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Making Sense of Negative Nominal Interest Rates*

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Abstract

Several advanced economies implemented negative nominal interest rates in the middle of the last decade, seeking to provide further monetary accommodation once cuts in positive territory had been exhausted. Negative rates affect banks in novel ways, mostly because during times of negative policy rates the interest rate that banks pay households on their deposits usually remains close to zero. In this review, we analyze the large literature that studies the impact of negative nominal interest rates, proceeding in four steps. First, we explain the theoretical channels through which negative rates affect banks. Second, we discuss the empirical findings about bank outcomes under negative rates. Third, we describe the aggregate transmission channels that influence the macroeconomic implications of a policy rate cut in negative territory. Finally, we compare the general-equilibrium models that have been used to quantify the effectiveness of negative rates and highlight why they have obtained mixed results. We conclude that, if properly implemented, negative rates are a valuable tool that central banks should not discard outright. However, negative rates can have quantifiable costs for the financial sector, and their effectiveness is likely to decline if implemented for long periods.

JEL codes: E32, E44, E52, E58, G21.

Keywords: Negative Interest Rates, ZLB, ELB, Monetary Policy, Bank Profitability.

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1 Introduction

Since 2014, central banks in several advanced economies have implemented negative nominal interest rates, aiming to provide further monetary accommodation once cuts in positive territory had been exhausted. The trajectory of nominal policy rates in these economies is depicted in Figure 1. Since their first implementation, the effectiveness of negative nominal interest rates has been studied extensively. A broad range of channels through which negative rates impact the economy – positively and negatively – has been proposed, and the quantitative estimates of the magnitudes of specific channels have ranged widely. Consequently, the overall macroeconomic impact of negative rates remains a subject of heated debate, making it difficult to draw normative implications. For example, the latest program report of the NBER monetary economics program lists negative nominal interest rates as one of the main open questions in monetary economics going forward (Nakamura and Steinsson, 2021).

The literature analyzing negative rates has placed a special emphasis on how this phenomenon affects banks, critical institutions at intermediating the flow of funds between savers and borrowers. Negative rates are usually implemented by lowering the remuneration on excess reserves below zero. This implies banks earn a negative interest rate – in other words, they pay – on the reserves they hold at the central bank in excess of regulatory requirements.[1] Crucially, banks are generally unable to lower their nominal retail deposit rates below zero, due to households' ability to save using cash. When banks are charged to keep reserves at the central bank and cannot pass this on to depositors, bank profitability can be negatively impacted. However, banks can benefit from capital gains when negative rates are implemented, and over time they may also adapt to low rate environments by taking on more risk or switching to more fee-based business models. For these reasons, the overall impact of negative rates on banks is not obvious and has emerged as a crucial issue in the negative-rates literature.

In this paper, we analyze the large and growing literature on the impact of negative nominal interest rates in four steps. First, we specify the theoretical channels by which negative rates impact bank profitability and lending, emphasizing how these channels operate differently than when rates are positive. Second, we discuss the empirical findings about bank outcomes under negative rates, examining how different identification strategies, methodological choices, and data samples can drive disparate results. Third, we broaden our scope and examine the aggregate transmission channels that impact the effectiveness of negative rates. Finally, we consider the general equilibrium models that have quantified the impacts of negative rates and explore why they have obtained mixed results. The following paragraphs provide details on these four steps, and Figure 2 provides a visual representation of the channels discussed.

In our first step, we specify the theoretical channels through which negative nominal in-

[1] As noted in Figure 1, the specific concept of interest rate used in each of the countries that implemented negative rates differs slightly, but they all essentially represent the rate paid by the central bank on excess reserves.

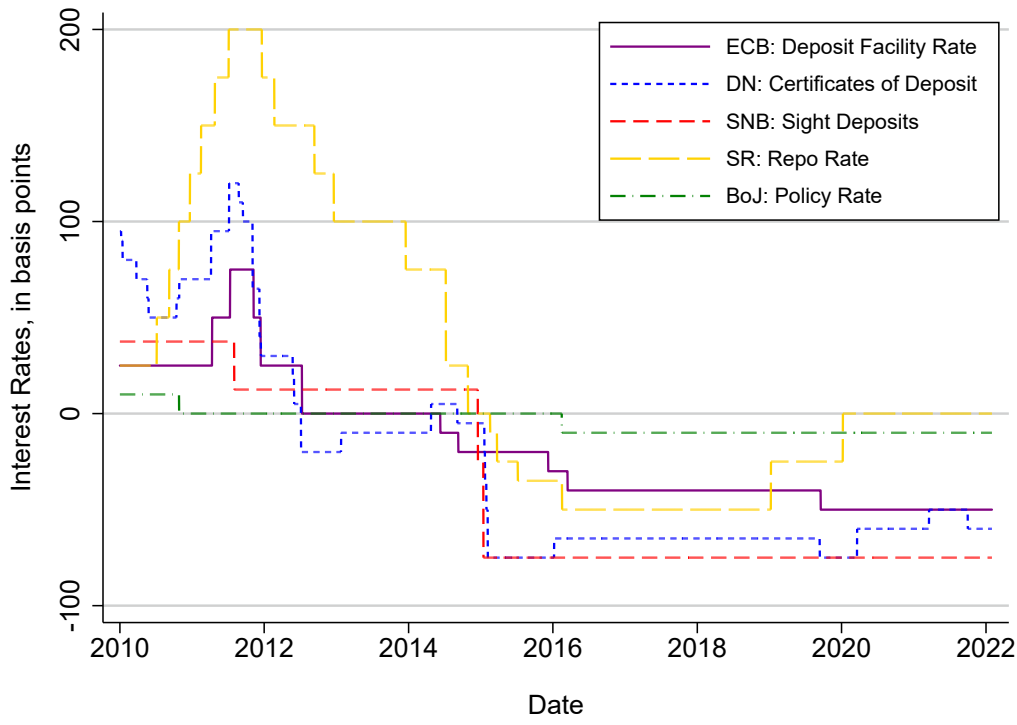

Figure 1: Negative rates experience

Notes: This figure shows the rates paid by the Central Bank of Denmark (DN), the ECB, the Central Bank of Sweden (SR), the Swiss National Bank (SNB), and the Bank of Japan (BoJ), in b.p.s, between 2010 and 2022. The concept of interest rate used for each region is described in the legend. The data was gathered directly from each central bank. This figure is similar to one that appears in Ulate (2021b) but with updated data.

terest rates impact banks. There are four main channels driving the effect of negative rates on bank profitability. The deposit margin channel refers to the fact that negative rates lead to a contraction in the profits that banks earn from their deposit franchise. This stems from the aforementioned fact that nominal deposit rates stay close to zero when policy rates become negative. By contrast, the capital gains channel improves bank profitability, in that a cut in the policy rate can generate capital gains for banks due to maturity mismatch or the presence of long-lived securities. Capital gains are likely to be short term, but may be more potent when interest rates are low or negative. In addition, cuts in the policy rate may have a beneficial impact on bank profitability through general equilibrium effects, for example, by increasing loan demand or decreasing default rates and loan loss provisions. In the medium and long run, negative rates can also lead banks to adjust their business models, for example by engaging in more risk taking or moving to more fee-based lines of business.

