Cross-Border Macroprudential Policy Spillovers and Bank Risk-Taking*

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We test whether there was a change in risk-taking by Irish banks in the U.K. mortgage market following the introduction of macroprudential limits on loan-to-value (LTV) and loan-to-income (LTI) ratios in Ireland in early 2015. Using confidential loan-level data on lending in the Irish and U.K. mortgage markets, we provide evidence of risk spillovers whereby Irish banks increased their LTV and LTI ratios on lending abroad in response to the regulatory macroprudential tightening at home. We find heterogeneous effects across groups of borrowers, with LTVs and LTIs increasing most for first-time homebuyers (FTBs). We estimate that, relative to a control group of local lenders, the probability of a high-risk loan being issued by an Irish bank in the U.K. mortgage market increased by 16 percent overall, and by 28 percent in the FTB segment, after the policy introduction.

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1. Introduction

As the implementation of macroprudential policies, which aim to promote system-wide financial resilience, has become more widespread, policymakers and researchers have paid attention to the possibility that the prudential benefits of regulation of a bank's activity in one sector or country may be eroded through changes in behavior not covered by the regulation. The recent empirical literature has identified a number of mechanisms through which such "spillovers" or "leakages" may occur. Firstly, a domestic regulator may deploy a regulatory instrument, such as those relating to a bank's capital level, which only apply to domestically resident lenders. In such cases, total credit growth in the domestic market may not decrease if unregulated entities such as foreign-owned branches or non-banks "step into the gap" by increasing their lending to offset the credit reduction among regulated firms. Aiyar, Calomiris, and Wieladek (2014) show that precisely this form of prudential spillover arose from bank-varying changes to minimum capital requirements imposed on U.K. lenders in the 1990s and 2000s.

A second form of spillover from prudential regulation may occur when the regulatory instrument deployed targets a specific product or sector within the domestic credit market. A prominent example of such an instrument is the "borrower-based measure," such as a limit on the origination loan-to-value (LTV), loan-to-income (LTI), or debt-service-to-income (DSTI) ratio. Such an instrument targets all loans in the domestic market, regardless of the ownership or residency of the lender. The possible spillover that may arise from such a restriction is the mirror image of the first case: now, banks with operations in multiple countries or asset classes may respond to macroprudential product-based restrictions in the regulated market by changing the volume or profile of their lending in unregulated markets, such as foreign mortgage markets or both domestic and foreign commercial lending markets. Gaining an understanding of the nature and extent of spillovers is an important element of the emerging literature on the effectiveness of macroprudential policy.

In this paper, we use loan-level data for the United Kingdom and Ireland to test for cross-border spillovers from macroprudential regulations in the mortgage market. Using loan-level data on mortgages from Irish-headquartered banks active in both the Republic

of Ireland and the United Kingdom, coupled with loan-level data on U.K.-only lenders, we test whether there was a change in risk-taking by Irish banks in the United Kingdom following the introduction of macroprudential regulations in Ireland in February of 2015. Our study is the first to identify this credit risk spillover channel through cross-border lending activity following macroprudential regulations using loan-level information.

Our identification strategy is twofold. First, we use a simple difference-in-difference strategy with loan-level data to compare the lending activity of Irish banks in the United Kingdom with their Irish lending before and after the introduction of macroprudential limits on loan-to-value and loan-to-income ratios in their Irish home market. This comparison provides a first test of whether the behavior of the Irish banks diverged between the two jurisdictions concurrent with the change in regulatory regime in Ireland. Second, to assess whether the risk-taking behavior of the Irish banks changed relative to other banks in the United Kingdom after the policy change, we compare Irish banks' lending conditions (LTV and LTI ratios) in the United Kingdom with that of other mortgage lenders for whom loan-by-loan mortgage data are available from the European Central Bank's European Data Warehouse (EDW). In this second set of specifications, foreign activity of Irish entities is being compared with the activity of local lenders completely unaffected by the Irish mortgage restrictions. We also exploit the granularity in our data by considering whether the Irish banks' lending conditions changed for different buyer types in the market. We focus separately on first-time homebuyers (FTBs), second and subsequent home buyers (SSBs), and refinancing borrowers (Refi).

Two particular econometric issues arise in both our difference-in-difference specifications. First, our objective is to identify supply-side shifts in lending conditions following the regulations. As the loan data are repeated cross-sections of newly issued loans, we are not able to follow the individual borrower over time and include a within-group fixed effect which would directly identify credit demand factors. While such data are more commonplace for enterprises (De Jonghe et al. 2016), it is more difficult to obtain for households, as house purchase decisions are infrequent and lumpy (most households purchase one or two houses in their lifetimes). Indeed, to deal with this issue, the optimal data set would require the

universe of both U.K. and Irish micro data in a joint data set with unique U.K. and Irish household identifiers. However, these data sets are not currently compiled by any regulatory authority or other body.

To operationalize the best identification strategy given our data—in particular, dealing with confounding demand-side factors—we saturate the model with a rich set of "loan-borrower type" fixed effects to attempt to purge credit demand effects at as disaggregated a level as possible. This method follows the spirit of Auer and Ongena (2016), De Jonghe et al. (2016), and Khwaja and Mian (2008) and allows us to aim at an identification of changes in the bank risk appetite from a supply side following the policy shift. To create the loan-borrower fixed effects, we use the following borrower and loan characteristics: three borrower age groups for borrowers aged eighteen to thirty-five, thirty-six to forty-five, and forty-six to sixty-nine; year-country house price quartiles; year-country income quartiles; an indicator for four property types (detached houses, semi-detached, terraced houses, apartments), and an indicator for capital cities and their surrounding commuter zones (taking a value of one for Dublin and the mideast regions in the Republic of Ireland (ROI), and London and the (outer) southeast regions in the United Kingdom). This leads to 2,382 groups which are included in the final model once we exclude all cells with one loan.

Second, the repeated cross-sectional nature of the data pose the risk of changes in borrower composition that are affected by the policy. To deal with this issue, we use a multinomial logit inverse probability weighting technique as in Stuart et al. (2014) to deal with selection on observables and to restore the sample composition to be comparable to the pre-policy treatment group.

We find evidence that Irish banks loosened LTVs and LTIs for their U.K. mortgage lending relative to both their Irish lending and the broader lending activity in the U.K. market following the policy change in Ireland. This result demonstrates a risk-shifting channel by which Irish banks take more risk abroad following prudential limits at home. For LTV ratios, we find a 5.3 percentage point difference in the average LTV between Irish banks' ROI and U.K. lending, with the impact strongest for first-time buyers and second and subsequent buyers, relative to buy-to-let and refinance mortgages.

When local U.K. mortgage lenders are used as a control group, the LTV ratios for Irish banks are shown to increase by 1.1 percentage points overall, 3.1 percentage points for first-time buyers (FTBs) and 1.4 percentage points for second-time buyers. There is no difference for refinancing loans. Considering LTIs, we again find evidence of a credit loosening by Irish banks relative to other banks in the United Kingdom after the policy introduction, with this effect limited to borrowers in the FTB segment. Relative to a mean LTI ratio of 2.6 in the United Kingdom over our regression sample period, we estimate a sizable loosening in response to the policy of 0.45.

Our final set of regressions focuses on the probability of issuance of high-risk loans. One could argue that, rather than looking at average LTVs and LTIs, the removal of loans from the right tails of the LTI and LTV distribution may be more relevant when considering the goals of macroprudential policy (to enhance the resilience of borrower and bank balance sheets).[1] We therefore explore whether the Irish banks undertook more "high-risk" lending in the United Kingdom after the Irish macroprudential restrictions were introduced. We define a "high-risk" loan in the United Kingdom to be one with either an LTV above 85 percent or an LTI above 4 (covering between 10 and 15 percent of loans across our sample). We find sizable effects using this approach: Irish banks increased the probability of a high-risk loan by 16 percent relative to the counterfactual, with this effect being 28 percent in the FTB segment. That FTB borrowers experienced the greatest relaxation in credit standards is also noteworthy in terms of understanding the impact of macroprudential regulations, given that FTBs are often faced with downpayment constraints (Engelhardt 1994) and are often the most affected by tightening credit terms. It is clear from this evidence that the spillovers occurred with an increase in credit risk for the Irish lenders, which runs counter to the objectives of the original policies and highlights the difficulties for national regulations in a globalized banking environment.

Our approach is similar in spirit to that of Auer and Ongena (2016), who focus on a cross-asset-class, rather than cross-border,

[1] See Kelly and O'Toole (2018) for discussion.

version of an outward spillover. Using a residential-mortgage-related activation of the countercyclical capital buffer in Switzerland in 2012 as an experiment, they provide evidence that commercial lending increased disproportionately among those lenders with the greatest ex ante mortgage market exposure. Such a finding tallies with the results presented here: where product-specific or asset-class-specific regulation is imposed, lenders may respond by loosening credit conditions on unregulated parts of their balance sheet.

The evidence from the emerging literature on international spillovers from macroprudential regulation is mixed. Buch and Goldberg (2016) report on the results of fifteen separate country studies investigating the international spillovers of prudential policy changes, and find evidence that the effects of prudential instruments sometimes spill over through cross-border bank lending. They show further that bank-specific factors like balance sheet conditions and business models are important drivers of heterogeneity in spillovers, but by no means do they suggest that outward spillovers are a universal consequence of prudential regulation. Using aggregate cross-border lending data, Houston, Lin, and Ma (2012) find that bank flows are positively related to the number of activity restrictions and the stringency of capital regulation imposed on banks in their source country, and negatively related to restrictions and regulations in the recipient country, suggestive of spillovers in activity towards jurisdictions with less regulation. Ongena, Popov, and Udell (2013) show that when more general forms of bank regulation such as barriers to entry and restrictions on bank activity are tighter at home, a multinational bank is more likely to have looser credit standards in its foreign lending, prima facie evidence of an outward risk spillover from domestic regulation.

