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The changing relationship between affordability and house prices: a cross-country examination

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Abstract: The recent increase in house prices across the OECD highlights again the importance of understanding the different determinants of residential property demand. Sustained activity in housing markets across a number of countries was one of the contributing factors to the financial sector vulnerabilities underpinning the crisis of 2007/2008. While much of the increases in prices observed was due to changes in key economic variables such as income levels and interest rates, it is apparent that actual price movements in the period leading up to 2007 were often in excess of what underlying economic conditions might have suggested. In this paper we apply a theoretical model of house price determination that is driven by changes in income, interest rates and, which crucially allows for changes in the relationship between these variables and house prices through time. Allowing for this complexity in the relationship between fundamental economic variables and house prices is particularly important, not least in facilitating more efficient implementation of both monetary and macroprudential policy in international housing markets.

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1. Introduction

Following a substantial and protracted downturn across many international residential property markets, house prices have, since 2012, started to increase again. As measured by the IMF's Global House Price Index[1], house prices, in nominal terms, as of 2016 are now almost back to their pre-financial crisis peak. The strong recovery in property markets globally heightens the need for greater understanding of house price developments. Traditionally, assessments of house prices have focused on the role played by "fundamental variables", where fundamentals typically consists of income, interest rates and demography (see the reduced-form inverted demand model in Peek and Wilcox (1991), Muellbauer and Murphy (1994, 1997), Meen (1996, 2000) and Cameron, Muellbauer, and Murphy (2006) for example).

Across countrys, the period from the early 1990s to 2007 saw substantial improvements in macroeconomic conditions; the *great moderation* witnessed consistent improvement in living standards at a time when interest rates and monetary policy generally was accomodative. Many European countries enjoyed a low interest rate environment associated with membership of the European Monetary Union (EMU), while compared with the relatively turbulent nature of interest rates in the 1980's and early 1990's, the United States, the United Kingdom, Canada, Australia and Sweden also experienced more favorable interest rate conditions. Therefore, housing demand for this period across a number of countries was strongly influenced by improvements in fundamental variables.

However, the period preceding the financial crash of 2007/08 saw house prices in a number of countries increase significantly with respect to price levels indicated by fundamental variables. The growing wedge between these two prices, commonly regarded as an indication of a 'bubble' was attributed by many to increased credit availability. Financial sector developments post 2000 such as the perceived ability of credit institutions to better manage risk through more use of derivatives and repurchase (repo) agreements facilitated greater cross-country borrowing amongst financial institutions. Consequently, certain mortgage markets, such as the Irish and Spanish cases, which had already experienced considerable growth in housing activity, from the early 2000s

[1] Which is a simple average of real house prices for 57 countries

witnessed a significant expansion in mortgage lending. Greater credit availability meant that, for a given level of fundamental variables, housing demand and, thus, prices increased.

In the period immediately after 2007/08, many of these same housing markets experienced a sharp reversal of both of these conditions; namely unemployment levels increased, disposable income levels fell and access to credit weakened as financial institutions across Europe and the United States deleveraged their balance sheets due to pressures associated with the financial crisis. Therefore, housing markets were confronted by both a marked disimprovement in fundamental variables and a lower elasticity of prices with respect to fundamental variables.

All of these developments indicate the need for empirical models of house prices to allow for a more sophisticated interaction between fundamental variables and house prices. In this paper we apply a theoretical model of house price determination that is mainly influenced by changes in income, interest rates and, crucially, allows the relationship between these variables and house prices to change through time. In particular, the current level of income and interest rates determine how much an individual can borrow from financial institutions to purchase housing and ultimately this is a key driver of house prices. However, in light of developments in credit markets over the past 20 years, the present application allows the elasticity of house prices to affordability levels to vary through time and across countries. The model is applied to 16 OECD countries over the period 1980 to 2014.

Identifying the complex, changing relationship between interest rates and house prices has important implications in terms of the implementation of both macroprudential and monetary policy. Importantly, we believe that the present model captures two non-linear relationships which underpin cross-country house price movements; one is the role played by interest rates, where the non-linear rate impact of rates is captured by the annuity formula used to measure affordability and the second is the changing elasticity of house prices with respect to the affordability concept. The changing role played by credit conditions in this sense appeals to the notion of the "excess elasticity" of the international monetary and financial system as identified by Borio and Disyatat (2011); they argue that the build-up of unsustainable credit and asset price booms owes more to credit creation as opposed to the more popularly cited "excess saving".

The rest of the paper is laid out as follows; in the next section we outline the affordability model and examine the results from the empirical application. We then focus on the non-linear nature of the model, while a concluding section offers some final thoughts.

2. A Theoretical Model of Cross-Country House Prices

In reviewing the house price literature McQuinn and O'Reilly (2008)[2] note the difficulty standard house price models experience in incorporating the impact of nominal interest rates; in a number of house price models, interest rates often appear with the wrong sign or are found to be insignificant. The interest rate variable, when entered freely into the regression specification, can often be "swamped" in the estimation yielding a very small and minor semi-elasticity effect. For example, in models estimated for eight different US States, Case and Shiller (2003) acknowledge that the mortgage rate had an insignificant coefficient in all but one of the regression models. Mayer (2003) also notes that the results from such regression models suggest that, historically, house purchase behaviour and housing values may not have been very responsive to changes in interest rates.

To address this issue, McQuinn and O'Reilly (2008) propose a simple intuitive theoretical model of the housing market which captures the important role of credit, income and interest rates as drivers of housing demand. More specifically, the demand-side determinants of house prices are modelled as a function of the average amount borrowed by households given current disposable income levels and interest rates. In reality, the amount lent by a mortgage institution to an individual is critically dependent on current disposable income and interest rates. Based on a standard annuity formula, the amount a financial institution would lend an individual given plausible assumptions can be calculated. Ultimately, this value should be an important determinant of housing demand as it reflects the fact that most house purchases are mortgage-financed and the amount that mortgage providers are willing to lend is ultimately a function of income and interest rates.

[2] McQuinn and O'Reilly (2008) apply the model in the case of Ireland.

We believe the model applied by McQuinn and O'Reilly (2008) has a number of advantages; first, the model is intuitively appealing, familiar as it is to most people who have taken out a mortgage. In addition, it models, in a plausible fashion, how mortgage institutions decide how much to lend. Secondly, since we impose a realistic theoretical relationship between interest rates, income and how much one can borrow, we avoid the shortcomings of having an insignificant or incorrectly signed interest rate response - something that is characteristic of much of the previous literature. Moreover, we highlight one possible reason for the failure of standard regression specifications to find a significant response of house prices to interest rates. The theoretical model suggests there is a nonlinear relationship between house prices and interest rates while standard approaches only permits interest rates to enter linearly. In support of this hypothesis we demonstrate that if one includes higher order powers of the interest rate, the coefficient on the interest rate term switches from being insignificant in the linear specification to being significantly negative in the more general specification. The inclusion of higher powers of the interest rate is entirely consistent with the affordability model.

In their application of the model McQuinn and O'Reilly (2008) assume a fixed relationship between house prices and the affordability concept through time. However, this assumption is questionable particularly, given the changing levels of credit provision in housing markets over the past 20 years. Consequently in the present, cross-country application of the model, we explicitly test the hypothesis of a constant relationship between house prices and affordability. We demonstrate that the relationship has changed, to varying degrees across different countries, over the past 15 years. Therefore, we allow for time-varying parameters in our econometric application of the model thereby demonstrating the changing elasticity of house prices across countries and through time to the affordability concept. This, ultimately, provides a greater understanding of the responsiveness of house prices to interest rates in an international context.

The model uses the following variables

$$\begin{aligned} P_t &= \text{actual house prices.} \\ B_t &= \text{amount that can be borrowed.} \\ S_t &= \text{supply of housing.} \\ Y_t &= \text{GDP per capita.} \\ R_t &= \text{mortgage interest rate.} \\ \tau &= \text{duration of mortgage.} \end{aligned}$$

The demand for housing is taken to be a function of the amount that can be borrowed from a financial institution based on current income and the existing mortgage interest rate. In particular, the amount lent out by financial institutions to their customers is based on the present value of an annuity, where the annuity is some fraction of income discounted at the current mortgage interest rate for an horizon equal to the term of the mortgage. This amount which can be borrowed is given by the following formula

$$B_t = Y_t \left(\frac{1 - (1 + R_t)^{-\tau}}{R_t} \right). \tag{1}$$

Clearly, an upward shift in income or downward movements in the interest rate yields an increase in the amount which can be borrowed prompting additional demand for housing.

We now seek to nest this expression for income and interest rates within a general model of the housing market. The expression is incorporated within the following inverted demand function:

$$P_t^D = \eta B_t S^{-\mu}. \tag{2}$$

The supply variable S enters negatively in this function through the own price elasticity of demand μ. An inverted housing supply equation is given by the following

$$P_t^S = \delta S^{\phi}. \tag{3}$$

where δ, the intercept in the supply function, can be regarded as a standard supply side shifter.