We then turn our focus to bank loan supply, separating channels driven by profitability from those that are not. The three main explanations linking bank loan supply to bank profitability are the risk bearing channel, balance sheet constraints, and reaching for yield. The risk bearing channel refers to the idea that regulatory constraints or risk aversion can limit lending

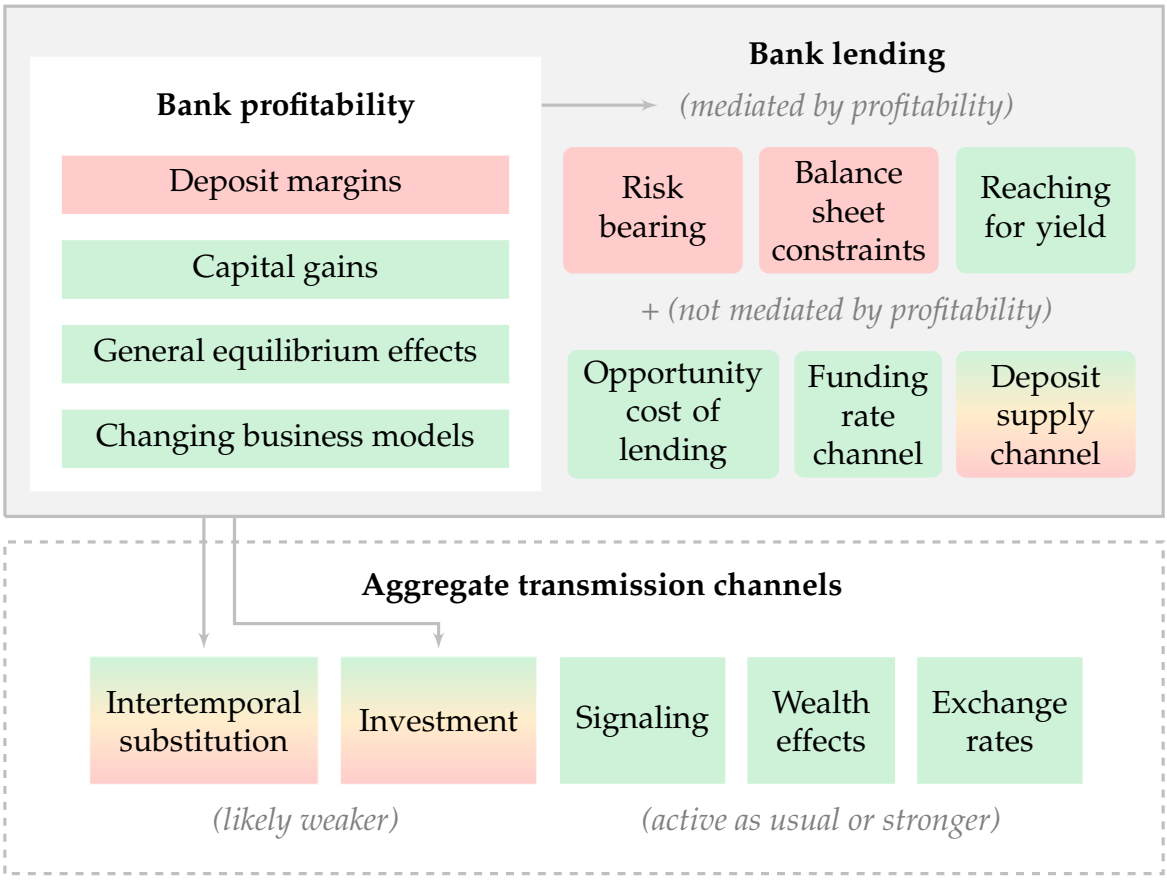

Figure 2: Negative rates channels and direction of effects

Notes: This figure shows the theoretical channels through which bank profitability, bank lending, and the aggregate economy are affected in a negative-rate environment. The colors indicate whether the channel is generally negative (red) or positive (green) for the outcome described. The rainbow shaded boxes indicate a range of possible effects.

after a fall in bank profitability. Similarly, models with balance sheet constraints imply that low profitability may limit banks' ability to obtain funding, for example due to moral hazard, restricting banks' lending capacity. By contrast, reaching for yield highlights the notion that decreasing profitability could increase incentives for bank risk-taking, perhaps leading them to lend more or to take on riskier borrowers.

Additionally, there are three channels affecting bank loan supply that are not mediated by profitability. We use the term "opportunity cost of lending channel" to describe the idea that negative rates could put downward pressure on bank lending rates if banks hold excess reserves, as the opportunity cost of making a new loan in this case is the policy rate. The "funding rate channel" indicates that if a bank has no excess reserves, its loan rate will be tied to its funding rate. As the retail deposit rate – an important component of bank funding – has stayed close to zero during times of negative rates, this channel may be muted in negative territory. However, the rate that banks pay to obtain wholesale funding does continue to fall

with the policy rate – even in negative territory – possibly reactivating this channel. Finally, household substitution over different saving products affects their deposit supply to banks, and this, in turn, may lead to changes in bank loan supply. As illustrated in Figure 2, the ways in which individual channels affect loan supply differ, which raises questions about the direction and magnitude of overall effects. To elucidate this, we turn to empirical work.

Our second step maps the vast body of empirical evidence on bank outcomes in negative interest rate environments to the theoretical channels described above. The empirical evidence to date provides a fairly consistent record that negative rates have a detrimental effect on bank profitability. This is found across many papers using different identification schemes, including high frequency identification, cross-country regressions that rely on common macro shocks, and studies that compare banks within a region based on measures of their exposure to negative rates. That bank profitability declines across different samples of banks, time periods, and measures (e.g., net interest margins, return on equity, or stock prices) underscores the quantitative importance of the deposit margin channel – the main channel by which bank profitability decreases – relative to capital gains, general equilibrium effects, and changing business models.

The empirical evidence on bank lending and risk-taking is less homogeneous than the evidence on bank profitability. Nonetheless, most studies find increases in bank lending volumes and risk, and a minority report decreases or neutral effects. While it is difficult to tease out the balance of channels affecting loan supply, there is evidence to support both the opportunity cost of lending channel and reaching for yield as significant drivers of bank lending, which are larger in strength than the risk-bearing or balance sheet channels. However, the results of some papers indicate that the positive effects of negative rates on lending may diminish over time, possibly even becoming negative at some point. The different results here may also be driven in part by economic conditions, which can influence both bank profitability and loan demand.

In a third step, we discuss five aggregate transmission channels through which a cut in the policy rate in negative territory can impact the economy. The first two of these channels are likely to be weaker in negative territory, while the remaining three are likely to have similar or larger magnitudes. The intertemporal substitution channel could be inactive in negative territory if the relevant interest rate for the household's Euler equation is the deposit rate and this rate stays at zero when the policy rate goes negative. However, if the bond rate or the bank-based lending rate also enter the Euler equation, this channel could still be partially active. Similarly, the investment channel could be impaired in negative territory if bank profitability declines and banks are unable to pass on lower rates to their borrowers. However, if banks with excess reserves and monopoly power can still lower the lending rate (i.e., the opportunity cost of lending channel), or if firms can borrow from non-bank sources whose rate follows the policy rate, such as the bond market, the investment channel can still be operational.

By contrast, there are other aggregate transmission channels that are likely to remain effective or even strengthen in negative territory. The signaling channel refers to the ability of

negative policy rates to signal a prolonged environment of low rates. The wealth channel indicates that a cut in the policy rate can drive up the prices of stocks, bonds, or housing held by households, and this can increase their spending. The exchange rate channel posits that a cut in the policy rate can make it less attractive to invest in domestic assets, possibly leading to a depreciation of the home currency, which stimulates the economy through international trade.

Our fourth and final step studies how theoretical negative-rates papers have differed in their assumptions and results. In terms of bank profitability, these papers have generally incorporated a negative deposit margin channel, a positive capital gains channel, and sometimes positive general equilibrium effects. On balance, most studies have found detrimental effects for bank profitability, but a minority has found beneficial ones. This has mostly depended on the calibration strategy and data sources. Since in these theoretical models there is no clear consensus regarding the effects on bank profitability, the effects of negative rates on bank lending through profits are also ambiguous (albeit mostly negative). The effects on bank lending not mediated by profitability are some of the main points of contention. Papers incorporating excess reserves and monopoly power (i.e., Ulate, 2021b) or those that "reactivate" the funding rate channel (i.e., Onofri et al., 2021) have found greater effectiveness than papers like Eggertsson et al. (2019). Finally, regarding aggregate transmission channels, the intertemporal substitution and signaling channels have typically been found to be stimulative, the investment channel has been mixed, and the remaining channels have not been incorporated yet.

