]	[1.757]	[1.823]	[1.995]
	$R^2 = 0.560$, Adj.$R^2 = 0.504$								

Δsmg_t	CEq1$_{t-1}$	CEq2$_{t-1}$	Δsmg_{t-1}	Δgdp_{t-2}	c
	-0.029	-0.102	-0.179*	-0.471	0.034**
	[-0.850]	[-1.637]	[-2.068]	[-1.751]	[5.086]
	$R^2 = 0.110$, Adj.$R^2 = -0.003$				

Table A4:

Restricted VECM estimation using Mortgage Stocks

This table reports the output estimation of the restricted VECM. The endogenous variables included in the analysis are the real housing price index ($rhpi_t$), building permits (bp_t), real construction cost index (cc_t), real stock of mortgages (smg_t), real mortgage rate (r_t) and real GDP per capita (gdp_t). All variables are expressed in logs, except the mortgage rate that is measured in percent *p.a.* Panel A displays the estimated cointegrating equations, which correspond to the first part of the estimation output and are expressed as $CEqi_t = \sum_y \beta_{y,i} y_t + c_i$, where $y = \{rhpi, smg, bp, r, cc, gdp\}$ and $i = \{1, 2\}$. Panel B presents the (partial) estimated short-term dynamics for $\Delta rhpi_t$ and Δsmg_t (for brevity, we also only display adjustment coefficients and coefficients that are statistically significant at the 10% level). T-statistics are shown in brackets and *(**) represents statistical significance at the 5% (1%) level. The sample period is 1980Q4–2017Q1.

Panel A: Cointegrating Equations

	$rhpi_t$	smg_t	bp_t	r_t	cc_t	gdp_t	c
CEq1	1	-1.877**	0.550**	-0.1	-20.414**	6.299**	85.272
		[-21.344]	[5.271]		[-6.673]	[9.347]	
CEq2	-0.322**	1	0	0.036**	10.394**	-4.037**	-44.155
	[-3.214]			[7.668]	[5.936]	[-10.528]	

Panel B: Short-term Dynamics

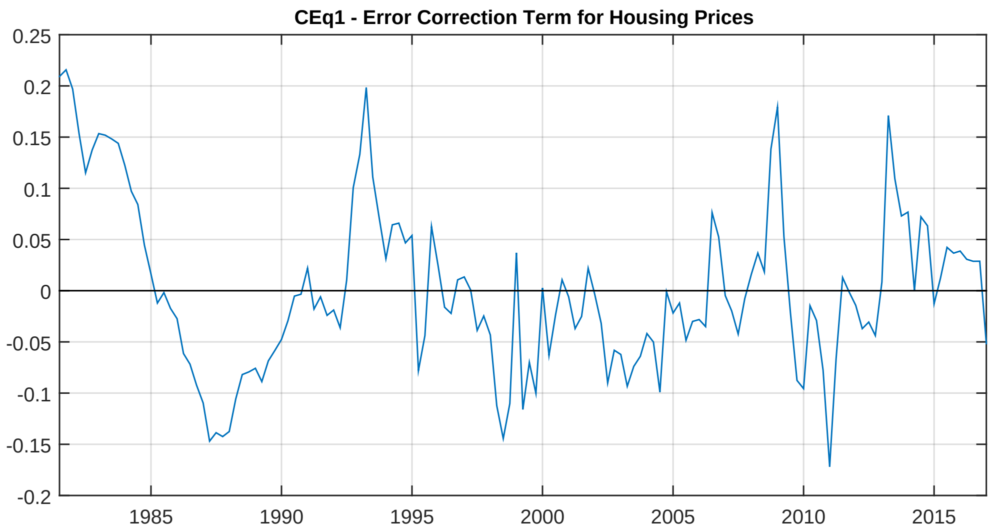
$\Delta rhpi_t$	CEq1$_{t-1}$	CEq2$_{t-1}$	$\Delta rhpi_{t-1}$	$\Delta rhpi_{t-2}$	Δbp_{t-2}	Δbp_{t-2}	Δcc_{t-1}	Δgdp_{t-1}	c
	-0.067**	-0.125**	0.258**	0.259**	0.055	0.078*	-0.471*	0.125*	0.003*
	[-4.236]	[-4.517]	[2.709]	[2.799]	[1.834]	[2.518]	[-2.093]	[1.968]	[2.145]
	$R^2 = 0.553$, Adj.$R^2 = 0.504$								

Δsmg_t	CEq1$_{t-1}$	CEq2$_{t-1}$	Δsmg_{t-1}	Δgdp_{t-2}	c
	-0.010	-0.059	-0.180*	-0.437	0.032**
	[-0.138]	[-0.463]	[-2.080]	[-1.659]	[4.874]
	$R^2 = 0.098$, Adj.$R^2 = 0.000$				

Figure A1:

Long-Run Residuals with Weak Exogeneity of Other Variables

This figure displays the time-series of the two error correction terms (used in Panel B of Table A1). These are the long-run residuals, i.e. the differences between the actual series and the estimated fundamental values. CEq1 and CEq2 are estimated using the first step Johansen's procedure for the restricted cointegrating vectors, when also imposing weak exogeneity on cc_t, bp_t, r_t, mi_t and gdp_t. The sample period is 1980Q4–2017Q1.