Certain papers have shown how domestic capital tightening can have contractionary effects on foreign lending of global banks (Aiyar et al. 2014). In this vein, Tripathy (2017) uses municipality-level data in Mexico to test the impact of macroprudential regulation in Spain on the Mexican subsidiaries of Spanish banks. The research finds that capital regulatory tightening in Spain caused a drop in the supply of household credit in Mexico following the regulatory shock. This "outward transmission" leads to less risk-taking abroad as a response to domestic capital regulation, which is in direct contrast to the cross-border "outward spillover" being tested here, where

lenders take more risk in foreign markets in response to LTV and LTI restrictions that have effects only in the domestic mortgage market.

The aforementioned studies all test for the presence of spillovers from policy changes on the volume of lending. Our research differs from the extant literature in that it explores the change in risk-taking by explicitly measuring the LTV and LTI ratios of new loans. In this vein our paper is close to Demyanyk and Loutskina (2016), who test whether differences in the regulatory regime between deposit-taking institutions and mortgage companies in the United States resulted in regulatory arbitrage to loosen credit conditions. They find that subsidiary mortgage companies of broader banking groups originate riskier mortgages at looser credit conditions than their deposit-taking arms. The argument is predicated on the fact that banks have a particular risk appetite and, when faced with a regulatory regime which limits risk-taking, they will find ways to circumvent the regulations and continue to take the risk.

In addition to the aforementioned studies that directly address spillovers from domestic financial regulations, our study is also related to that by Reinhardt and Sowerbutts (2015), who show that "inward spillovers" appear to be prevalent after domestic macroprudential regulation, in the sense that foreign bank lending to domestic non-banks increases after a domestic macroprudential capital action. The authors, however, find no evidence that such inward spillovers occur when domestic product regulations such as LTV restrictions are implemented. Our research is also linked to the burgeoning literature on the impact and effectiveness of macroprudential policies (Cerutti, Claessens, and Laeven 2017; Cizel et al. 2016; Vandenbussche, Vogel, and Detragiache 2015) and the literature considering the impact on the mortgage market of bank capital requirements (Basten and Koch 2015; Jimenez et al. 2017).

The paper proceeds as follows: Section 2 introduces the policy and economic context in Ireland and the United Kingdom in the period around the introduction of macroprudential mortgage restrictions by the Central Bank of Ireland; section 3 presents a model of Irish banks' risk-taking at home and abroad; section 4 presents a model comparing ROI banks' risk-taking in the United Kingdom with that of local competitor banks; section 5 assesses the impact of the regulations on the probability of high-risk loans being issued; and section 6 concludes.

2. Policy and Economic Context

2.1 Macroprudential Measures in the Irish Mortgage Market

The role played by mortgage finance in the global financial crisis has been well documented (Adelino, Schoar, and Severino 2016; Duca, Muellbauer, and Murphy 2010, 2011). Loosening credit standards led to a buildup of vulnerabilities and a wave of mortgage defaults in the United States and other markets with housing booms like Ireland and Spain. The outcome was the onset of systemic financial crises in these countries. To prevent a reoccurrence, macroprudential policies on borrower credit such as LTV, LTI, and debt service limits (DSRs) have become more common in the post-crisis era. Such measures have been in place in many Asian economies following the financial crisis in the late 1990s into early 2000s (International Monetary Fund 2013). However, their adoption has become more widespread since the global financial crisis. In 2015, the European Systemic Risk Board (ESRB) reported that a total of seventeen European countries had LTV limits in place, with a number of countries also having income restrictions (ESRB 2016).

On February 9, 2015, the Central Bank of Ireland introduced measures to limit the LTV and LTI ratios applying to new residential mortgage lending in the Irish republic. With many mortgage holders struggling to meet their repayments, and an arrears rate still among the highest in Europe, the measures were enacted with a view to improving the resilience of households and the banking sector to financial shocks and reducing the risk of future bank credit and house price spirals. In Ireland, following the financial crisis, house prices fell by between 50 and 60 percent from peak levels, while 20 percent of mortgages were in arrears at the peak of the crisis in 2013. This highlights the scale of the difficulties in Ireland and the requirement for policies to safeguard financial stability into the future.

Table 1 provides an overview of the measures as they applied to FTBs and second and subsequent buyers (SSBs) from the implementation date until the end of 2016.[2] For FTBs, a sliding LTV

[2]In late 2016, an amendment to the regulations was announced which loosened credit conditions for first-time buyers. Due to data availability at the time of writing, this paper does not analyze developments after this announcement of loosening, focusing instead on the initial calibration of the regulations.

Table 1. Overview of Macroprudential Regulations for Mortgage Lending

Loan-to-Value Limits	Primary Dwelling Homes	FTBs: Sliding LTV limit from 90 percent* SSBs: 80 percent
Loan-to-Income Limits	Primary Dwelling Homes	3.5 times LTI limit

*FTBs are allowed a 90 percent LTV up to a house value of €220,000. An 80 percent LTV applies above this value.

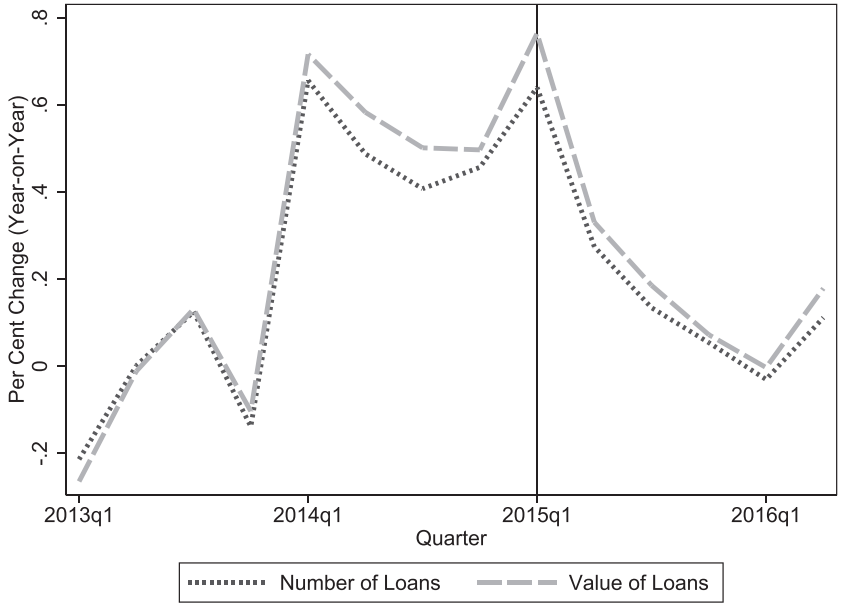
limit applies, with the first €220,000 of their purchase requiring a 10 percent deposit and any balance above €220,000 requiring a 20 percent deposit. For SSBs, a maximum LTV of 80 percent applies to all property purchases. Both borrower types are subject to an LTI limit of 3.5 times gross income. The regulations also allow for a certain value of new lending to exceed the limits, as it follows a proportional allowances model. Financial institutions are permitted to lend up to 15 percent of the value of new principal dwelling house (PDH) lending in excess of the LTV limit and up to 20 percent of the value of their new PDH lending in excess of the LTI limit.[3] Buy-to-let investors are subject to a 70 percent LTV cap.

Our main research hypothesis predicts a spillover of risk from the home to foreign markets as the Irish banks faced restrictions on risk-taking activity domestically. While it is not the objective of this paper to assess the direct impact of the introduction of mortgage measures in Ireland, it is important to demonstrate a material impact of the measures in Ireland on the activity of Irish banks. Our approach to this is twofold: first, we draw on aggregate data to demonstrate the overall impact on mortgage lending, and second, we draw on existing research to demonstrate the impact of the rules on the lending conditions (LTV and LTI ratios in the market).

The introduction of the regulations in Ireland occurred in February 2015 and were announced to the market in October 2014 when

[3]Self-builds are also subject to the regulations, as are refinances/switchers with an increase in capital. There are number of exemptions to the regulations for negative equity loans, mortgage resolution agreements, and refinances/switchers without an increase in capital.