Overall, the majority of the theoretical negative rates papers (specifically, Ulate, 2021b; Brunnermeier and Koby, 2018; Rognlie, 2016; de Groot and Haas, 2021; Onofri et al., 2021) find that a temporary excursion into negative territory to fight a recession can be effective, with some caveats. The first caveat is that the effectiveness of a cut in the policy rate in negative territory is universally found to be less that the effectiveness of a cut in positive territory. The second caveat is that the effectiveness of negative rates can wane or even reverse as rates become more negative or more time is spent in negative territory. The cautiously positive conclusions described above imply that negative rates are a valuable tool that central banks should not discard outright, but also that they need to be deployed carefully. Namely, the health of the banking sector should be closely monitored, and negative rates should not be used as a long-term policy tool. Importantly, most theoretical papers reach the conclusions described above even though they do not incorporate several aggregate transmission channels that are likely to increase the effectiveness of negative rates (i.e., the exchange rate and wealth effects channels). They also do so despite capturing the mostly negative impact on bank profitability documented by the empirical negative-rates literature.

At this point, it is important to discuss limits on how negative the policy rate can be set. Even though the experience with negative nominal interest rates to date has shown that the zero lower bound is not as much of a constraint as was once thought, there is still a limit to how negative the policy rate can go if physical cash remains available. The rate on reserves at which

commercial banks would switch from maintaining reserves at the central bank to holding cash has been referred to as the "Physical Lower Bound" (PLB). Some advanced countries went as negative as -75 basis points without signs of a flight to cash, indicating that the physical lower bound is likely to be below that level. The precise location of the physical lower bound is unknown, but it may be somewhere between minus one and minus two percent.[2] Some may argue that the policy space between zero and -1% or -2% is not significant enough to make negative rates an important topic. However, one or two percentage points of monetary policy room is substantial, equivalent to the extra space that could be gained from moving the inflation target from 2% to 3% or 4%, a proposal backed by some prominent economists.

Besides the zero and physical lower bounds, the "Effective Lower Bound" (ELB) is a third threshold that warrants discussion. The effective lower bound is the policy rate where further cuts in the policy rate are contractionary instead of expansionary, making it "ineffective" to take the policy rate below this point. The effective lower bound is likely to be between the zero lower bound and the physical lower bound; the balance of stimulative effects of cuts in negative territory and their contractionary effects (mainly operating through bank profitability) will determine its exact location. The concept of "reversal rate" introduced by Brunnermeier and Koby (2018) is similar to that of the effective lower bound, but focuses more on the effect for bank lending, whereas the effective lower bound measures the effect for the overall economy (i.e., GDP, inflation, unemployment, etc.).

As a review of the literature on negative rates, this paper is related to a large amount of empirical and theoretical papers on this subject. Section 3 discusses some of the most prominent empirical papers and Section 5 discusses the theoretical ones. Our paper is most closely related to three other reviews of the negative-rates literature, namely: Heider et al. (2021), Brandao-Marques et al. (2021), and Tenreyro (2021). Our review differs from these others by being wider in scope, more explicitly describing the channels through which negative rates affect banks, and emphasizing the importance of aggregate transmission channels.

There is evidence that long-run nominal interest rates may have declined significantly in recent decades (cf., Kiley and Roberts, 2017). As a consequence, developed countries find themselves more constrained by the zero lower bound when hit by adverse shocks. This may become even more likely in the future if long-run real interest rates continue to fall. In this environment, knowing how negative nominal interest rates impact the effectiveness of monetary policy and how they interact with other unconventional monetary policy tools becomes crucial. Using the empirical and theoretical evidence accumulated so far to answer these questions is the overarching objective of this paper.

[2]Steps can be taken by the central bank to prevent banks from withdrawing their reserves, like varying the exemption threshold for reserves to which negative rates do not apply, as has been done in Switzerland. There are also proposals to make the PLB less binding by taxing cash (cf., Agarwal and Kimball, 2019; Rogoff, 2014).

2 Theoretical bank transmission channels

We first discuss the channels through which negative nominal interest rates affect banks. While the channels we study are not necessarily specific to negative rates, we highlight those for which a negative rate environment is particularly important. To structure the discussion, it is useful to have in mind a simplified bank balance sheet. On the asset side, banks holds reserves R, securities S, and loans L. Bank liabilities consist of deposits D and wholesale funding W, and banks also issue equity E. This balance sheet is depicted in Table 1.

Table 1: Bank balance sheet

Assets		Liabilities & Equity	
R	Reserves	D	Deposits
S	Securities	W	Wholesale Funding
L	Loans	E	Equity

In the negative-rates literature, banks are sometimes assumed to have market power on both loan and deposit markets.[3] In contrast, they are generally assumed to be price takers in securities, reserves, and wholesale funding markets. There are costs to running banks, which depend on factors such as the volume of lending (e.g., due to monitoring costs), the composition of funding (D vs W), asset management costs, and fixed or variable costs of operating branches and ATMs. Banks may also face financial constraints, which are sometimes modeled as the basis for operating costs. Examples of such constraints include balance sheet constraints, cash flow constraints, or constraints that arise from incentive problems that the bank may face.

Overall, the problem a bank faces can be characterized as choosing the interest rate to charge on loans, the interest rate to pay on deposits, and the amounts of wholesale funding and securities in order to maximize expected profits, taking as given costs, constraints, and initial net worth. The net interest income of a bank can be written as the sum of two components: $(i^\ell - i)L + (i - i^d)D$, where i is the policy rate, i^ℓ is the lending rate, and i^d is the deposit rate. This decomposition will be useful later on.

Our main outcome of interest in this section is bank lending – its quantity, price, and risk – because the primary reason frictional financial intermediation (e.g., banks) is usually introduced in macroeconomic models is to characterize how financial conditions impact lending and consequently the real economy. However, the impact of negative interest rates on bank profitability is sufficiently rich to be studied on its own, and bank profitability is a key input to bank lending. Consequently, prior to discussing the impact on bank lending, we discuss the impact negative rates have on bank profitability.

[3]The existence of monopoly power in bank loan-making and deposit-taking is well documented empirically. See, e.g., Berger et al. (2004), Degryse and Ongena (2008), Drechsler et al. (2017), and Drechsler et al. (2018).

2.1 Effects on bank profitability

In the short run, the effects of an interest rate cut on bank profitability come primarily from two opposing forces: the **deposit margin channel**, which reduces bank profitability, and the **capital gains channel**, which increases it. Additionally, **general equilibrium effects** can also affect bank profitability after negative rates are implemented. Over the medium and long run, capital gains and general equilibrium effects lose prominence and **changing business models** might start playing a more important role. We provide details on each of these channels below.

The **deposit margin channel** refers to the fact that negative rates lead to a contraction in the amount of profits that banks obtain from their deposit franchise. The banking literature has long recognized that banks hold significant market power on some of their liabilities, particularly in the market for liquid deposits such as checking or savings accounts. On these products, banks offer interest rates significantly below the marginal rate at which the funds are invested.