In the short-run, supply is assumed to be inelastic, i.e. $S = \overline{S}$. Therefore, the short-run price of housing depends on the amount that can be borrowed. In order to derive the long-run equilibrium price level, we set $P_t^D = P_t^S$ and solve, yielding the following equilibrium expression for S^{LR}

$$S^{LR} = \left(\frac{B_t}{\delta}\right)^{\frac{1}{(\phi+\mu)}}. \tag{4}$$

The corresponding expression for the long-run price is given as

$$P^{LR} = \delta^{\frac{\mu}{(\phi+\mu)}} B_t^{\frac{\phi}{(\phi+\mu)}}. \tag{5}$$

Taking logs of equation (5) yields the following, where lower case denotes a variable is in logs

$$p^{LR} = \left(\frac{\mu}{\phi+\mu}\right) log(\delta) + \left(\frac{\phi}{\phi+\mu}\right) b_t. \tag{6}$$

Grouping the constants together, we simplify this expression to

$$p_t = \alpha + \psi b_t. \tag{7}$$

From the long-run model, an estimate of $[\frac{\phi}{\mu+\phi}]$ can be retrieved from the coefficient ψ. House prices are a function of how much can be borrowed and the own price elasticities of the demand and supply. The intercept α is a composite of the supply shifter δ and the parameters ϕ and μ.

In the initial estimation we assume that ψ, the elasticity of house prices with respect to the affordability variable, is constant through time, however, we subsequently relax this assumption.

2.1. Data

Quarterly data for 16 OECD countries[3] is used in the paper. While all countries have data at least from 1980:1 to 2014:Q4, some countries have data starting in 1970. The data comes from three main sources. Real quarterly house price data are taken from a Bank of International Settlements (B.I.S.) dataset. Prices are available in index form with values = 100 in 1995.

Quarterly GDP, interest rates and the GDP deflator data are taken from the IMF's International Financial Statistics (IFS) database. Typically, most country level mortgage markets are characterised, in the aggregate, by a preference for variable or fixed rate mortgages. A survey paper, ECB (2003), based on questionnaires conducted by national Central Banks (NCBs), provides some information on the nature of mortgage contracts in individual EU countries. The interest rate adjustment in each country, is characterised as being fixed (F) or variable (V). For an interest rate to be classified as fixed, it must be fixed for more than five years, or, until final maturity, whereas in the case of the variable rate, it is either negotiable after one year, or, is tied to market rates, or, is adjustable at the discretion of the lender.[4] Based on these observations, each country in our sample is classified into a variable or fixed rate category where the variable (fixed) rate mortgage rates are proxied by country specific short-term money market rates (long-term Government bond rates). Annual population data is taken from either a country's national statistical agency or EuroStat's NewCronos. These series are then interpolated and along with the GDP data are combined to arrive at a quarterly GDP per capita series for each country.

Table 1 provides a summary of the core data used. Of the 16 countries, 6 are assumed to have fixed rate mortgages with the remainder having variable rate mortgages. Over the period, the countries registering the greatest increase in prices are Norway, the UK and Ireland. Table 2 provides a summary of unit root tests performed on both house prices and the affordability variable. In nearly all cases, the null hypothesis of a unit root cannot be rejected.

[3]The countries are respectively Australia, Canada, Denmark, Finland France, Italy, Ireland, Japan, Spain, Sweden, Switzerland, the Netherlands, Norway, the US and the UK.

[4]See Table 5.1 of ECB (2003) for more details.

3. Empirical Approach

3.1. Initial estimates

We initially estimate the following long run relationship identified in (7) between the log of actual house prices and the log of B_t - the average amount which can be borrowed:

$$p_t = \alpha + \psi b_t.$$

In the interests of robustness, we use three different estimators to estimate (7) - standard OLS, dynamic OLS (DOLS) and FMOLS. The use of alternative estimators such as DOLS and FM-OLS enables inference to be based on standard errors adjusted for considerations such as correlation between the regressors and the error process and serial correlation. The DOLS approach of Stock and Watson (1993) falls under the single-equation Engle and Granger (1987) approach to co-integration, while allowing for endogeneity within the specified long-run relationship. The Philips-Hansen fully-modified OLS procedure is designed to allow for statistical inference in multivariate linear regressions with integrated processes.[5] With each estimator the variables are significant and have the hypothesised sign. There are very little discrepancies across the three estimators in terms of coefficient size. The estimates are presented in Table 3.

The relative size of the different long-run parameters, ψ, i.e. the long-run response of each country's actual price to changes in the average amount borrowed can be potentially rationalised by cross country differences in individual country housing markets. For example, the relative size of the long-run parameters can be a function of the stickiness of supply in a particular country. The more elastic supply is, i.e. the greater the size of $[\frac{\phi}{\mu+\phi}]$ in (6), the smaller will be the long-run relationship between the actual price and the amount borrowed. ECB (2003) contends, that while information on the supply response in different EU countries may be sketchy, what information is available suggests that the supply of new housing is more responsive to house prices in Germany than in the UK, the Netherlands or the Nordic countries. Our estimate of the long-run parameter for Germany is the second lowest in the sample.

[5] These approaches have been used in an Irish context in Kelly and McQuinn (2014) and Fitzpatrick and McQuinn (2007).

Alternatively, cross country differences in the coefficients in the long-run relationship may reflect heterogenities across countries on the demand side. We examine this issue in greater detail in a later section.

The estimates in Table 3 are in nominal terms, however, we also estimate (7) with real GDP per capita and real interest rates. The results are in Table 4. Overall, the results are quite similiar to the nominal estimates; the coefficient on b_t is smaller, however, it is significant in all cases and, while there is a little more heterogeneity across the different estimators in terms of the ψ coefficient, the country rankings, in terms of the scale of the elasticity, remain relatively unchanged.

3.2. Nonlinear Effect of Interest Rates

An alternative way of thinking of the approach adopted here is that interest rates have a nonlinear effect on housing demand which isn't captured by a standard regression specification where interest rates enter linearly. This nonlinear effect is illustrated in Figure 1. The value of an annuity is plotted as the interest rate varies for three different annuity maturities, i.e., the value of an annuity that pays out one euro each year for 10 years, 20 years and 30 years respectively. The annuity value is clearly a nonlinear function of the interest rate and regression specifications where the interest rate enters linearly will not capture this phenonemon.

To further explore this issue, we estimate for each country two specifications where interest rate enter in a standard linear or nonlinear fashion. Hence, we estimate the following two variants of the standard reduced form house price regression

$$p_t = \alpha + \beta y_t + \sum_{i=1}^{2} \omega_i R_t^i. \tag{8}$$

where i = 1 and i = 2. In the first regression, the interest rate variable enters in a standard linear fashion along with income, while in the second specification, both the level and the square of the interest rate variable are included.

In the linear specification, the interest rate variable enters the regression with either a positive and/or an insignificant coefficient in all but one of the 16 countries. This result highlights the issue outlined earlier concerning the problematic nature of the interest rate response in reduced form estimates of house prices. However, the introduction of the square of the interest rate results in a significant and negative coefficient on the level interest rate variable in 9 countries. The impact of the level interest rate variable is, also, considerably larger under the augmented model. In Table 5, we report the "linear" and "nonlinear" estimates of equation (8) for these nine countries. Apart from Germany and Sweden, the coefficient on the level interest rate in the linear model is positive. Including the square of the interest rate as a regressor brings about a significant change in the overall interest rate effect on house prices. In the case of some countries, this change is quite substantial with France and Switzerland registering the largest impact for the interest rate in the non-linear model.

The results in Table 5 are again for nominal variables, however, we also examine this issue with the real counterparts. In Table 6, it can be observed that adding the nonlinear real interest rate variable also makes a significant difference to the model. In 9 cases, the addition of the nonlinear term either causes a positive real interest rate effect to become negative and significant or it increases the scale of the negative real interest rate effect.

In the next section, we examine the stability of the relationship between the affordability concept and house prices over time.

3.3. Changing credit markets and time-varying estimates

As noted in section 3.1, differences on the supply-side of the property market are one reason why the sensitivity of house prices to affordability may vary across countries. Another potential difference is the degree of flexiblity of credit markets in a particular country. Survey papers prior to the financial crisis by OECD (2005) and Giuliodori (2004) examine mortgage markets in a number of countries. For example, Giuliodori (2004), quoting EMF (1998) and the ECB (2003) amongst others, suggests that the UK, which has one of the largest ψ's, has a very high loan to value ratio by international standards. Similarly, the OECD (2005), quoting Scanlon and Whitehead (2004) and the Canada Mortgage and Housing Corporation (2005), suggests that innovation in mortgage products tends to be highest in countries such as the UK, Australia and the Netherlands. All three of these countries have long-run parameters that are amongst the highest in our sample.