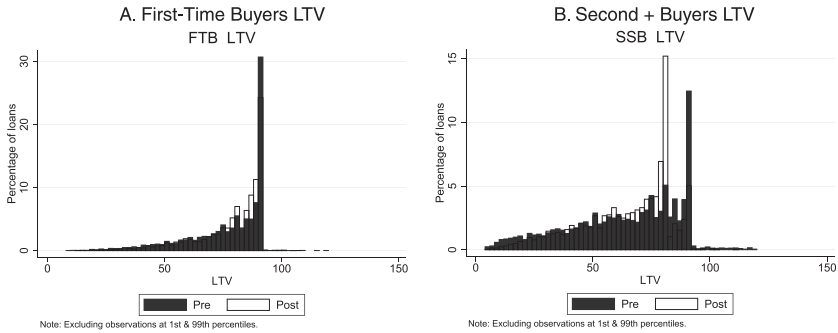
Figure 1. Growth in New Mortgages: ROI, 2013:Q1–2016:Q2



Source: Banking and Payments Federation Ireland.
Note: Vertical line indicates introduction of policy.

the central bank published research on their potential benefits (Hallissey, Kelly, and O'Malley 2014) as well as opening a public consultation on the proposed regulations. This move was not expected by the market, and their unanticipated announcement represented an exogenous change to the loan-to-value and loan-to-income limits applying to new mortgage loans to a market which had not had such a framework before. The overall result of the introduction of the measures was a reduction in the growth rate of mortgage loans. Figure 1 presents the growth in new mortgage drawdowns (number of loans and the value of lending) from the period 2013:Q1 to 2016:Q2 for the Irish market. The data are taken from the Banking and Payments Federation Ireland and mainly cover the five largest lenders in the Irish market: Allied Irish Banks (including EBS Building Society), Bank of Ireland, KBC, Permanent TSB, and Ulster

Figure 2. Distributional Comparisons of LTV by Buyer Type



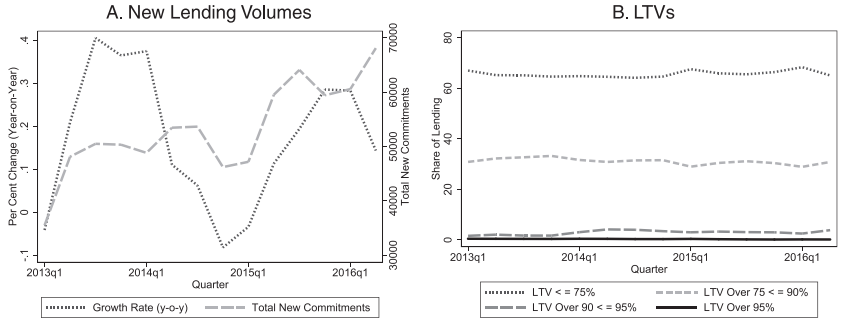
Source: Kinghan, McCarthy, and O'Toole (2017).
Notes: Pre-policy period: 2013:Q1–2014:Q3. Post-policy period: 2015:Q1–2016:Q2.

Bank. It can be seen that following the regulations, there was a marked slowdown in the growth of new lending.

To explore the impact of the regulations on the actual lending conditions in the market, we draw on two research papers that explore the changes in borrower leverage following the introduction of the measures. Kinghan, McCarthy, and O'Toole (2016) assess the LTV and LTI ratios in the market before and after the introduction of the regulations. They find that while on average there was actually a small rise in the indicators, for borrowers with a high demand for leverage,[4] there were falls in both the loan-to-income and loan-to-value ratios. For SSBs, the LTV for this group fell by up to 4 percentage points. Further research by Kinghan, McCarthy, and O'Toole (2017) highlights the fall for FTBs in LTV of up to 1.4 percentage points. Data in Kinghan, McCarthy, and O'Toole (2016) also highlight a statistically significant increase in incomes for FTBs in the market, which may be indicative of some change in borrower composition. Figure 2, reproduced from Kinghan, McCarthy, and O'Toole (2017), clearly demonstrates that the rules curbed the upper end of the LTV distribution, thus materially tightening the risk-taking of Irish banks.

[4]They define borrowers with a high demand for leverage as those with an LTV greater than or equal to 80 percent or an LTI greater than or equal to 3.

Figure 3. Overview of Activity in U.K. Mortgage Market



Source: Bank of England, MLAR Statistics.

2.2 The U.K. Mortgage Market and the Irish Connection

Mortgage debt in the United Kingdom accounts for approximately two-thirds of all outstanding loans (Bank of England 2016). While the Irish housing market suffered following the financial crisis, the effects in the United Kingdom were much less pronounced, with mortgage lending and house prices continuing to rise from 2013 onwards. A comparative description of house price developments for the United Kingdom and ROI is presented in appendix 1. Figure 3 presents an overview of activity in the U.K. mortgage market from 2013 to 2016 (the period under investigation in this paper). It can be seen that while the growth rates dropped in 2014, there has been a marked pickup more recently. In terms of risk-taking appetite in the United Kingdom, a majority of U.K. loans are issued at low LTVs (less than 75 percent) and, furthermore, there has been no discernible change in the level of LTVs on loans over the period.

Despite the relative stability in the mortgage market and the low level of mortgage delinquencies, in June 2014 the Financial Policy Committee of the Bank of England introduced a package of mortgage measures aimed at insuring against the risk of a marked loosening in underwriting standards in the owner-occupier mortgage market.[5]

[5]The Bank of England monitors delinquencies in the U.K. mortgage market in its annual Financial Stability Reports and the level is low. Kelly and O'Toole (2018) describe the level of delinquencies in the United Kingdom experienced by Irish lenders.

These measures included an affordability test and an LTI limit of 4.5 times income with a 15 percent allowance. The policies were not meant to be currently binding in the market, and a subsequent review of their functionality found they only had a very modest effect, with most lenders already applying more critical tests than the regulatory minimum (Bank of England 2016). This limit compares to a much stricter regime in Ireland, which may have left open the possibility for cross-border risk shifting such as that tested in this paper.

In terms of the presence of Irish lenders in the United Kingdom, there has been a long tradition of Irish involvement in direct lending in the United Kingdom which pre-dates Irish independence and continued thereafter (McGowan 1988). This was particularly strong in the case of Northern Ireland, with large subsidiaries of Irish banks continuing to operate north of the border. In the case of the banks present in our sample, Irish bank involvement in the U.K. market in the present day is not restricted to activity in Northern Ireland, but rather is distributed more generally across regions.

Presently, and of critical importance for this current paper, is that two main banking groups in Ireland (Bank of Ireland and AIB) have considerable ongoing activities in the U.K. market. Bank of Ireland has a particularly large presence in the United Kingdom. Its acquisition of Bristol and West Building Society in the 1990s gave it a foothold in the market and, currently, it lends directly as Bank of Ireland UK but also provides savings and loans products through its strategic alliance with the U.K. Post Office. Using data from its annual report, as of 2016:Q3, the total stock of U.K. mortgage loans outstanding for Bank of Ireland was valued at €23.8 billion, which is only marginally smaller than their Irish portfolio with €24.4 billion outstanding. In fact, at year-end 2016, the value of new mortgage lending was nearly two times larger in the United Kingdom, at €2.8 billion as compared to €1.4 billion in ROI.

For AIB, its U.K. presence is more regional, with a majority of activity being worked through First Trust, its wholly owned subsidiary in Northern Ireland. AIB also lends through AIB UK Group directly into the U.K. market. In total, AIB held €1.5 billion worth of U.K. mortgages outstanding.

3. Irish Banks' Lending at Home and Abroad

For our first empirical model, we use a simple difference-in-difference framework with loan-level data to compare the lending activity of Irish banks in the United Kingdom with their Irish lending before and after the introduction of macroprudential limits on LTV and LTI ratios in their Irish home market. This section documents the data and results for this comparative exercise.

3.1 Data and Identification Strategy

To investigate cross-border spillovers from macroprudential mortgage measures, we exploit loan-level data on the activity of Irish banks both domestically and abroad. The data come from regulatory loan-by-loan information that was submitted to the Central Bank of Ireland on a six-month basis since 2010. These data capture the universe of all outstanding loans for the Irish banks. These data were first provided as a requirement for the Prudential Capital Assessment Review (PCAR), which estimated the recapitalization requirements of the lenders following the financial crisis. The loan-level data (LLD) are currently collected from the five main lenders: Allied Irish Banks (including EBS), Bank of Ireland, KBC, Permanent TSB, and Ulster Bank.

For this particular paper, we draw on one specific drop of the LLD which includes all loans outstanding as of June 2016 for a subset of lenders with exposures in both the ROI and U.K. markets. In the ROI mortgage market, the loans covered account for around two-thirds of total mortgage market exposures. The data set is rich in capturing information that is recorded at origination for the purposes of credit risk assessment and lending allocation decisions. This includes loan characteristics including loan term, LTV, LTI, interest rate, interest rate type, drawn balance at origination, and loan type as well as borrower characteristics and property characteristics (price, region, dwelling type). The borrower characteristics are income (in euros or pounds sterling), age in years, employment status (employee, self-employed, other), and marital status (married, single, divorced, other). The property dwelling type takes the following categories: detached houses, semi-detached, terraced houses, and apartments.

Not all of the Irish banks have lending activity in the U.K. market. Requiring banks to have both U.K. and Irish lending leads us to construct a pooled cross-sectional data set of all loans issued by two Irish lenders who are active simultaneously in issuing new loans in both the ROI and U.K. mortgage markets during our target sample period. In order to create a balanced data set around the introduction of the macroprudential mortgage regulations in February 2015, we restrict the data to all loans issued between January 2013 and June 2016. Due to confidentiality constraints, we are not able to present summary statistics for the differential trends in lending volumes and credit conditions for both lenders in the U.K. and Irish markets, as would be normal in a setup like ours. However, we can consult the annual report of Bank of Ireland, the largest Irish-resident mortgage lender in the United Kingdom, which states the following:

> A key objective for 2015 was to continue to grow our mortgage business, building on the progress we made last year. In 2015, our new mortgage lending was GBP 3.3 billion compared with GBP 1.8 billion in 2014.

While clearly not causal, the above statement shows that, in aggregate terms, new lending expansion by the largest mortgage player was indeed occurring in the first year after the introduction of the domestic macroprudential mortgage restrictions in Ireland.