The degree of market power banks have in issuing deposits is likely to depend on the level of nominal interest rates, especially when rates are low or negative. This occurs because money, a key competitor to banks' liquid products, has a nominal return fixed at zero. Hence, the profits that banks obtain from offering deposit services decreases as nominal rates fall into negative territory, due to the higher relative return of cash holdings. An additional driver of the dependence between bank profitability and nominal rates is that households may become more attentive to the spread between deposit and money market interest rates as rates become low or negative. All of this makes deposit market power directly dependent on the level of interest rates, with negative rates affecting banks in especially pronounced ways. This channel has been emphasized in virtually all the theoretical papers studying negative rates (see, e.g., Brunnermeier and Koby, 2018; Ulate, 2021b; Eggertsson et al., 2019).

On the other hand, the **capital gains channel** refers to the fact that a cut in the policy rate can generate capital gains for banks. These gains may stem from the maturity mismatch present in most banks. When liabilities have short duration and assets have long duration, a surprise cut in the policy rate can decrease interest expenses without decreasing interest income, temporarily benefiting banks. Capital gains can also originate from long-lived securities that increase in value after a cut in the policy rate (like equities or long term bonds). This channel is present in papers like Brunnermeier and Koby (2018) and Wang (2019). Cuts in the policy rate can also generate capital gains in models that do not feature maturity transformation per se, if the loan rate is more sensitive to the state of the economy than the deposit rate, like in Ulate (2021b) or de Groot and Haas (2021).[4]

There are indications that negative nominal interest rates may have generated particularly

[4] In these last two papers both deposits and loans have a duration of one period, but the deposit rate is deterministic while the loan rate is stochastic. In essence, this means that there is a maturity mismatch of one quarter, even though assets and liabilities both expire after one period.

large capital gains for banks, for two reasons. The first is convexity: the same ten basis point cut in rates generates a larger capital gain on a fixed coupon bond when rates are one percent than when rates are five percent. The second effect arises when a normal-size cut in the short-run policy rate leads investors' expectations of long-end yields to decrease by a large amount, typically when the "zero lower bound" is broken for the first time. The first time a given central bank breaks through the zero lower bound, it signals its capacity and willingness to implement negative rates, and investors realize that prolonged periods with negative rates are more likely. This can lead investors to significantly adjust their expectations of long-term rates, generating substantial capital gains for banks from long-lived securities.

Additionally, through **general equilibrium effects**, cuts in the policy rate can have a beneficial impact on bank profitability. To the extent that cuts in the policy rate in negative territory are able to stimulate the aggregate economy, they may increase bank profitability by leading to higher loan demand. If the economy is stronger, bank borrowers may also default less, allowing banks to reduce their loan loss provisions and boost their profitability. These general equilibrium effects feature in some theoretical models like Ulate (2021b) or de Groot and Haas (2021), and some empirical papers like Borio et al. (2017) and Altavilla et al. (2018).

In the medium and long run, negative rates may cause banks to make strategic decisions regarding **changing business models**, for example by engaging in more risk-taking or implementing more fee-based lines of business. As we describe in the next section's discussion of reaching for yield, banks may engage in more risk taking after negative rates are introduced, effectively trading off higher expected profits for higher variance.[5] Banks can also charge more fees to customers in order to adapt to the negative rate environment. This might be optimal if banks believe that depositors are unwilling to accept negative retail deposit rates but are, for behavioral reasons, not as averse to an increase in fees. Banks can also close bank branches that are no longer profitable under low or negative nominal interest rates, cut costs, or change their cost structure to adapt to the new environment. These actions (charging higher fees, closing branches, cutting costs) could help sustain bank profitability in a negative-rate environment. This channel has not been featured in theoretical negative-rates papers, but it has been prominent in empirical papers like Basten and Mariathasan (2018), Demiralp et al. (2019), Lopez et al. (2020), and Hong and Kandrac (2018), among others.

Table 2 summarizes the four main channels through which negative rates impact bank profitability, indicating in what direction the effect is likely to go, and whether these channels are active in the short or long run. The main headwind for bank profitability in a negative-rates environment is the deposit margin channel, which is active both in the short run and the long run. Capital gains provide short-run benefits, which run out over time. General equilibrium effects, operating via increased loan demand or lower default rates, can also shore up bank

[5] Realized profits could, of course, end up being higher or lower than expected profits due to economic conditions or shocks, such as the ex-post solvency of riskier firms that banks start lending to.

Table 2: Channels affecting bank profitability

Channel	Direction of effect as rates become negative	Short run	Long run
Deposit margin	-	✓	✓
Capital gains	+	✓	
General equilibrium effects	+	✓	
Changing business models	+		✓

Notes: This table summarizes the theoretical channels through which negative rates affect bank profitability, and over what horizon (short run, long run) these channel are active. A green plus sign denotes positive effects for bank profitability and a red negative sign denotes negative effects.

profitability and are likely to be primarily active at a short-run horizon.[6] Changes to business models can improve bank profitability, but usually take time to implement. Consequently, these are active primarily in the medium/long run. Since not all of these effects go in the same direction, it is not *a priori* clear whether bank profitability rises or falls.

So far, we have described the aforementioned channels in a way that applies to "banks" in a general sense. While these channels are likely to be operational for the aggregate group of banks in the economy, they might also have different strengths for individual banks. As an example, take the deposit margin channel. Most banks obtain a significant fraction of their funding from household deposits. Therefore, it is likely to be the case that, for the banking sector as a whole, negative rates contract the deposit margin and have a detrimental impact on profitability. This indicates that the channel is active at the aggregate level. Simultaneously, some banks have higher-than-average shares of deposits in their funding structure. These banks are likely to be more affected by the deposit margin channel than banks that rely more heavily on wholesale funding. This indicates that the channel can operate to different extents across banks with different characteristics.

2.2 Effects on bank loan supply

A cut in the policy rate in negative territory can affect bank loan supply in various ways. Some of the effects on bank lending operate through bank profitability. We describe these first, and then discuss other effects that are not necessarily mediated by it.

2.2.1 Effects on bank lending mediated by profitability

Theoretical justifications have been proposed for bank profitability having both positive and negative effects on bank lending. The **risk bearing channel** emphasizes regulatory con-

[6] Effects on loan demand and/or default rates will be active as long as monetary policy (specifically negative rates) can have real effects, which is likely in the short/medium run but not as likely in the longer run.

straints or risk aversion in driving reductions in lending after a fall in bank profitability. Additionally, models with **balance sheet constraints** imply that profitability may limit banks' ability to obtain funding, for example due to moral hazard considerations, restricting lending capacity. On the other hand, **reaching for yield** highlights that decreasing profitability could increase incentives for bank risk-taking, either through more overall lending or through lending to riskier borrowers. We elaborate on each of these channels below.

The **risk bearing channel** describes how bank profitability affects bank risk-taking through regulatory constraints or risk aversion. Regulatory restrictions on banks often take the legal form of limiting their risk exposure to a function of their net worth or book equity. This implies that the latter becomes a constraint on banks' ability to make loans to firms. In practice, the risk weight assigned to specific assets differs, as does the weight of different types of equity investments in counting towards the constraint. If bank profitability falls and banks do not raise more equity or reduce dividend payouts, this negatively affects bank net worth. Once constraints are close to binding, the risk-taking ability of banks decreases and lending supply shrinks. This can lead to increased loan rates or spreads and lower lending in equilibrium.[7] This is the main channel limiting lending after negative rates are implemented in the models of Ulate (2021b) or Brunnermeier and Koby (2018).

Additionally, **balance sheet constraints** assume that the total amount of deposits or even wholesale funding that a bank can raise is constrained by bank net worth due to moral hazard or asymmetric information problems. For example, if a bank has low net worth, lenders to the bank might not be convinced that its managers will spend enough effort and resources monitoring borrowers, due to a principal-agent problem. This leads lenders to fear that bank debt is insecure. If the restriction on bank borrowing is large enough, banks may be able to fund a smaller amount of loans. This is the main mechanism linking bank net worth with the amount of deposits – and hence overall funding availability and lending capacity – in the model of Gertler and Karadi (2011), as well as in negative-rates papers that use such a framework, like Sims and Wu (2021), de Groot and Haas (2021), Onofri et al. (2021), and Darracq et al. (2020).