However, ψ may also vary through time. Indeed the period since 2000 has seen significant changes in credit markets across countries with substantial increases in credit extension prior to 2007 giving way to significant deleveraging and contraction in lending in certain mortgage markets thereafter. A large number of papers have examined the role played by changes in the provision credit in the persistent increase in house prices prior to 2007; Fernandez-Corugedo and Muellbauer (2006), Jansen and Krogh (2011), Kelly and McQuinn (2014), McCarthy and McQuinn (2016) and Favara and Imbs (2015), amongst others, have all examined the role exogenous changes in credit standards contributed to house price increases across different countries in the OECD over the past 15 years. McCarthy and McQuinn (2016), in particular, discuss some of the changes in international finance post 2000 which facilitated this increase in lending. They also, through use of granular loan-level banking data, identify the main channels through which this lending occurred in the case of the Irish property and mortgage market.[6]

In Figure 2, the difference between actual house prices and the fitted value from (7) are plotted. In much of the house price literature comparing actual prices with the model based prediction is a popular way of gauging the sustainability or otherwise of the housing market i.e. if house prices are significantly above the model based estimate, than the market may well be overvalued or displaying symptoms of "bubble" like behaviour. On that basis, the evidence presented in Figure 2 indicates that a number of countries experienced a property bubble in the lead up to 2007; Ireland, France, the United Kingdom, the United States, Canada, Spain, Sweden, Denmark and the Netherlands all had positive gaps in and around the 20 per cent mark for the period 2004 - 2008. After 2007/08 many of these countries experienced substantial declines in house prices suggesting that the housing markets in each case may have "overcorrected" or fell by more than what changes in affordability levels would have warranted.

From an econometric perspective, such deviations between the actual and fitted values from the regression suggests issues with parameter stability over the period. To investigate this more formally, we perform a series of parameter stability tests on (7). In particular we estimate a Cusum test statistic (Brown, Durbin and Evans (1975)) for the ψ parameter. Under the null hypothesis, the cumulated sums of the recursive residuals

[6]Another reason for the deviation between actual and fitted house prices may be due to the role of consumer expectations; Ling, Ooi and Le (2015) demonstrate that the relationship between sentiment and house prices can contribute to the persistence typically observed in house price movements.

from the regressions should act like a random walk. If there is a structural break, the residuals will drift above the bounding lines which are typically set for the 0.05 level. In Figures 3a and 3b, we plot the cumulated residuals for each country along with the standard error bands. It is clear that a significant number of countries exhibit a structural break in the relationship between house prices and affordability over the period; the test statistic in the Irish, French, British, Canadian, American, Australian, Swedish, Danish and Dutch cases all exceeds the upper standard error band.[7] In most cases the break occurs between 2004 and 2006, while in the case of Ireland and the Netherlands the break occurs somewhat earlier (2000 and 1993 respectively). The timing of the break lends considerable credence to the arguement that the temporal variations in the ψ parameter are likely due to financial market liberalisation and the resulting greater elasticity of credit.[8]

The results of the structural break tests motivate our use of a time-varying estimator for (7). In particular, we use the Kalman filter technique. The filter is a fast, recursive algorithm for estimating dynamic linear models. In the case of a single linear model (such as (7)), the filter is used for examining the stability of a linear relationship.

Specifying the Kalman filter approach in terms of (7) involves the following:
ψ is now a vector of coefficients at time t, with the following measurement equation

$$p_t = \alpha + \psi_t b_t + u_t. \tag{9}$$

where the variance of u_t is η_t. The state vector follows the process

$$\psi_t = \psi_{t-1}\alpha + v_t. \tag{10}$$

with the variance of $v_t = \omega_t$. u_t and v_t are independent and η_t and ω_t are assumed to be known.

To use the filter we need estimates for $\psi_{0|0}$, the initial state vector, $\sum_0$, the initial covariance matrix of the states, η_t and ω_t. Following most applications we assume that $\omega_t = 0$ and that the variance of u_t, η_t, is constant. We obtain initial estimates of $\psi_{0|0}$ and

[7] Hansen (1990) tests for each country also indicates the presence of a structural break in the relationship between house prices and affordability.

[8] The results of the structural break tests for when (7) is estimated on a real basis are also available, upon request, from the authors. The results are much the same as the nominal estimates.

$\sum_0$ from a preliminary regression of (7) over the period 1980 - 2000.

In the interests of brevity[9], we summarise the results of the Kalman filter by presenting plots of ψ_t for each country in Figures 4a and 4b. With the exception of the Japanese case, we can see that all countries experience an increase in the ψ coefficient over the period 2000 to 2014. Figure 5 summarises the percentage change in the elasticity, splitting the 2000 - 2014 period into subperiods 2000 - 2008 and 2009 - 2014. Overall, France, Sweden, Denmark and Norway experience the largest increases in elasticity over the entire period. In the French case the elasticity increased by 62 per cent from 0.46 to 0.75, with the Swedish elasticity increasing from 0.41 to 0.63 over the same period, indicating that both interest rates and income levels have a much more significant impact on house prices at the end of the period then they had in 2000. Most of these increases occurred over the initial period 2000 - 2008 at a time when mortgage lending across different markets was increasing significantly. For the sample of OECD countries[10], the average elasticity ranges from 0.53 in 2000 to 0.64 in 2008 and 0.66 in 2014. This suggests that monetary policy, in particular, is likely to have a greater impact on international housing markets now then it did in 2000.

Post 2008, Ireland, the United States, the United Kingdom, Spain and the Netherlands all experience a decline in the value of the elasticity. Again, this correlates with the idea that changes in the ψ coefficient are related to variations in credit markets as a number of these countries were the most adversely affected by the financial crisis. The deleveraging which took place amongst Irish, US, UK and Spanish financial institutions post 2008 almost certainly had a negative impact on mortgage lending, thereby potentially reducing the elasticity of house prices with respect to affordability levels. Notwithstanding this decline post 2008, however, it is important to note that in the case of each of these countries, the elasticity of house prices with respect to affordability is still larger at the end of the sample than what it was in 2000.

Figures 6a and 6b summarises the results of the Kalman filter where the estimation is conducted with real variables. As noted in section 3.1, while the average size of the ψ coefficient is smaller when real data is used, apart from the Swiss case, the trends in the movement of the ψ coefficient are very similiar across countries between the nominal

[9]Full regression results are available, upon request, from the author.
[10]Excluding Japan.

and real approaches.

Finally, in Figure 7 we plot the cross-country correlation coefficients between the affordability variable B_t and the elasticity ψ_t. Apart from the Swiss, Dutch and Italian case, it is evident that there is a strong positive relationship between the two, suggesting that changes in the elasticity, and hence, developments in mortgage credit provision, are pro-cyclical for the period.

4. Concluding Comments

The significant recovery in the demand-side of property markets across most OECD countries since 2013 highlights again the importance of understanding house price movements. It is evident that the substantial increases in house prices which occurred prior to 2007 were due to a confluence of improvements in key economic variables such as incomes and interest rates and changes in international financial systems which facilitated a greater level of credit provision. Similarly much of the change in prices since 2007 has also been due to these two interrelated developments.

The empirical model applied in the present case seeks to incorporate both changes in affordability levels and the observed change in the elasticity between house prices and affordability. The affordability concept itself is important as it captures the nonlinear impact of interest rates. Much of the change in the elasticity is likely attributable to changes in credit markets. Importantly, nearly all of the empirical results presented are invariant to whether the underlying data is nominal or real.

In demonstrating the interrelationship between the changing elasticity and affordability levels our results have important policy implications for both monetary and macroprudential policy. It is clear that changes in interest rates can have different impacts depending on the degree of credit provision in mortgage markets. Changing rates, say at a time of credit rationing, will have a lesser impact on house prices, *ceterus paribus*, than when credit conditions are more relaxed. Additionally, it is also evident, across countries, that changes in the elasticity tend to be positively correlated with trends in affordability, indicating that measures which curb the provision of credit, such as macroprudential measures, will also vary in impact depending on the economic cycle.

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Table 1: Summary of Data: 1980:1 - 2014:4

	Sample Means			R_t
Country	P_t	Y_t	R_t	Classification
Australia	151.0	86524	7.7	V
Canada	127.7	32649	7.7	V
Denmark	149.6	557935	7.7	F
Finland	152.2	59683	6.6	V
France	138.8	54580	7.0	F
Germany	97.2	56345	5.5	F
Ireland	177.9	57969	6.9	V
Italy	108.8	43109	8.3	V
Japan	80.2	35323	2.6	V
The Netherlands	151.6	60709	5.8	F
Norway	173.5	751950	7.5	V
Spain	140.9	32944	7.6	V
Sweden	154.4	590948	6.9	V
Switzerland	102.8	145617	3.6	F
United Kingdom	162.9	39414	6.8	V
United States	131.3	32417	6.6	F

Note: All monetary variables are in nominal terms. House prices, (P_t), are in index form with 1995 = 100, GDP per capita, (Y_t), is in the national currency and interest rates, (R_t), are in percentages. F = fixed and V = variable. Fixed interest rates are fixed for more than five years, or, until final maturity, variable interest rates are renegotiable after one year, or, are tied to market rates, or, are adjustable at the discretion of the lender.