Table 2 presents summary statistics for the regression sample. Overall, there are 60,540 mortgages issued across the two jurisdictions by our sample banks between 2013:Q1 and 2016:Q2. The average LTI is 2.54 across all loans, while the average LTV ratio at origination is 72.04 percent. The average mortgage term is 290 months (24.17 years), while the average interest rate is 3.31 percent and the average borrower age is 37.57 years. The average unemployment rate across all regions and quarters is 7.37, while the average increase in the regional house price index from 2012:Q2 was 17.72 percent. In the second panel, we report the share of certain key categorical variables in the total sample. 41.9 percent of all mortgages were issued in Dublin, London, or their surrounding commuter regions (mideast in the ROI, southeast in the United Kingdom). 38.1 percent of mortgages were to first-time buyers, 27.2 percent to

Table 2. Summary Statistics for ROI-UK Regression Model

Variable	N	Mean	Std. Dev.
LTI	60,540	2.54	1.10
LTV (%)	60,540	72.04	18.92
Term	60,540	289.93	89.31
Interest Rate	60,540	3.31%	0.01
Age	60,540	37.57	8.32
Unemployment	60,540	7.37	2.47
House Price Index	60,540	117.72	17.10
Capital City or Commuter Belt	60,540	41.9%	
First-Time Buyer	60,540	38.1%	
Second and Subsequent Buyer	60,540	27.2%	
Refinance	60,540	24.7%	
Buy to Let	60,540	10.0%	
Salaried Employee	60,540	89.6%	

Notes: This table includes the summary statistics for the Irish lenders only used in the regression sample. LTI: loan-to-income ratio; LTV: loan-to-value ratio; Term: loan term in years. Capital city or commuter belt counties surround Dublin and London.

second and subsequent buyers, 24.7 percent for refinancing activity, and 10 percent for buy-to-let purchases. Finally, 89.6 percent of mortgages were to salaried employees, with the remainder going to self-employed borrowers.

Our main goal is to test how the lending standards of Irish banks changed in the United Kingdom following the regulations in Ireland, as measured by changes in LTV and LTI ratios. To this end, we estimate the following equation:

$$Y_{ijt} = \beta_1 UK + \beta_2 Post + \beta_3(UK \times Post) + \beta_{4,5} X_{ijt} + \beta_{6,7} X_{rt} + \delta_{LoanGroup} + e_i, \quad (1)$$

where Y_{ijt} is the LTV and LTI of mortgage i which was issued in country j in quarter t; X_{ijt} are a set of loan-level control variables which are not used to construct $\delta_{LoanGroup}$, such as the loan's interest rate and term at origination; and X_{rt} are regionally varying

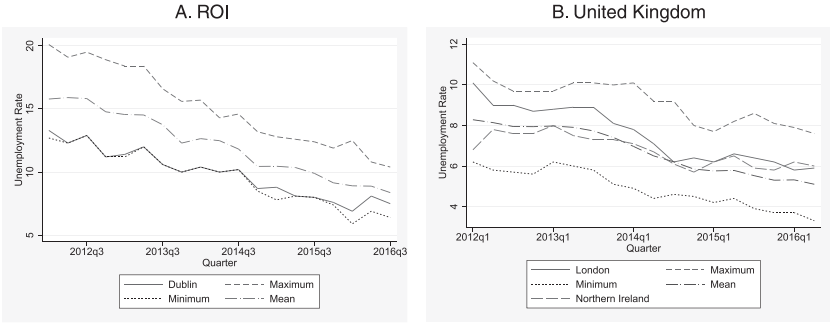
measures of economic performance which are likely to affect the demand for loans, such as the regional unemployment rate and the regional house price index, based to 100 at 2012:Q1 for each region across both jurisdictions.

$\delta_{LoanGroup}$ are a set of "loan-borrower group" fixed effects which saturate elements of loan-specific demand for debt which are likely to be common across borders, similar in spirit to those used by Auer and Ongena (2016). To construct these δ, we create buckets based on unique combinations of the following indicators for borrower types: three borrower age groups for borrowers aged eighteen to thirty-five, thirty-six to forty-five, and forty-six to sixty-nine; year-country house price quartiles; year-country income quartiles; an indicator for four property types (detached houses, semi-detached, terraced houses, apartments); and an indicator for capital cities and their surrounding commuter zones (taking a value of one for Dublin and the mideast regions in ROI, and London and the (outer) southeast regions in the United Kingdom). This leads to 2,382 groups that are included in the final model once we exclude all cells with one loan. The average number of loans in a cell is 351, with the median being 107 and the maximum being 3,720. Our empirical identification strategy relies on the assumption that, within each of these groups, any difference in LTV or LTI across borders over time which is not attributable to banks' supply decisions is controlled for in the X_{ijt} and the X_{rt}.

The crux of our empirical analysis is the coefficient on ($UK \times Post$). The coefficient on UK will control for any differential in LTV or LTI between ROI and UK which is constant over the 2013–16 period; $Post$ will control for LTI and LTV differences that are common across jurisdictions in the period before and after February 9, 2015; and the term ($UK \times Post$) is the difference-in-difference (DiD) coefficient that will capture the LTV or LTI differential across geographies which exists solely in the period after the introduction of the regulations, all the time controlling for the set of X_{ijt}, X_{rt}, and $\delta_{LoanGroup}$.

Unlike the majority of studies of the effect of policy interventions using DiD methods, careful attention must be paid to the fact that treated and control loans in our setting are located in different countries. As well as having different structural time-invariant features such as preferences for homeownership, enforceability of collateral,

Figure 4. Unemployment across the Two Jurisdictions: 2012 to 2016



and government housing market policy, loans in the treated and control groups are also likely to be facing different aggregate economic conditions during the period under study. To control for the possibility that such economic factors may introduce bias into our estimate of the treatment effect for U.K. loans issued after February 9, 2015, we include unemployment rates and house price indexes in our models, both of which vary at the region-quarter level. Figure 4 plots the maximum, minimum, and mean unemployment rate across Ireland's eight NUTS3 regions from 2012 to 2016, as well as selecting the Dublin rate for exposition. The right-hand panel does so similarly for the United Kingdom's fourteen NUTS3 regions, while selecting the London rate. The graphs show a clear improvement in economic performance in both countries over the period, with significant variation across regions within each country which can be controlled for in our empirical framework.

The standard difference-in-difference model relies on the assumption that while counterfactual levels of the treated and non-treated groups can be different, their counterfactual time variation must be similar. In the context of our current study, we need it to be the case that in the absence of macroprudential policy in the Republic of Ireland, the LTV and LTI on new loans, controlling for level differences in the outcome variable across the two jurisdictions and the set of X_{ijt}, X_{rt}, and $\delta_{LoanGroup}$, would have evolved in the same way.

While controlling for observables can do much of the work in ensuring that our β_3 is interpretable as the difference between ROI banks' U.K. risk-taking under the policy versus under the

counterfactual no-policy scenario, issues can still remain in the case where repeated cross-sections with time-varying sample composition are being used, rather than panel data. Given that our data set reports the profile of newly originated mortgages, a layer of complexity is added, as we are not analyzing two groups of loans (treated and control, both of which were observed before and after the policy change) but four groups of different loans (pre-policy treated, pre-policy control, post-policy treated, post-policy control). This is precisely the type of pooled cross-sectional data where changing sample composition can hamper the interpretation of β_3 as a true DiD coefficient. To give a concrete example, if the share of first-time buyers in total originations has shifted dramatically between the pre- and post-policy period in ROI as a result of the policy, and we run an unweighted model to estimate β_3, it may be that the DiD coefficient is actually being driven by the changing sample composition, (with first-time buyers always being more likely to have higher-LTV loans), rather than by true, ceteris paribus changes in risk-taking for a given loan.

To address this issue, we use a propensity-score matching approach to match the borrowers on observables and then use these propensity scores to weight the DiD regression, proposed by Stuart et al. (2014). This involves estimation of a multinomial logit model to deal with the four-group nature of the selection issue. Using the estimated multinomial logit model, each observation in the data set gets a predicted probability of being in each of the groups, $Pr_g(X_i)$: (i) pre-policy treated, (ii) pre-policy control, (iii) post-policy treated, and (iv) post-policy control. The following inverse probability weights are then calculated:

$$w_i = \frac{Pr_1(X_i)}{Pr_g(X_i)}, \tag{2}$$

$$where\ 1 = \left(\sum_{g=1}^{4} Pr_g(X_i) \right) \forall i.$$

These weights can then be used in the DiD of equation (1) to account for changing sample composition. All regressions run for the remainder of this paper include weights derived from a multinomial logit model where a loan's position in the above four-category

variable is explained by dummies for salaried employee, interest rate type (fixed versus variable), property type, within year-country house price quartiles, within year-country income quartiles, and buyer types (for the overall model).

3.2 Empirical Results

Table 3 provides estimates of equation (1) where Y_{ijt} is the LTV of mortgage i issued in country j (ROI or United Kingdom) in quarter t. The term $UK^{*}Post$ corresponds to β_3 from equation (1). The interpretation of the coefficient is that, controlling for a host of loan- and household-level controls which capture the composition of lending, as well as regional, time, and bank dummies, there is a 5.35 to 5.66 greater LTV on U.K. mortgages after the introduction of the regulations. This corresponds to close to one-third of a standard deviation of originating LTV in the estimation sample and is robust to the inclusion of a continuous and region-varying measure of unemployment (which is measured at quarterly frequency) and house price indexes in columns 2 and 3, both of which are expected to capture much of the local aggregate economic developments, which could explain diverging paths in LTV that are not due to the regulations.

We investigate where banks' risk-taking spillovers are confined to particular classes of borrower in columns 4–7. This breakdown suggests that the largest effect is found in the first-time buyer segment (a DiD coefficient of 6.88), where one would generally expect to find the most credit-constrained borrowers. A large and significant estimate of β_3 (an LTV differential of 5.78 points) is also found in the mover-purchaser (SSB) market. Among refinancing mortgages, the coefficient on β_3 is not statistically different from zero, whereas in the buy-to-let market U.K. loans in the post-period are estimated to have lower LTV, although this effect is insignificant at the 5 percent level.