By contrast, **reaching for yield** provides reasons why bank lending and risk may increase after a fall in bank profitability brought about by negative nominal interest rates. It may be rational for bank managers to take additional – and potentially excessive – risk, if they have limited liability and so do not fully bear the potential negative consequences of risky decisions. Such hypotheses emphasize management incentives and sometimes fall under the umbrella of "gambling for resurrection". Bank managers may also be incentivized not to recognize loan losses when doing so could trigger solvency issues, instead making additional "evergreened" loans to insolvent borrowers. In addition, some behavioral models of banking suppose that

[7] Liquidity ratios are also common regulatory constraints. These have typically not been emphasized in the negative interest rates literature, because high levels of bank liquidity under low and negative rates imply that the liquidity ratios have not been binding.

managers target a specific level of overall returns on their assets, and thus increase risk to meet those targets as the rate of return on safe assets falls. This effect may become increasingly pronounced once rates turn negative, as there are fewer opportunities to make investments with positive returns. Under these assumptions, a decrease in bank profitability results in higher risk-taking to meet return targets. An increase in bank risk-taking can materialize in two different ways: banks can substitute reserves or other safe assets for more loans, or they could keep their loan share fixed but lend to riskier borrowers. Only the first of these options implies higher overall lending. The reaching for yield channel has been emphasized in empirical papers like Demiralp et al. (2019) and Hong and Kandrac (2018).

The opposing effects described in this section complicate the assessment of the overall impact of a cut in the policy rate in negative territory on bank lending. Not only are the effects on bank profitability ambiguous, but also the link between bank profitability and lending can be modeled as having both positive or negative effects. Further complicating matters, additional channels not mediated by profitability may also arise, as we describe next.

2.2.2 Effects on bank lending not mediated by profitability

Negative rates can also have direct effects on lending that are not mediated by profitability. A direct link from the return on excess reserves to bank loan rates could lead to lending effects, which we refer to as the **opportunity cost of lending channel**. By contrast, the **funding rate channel** indicates that if a bank has no excess reserves, its loan rate will be tied to its funding rate. If the funding rate stays close to zero during times of negative rates, the pass-through from the policy rate to the lending rate could be reduced. Finally, the **deposit supply channel** arises from household substitution across bonds, bank deposits, and cash, which can lead to a change in the supply of deposits to the banking system when negative rates are implemented.

The **opportunity cost of lending channel** is the way we describe that if banks have excess reserves, they have the option of making a loan by decreasing these reserves, linking the opportunity cost of lending, and therefore the loan rate, to the interest rate on excess reserves. Therefore, when banks have substantial excess reserves, a cut in the policy rate in negative territory can lead directly to a fall in the loan rate, even if the deposit rate is stuck at zero. In theoretical papers with monopoly power and where banks hold excess reserves, like Ulate (2021b) and Brunnermeier and Koby (2018), the opportunity cost of making a loan is tied to the rate on excess reserves and this leads to a fall in the loan rate after negative rates are implemented. These papers generally find a higher effectiveness of negative rates than papers without monopoly power like Eggertsson et al. (2019).[8]

[8]Having excess reserves in a regulatory sense is necessary but not sufficient for this channel to be operational. If banks hold reserves over the regulatory minimum for liquidity management purposes, they are unlikely to be willing to decrease these reserves to make an additional loan. On the other hand, if the marginal unit of excess reserves is present in a bank due to its monopoly power in the loan market, this is what really ties the loan rate to

On the other hand, the **funding rate channel** indicates that if banks have no excess reserves, they must raise funds to make new loans, tying the bank lending rate to the bank funding rate. During normal times – when nominal rates are above zero – the bank funding rate typically co-moves with the policy rate. Therefore, a cut in the policy rate lowers the bank funding rate, leading to a fall in the loan rate. By contrast, if the bank funding rate stops moving with the policy rate during times of negative rates (e.g., due to the deposit zero lower bound), banks will be unable to lower their lending rate after a cut in the policy rate. This would indicate that the funding rate channel might be inactive in negative territory, which is what occurs in papers like Eggertsson et al. (2019) or de Groot and Haas (2021). However, it is possible that the bank funding rate is not simply given by the retail deposit rate, but is also influenced by sources that, to some extent, follow the policy rate into negative territory. Examples of these sources of funding are corporate deposits, wholesale funding, or interbank loans. In this case, negative rates can lower the funding cost of making a loan, even in the presence of a zero lower bound on retail deposit rates, leading to a fall in the loan rate. This occurs in Onofri et al. (2021).

Another way in which negative rates can affect bank lending is through the **deposit supply channel**. Depositors might increase or decrease their deposit savings in the banking system because of the changing relative price of the two main alternatives to bank deposits: cash and securities. If banks have no excess reserves, a change in deposits that is not compensated by a change in funding elsewhere will translate into a change in lending. In Drechsler et al. (2017), for example, fixed income savings instruments become less attractive in a low nominal interest rate environment and are then substituted for bank deposits. However, in that paper these results are only explored above a nominal rate of zero. Below zero, the dominant force could be the substitution of deposits for cash, especially if a combination of zero deposit rates plus fees makes deposits less appealing for households than cash, or if retail deposit rates eventually turn negative. Importantly, banks need to have limited access to wholesale funding (or face some minimum regulatory ratio of stable funding, i.e. deposits) for this channel to matter.

Table 3 summarizes the lending channels described above, and whether they are likely to impact lending positively or negatively when negative rates are implemented. The first column indicates in which direction lending is likely to evolve as rates become negative. For this table, we assume that negative rates lead to an overall decline in bank profitability.[9] The risk bearing and balance sheet channels imply that lending declines as nominal interest rates turn negative. By contrast, reaching for yield and the opportunity cost of lending channel predict that lending increases. In positive territory, the funding rate channel leads to increased lending when policy rates fall; in negative territory this effect may become smaller or stop affecting lending entirely

the rate on reserves. This is why we emphasize the existence of monopoly power when discussing this channel.

[9] As discussed in Section 2.1, the overall effect on bank profitability after negative rates are implemented is theoretically ambiguous, but a negative effect is the one most commonly described in the empirical literature. To be able to "sign" the effect of the lending channels mediated by profitability, we need to take a stance on the impact on bank profitability.

Table 3: Mechanisms and direction of effects on bank loan supply

Channels	Direction of effect as interest rates become negative	Mediated by profitability
Risk bearing channel	-	✓
Balance sheet constraints	-	✓
Reaching for yield	+	✓
Opportunity cost of lending	+	
Funding rate channel	+	
Deposit supply channel	+/-	

Notes: This table contains a mapping of the theoretical channels through which negative nominal interest rates affect bank loan supply, and whether the channels are mediated by bank profitability. A green plus sign denotes positive effects for bank lending, a red negative sign denotes negative effects, and orange signs denote that the effect could go either way (ambiguous).

(if the funding rate becomes stuck, for example).[10] The direction of the effect of the deposit supply channel is unclear. The second column indicates whether the channel operates through bank profitability (which itself can be influenced by the factors described in Section 2.1).

As theoretical mechanisms exist to justify different effects of negative nominal interest rates on lending both independently and through profitability, it becomes apparent that these channels could be active to different extents depending on the context. In practice, where several mechanisms may simultaneously be active, it is not theoretically clear what balance will drive the overall result. Importantly, this overall effect could depend on how negative the policy rate is, or on how long negative rates have been implemented for. This is a significant challenge for empirical research, which we turn to now.