Table 2: Unit Root Tests

Variable	P_t		B_t	
	ADF t-test	ADF Z-test	ADF t-test	ADF Z-test
Australia	-2.07	-1.19	-0.81	-0.80
Canada	-1.88	-1.63	-0.79	-0.76
Denmark	-2.14	-1.86	-1.94	-1.29
Finland	-2.44	-2.65	-1.07	-1.05
France	-2.25	-2.23	-1.83	-1.24
Germany	-2.47	-3.11	-1.07	-0.75
Ireland	-2.11	-2.93	-1.39	-1.31
Italy	-3.42	-3.26	-1.36	-1.21
Japan	-2.56	-6.34	-2.53	-3.45
The Netherlands	-1.59	-2.86	-0.06	-0.04
Norway	-1.11	-0.96	-0.77	-0.99
Spain	-2.80	-2.62	-1.32	-0.86
Sweden	-0.80	-0.98	-1.14	-1.53
Switzerland	-1.41	-2.38	-2.24	-1.65
United Kingdom	-2.00	-1.83	-1.08	-1.14
United States	-1.59	-1.96	-1.17	-0.77

Note: Note the 5 per cent critical value for the ADF t-test and ADF Z-tests are -2.88 and -14.0 per cent respectively.

Table 3: Country-by-Country Long-Run Estimates

	DOLS		OLS		FM-OLS	
Country	Coefficient	T-Stat	Coefficient	T-Stat	Coefficient	T-Stat
Australia	0.85	8.13	0.85	43.27	0.84	31.48
Canada	0.68	6.00	0.68	35.02	0.68	25.47
Denmark	0.65	4.85	0.65	34.29	0.65	24.49
Finland	0.58	6.59	0.59	28.01	0.58	21.18
France	0.75	3.60	0.75	31.41	0.75	22.06
Germany	0.17	5.67	0.17	36.75	0.17	25.78
Ireland	0.61	6.22	0.60	37.45	0.61	27.10
Italy	0.57	8.51	0.57	47.18	0.56	33.57
Japan	0.05	0.09	0.02	0.62	0.02	0.43
The Netherlands	0.96	5.09	0.95	40.82	0.96	30.58
Norway	0.70	7.12	0.68	34.75	0.68	25.56
Spain	0.76	4.80	0.76	40.64	0.76	28.93
Sweden	0.65	4.36	0.64	31.96	0.65	24.43
Switzerland	0.48	2.11	0.50	18.18	0.49	12.86
United Kingdom	0.79	5.70	0.79	37.74	0.78	27.00
United States	0.66	5.94	0.66	38.38	0.66	27.20

Note: In our application the error process in the DOLS regression is assumed to follow an AR(2) process, while k - the number of leads and lags is set equal to 2.

Table 4: Real Country-by-Country Long-Run Estimates

	DOLS		OLS		FM-OLS	
Country	Coefficient	T-Stat	Coefficient	T-Stat	Coefficient	T-Stat
Australia	0.70	4.17	0.74	23.52	0.68	16.90
Canada	0.49	2.90	0.49	21.05	0.48	13.48
Denmark	0.65	4.85	0.39	12.71	0.47	10.65
Finland	0.33	2.53	0.34	11.93	0.33	8.47
France	0.62	2.11	0.62	21.07	0.61	11.28
Germany	0.00	0.00	-0.24	-25.92	-0.26	-15.07
Ireland	0.43	3.28	0.41	17.75	0.43	13.43
Italy	0.20	1.84	0.20	11.08	0.20	7.92
Japan	-0.09	-0.30	0.13	5.51	-0.08	-1.95
The Netherlands	0.93	3.35	0.78	18.15	0.91	17.90
Norway	0.47	3.91	0.53	21.57	0.45	12.70
Spain	0.56	2.37	0.53	19.87	0.55	13.74
Sweden	0.47	2.26	0.43	13.46	0.45	10.60
Switzerland	0.48	2.11	0.10	3.25	0.49	12.86
United Kingdom	0.64	2.95	0.66	18.51	0.63	14.04
United States	0.47	2.50	0.59	20.87	0.46	12.16

Note: In our application the error process in the DOLS regression is assumed to follow an AR(2) process, while k - the number of leads and lags is set equal to 2.

Table 5: Select Country-by-Country Reduced-Form Estimates

	Linear		*Nonlinear*		
Country	β	ω_1	β	ω_1	ω_2
Denmark	1.34	0.017	0.996	-0.069	0.003
	(11.38)	(1.600)	(7.901)	(-3.66)	(5.241)
France	1.617	0.031	1.47	-0.105	0.007
	(11.88)	(2.299)	(13.98)	(-6.159)	(9.914)
Germany	0.197	-0.009	0.213	-0.052	0.004
	(15.089)	(-4.262)	(23.621)	(-14.013)	(12.555)
Italy	1.028	0.005	1.180	-0.035	0.003
	(20.697)	(1.042)	(29.569)	(-6.569)	(10.434)
Canada	1.338	0.011	1.259	-0.019	0.002
	(26.522)	(2.455)	(23.372)	(-1.855)	(3.367)
Norway	1.203	0.022	1.158	-0.030	0.003
	(34.658)	(4.532)	(34.015)	(-2.436)	(4.497)
Sweden	1.030	-0.003	0.870	-0.043	0.001
	(20.629)	(-0.668)	(13.833)	(-3.797)	(3.875)
Switzerland	0.808	0.016	0.712	-0.177	0.026
	(17.000)	(1.938)	(19.576)	(-9.249)	(10.647)
United Kingdom	1.374	0.017	1.358	-0.022	0.003
	(33.684)	(3.250)	(39.058)	(-2.378)	(4.839)
Regression:	$p_t = \alpha + \beta y_t + \sum_{i=1}^{2} \omega_i R_t^i$				

Note: T-stats are in parentheses.

Table 6: Select Real Country-by-Country Reduced-Form Estimates

	Linear		*Nonlinear*		
Country	β	ω_1	β	ω_1	ω_2
Australia	1.688	-0.005	1.693	-0.022	0.002
	(43.437)	(-2.057)	(45.296)	(-4.088)	(3.506)
France	1.722	-0.043	1.47	-0.207	0.019
	(14.033)	(-5.377)	(12.38)	(-6.922)	(5.651)
Germany	-0.582	-0.008	-0.573	-0.018	0.002
	(-29.335)	(-4.120)	(-29.212)	(-4.582)	(2.847)
Italy	0.787	-0.010	0.770	-0.020	0.001
	(8.879)	(-2.774)	(8.665)	(-2.756)	(1.511)
Canada	1.544	-0.001	1.489	-0.017	0.002
	(14.695)	(-0.239)	(14.057)	(-1.992)	(2.309)
Finland	1.345	0.001	1.312	-0.012	0.001
	(21.452)	(0.002)	(21.054)	(-2.192)	(2.756)
Sweden	1.304	-0.006	1.107	-0.040	0.001
	(15.017)	(-1.458)	(11.866)	(-4.567)	(4.350)
Switzerland	0.434	-0.001	0.371	-0.018	-0.002
	(4.917)	(-0.552)	(4.274)	(-3.282)	(-3.535)
United States	0.949	-0.017	0.947	-0.028	0.001
	(11.949)	(-2.623)	(11.886)	(-1.800)	(0.726)
Regression:	$p_t = \alpha + \beta y_t + \sum_{i=1}^{2} \omega_i R_t^i$				

Note: T-stats are in parentheses.