Table 4 runs the same equation with the loan-to-income (LTI) ratio as the dependent variable. Overall, and in the SSB and refinancing segments, there is in fact a negative coefficient on β_3. This implies that, in the period after the introduction of macroprudential mortgage regulation in Ireland, LTIs on Irish banks' mortgages grew by a relatively larger amount in the ROI relative to the United Kingdom. These effects may possibly be explained by the fact that the

Table 3. Difference-in-Difference Model of Irish-Headquartered Banks' ROI and U.K. Lending: LTV

	(1) All	(2) All	(3) All	(4) FTB	(5) SSB	(6) Refi	(7) BTL
UK × *Post*	5.354***	5.661***	5.606***	6.882***	5.784***	1.564	−4.230*
	(0.786)	(0.845)	(0.839)	(1.185)	(1.223)	(3.152)	(2.165)
United Kingdom	6.952***	5.611***	6.217***	3.133*	4.938***	13.05***	12.21***
	(0.928)	(1.407)	(1.381)	(1.627)	(1.674)	(3.656)	(2.474)
Post	−1.699**	−2.275***	−1.793**	−1.338	−1.660	1.680	6.237***
	(0.721)	(0.872)	(0.853)	(1.259)	(1.284)	(3.157)	(2.164)
Loan Term	0.0873***	0.0869***	0.0870***	0.0695***	0.100***	0.0992***	0.0513***
	(0.00361)	(0.00356)	(0.00355)	(0.00484)	(0.00684)	(0.00738)	(0.00497)
Regional		−0.303	−0.310*	−0.368	−0.0191	−0.356	0.237
Unemployment		(0.185)	(0.187)	(0.270)	(0.206)	(0.400)	(0.263)
Regional HP			−0.0485*	−0.0255	−0.107***	−0.0378	0.0665
			(0.0250)	(0.0270)	(0.0274)	(0.0560)	(0.0426)
Observations	71,597	71,593	71,593	28,611	20,149	16,687	6,526
Loan Group FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, within-year house price quartile, within-year income quartile, and property type. In columns 1–3 it also distinguishes between first-time buyer, second and subsequent buyer, and refinance transactions. The model uses a linear specification estimated by OLS. Standard errors are robust to heteroskedasticity. Columns 4–7 estimate the regression specifically on the subsamples: FTB, SSB, Refi, and Buy-to-Let (BTL). The dependent variable is the loan-to-value ratio. Mlogit PSM weights are generated from multinomial logit specification as described in section 3.1.

Table 4. Difference-in-Difference Model of Irish-Headquartered Banks' ROI and U.K. Lending: LTI

	(1) All	(2) All	(3) All	(4) FTB	(5) SSB	(6) Refi	(7) BTL
UK × *Post*	−0.292***	−0.285***	−0.284***	0.303***	−0.217***	−0.643***	0.217***
	(0.0450)	(0.0506)	(0.0505)	(0.0449)	(0.0563)	(0.118)	(0.0815)
United Kingdom	0.587***	0.559***	0.542***	0.217***	0.598***	0.565***	−0.0861
	(0.0401)	(0.686)	(0.0680)	(0.0545)	(0.0776)	(0.139)	(0.113)
Post	0.281***	0.269***	0.255***	−0.123***	0.186***	0.410***	−0.0985
	(0.0370)	(0.0489)	(0.0490)	(0.0456)	(0.0564)	(0.112)	(0.0783)
Loan Term	0.00392***	0.0391***	0.00391***	0.00331***	0.00503***	0.00363***	0.00232***
	(0.000166)	(0.000166)	(0.000166)	(0.000195)	(0.000349)	(0.000317)	(0.000258)
Regional		−0.00639	−0.00618	−0.0577***	−0.00232	0.00466	−0.0580***
Unemployment		(0.00973)	(0.00976)	(0.00928)	(0.0113)	(0.0158)	(0.0139)
Regional HP			0.00131	0.00665***	0.00346**	−0.00374**	0.00929***
			(0.000999)	(0.00118)	(0.00168)	(0.00189)	(0.00281)
Observations	72,358	72,354	72,354	28,900	20,627	16,703	6,505
Loan Group FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, within-year house price quartile, within-year income quartile, and property type. In columns 1–3 it also distinguishes between first-time buyer, second and subsequent buyer, and refinance transactions. The model uses a linear specification estimated by OLS. Standard errors are robust to heteroskedasticity. Columns 4–7 estimate the regression specifically on the subsamples: FTB, SSB, Refi, and Buy-to-Let (BTL). The dependent variable is the loan-to-income ratio. Mlogit PSM weights are generated from multinomial logit specification as described in section 3.1.

LTI limits set by the regulation were comfortably above the typical LTI being issued in the Irish market in 2014, meaning that there was scope for Irish banks' ROI LTIs to grow substantially while remaining within the limits set by the regulations. This intuition is confirmed in the ROI market by Kinghan, McCarthy, and O'Toole (2016), who show that the average LTI went from 2.7 to 2.9 in the FTB segment of the Irish mortgage market after the introduction of the LTI limit in early 2015. The only borrower group in which the expected risk spillover is found is the first-time buyer group, in column 4. The estimated effect (an LTI increase of 0.3) in this case is one-third of a standard deviation in magnitude.

Our baseline empirical specifications do not include the mortgage interest rate as a control variable, on the basis that banks in general price their lending products as step functions of the loan-to-value ratio, with higher-leveraged loans paying an interest premium. Given this schedule, there is a concern that the coefficient on the interest rate in a model of LTV or LTI would be mechanically determined. However, in order to confirm that our DiD results are robust to the possibility that the interest rate is in fact an appropriate control variable to include in the empirical models, we repeat the specifications from tables 3 and 4 with the interest rate included in all cases. The results are reported in appendix 2 in tables 11 and 12, and in most cases the DiD coefficients are of similar sign, magnitude, and statistical significance. In particular, the positive spillover coefficient for LTV across the entire market as well as in the FTB and SSB segments is robust, as is the LTI coefficient in the FTB segment.

4. Comparing Irish and U.K. Banks' Activity in the U.K. Mortgage Market

As noted in the previous section, our difference-in-difference approach based on comparing the Irish banks' lending in both the United Kingdom and Ireland requires that, in the absence of macroprudential policy in the Republic of Ireland, the LTV and LTI on new loans, controlling for observables, would have evolved in the same manner (parallel trends). This is a strong assumption and could be violated if the lending trends in the United Kingdom were diverging from those observed in Ireland and this divergence happened

to coincide with the introduction of limits on borrower measures in Ireland.

To establish that the Irish banks' risk-taking diverged from other banks in the U.K. market after the macroprudential limits in Ireland, the correct identification strategy would compare the risk-taking of "treated" Irish banks with that of a "control" group of other banks, both lending to similar borrowers in the U.K. market. This would ensure that the overall market trends and the Irish banks' idiosyncratic risk appetite are controlled for and any difference between the groups in the period after the Irish regulations can be attributed to a change in the Irish banks' behavior. In this section, we introduce data from other U.K. lenders and attempt to empirically test this proposition.

4.1 Data and Identification Strategy

To undertake an assessment within country for the United Kingdom, testing whether Irish banks' lending conditions changed following the introduction of macroprudential regulations in their home market, we append loan-by-loan data from a selection of U.K. lenders to our proprietary supervisory data on the Irish banks. The data are taken from the loan-by-loan information submitted to the European Data Warehouse as part of the asset-backed securities collateral reporting requirements of the Eurosystem. We capture data from securitized pools of U.K. mortgages that were submitted since 2013 and cover loans originated from January 2013 to December 2016. The data cover the following lending institutions: PSB, Skipton Building Society, TSB, and Virgin Money plc.

Using the data from these banks and the Irish data, we respecify our difference-in-difference equation as follows:

$$Y_{ibt} = \beta_1 ROILenders + \beta_2 Post + \beta_3 (ROILenders \times Post) + \beta_4 \mathbf{X_{ijt}} + \gamma_{r,post} + \delta_{LoanGroup} + e_i, \quad (3)$$

where Y_{ibt} are the LTV and LTI of mortgage i which was issued by bank b in period t. The β_1 parameter captures the difference in the LTI and LTV for Irish banks relative to U.K. banks as measured by the Irish bank identifier *ROI Lenders*. The β_2 parameter captures any difference between the pre- and post-regulation periods on average. Most importantly, the difference-in-difference parameter β_3

captures how much higher the Irish banks' LTV and LTI levels were in the post-regulation period.

As in equation (1), X_{ijt} is a vector of loan-level control variables including the interest rate type on the contract (fixed or adjustable), and the mortgage term at origination. To purge the model of considerable influences from the borrower-demand side, we also saturate the model with the "Loan Group" fixed effects, $\delta_{LoanGroup}$, which are documented previously.

In our cross-country difference-in-difference setting, we required variation at the country-time level for identification, which implied that we could not include interaction terms between regional and time dummies, as these would be collinear with the difference-in-difference parameter. This motivated the inclusion of the time-varying unemployment and house price indexes. However, in this specification, given that we have lending by both treatment and control banks in all regions and all time periods, we can include interactions of regional dummies and quarterly time dummies to purge any region-specific effects and confounding factors from the local economies at this level of variation. We therefore include interactions of regional dummies with the *Post* dummy to purge these confounding factors. As before, the model is estimated using the multinomial logit propensity-score weights.