3 Empirical evidence on bank effects

Having established the theoretical channels through which negative nominal interest rates affect banks, we now turn to the large and growing body of related empirical evidence. In this literature, there is not only disagreement over what empirical measures of profitability and lending are most relevant, but also mixed views on which mechanisms described above are most likely to be active – and to what degree. The somewhat disparate findings in the literature are further complicated by methodological choices. Empirical identification strategies are typically in one of three categories: (1) cross-country regressions, (2) within-country or regional studies that identify relative effects across banks, and (3) high-frequency identification using asset prices. A broad list of citations and the regions that they study is shown in Table 4. The papers are grouped by identification strategy, and the region, number of banks, and time pe-

[10] However, as explained above, this channel can also predict lower lending rates (and hence higher lending), if the funding rate can still fall in negative territory, as in Onofri et al. (2021).

riod of analysis are noted. Before comparing the papers' findings by topic, some comments on the details and limitations of the main identification strategies are warranted.

Cross-country studies identify the aggregate effects of negative rates on profitability or lending amounts using realized bank outcomes, reported at quarterly or annual frequencies. As these outcomes are influenced by macroeconomic conditions beyond interest rates, these results are identified under the assumption that the economies in the sample co-move similarly with the world economy, and hence macroeconomic conditions can be captured by time fixed effects. To the extent that variation exists in the policy rate across countries, this approach can be understood to identify aggregate effects. To that point, the cross-country methodology can be critiqued on the grounds that it may not be sufficient to condition on time fixed effects, as economic conditions in all countries may not perfectly co-move. Macroeconomic conditions that remain unexplained potentially conflate bank with aggregate transmission channels.

By contrast, studies that compare across banks within a country identify relative effects for banks that are more versus less exposed to the negative interest rate environment (i.e. "exposure" studies). This is by far the most popular approach. These studies measure relative rather than aggregate effects, as in this methodology time fixed effects absorb macroeconomic conditions which are common across banks. The identification assumption here is that other unobservable factors such as shocks that send interest rates to negative territory do not affect the measured outcomes of interest in the cross section of banks in a way that is correlated with banks' exposures to the rate environment. Additionally complicating synthesis, in this type of study, different empirical measures are used to proxy for banks' exposure to interest rates.

Finally, high frequency studies measure the effect of monetary shocks using the price response of assets such as bank stocks over a narrow window of time. The identification assumption in this class of papers is that within the narrow window around a policy announcement, asset price changes reflect only the effect of the monetary shock. The outcomes that can be measured at high frequency are typically limited to prices, such as bank stock prices, interbank rates, floating loan rates, and bond rates. One advantage of these studies is that asset prices are forward-looking, and incorporate forecasts of future outcomes. Therefore, these studies give us an idea of the consequences of negative rates for banks beyond the very short run.

Keeping both the identification strategies and differences in samples in mind, we first discuss studies of how negative nominal interest rates have affected bank profitability and net worth, and then examine the measured impact on bank lending and risk taking.

3.1 Effects on bank profitability

There is broad agreement that the overall effect of negative rates on bank profitability is detrimental. This is summarized visually in column (4) of Table 4. Of the 20 papers that study bank profitability, 17 find that either bank profitability decreases under low or negative

rates, or that the profitability of banks more exposed to the negative interest rate environment declines on a relative basis (in the case of exposure studies). Three papers find that the effects are neutral, either due to offsetting capital gains or fee income, or because general equilibrium conditions improve sufficiently to balance out the deposit margin channel net of capital gains. The overall extent of agreement is surprising given the differences between the papers, and the theoretical ambiguity of the direction of the balance of channels listed in Section 2.

While their focus is on low interest rates rather than negative ones, Borio et al. (2017) and Claessens et al. (2018) provide evidence that among global banks, low interest rates are associated with declining bank profitability. Borio et al. (2017) focus on a sample of 109 large international banks from 14 countries over the period 1995-2012, and find evidence that low interest rates decrease bank profitability, as measured by net interest margins and return on assets. Claessens et al. (2018) study 3,385 banks from 47 countries from 2005 to 2013, and find broadly similar results for both profitability measures. Boungou and Hubert (2021) also obtain comparable results using net income.

Using return on equity and a cross-country empirical strategy, Ulate (2021b) provides consistent evidence for 5,405 banks in 19 countries between 1990 and 2017, which includes the negative rates environments in the Euro Area, Sweden, Switzerland, Denmark, and Japan. Conditioning on a low interest rate threshold (of roughly 50 basis points), he finds that bank profitability declines sharply as the policy rate falls below this threshold. The effect is driven by non-linearity in the pass-through of low and negative interest rates to depositors. This provides evidence for the deposit margin channel being central to declining profitability, because of the reluctance of banks to pass through policy rate changes to depositors when nominal interest rates are low or negative.

By contrast, Lopez et al. (2020) uses cross-country evidence from a similarly broad sample – 5,200 banks in 27 advanced European and Asian countries between 2010 and 2017 – to argue that banks offset the decline in interest income under negative rates through increases in non-interest income, primarily capital gains, as well as lower expenses. This study uses a dummy variable for countries that implemented negative rates as an explanatory variable, rather than the level of interest rates as in Ulate (2021b). As such, the results in Lopez et al. (2020) can be read as the average level of profitability in negative rate environments, relative to time-invariant bank and year averages. The coefficient in Ulate (2021b) is interpreted as the change in profitability associated with a change in the policy rate below the threshold, with the same fixed effect structure. Both papers include data from banks in 15 countries, but Lopez et al. (2020) includes data from banks in 12 additional EU countries, whereas the additional countries in Ulate (2021b) are regions that have set very low rates (U.S., Canada, Norway, and Australia). This perhaps also contributes to the differences in empirical findings.

Among "exposure" studies that compare across banks with different exposure to the negative rate environment, all but one find bank profitability declines under negative rates for more