Figure 1: Value of Annuity for Differing Interest Rates and Maturities

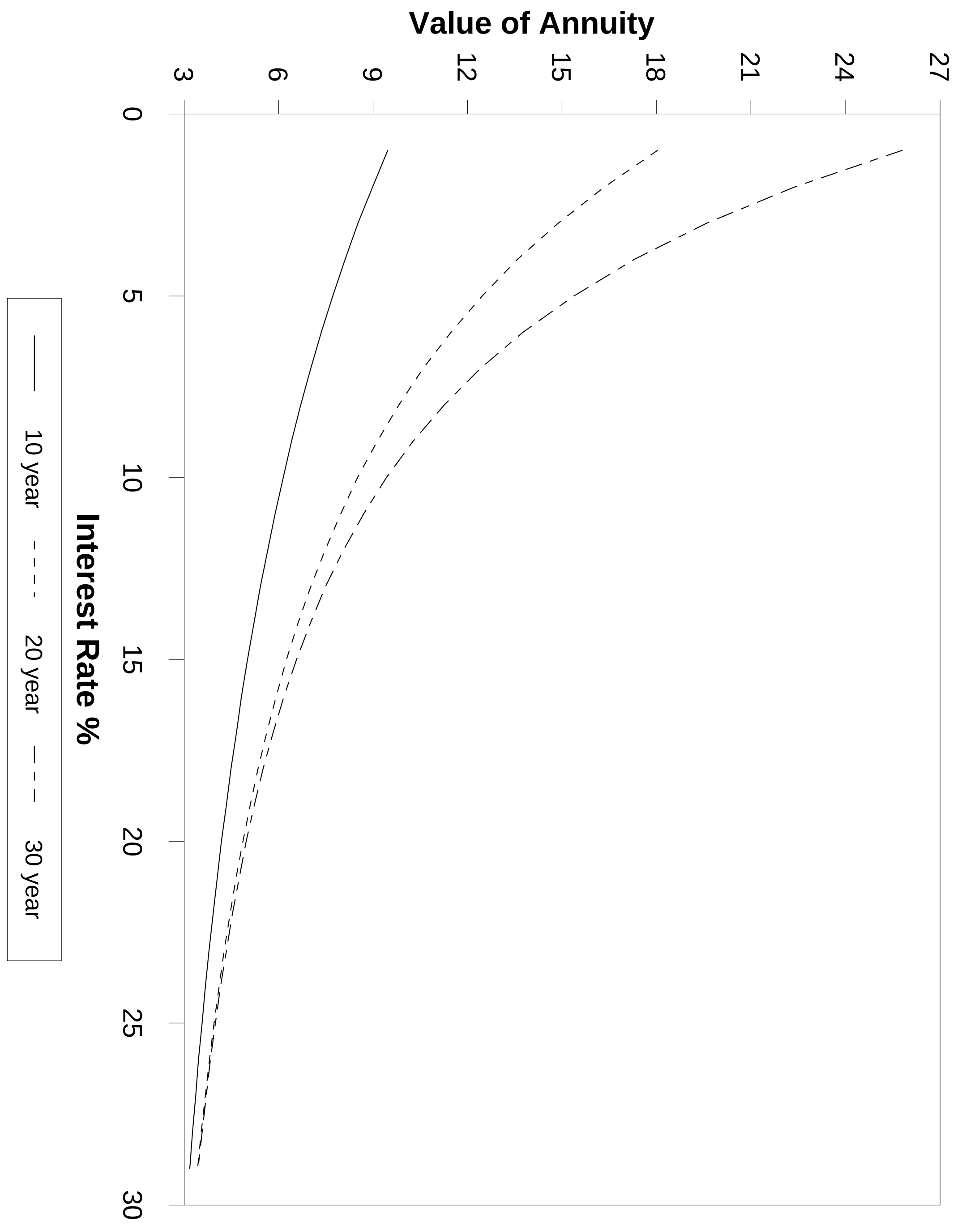


Figure 2: Difference between Cross-Country Actual and Fitted prices

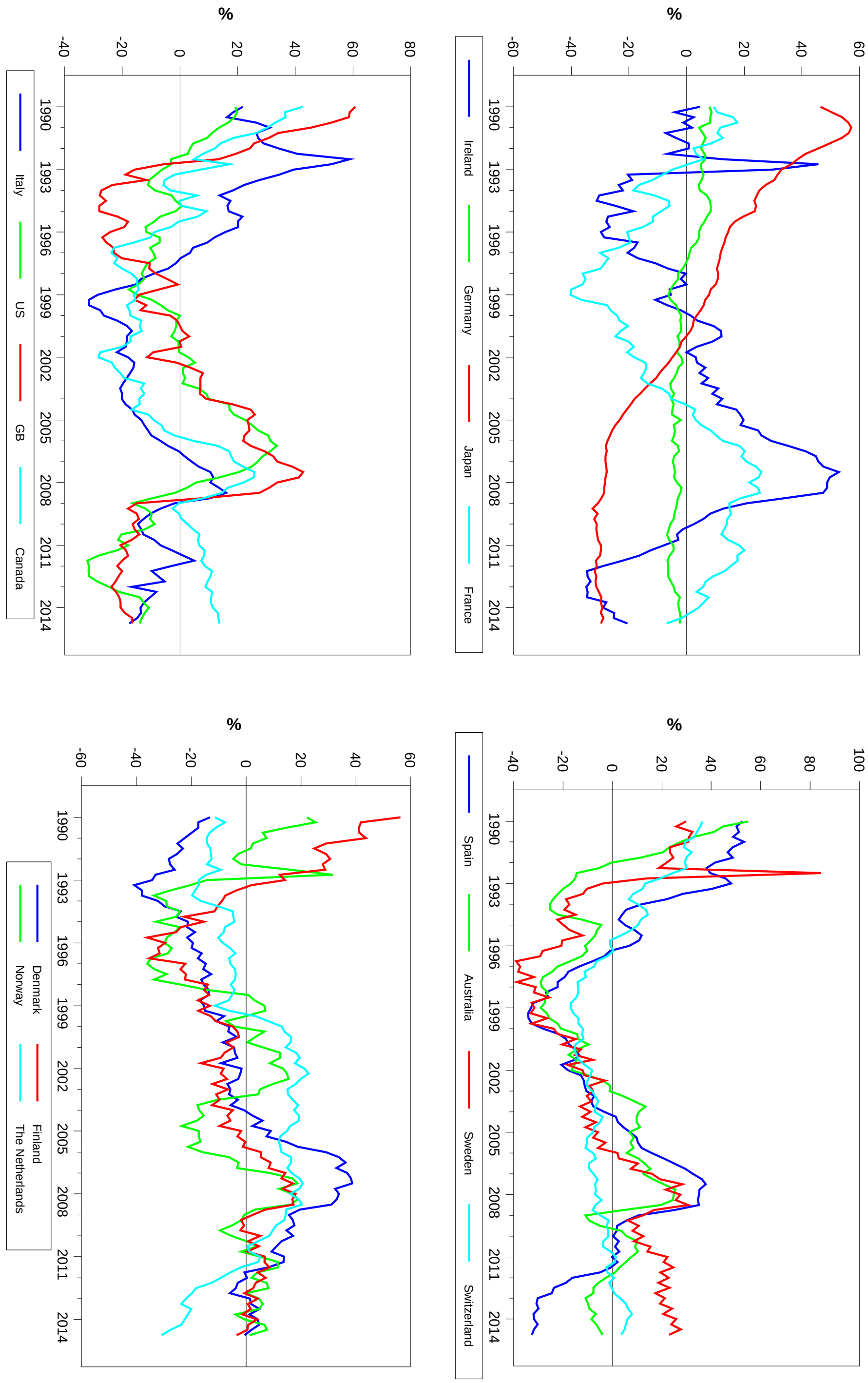


Figure 3a: Cross-Country Cusum Tests