One limitation of the control sample of other U.K. lenders is that the data are only taken from loans that were securitized and used as collateral for access to central bank funding. This has two limitations: (i) the loans do not cover the population of mortgages in the United Kingdom and (ii) the loans are not the full set of mortgages issued by these institutions during this time frame. The data purely cover the loans put into securitized pools by these banks. In this regard, any selection biases regarding the type of loans and the institutions that are covered by this process may affect the estimation. However, given that this is a difference-in-difference strategy, any time-invariant selection into securitized pools is controlled for. Furthermore, given the lack of any other loan-level data for the United Kingdom to do this comparison, our use of these data to address this research questions is still a major contribution relative to the existing literature.

The combined data set contains approximately 80,000 observations. Summary statistics for the overall sample of U.K. and Irish

Table 5. Summary Statistics for Within-U.K. Regression Model

Variable	N	Mean	Std. Dev.
LTV (%)	79,745	64.64	20.40
LTI	79,745	2.60	1.26
Interest Rate	76,793	2.86%	0.88
Term	79,745	21.5	7.6
UKH (East of England)	79,745	7.9%	
UKI (London)	79,745	15.9%	
UKJ (Southeast England)	79,745	11.6%	
UKK (Southwest England)	79,745	9.1%	
UKL (Wales)	79,745	4.3%	
UKM (Scotland)	79,745	6.4%	
Other Regions	79,745	44.8%	
First-Time Buyers	79,745	17.0%	
Second and Subsequent Buyers	79,745	50.4%	
Refinance	79,745	32.6%	

Notes: Statistics cover Irish lenders' U.K. activity and EDW U.K. bank lending data. LTI: loan-to-income ratio; LTV: loan-to-value ratio; Term: loan term in years.

banks are included in table 5. Due to confidentiality constraints relating to the underlying data, it is not possible to provide charts which split out parallel trends or show the observations before and after the policy intervention for the treated and control group, as would be standard in this context. The mean LTV was 64 percent and the mean LTI was 2.6. The highest share of lending took place in the London region (UKI), with 15.9 percent of loans issued. There is an "Other Regions" category which is constructed by the authors. A region is placed into this category where there is no variation in the difference-in-difference variable within this region, i.e., for a region to be included in the model with its own fixed effect, there must be lending by both an Irish and a U.K. bank, in both the pre- and post-regulation periods, in that region. After applying this criterion, 44.8 percent of observations are placed into the "Other Regions" category. Just over half of the borrowers in the sample were second and subsequent borrowers, while 32 percent were refinancing borrowers and approximately 17 percent were first-time buyers.

Table 6. Difference-in-Difference LTV Model: U.K. Lending of Irish Banks vs. U.K. Lending of Local Banks

	(1) Baseline	(2) FTB	(3) SSB	(4) Refinance
Post × *ROI Lenders*	1.1021**	3.1194***	1.4042*	−0.6643
	(0.383)	(0.430)	(0.638)	(0.774)
ROI Lenders	2.5019***	2.8897***	1.5531***	3.7255***
	(0.278)	(0.367)	(0.438)	(0.554)
Post	4.6204***	3.4955***	4.4738***	5.3810***
	(0.210)	(0.337)	(0.332)	(0.392)
Loan Term	1.1519***	0.5673***	1.2513***	1.4046***
	(0.024)	(0.027)	(0.041)	(0.043)
Observations	79,745	13,586	40,195	25,964
Of Which No. FE	714	192	192	192
Region * Post FE	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, within-year house price quartile, within-year income quartile, and property type. In column 1 it also distinguishes between first-time buyer, second and subsequent buyer, and refinance transactions. The model uses a linear specification estimated by OLS. Standard errors are robust to heteroskedasticity. Mlogit PSM weights are generated from multinomial logit specification as described in section 3.1. Columns 2–4 estimate the regression specifically on the subsamples: FTB, SSB, Refi, and Buy-to-Let (BTL). The dependent variable is the loan-to-value ratio.

4.2 Empirical Findings

In this section, we present the main findings of the within-UK regressions for LTV and LTI. In both tables, column 1 contains the overall sample results, column 2 restricts the sample to first-time buyers (FTB), column 3 restricts the model to second and subsequent borrowers (SSBs), and column 4 estimates the model on the sample of refinancing borrowers. In all of these specifications, we include loan group fixed effects, region-time dummies, and loan term. All models are also weighted using the multinomial logit probability weights to deal with shifts in sample composition.

In column 1 of table 6, the β_3 estimate suggests that Irish banks' LTVs grew by 1.1 percentage points more than their U.K.

Table 7. Difference-in-Difference LTI Model: U.K. Lending of Irish Banks vs. U.K. Lending of Local Banks

	(1) Baseline	(2) FTB	(3) SSB	(4) Refinance
Post × *ROI Lenders*	0.0852***	0.4537***	−0.1410***	0.0070
	(0.023)	(0.033)	(0.034)	(0.044)
ROI Lenders	−0.0706***	−0.1147***	−0.0890***	0.0734*
	(0.016)	(0.028)	(0.022)	(0.033)
Post	−0.3610***	−0.3779***	−0.4628***	−0.1943***
	(0.013)	(0.024)	(0.019)	(0.022)
Loan Term	0.0591***	0.0365***	0.0561***	0.0769***
	(0.001)	(0.002)	(0.002)	(0.003)
Observations	79,745	13,586	40,195	25,964
Of Which No. FE	714	192	192	192
Region * Post FE	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, within-year house price quartile, within-year income quartile, and property type. In column 1 it also distinguishes between first-time buyer, second and subsequent buyer, and refinance transactions. The model uses a linear specification estimated by OLS. Standard errors are robust to heteroskedasticity. Mlogit PSM weights are generated from multinomial logit specification as described in section 3.1. Columns 2–4 estimate the regression specifically on the subsamples: FTB, SSB, and Refi. The dependent variable is the loan-to-value ratio.

counterparts between the pre- and post-regulation periods. Columns 2 and 3 show that this effect was more than twice as large in the FTB as it was in the SSB segment (3.1 versus 1.4 LTV points). This provides further evidence that Irish banks may have targeted loosened credit conditions at FTBs in the post-regulation period in the United Kingdom, with their LTV expansion being shown here to be greater than competitor U.K. banks. This pattern complements the findings of the previous section, which showed that the Irish banks' U.K. LTVs expanded by more than their ROI LTVs.

Table 7 presents the results for spillovers along the LTI channel. In column 1 for the full sample, the parameter is positive and statistically significant at the 0.1 percent level. This suggests that, in the period following the introduction of macroprudential measures in the

Irish mortgage market, Irish banks loosened loan-to-income ratios for their U.K. loans relative to a sample of U.K. banks. The magnitude of the coefficient suggests a 0.085 percentage point increase in the loan-to-income ratio following the Irish regulations, which is small relative to the sample standard deviation in originating LTI of 1.26.

The DiD estimates in columns 2–4 suggest that the loosening occurred in the FTB segment, and there is no evidence that a similar loosening occurred for SSBs or refinance loans. The magnitude of the effect for FTB is large relative to the overall effect, at 0.45 (over one-third of a standard deviation in LTI).

As in the previous section, we repeat the specifications of tables 6 and 7 while including the interest rate as a control variable, to ensure that the results are robust to the importance of loan pricing in borrowers' LTV and LTI choices. Table 13 for LTV and table 14 for LTI (both reported in appendix 2) confirm that the direction, magnitude, and statistical significance of many of our spillover findings are maintained when including this control variable. In particular, the credit loosening for FTBs along both the LTV and LTI channel is robust, along with the overall LTV loosening.

5. A Focus on High-Risk Loans

We extend the analysis by moving away from estimations of linear models on changes in average LTV and LTI across groups, to focus on the probability of high-risk loans being issued rather than on average effects stemming from continuous variation in LTV and LTI. From a financial stability standpoint, the share of loans being issued in this right tail of the distribution may in fact be more relevant than changes in average LTI and LTV, given the likelihood that future defaults are concentrated in this region. In this section, we restrict our analysis to the U.K.-only models, comparing the propensity of ROI and local lenders to issue such high-risk loans before and after the policy introduction. Tables 8 and 9 present the results of these alternate specifications. For the dependent variable, we create a "high-LTV" dummy variable which takes a value of one above the LTV value of 85 percent (which covers 11.6 percent of loans issued in our U.K. data) and a "high-LTI" dummy which takes a value of

Table 8. Difference-in-Difference U.K. Lending Model: Probability of High-LTV Loan Being Issued

	(1) Baseline	(2) FTB	(3) SSB	(4) Refinance
Post × *ROI Lenders*	0.1020***	0.1911***	0.0606***	0.0541**
	(0.009)	(0.020)	(0.011)	(0.019)
ROI Lenders	0.0660***	0.1000***	0.0155*	0.1181***
	(0.007)	(0.017)	(0.008)	(0.014)
Post	0.0981***	0.1185***	0.0842***	0.1072***
	(0.005)	(0.014)	(0.005)	(0.010)
Loan Term	0.0144***	0.0191***	0.0067***	0.0211***
	(0.000)	(0.001)	(0.001)	(0.001)
Observations	79,745	13,586	40,195	25,964
Of Which No. FE	714	192	192	192
Region * Post FE	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, within-year house price quartile, within-year income quartile, and property type. In column 1 it also distinguishes between first-time buyer, second and subsequent buyer, and refinance transactions. The model uses a linear specification estimated by OLS. Standard errors are robust to heteroskedasticity. Mlogit PSM weights are generated from multinomial logit specification as described in section 3.1. Columns 2–4 estimate the regression specifically on the subsamples: FTB, SSB, and Refi. The dependent variable is the dummy for loan-to-value > 85 percent.

one above a value of 4 (which covers 14.3 percent of our sample). A linear probability model is then run for both LTV and LTI in much the same format as the specifications of tables 6 and 7.