Table 4: Classification of Empirical NNIR Papers

Identification Strategy (1)	Scope (2)	Citation (3)	Profit (4)	Loans (5)	Risk (6)	Banks (7)	Period (8)	Notes (9)
Cross-country	14	Borio et al. (2017)	↓			109	1995-2012	ST rate and flat yield curve both matter
	14	Borio and Gambacorta (2017)	↓	↓		108	1995-2014	Highlights potentially diminishing effectiveness
	47	Claessens et al. (2018)	↓			3,385	2005-2013	Non-linearity, greater effect over time
	59	Boungou and Hubert (2021)	↓			3,637	2011-2018	Size, liquid assets, HHI
	19	Ulate (2021b)	↓	↑		5,405	1990-2017	Nonlinearities around threshold, DSGE model
	27	Lopez et al. (2020)	○	↑		5,200	2010–2017	Small, low deposit banks offset effects
	33	Bongiovanni et al. (2019)			↓	2,371	2012–2016	Prudential regulation and market power
	59	Boungou (2020)			↓	9,421	2009–2018	Bank capitalization and size
Exposure	CH	Basten and Mariathasan (2018)		↑	↑	50	2013-2016	Excess reserves
		Schelling and Towbin (2020)		↑	↑	20	2013-2016	Deposit ratio, loan-level data
	DE, PT	Bittner et al. (2022)	↓	↑	↑	1,140	2010-2016	Deposit ratio, credit registry data
	EA	Nucera et al. (2017)			↑	111	2012-2015	Compares banks by business model
		Demiralp et al. (2019)		↑	↑	196	2007-2018	Compares banks by excess liquidity
		Heider et al. (2019)	↓	↓	↑	70	2013-2015	Deposits-to-liabilities, syndicated lending
		Bubeck et al. (2020)	↓		↑	26	2013-2015	Deposits-to-liabilities, securities registry
		Arce et al. (2018)		○	↓	122	2014-2017	Self-assessments, Spanish credit registry
	FR	Grandi and Guille (2020)		↑	↑	40	2012-2017	Deposit ratio, credit registry data
		Girotti et al. (2021)		↑	↑	77	2012-2016	Reserves and cash, credit registry data
	IT	Amzallag et al. (2019)		↓		71	2013-2015	Retail overnight deposits to total assets
		Bottero et al. (2021)	○	↑	○	95	2012-2016	Interbank positions, liquidity
	JP	Hong and Kandrac (2018)	↓	↑	↑	77	2015-2016	Compares banks by stock price response
		Balloch and Koby (2019)	↓	↓		111	1990-2017	Compares banks by deposit market power
	SE	Eggertsson et al. (2019)	↓	↓		11	2008-2018	Deposit share; theoretical model
High frequency	EA	Bräuning and Wu (2017)		↑		-	2009-2016	Interbank, bonds, stocks, monthly lending
		Ampudia and van den Heuvel (2019)	↓			56	1999-2017	ST, deposit dependence
		Bats et al. (2020)	↓			24	1999-2020	ST is more detrimental than LT
	US	Wang (2019)	↓	○		All US	1999-2018	ST and LT, theoretical model
Others	EA	Jobst and Lin (2016)	↓	↑		-	2005-2016	Surveys market conditions
		Arteta et al. (2016)	↓	↑		-	2005-2016	Highlights potential for excessive risk, policy
		Eisenschmidt and Smets (2019)	↓	↑		241	2007-2017	EA review, German banks analysis
		Altavilla et al. (2018)	○	↑		121	2007-2018	Controls for expected macro conditions
	DK, SE	Turk (2016)		↑		15	2005-2016	Large banks, notes capital inflow and FX motives

Notes: This table contains a classification of the empirical negative nominal interest rate papers according to their identification strategy, setting, and results for bank lending, profitability, and risk-taking. A green box with an upwards arrow indicates that the outcome is found to increase in response to interest rate cuts, a red box with a downwards arrow indicates decrease, and an orange ○ indicates a neutral result. For the cross-country papers, the scope lists the number of countries studied. Among the papers using an exposure-based identification strategy, the results are relative rather than aggregate.

exposed banks. Among the papers finding declining bank profitability, the bank exposure measure used is always related to banks' reliance on deposits, such as deposit-to-asset ratios (Heider et al., 2019; Bubeck et al., 2020; Eggertsson et al., 2019; Bittner et al., 2022), or market power in the deposit market as measured by initial deposit spreads (Balloch and Koby, 2019). Heider et al. (2019) and Bubeck et al. (2020) use data from 2013-2015 for 76 and 26 banks in the Euro Area, respectively; Eggertsson et al. (2019) focuses on the 11 largest banks in Sweden.[11]

The one paper among the exposure studies that does not find negative effects on profitability is Bottero et al. (2021), which measures banks' exposure using interbank or liquidity positions of Italian banks from 2012 to 2016. The authors show that in the six months following the introduction of negative rates, deposit-dependent banks increased fees for deposits-related banking services, which they claim potentially allowed banks to preserve intermediation margins and profitability after the introduction of negative rates. The quantitative magnitude of the evidence presented on rising deposit fees appears considerably smaller than the decline in deposit spreads, but the general idea is in line with the evidence in Lopez et al. (2020).

However, the overall evidence on banks' ability to increase fees is mixed. Turk (2016) shows descriptively that fees and commissions offset declines in interest income among Danish and Swedish commercial and mortgage banks, on average. Among Swiss banks, Basten and Mariathasan (2018) focuses on loan fees and net fee income, finding increases that appear to preserve bank profitability through 2016.[12] In cross-country evidence, Boungou and Hubert (2021) show that the magnitude by which net non-interest income increases is smaller than the amount that net interest income decreases. Similarly, Balloch and Koby (2019) find that in Japan the non-interest income banks are able to generate in response to low interest rates is not large enough to fully compensate for the decline in deposit margins. Lopez et al. (2020) finds no increase in fees for banks overall but an increase for large banks at the 5% confidence level. The results in Grandi and Guille (2020) are similarly mixed. Papers that find no increase in fees include Heider et al. (2019), Claessens et al. (2018), Bubeck et al. (2020), Altavilla et al. (2021), Urbschat (2018), and Tan (2019). Taken together, these papers indicate that changing business models to increase non-interest income may be feasible in some settings, but not others.[13]

Importantly, within country studies capture how effects vary across banks according to the exposure measure, and do not capture the aggregate effects of negative nominal interest

[11] Several cross-sectional papers do not study profitability but rather focus on outcomes such as bank lending and bank risk, we discuss these in the following section. They also vary in terms of the exposure variable used to compare banks, for example using bank business model (Nucera et al., 2017), excess liquidity (Demiralp et al., 2019), high-frequency stock-price responses to monetary policy announcements (Hong and Kandrac, 2018), or self-assessments (Arce et al., 2018).

[12] This is statistically significant in specifications with bank and year fixed effects, but not in specifications without.

[13] Loan loss provisions – funds that banks put aside to protect against borrower default – are also potentially important for bank profitability. Borio et al. (2017) find that lower policy rates decrease provisions because banks perceive them to decrease default probabilities. Using data on policy rate cuts and firm's default probability, Mendicino et al. (2021) argues that this channel operates similarly in positive and negative territory.

rates. Even if "more exposed" banks fare worse than "less exposed" banks, it is possible that both types of banks benefit from negative nominal interest rates. Cross-sectional results can therefore be useful for policy makers to determine how much to worry about macro-prudential issues or about imbalances across the distribution of banks, but cannot fully identify the overall effectiveness of negative rates. In measuring the impact or the effectiveness of negative rates, endogenous economy-wide variables like GDP growth or inflation are important factors – as emphasized by Altavilla et al. (2018) – and these variables are absorbed in single-country regressions by time fixed effects. While exposure studies are still useful in providing evidence for channels by which negative rates affect bank profits, the aggregate effect on certain variables can potentially be measured using high frequency identification.

Papers using high frequency identification primarily study equity values as an outcome of interest, measuring the reaction of bank stock prices to surprise changes in interest rates over a narrow window of time. To the extent that bank equity values correctly forecast future bank profitability, they can be used to assess the effect of monetary policy shocks. An important high frequency contribution is Ampudia and van den Heuvel (2019), which examines the effects of surprise changes in interest rates by the ECB on 56 banks' stock returns, between 1999 and January 2017. Comparing 10 minutes before the start of ECB press statements or press conferences to 20 minutes after, for 245 surprises, they find that the positive effects for bank stocks of expansionary surprises reverse once the policy rate becomes negative. By contrast, they do not find such a reversal for long term surprises. Bats et al. (2020) measure equity returns for a smaller group of banks, controlling for broad stock market movements, and argue that flattening the yield curve has a smaller negative effect on bank profitability than a yield curve shift. Taken together, these studies add evidence that deposit margin effects are dominant in leading to negatively affected bank profitability.

High frequency studies measure short horizon changes that reflect expectations about what the likely long-run impact of interest rate changes will be. Whether expectations correctly reflect what occurs in reality must be measured using longer-horizon and lower-frequency data. In this vein, Hong and Kandrac (2018) sort banks by their high-frequency response to the introduction of negative rates in Japan, and look at bank-level outcomes over longer time periods. The authors interpret their findings as agnostic about the specific channel or combination of channels through which negative interest rate policy affects individual banks' profitability, because the stock price reaction to the surprise announcement of negative rates would capture any theoretical channel. They show that more exposed banks (i.e. those with large stock price declines) did not end up suffering a fall in profitability in the medium-run, but instead increased their lending, took on more risk, and lowered their lending rates by less. As the authors note, it may be that banks that were initially more exposed to negative policy rates took on more risk in an attempt to offset declines in profitability that negative rates would have otherwise induced. In this light, stock price declines can be interpreted as responding to the

higher rate of return investors required for the rising risk profile of bank profits.