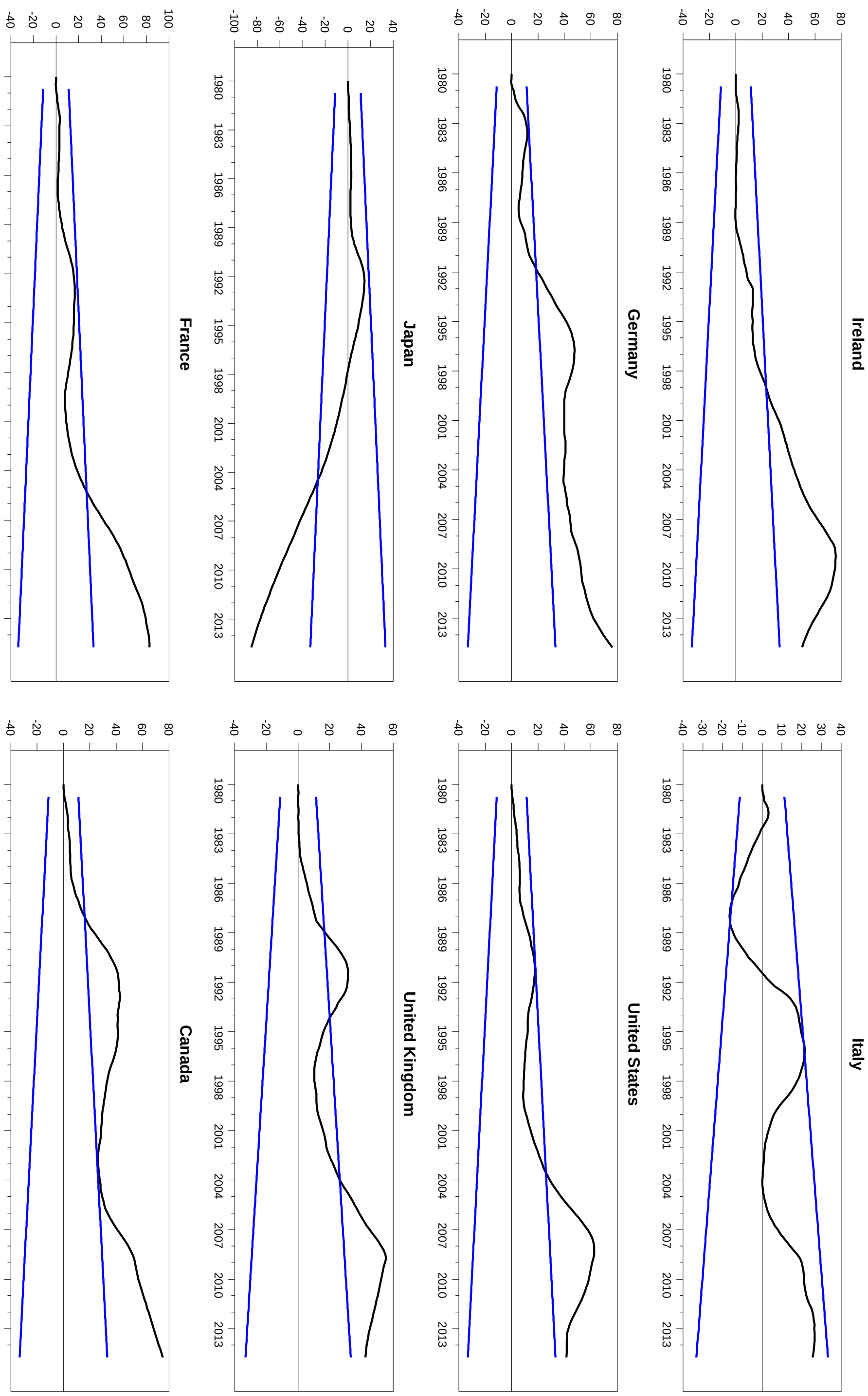


Figure 3b: Cross-Country Cusum Tests

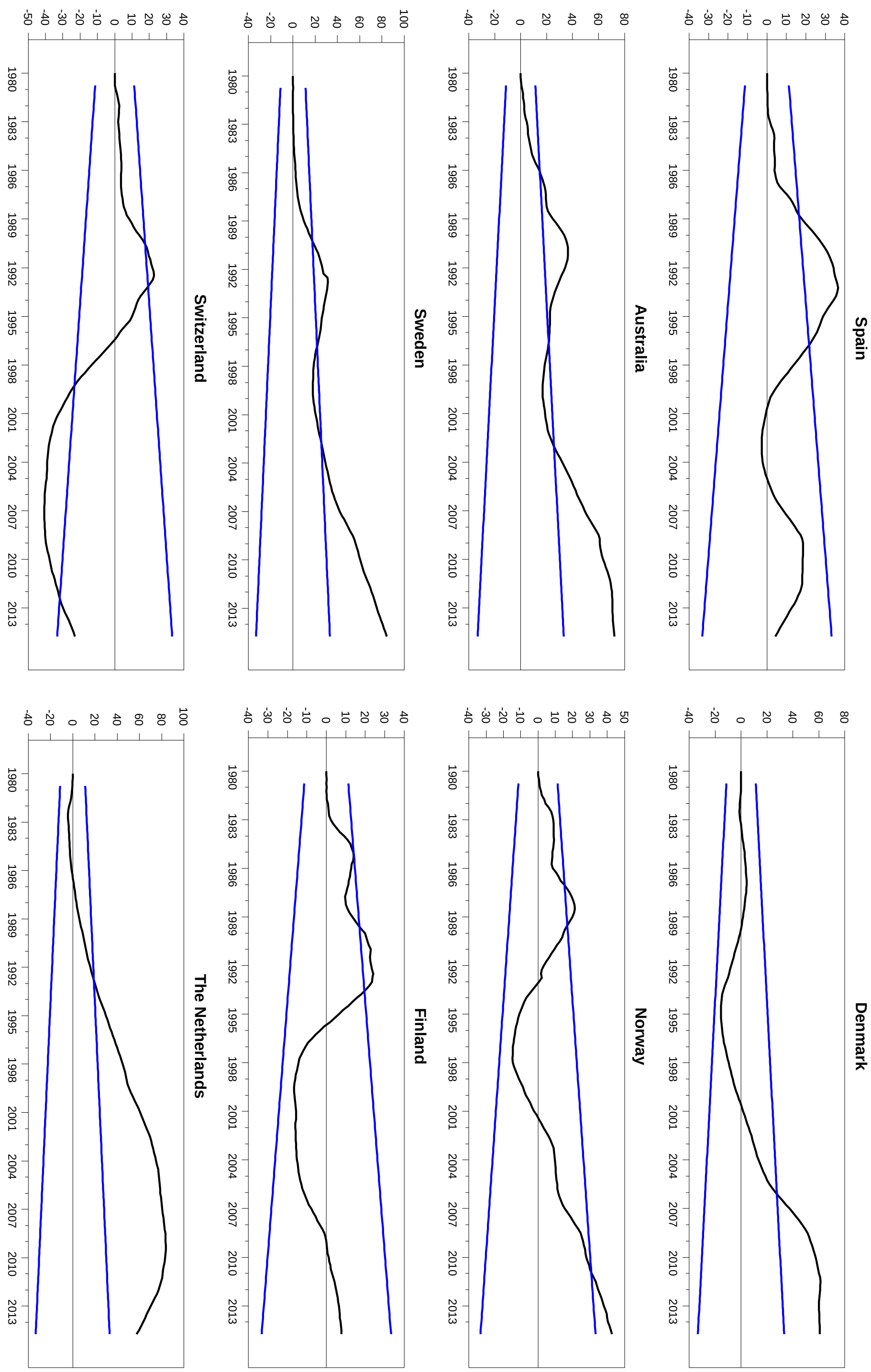


Figure 4a: Time-Varying Coefficient on Affordability Variable

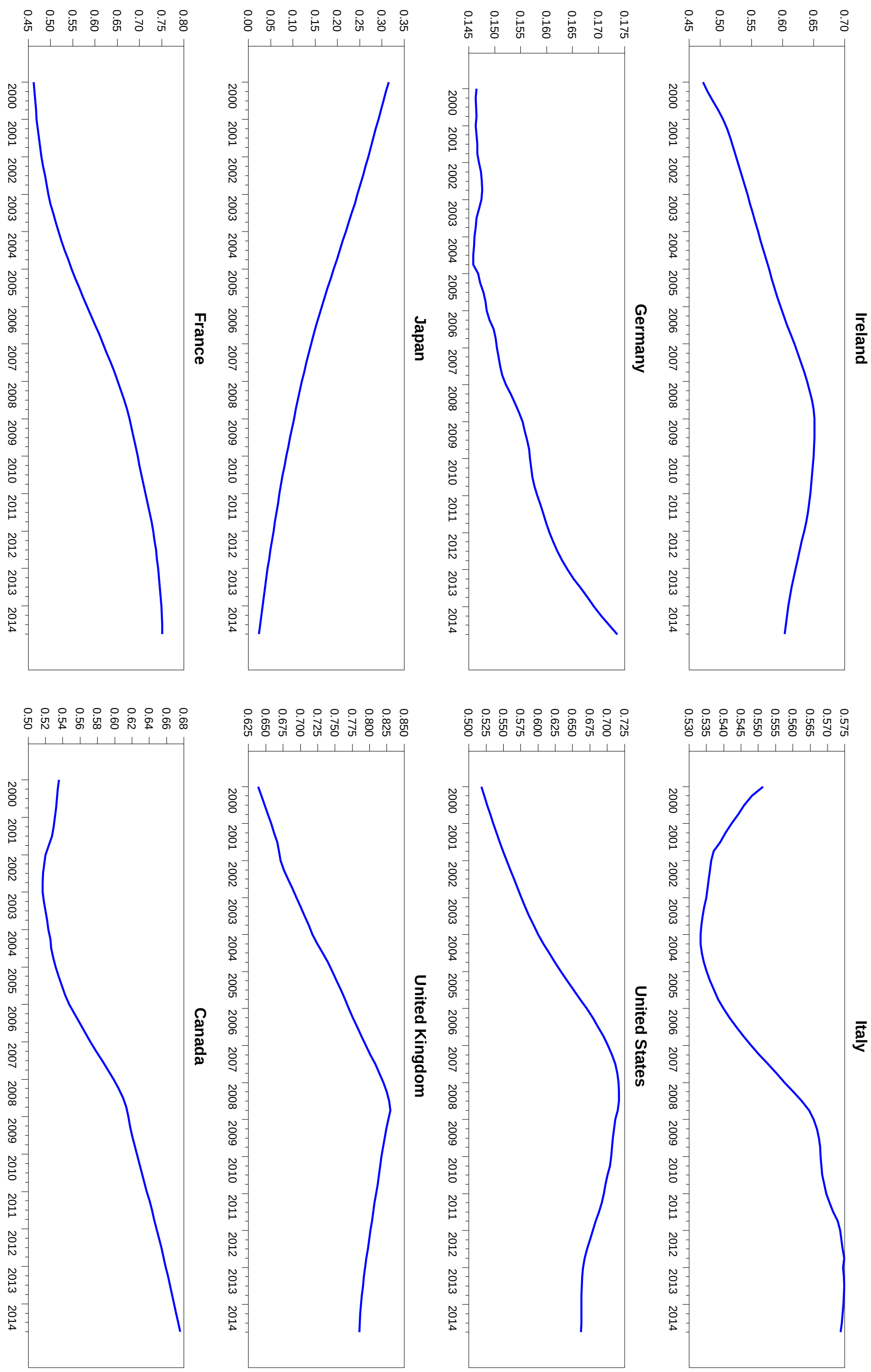


Figure 4b: Time-Varying Coefficient on Affordability Variable