The results of table 8 suggest that, when measured in this discrete way, spillover effects are present in all columns 1–4. According to our DiD specification, Irish banks in the post-regulation period were 10 percentage points more likely than their U.K. counterparts to issue a high-LTV loan to a similar borrower, with this effect being of the magnitude of 19 percentage points in the FTB segment and 6 percentage points in the SSB segment (with all three effects being precisely estimated at 99 percent or better). For refinancing mortgages, the effect of 5.4 percent is statistically significant at the 5 percent level.

Table 9. Difference-in-Difference U.K. Lending Model: Probability of High-LTI Loan Being Issued

	(1) Baseline	(2) FTB	(3) SSB	(4) Refinance
Post × ROI Lenders	0.1028***	0.1817***	0.0452***	0.1038***
	(0.007)	(0.019)	(0.006)	(0.012)
ROI Lenders	−0.0379***	−0.0860***	−0.0215***	−0.0136
	(0.005)	(0.015)	(0.004)	(0.009)
Post	−0.1230***	−0.1977***	−0.0695***	−0.1460***
	(0.004)	(0.012)	(0.005)	(0.007)
Loan Term	0.0089***	0.0117***	0.0053***	0.0114***
	(0.000)	(0.001)	(0.000)	(0.001)
Observations	79,745	13,586	40,195	25,964
Of Which No. FE	714	192	192	192
Region * Post FE	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, within-year house price quartile, within-year income quartile, and property type. In column 1 it also distinguishes between first-time buyer, second and subsequent buyer, and refinance transactions. The model uses a linear specification estimated by OLS. Standard errors are robust to heteroskedasticity. Mlogit PSM weights are generated from multinomial logit specification as described in section 3.1. Columns 2–4 estimate the regression specifically on the subsamples: FTB, SSB, and Refi. The dependent variable is the dummy for loan-to-income > 4.

Table 9 repeats the specification of table 8 for the loan-to-income channel. The probability of a high-LTI loan is shown to be higher for the Irish lenders in the post-regulation period in all models. The overall effect of a 10 percentage point higher probability is broken out into an 18 percentage point difference in the FTB segment and a 4.5 and 10.4 percentage point differential in the SSB and refinance segments, respectively.

A final specification looks at high-risk loans along both the LTV and LTI channels. In table 10, we define a high-risk loan to be a loan with both an LTI greater than 4 and an LTV above 85 percent. Running a similar model to the previous two tables with this dependent variable yields familiar results: for the first-time buyer segment, the probability of a high-risk loan is 27 percent higher for ROI banks in the post-period than for competitor domestic banks. Statistically

Table 10. Difference-in-Difference U.K. Lending Model: Probability of Combined High-LTI/High-LTV Loan Being Issued

	(1) Baseline	(2) FTB	(3) SSB	(4) Refinance
Post × ROI Lenders	0.1582***	0.2776***	0.1057***	0.1111***
	(0.010)	(0.020)	(0.013)	(0.020)
ROI Lenders	0.0297***	0.0256	−0.0056	0.0916***
	(0.007)	(0.017)	(0.008)	(0.015)
Post	−0.0157**	−0.0585***	0.0124	−0.0223
	(0.006)	(0.016)	(0.007)	(0.012)
Loan Term	0.0194***	0.0219***	0.0119***	0.0277***
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	79,745	13,586	40,195	25,964
Of Which No. FE	714	192	192	192
Region * Post FE	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes

Notes: High LTI is defined as above 4; high LTV is defined as above 85 percent. Standard errors are in parentheses. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, within-year house price quartile, within-year income quartile, and property type. In column 1 it also distinguishes between first-time buyer, second and subsequent buyer, and refinance transactions. The model uses a linear specification estimated by OLS. Standard errors are robust to heteroskedasticity. Mlogit PSM weights are generated from multinomial logit specification as described in section 3.1. Columns 2–4 estimate the regression specifically on the subsamples: FTB, SSB, and Refi.

significant effects of 10.6 and 11 percent are found in the SSB and refinance segments of the market also.

As with previous regression tables, the results of tables 8 and 9 are shown to be robust to the inclusion of the interest rate control in tables 15 and 16 in appendix 2. In all cases, the DiD parameters do not change materially in either magnitude or significance depending on the inclusion or exclusion of r.

6. Conclusion

In this paper, using loan-level data on mortgages from Irish-headquartered banks active in both the Republic of Ireland and the United Kingdom, coupled with loan-level data on U.K.-only lenders,

we test whether there was a change in risk-taking by Irish banks in the United Kingdom following the introduction of macroprudential regulations in Ireland. Our method deploys two separate difference-in-difference (DiD) estimations to test whether Irish banks loosened their LTV and LTI ratios abroad following a regulatory tightening of these lending standards at home.

We find evidence that, relative to the control group of local unaffected U.K. mortgage lenders, the probability of a high-risk loan (a loan with both a high LTI and high LTV) being issued by an Irish mortgage lender in the United Kingdom increased by 28 percent in the first-time homebuyer segment after the policy introduction. The effect is estimated to be smaller, yet sizable, at 11 percent in the mover-purchaser and refinance segments.

While our estimates show that risk-taking of Irish banks in the U.K. market was higher after the introduction of domestic restrictions on mortgage lending, particularly in the first-time buyer segment of the market, these findings do not imply that the policy instruments were ineffective. The stated aims of the macroprudential mortgage restrictions introduced in Ireland in February 2015 were not to improve banks' capital adequacy, but rather to ensure the resilience of Irish households to potential adverse developments in the housing market, as well as to dampen the procyclical relationship between credit and house prices in Ireland. The findings presented in this paper are consistent with the introduced policy meeting its stated aims. The implications of the results suggest that other capital-based regulatory tools that focus on the entire balance sheet of regulated entities may be warranted in conjunction with such product-specific mortgage measures in order to account for the potential for spillovers such as those identified here.

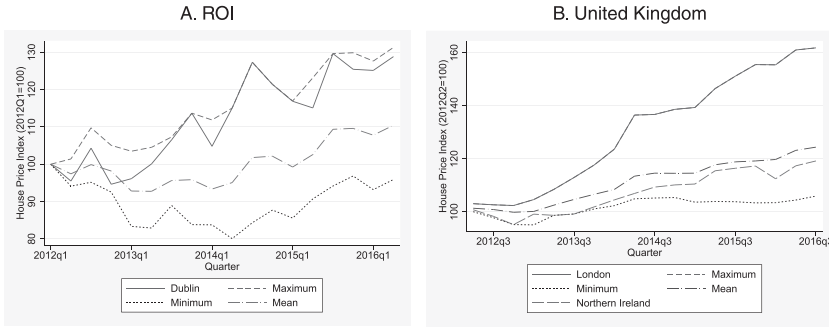
The potential need for international coordination in financial regulation has been recognized in academic and policy literature for quite some time. Referring to patterns of Japanese bank penetration into the U.S. banking market in the 1990s, Acharya (2003) suggests that uneven application of financial regulation (or "regulatory forbearance" in the terminology of the paper) may have provided Japanese banks with a competitive advantage in the ability to take risk. His paper points out that the presence of such variation in regulatory forbearance has the potential to undermine the international coordination efforts on other policy levers such as Basel capital

adequacy ratios. Vinals and Nier (2014) provide an overview of the issues at play in the international spillover debate, with a focus on the potential for international spillovers given the highly interconnected nature of the global financial system. They also point out that, unlike in the case of the countercyclical capital buffer where Basel Committee members are expected to act in a reciprocal way once an individual country applies the buffer, many other macroprudential instruments such as LTV and LTI restrictions do not have provisions in place to allow for such international coordination. Our research presents further evidence of the need to understand banks' international activities and, where possible, to ensure reciprocity and coordination in the implementation of macroprudential policies. Without such coordination, risks may continue to build.

Appendix 1. Macroeconomic Context

Figure 5 indexes the house price index of each region to its level in 2012:Q1, and shows again that there has been significant variation in the evolution of house prices since the tail-end of the crisis period in both jurisdictions. In particular, the disproportionately strong house price growth of both capital cities is evident in both panels, while in Ireland's case the worst-performing region had not even reached its 2012:Q1 level by 2016:Q2. In the United Kingdom, the London house price index had grown by just over 60 percent during the period, while the slowest-growing region by comparison was less than 5 percent above its opening level. Such geographic disparities are an important part of the setting for our study, with the graphs indicating that it is crucial that time-varying regional developments are controlled for before our DiD model can be reliably interpreted.

Figure 5. Regional House Prices, Indexed to 2012:Q1: 2012 to 2016



Appendix 2. Robustness of Results to Including the Interest Rate as a Control Variable

Table 11. Difference-in-Difference Eatimator for Originating Loan to Value, All ROI and U.K. Mortgages Issued by Irish-Headquartered Banks from 2013:Q1 to 2016:Q2

	(1) All	(2) All	(3) FTB	(4) SSB	(5) Refi	(6) BTL	(7) Est7
United Kingdom	10.21***	8.106***	7.862***	4.433*	5.735**	16.47***	14.60***
	(1.867)	(2.416)	(2.395)	(2.549)	(2.486)	(5.792)	(2.666)
Post	−1.824*	−2.415**	−2.607**	−0.839	−3.706**	2.562	4.919**
	(0.960)	(1.082)	(1.094)	(1.823)	(1.770)	(3.891)	(2.483)
United Kingdom × *Post*	4.692***	5.028***	4.812***	4.186**	5.396***	−0.671	−1.258
	(1.007)	(1.054)	(1.073)	(1.755)	(1.773)	(3.695)	(2.539)
Loan Term	0.0784***	0.0777***	0.0768***	0.0631***	0.0901***	0.0864***	0.0532***
	(0.00481)	(0.00464)	(0.00448)	(0.00642)	(0.00984)	(0.00858)	(0.00481)
Interest Rate	430.4***	430.5***	437.0***	486.9***	522.8***	477.7***	481.5***
	(23.59)	(23.31)	(23.03)	(27.08)	(46.15)	(45.17)	(58.66)
Regional		−0.551	−0.480	−0.425	−0.214	−0.828	0.0355
Unemployment		(0.368)	(0.344)	(0.388)	(0.365)	(0.794)	(0.244)
Regional HP			0.0641	0.00423	−0.0210	0.128	0.0131
			(0.0532)	(0.0189)	(0.0334)	(0.112)	(0.0250)
Observations	60,915	60,911	60,911	23,175	16,598	15,051	6,212
Loan Group FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, year-country house price quartile, year-country income quartile, property type, and an indicator for capital cities and their surrounding commuter zones. In columns 1–3 it also distinguishes between first-time buyer, second and subsequent buyer, refinance, and buy-to-let purchases.