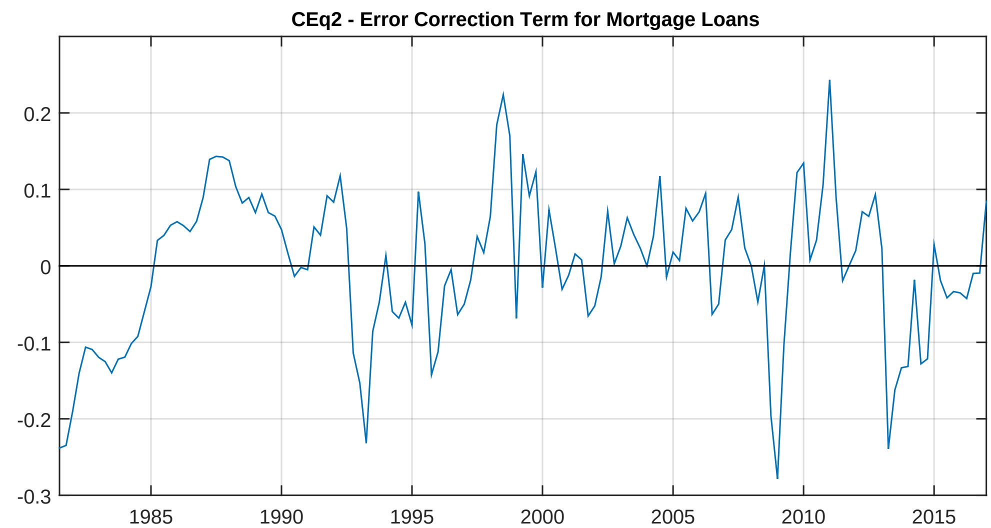
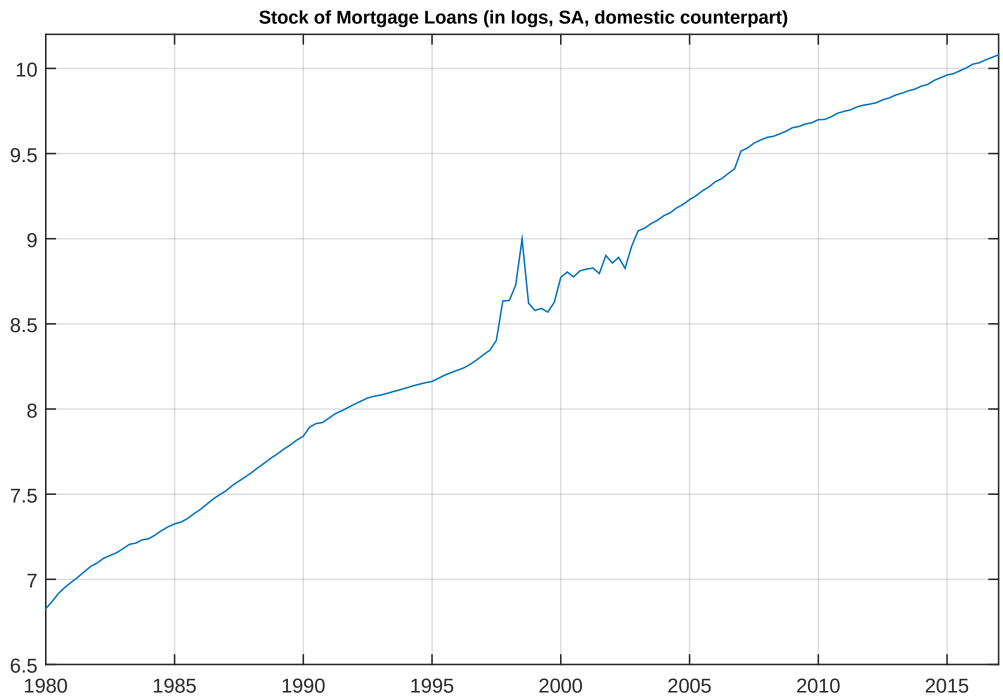


Figure A2:

Evolution of the Stock of Mortgage Loans

This figure displays the time-series of the real stock of mortgage loans (smg_t). The plot refers to mortgage loans with domestic counterpart, where the series is seasonally adjusted and measured in logs. The time-series of the stock of mortgage loans with Euro area counterpart (not represented) is very similar. The sample period is 1980Q1–2017Q1.



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