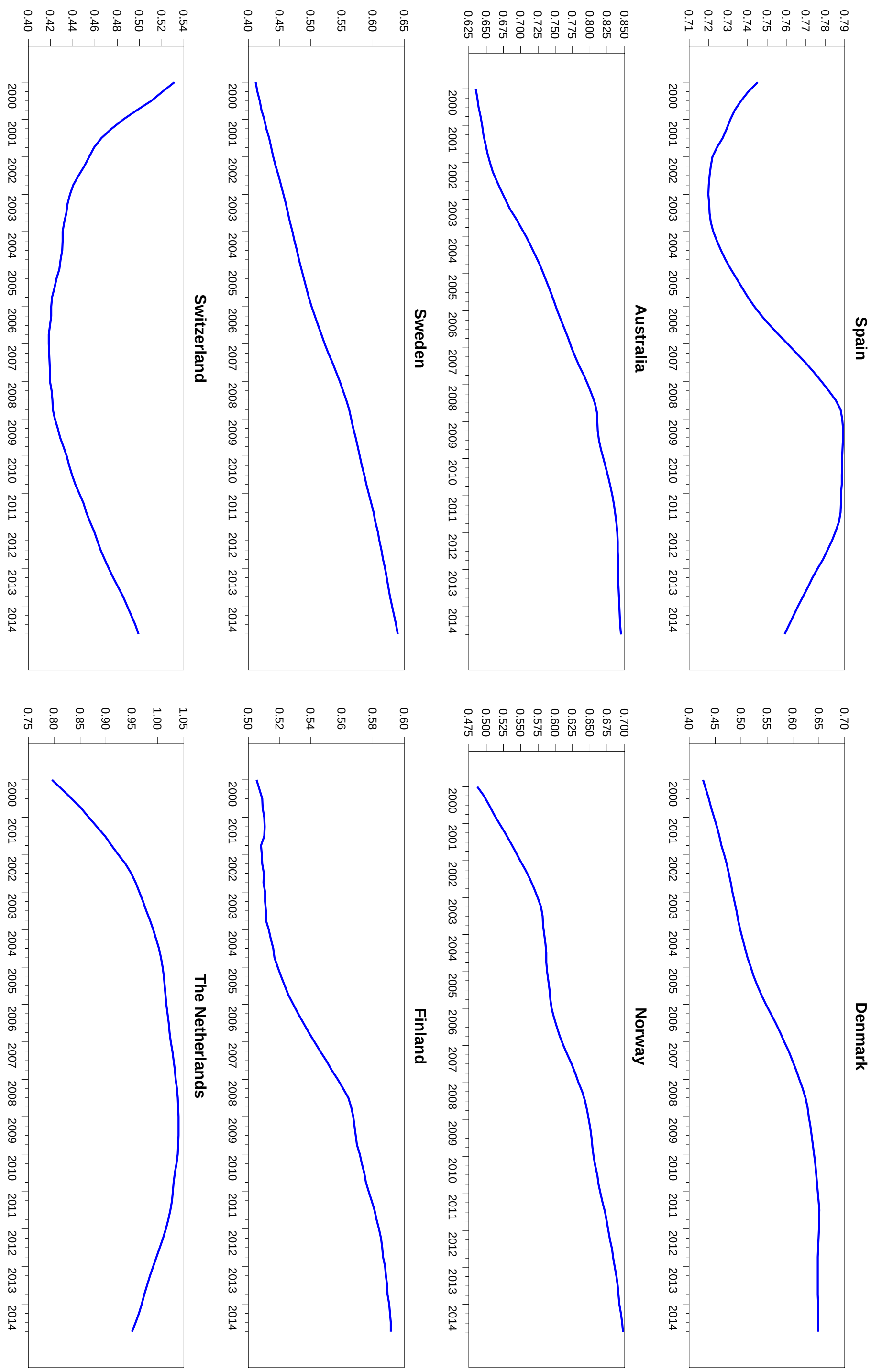


Figure 5: Change in the Elasticity of House Prices with Respect to Affordability

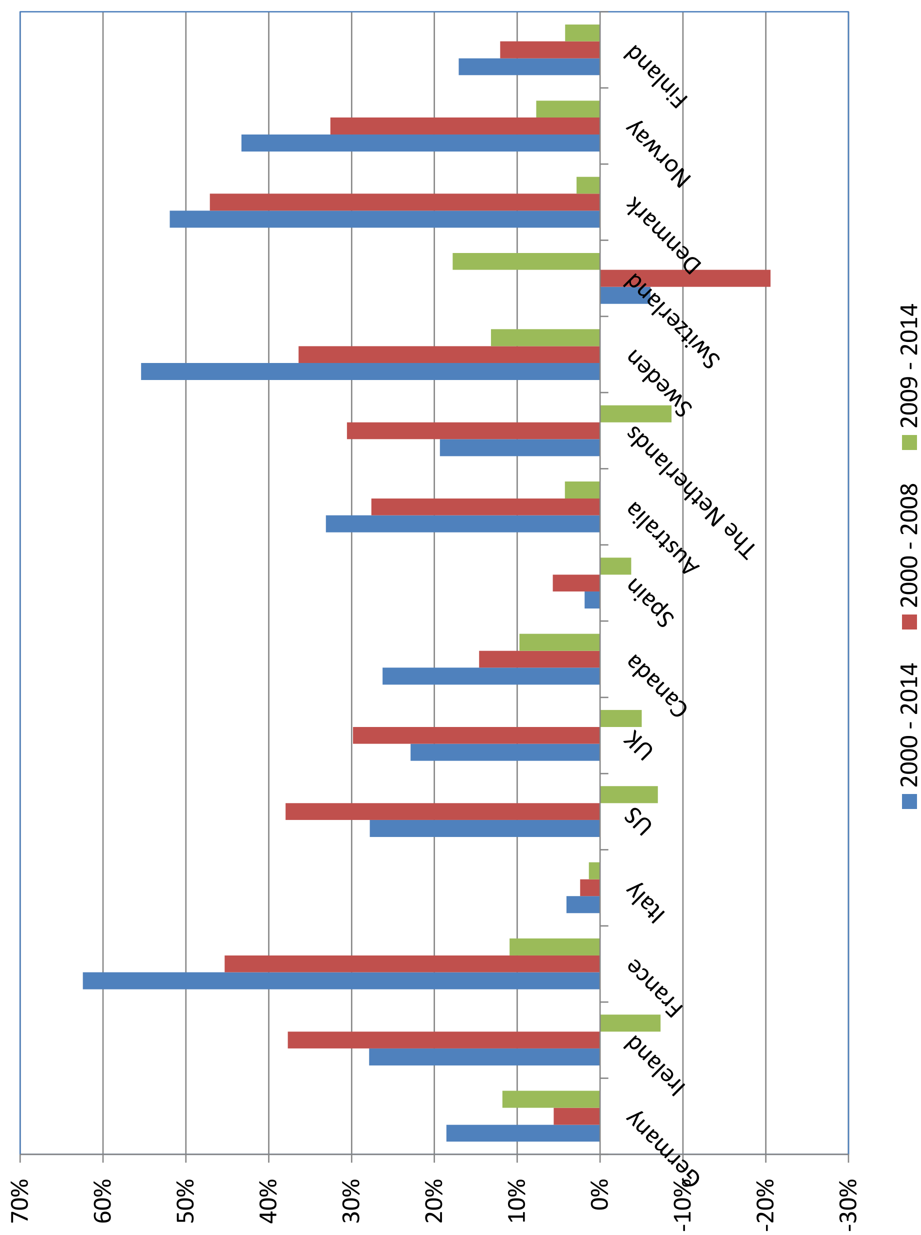


Figure 6a: Time-Varying Coefficient (Real) on Affordability Variable

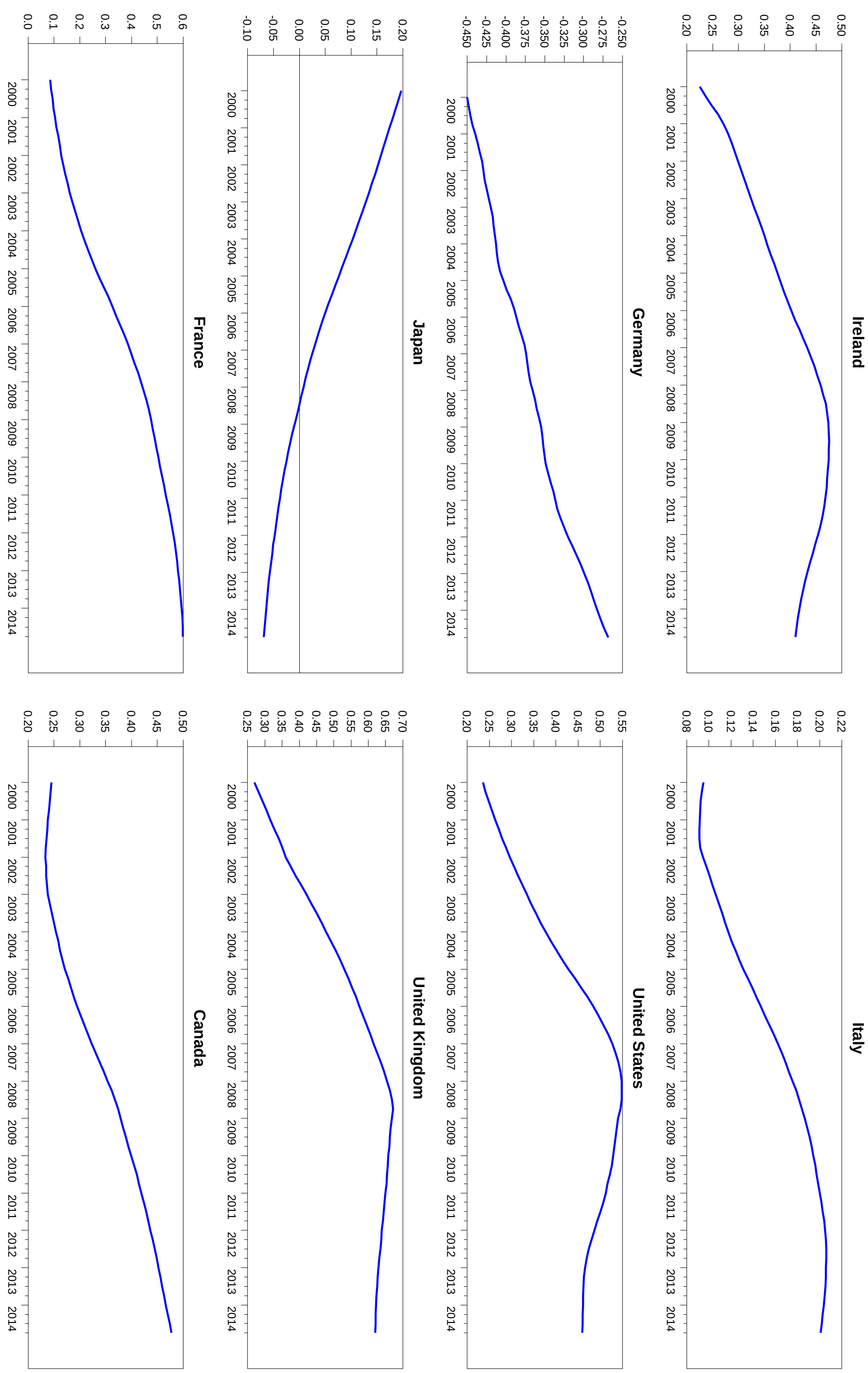