Table 12. Difference-in-Difference Estimator for Originating Loan to Income, All ROI and U.K. Mortgages Issued by Irish-Headquartered Banks from 2013:Q1 to 2016:Q2

	(1) All	(2) All	(3) All	(4) FTB	(5) SSB	(6) Refi	(7) BTL
United Kingdom	0.472***	0.336***	0.309***	−0.00532	0.376***	0.0695	−0.120
	(0.0810)	(0.113)	(0.111)	(0.0899)	(0.116)	(0.266)	(0.136)
Post	0.226***	0.188***	0.167***	−0.279***	0.0221	0.290	0.0538
	(0.0572)	(0.0642)	(0.0646)	(0.0770)	(0.0748)	(0.205)	(0.0955)
United Kingdom × *Post*	−0.182***	−0.161**	−0.184***	0.391***	−0.0816	−0.482**	0.0971
	(0.0617)	(0.0656)	(0.0647)	(0.0731)	(0.0751)	(0.208)	(0.0993)
Loan Term	0.00376***	0.00372***	0.00362***	0.00292***	0.00516***	0.00346***	0.00225***
	(0.000277)	(0.000274)	(0.000268)	(0.000409)	(0.000636)	(0.000399)	(0.000264)
Interest Rate	−18.76***	−18.74***	−18.03***	0.567	−13.07***	−47.11***	−17.46***
	(1.908)	(1.901)	(1.817)	(1.476)	(3.652)	(3.155)	(4.810)
Regional Unemployment		−0.0357**	−0.0279**	−0.0846***	−0.0111	−0.0365	−0.0503***
		(0.0144)	(0.0138)	(0.0137)	(0.0166)	(0.0255)	(0.0140)
Regional HP			0.00698***	0.0132***	0.00925***	0.00224	0.00617***
			(0.00149)	(0.00146)	(0.00167)	(0.00342)	(0.00184)
Observations	61,434	61,430	61,430	23,352	16,958	15,059	6,185
Loan Group FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, year-country house price quartile, year-country income quartile, property type, and an indicator for capital cities and their surrounding commuter zones. In columns 1–3 it also distinguishes between first-time buyer, second and subsequent buyer, refinance, and buy-to-let purchases.

Table 13. Within-U.K. Difference-in-Difference Model: Loan-to-Value Ratios

	(1) Baseline	(2) FTB	(3) SSB	(4) Refinance
ROI Lenders	2.9460***	3.1703***	2.6185***	3.4490***
	(0.283)	(0.334)	(0.455)	(0.547)
Post	4.5545***	3.3529***	4.4687***	5.2860***
	(0.207)	(0.315)	(0.329)	(0.388)
ROI Lenders × *Post*	0.1619	1.9254***	0.3038	−1.1627
	(0.366)	(0.390)	(0.590)	(0.749)
Current Interest Rate	2.8149***	4.6687***	2.5625***	2.1300***
	(0.152)	(0.113)	(0.245)	(0.286)
Loan Term	1.1154***	0.4258***	1.2340***	1.3860***
	(0.025)	(0.026)	(0.041)	(0.044)
Observations	79,745	13,586	40,195	25,964
Loan Group FE	Yes	Yes	Yes	Yes
Of Which No. FE	714	192	192	192
Region * Post FE	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Table 14. Within-U.K. Difference-in-Difference Model: Loan-to-Income Ratios

	(1) Baseline	(2) FTB	(3) SSB	(4) Refinance
ROI Lenders	-0.0927^{***}	-0.1139^{***}	-0.2090^{***}	0.0879^{**}
	(0.016)	(0.028)	(0.022)	(0.032)
Post	-0.3578^{***}	-0.3782^{***}	-0.4622^{***}	-0.1893^{***}
	(0.013)	(0.024)	(0.019)	(0.022)
ROI Lenders × *Post*	0.1320^{***}	0.4506^{***}	-0.0171	0.0330
	(0.021)	(0.033)	(0.031)	(0.042)
Current Interest Rate	-0.1401^{***}	0.0122	-0.2886^{***}	-0.1114^{***}
	(0.009)	(0.010)	(0.013)	(0.015)
Loan Term	0.0609^{***}	0.0361^{***}	0.0581^{***}	0.0779^{***}
	(0.001)	(0.002)	(0.002)	(0.003)
Observations	79,745	13,586	40,195	25,964
Loan Group FE	Yes	Yes	Yes	Yes
Of Which No. FE	714	192	192	192
Region * Post FE	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes

Notes: Standard errors are in parentheses. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 15. Difference-in-Difference U.K. Lending Model: Probability of High-LTV Loan Being Issued

	(1) Baseline	(2) FTB	(3) SSB	(4) Refinance
ROI Lenders	0.0849***	0.1141***	0.0438***	0.1063***
	(0.007)	(0.015)	(0.008)	(0.014)
Post	0.0953***	0.0113***	0.0840***	0.1032***
	(0.005)	(0.013)	(0.005)	(0.010)
ROI Lenders × *Post*	0.0620***	0.1310***	0.0314**	0.0327
	(0.009)	(0.018)	(0.010)	(0.019)
Current Interest Rate	0.1198***	0.2348***	0.0681***	0.0914***
	(0.004)	(0.005)	(0.005)	(0.007)
Loan Term	0.0128***	0.0120***	0.0063***	0.0203***
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	79,745	13,586	40,195	25,964
Loan Group FE	Yes	Yes	Yes	Yes
Of Which No. FE	714	192	192	192
Region * Post FE	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes

Notes: High LTV is defined as above 85 percent. Standard errors are in parentheses. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, within-year house price quartile, within-year income quartile, and property type. In column 1 it also distinguishes between first-time buyer, second and subsequent buyer, and refinance transactions.

Table 16. Difference-in-Difference U.K. Lending Model: Probability of High-LTI Loan Being Issued

	(1) Baseline	(2) FTB	(3) SSB	(4) Refinance
ROI Lenders	-0.0387^{***}	-0.0867^{***}	-0.0245^{***}	-0.0123
	(0.005)	(0.015)	(0.004)	(0.008)
Post	-0.1229^{***}	-0.1974^{***}	-0.0695^{***}	-0.1455^{***}
	(0.004)	(0.012)	(0.005)	(0.007)
ROI Lenders × *Post*	0.1046^{***}	0.1845^{***}	0.0482^{***}	0.1062^{***}
	(0.007)	(0.019)	(0.006)	(0.012)
Current Interest Rate	-0.0055^{**}	-0.0107	-0.0072^{***}	-0.0101^{**}
	(0.002)	(0.006)	(0.002)	(0.003)
Loan Term	0.0090^{***}	0.0120^{***}	0.0054^{***}	0.0115^{***}
	(0.000)	(0.001)	(0.000)	(0.001)
Observations	79,745	13,586	40,195	25,964
Loan Group FE	Yes	Yes	Yes	Yes
Of Which No. FE	714	192	192	192
Region * Post FE	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes

Notes: High LTI is defined as above 4. Standard errors are in parentheses. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, within-year house price quartile, within-year income quartile, and property type. In column 1 it also distinguishes between first-time buyer, second and subsequent buyer, and refinance transactions.

Table 17. Difference-in-Difference U.K. Lending Model: Probability of Combined High-LTV/High-LTI Loan Being Issued

	(1) Baseline	(2) FTB	(3) SSB	(4) Refinance
ROI Lenders	0.0449***	0.0364*	0.0196*	0.0825***
	(0.007)	(0.016)	(0.009)	(0.015)
Post	−0.0180**	−0.0639***	0.0123	−0.0254*
	(0.006)	(0.015)	(0.007)	(0.011)
ROI Lenders × Post	0.1262***	0.2319***	0.0796***	0.0947***
	(0.010)	(0.019)	(0.012)	(0.020)
Current Interest Rate	0.0959***	0.1788***	0.0607***	0.0699***
	(0.004)	(0.005)	(0.006)	(0.007)
Loan Term	0.0181***	0.0165***	0.0114***	0.0271***
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	79,745	13,586	40,195	25,964
Loan Group FE	Yes	Yes	Yes	Yes
Of Which No. FE	714	192	192	192
Region * Post FE	Yes	Yes	Yes	Yes
Mlogit PSM Weights	Yes	Yes	Yes	Yes

Notes: High LTI is defined as above 4. Standard errors are in parentheses. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. "Loan Group Fixed Effect" defines the unique combinations of borrower age groups, within-year house price quartile, within-year income quartile, and property type. In column 1 it also distinguishes between first-time buyer, second and subsequent buyer, and refinance transactions.

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