Figure 6b: Time-Varying Coefficient (Real) on Affordability Variable

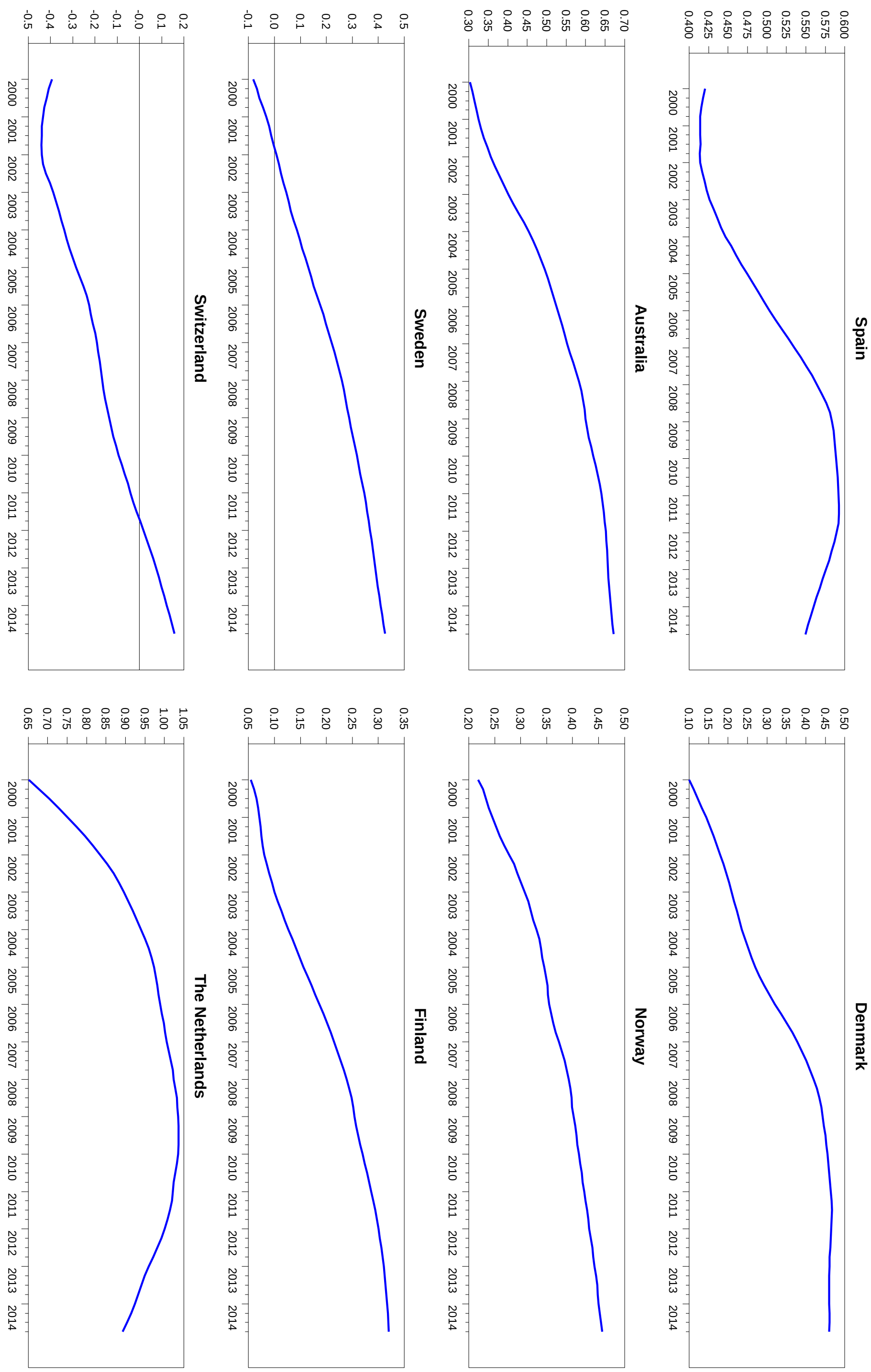
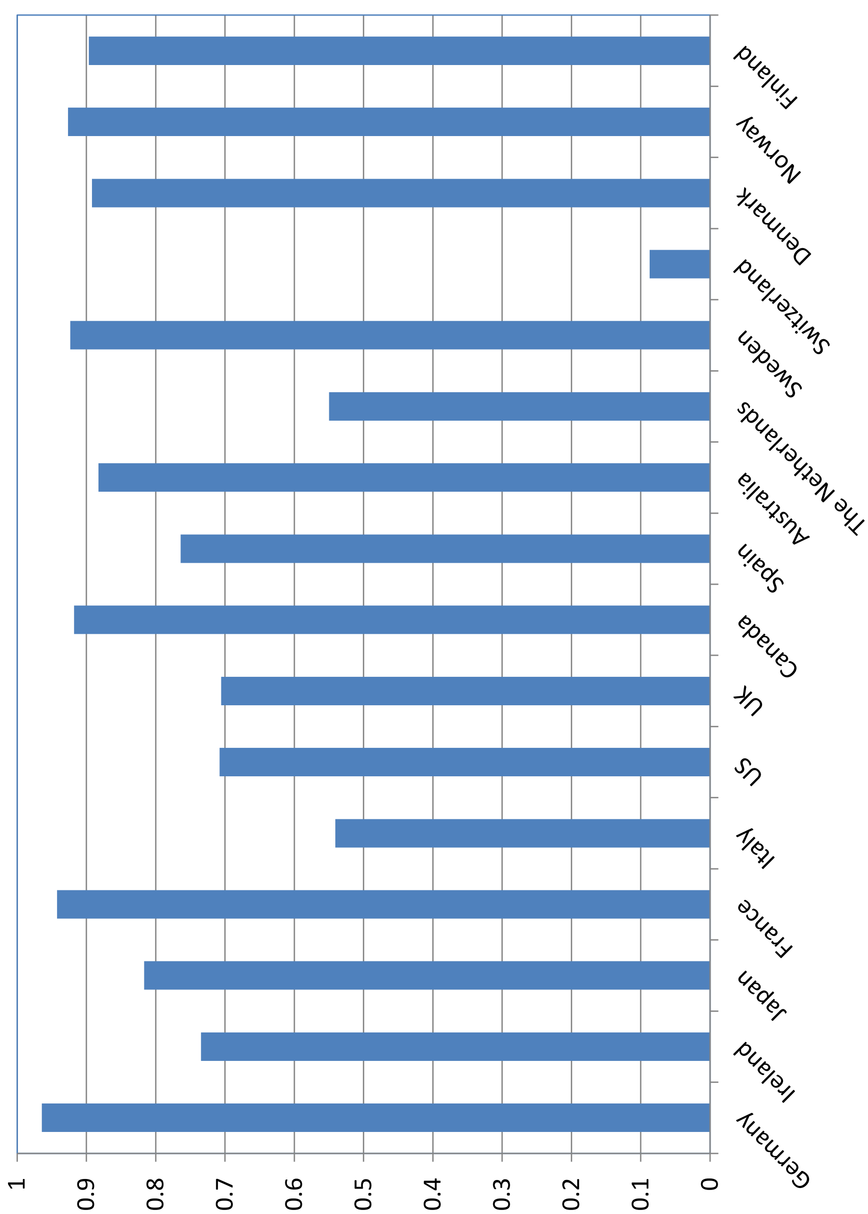


Figure 7: Correlation Coefficients between Affordability Levels and Elasticity Coefficients



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