Despite the apparent potential to reverse the decline in deposit margins associated with negative nominal interest rates via alternate channels such as capital gains, general equilibrium effects, or changing business models, the growing consensus appears to be that the deposit margin channel dominates, and the overall effect of negative interest rates on bank profitability is negative. As rates stay low for long periods of time, capital gains and general equilibrium effects fade and are not compensated enough by other adjustments like fees and cost reductions, leading to worsening profitability. As explained in the previous section, if banks are continually less profitable, and do not change their dividend payouts or raise capital, net worth declines. This will lead to effects on lending, as we explore next.

3.2 Effects on bank lending

As bank profitability does not necessarily matter for macroeconomic outcomes *per se*, many studies aim to study broader outcomes, primarily lending. As described in Section 2, profitability affects net worth, and this may affect the quantity or composition of bank lending. There are also channels through which lending is affected independently of bank profits. 23 papers listed in Table 4 study bank lending as an outcome in reaction to low or negative rates. The direction of lending results is summarized in column (5) when the results pertain to loan volumes, and column (6) for the 14 papers that discuss risk-taking outcomes. While there is less agreement over the direction in which lending goes than there is for profitability, the majority of papers find that negative rates, on balance, lead lending to increase. Recall that most papers find a negative result for profitability. In contrast, 16 of 23 papers find that lending increases in response to negative rates, five find that lending contracts, and two find neutral results. This dissonance is perhaps not surprising in light of the many channels described in Section 2.2, but requires careful consideration of the balance of channels to make sense of the results.

Loan volumes are not as straightforward to measure at high frequency as bank profitability. Therefore, there are fewer papers using high-frequency identification that study lending outcomes. Bräuning and Wu (2017) is one of the exceptions. This paper analyzes the transmission of negative rates in the Euro Area from 2009 to 2016, focusing on interbank lending rates, government bond yields, and bank lending measured by monthly loan origination and rates. The authors find a positive effect of interest rate cuts on lending in negative territory that is stronger than the reaction measured in the period before rates become negative. They interpret the results as being consistent with reaching-for-yield behavior. However, lending at a monthly frequency could also be driven by aggregate transmission channels, or general equilibrium effects. Using a similar approach, Wang (2019) documents incomplete pass through to loan rates in US data when policy rates are sufficiently low to weigh negatively on deposit margins, but not yet negative. While he does not measure loan volumes specifically, rising loan spreads

could imply reaching for yield, or a contraction in loan supply driven by other channels.

Among exposure studies, eight papers sort banks by their deposit dependence and study lending volumes or risk. Of the seven that study loan volumes, four find that lending declines, and all five that study risk show evidence of increased risk-taking among more-exposed banks. Heider et al. (2019) focus on risk in syndicated lending, and show that the risk profile of exposed banks' borrowers increases, while the relative volume of exposed banks' lending declines. The authors' explanation is that lower net worth lowers the incentive to screen and monitor risky borrowers. In a related paper, Bubeck et al. (2020) find increased relative risk as measured in securities investments, as well as lending. Both can be taken as evidence for the reaching for yield channel, which is driven by a decline in bank profitability. These results pertain to the entire Euro area, but quite a lot can be gleaned from comparing across countries.

Comparing core and periphery banks, Bittner et al. (2022) argues that bank net worth remains a primary driver of bank lending in Portugal, where despite negative rates banks maintained the ability to pass through changes in policy rates, due to high initial deposit rates. In contrast, German banks suffered greater margin compression, which induced risk taking among deposit-dependent banks. These banks granted more loans, particularly to riskier firms. Weakly capitalized banks in Portugal extend more credit (but not to safer or riskier firms). The contrast emphasizes that deposits are likely to be an important sorting variable only in a context where there is incomplete pass-through and pressure on bank deposit margins.

In line with Heider et al. (2019), evidence in Sweden, Italy, and Japan suggests that bank lending may contract under negative rates. In Sweden, Eggertsson et al. (2019) find negative effects on bank lending volumes, which is interpreted as arising from the risk bearing channel. In turn, this channel is driven by declining deposit profitability that capital gains are too small to offset. Eggertsson et al. (2019) and Amzallag et al. (2019) use evidence, from Sweden and Italy respectively, to argue that once the policy rate goes negative, mortgage rates stop responding to cuts in the policy rate (or even increase after a fall in the policy rate). In contrast to the previous studies, Schelling and Towbin (2020) find a decrease in mortgage spreads following the introduction of negative rates using data from Switzerland.

Importantly, Amzallag et al. (2019) show that the transmission of negative rates to fixed-rate mortgages in Italy is significantly different from the transmission to adjustable-rate mortgages. In particular, the authors find that more-exposed banks charge higher rates on fixed-rate mortgages originated after the implementation of negative rates compared to less exposed banks. Meanwhile, they find no such significant difference for adjustable-rate mortgages originated after the implementation of negative rates. They argue that banks may be more reluctant to transmit negative rates to mortgages on which future income is fixed than to assets where income adjusts based on market conditions. Additionally, the authors find evidence that more exposed banks become more likely to originate adjustable-rate mortgages under negative rates.

Evidence from Japan suggests that low interest rate environments are associated with

lower bank profitability in the long run, when capital gains have run out and the reach for yield channel is not beneficial. That more affected Japanese banks decrease lending is interpreted as consistent with a risk bearing channel (Balloch and Koby, 2019). Overall, the Japanese evidence suggests that over time, the expansionary effects of negative nominal interest rates on lending may run out. This is consistent with the cautionary findings in Claessens et al. (2018). Arce et al. (2018) shows further evidence for this view in Spain. The sample studied here includes evidence from Euro Area banks supplemented with detailed analysis of Spanish credit registry data, and includes a longer sample period than either Heider et al. (2019) or Bubeck et al. (2020). The authors report that banks facing more pressure from lower profitability – based on self-assessments – take less risk. Their results on loan volumes are neutral, and they posit that the risk bearing channel is likely to dominate in the medium term.

Moving away from deposits as an exposure variable, Boungou (2020) argues that banks' risk-taking falls when interest rates are negative, measuring risk taking via *levels* of risk-weighted assets, Z-scores, or loan loss provisions. This suggests that the risk bearing channel might be stronger than the incentive to reach for yield. However, loan loss provisions are expected to decline as rates decline, as emphasized in our general equilibrium channel. That Boungou (2020) shows stronger effects for small and well capitalized banks indicates that the accounting balance of such factors weighs negatively on risky asset levels. Bongiovanni et al. (2019) similarly finds that negative interest rates are associated with a reduction of risk in banks' asset holdings, measured as *growth* in risky assets. Yet, larger declines are found among poorly capitalized banks and in more competitive markets in which banks could not insulate their margins and profitability from the effects of negative interest rates.

Given that negative rates affect the return on excess reserves, a natural dimension on which to compare banks is reserves. In this spirit, four within-country studies use banks' liquidity measures to predict different relative effects on lending. These papers find consistent positive results for loan volumes, and mixed results on risk in lending. All four provide support for the role of reserves in monetary transmission when interest rates are negative, and for the opportunity cost of lending channel.

Demiralp et al. (2019) find positive lending effects for banks with greater excess liquidity in the Euro Area, and greater risk-taking in loans. The authors interpretation is that once banks' profitability declines, excess liquidity provides banks an opportunity to shift to higher-yielding lending opportunities. This combines the opportunity cost of lending channel and reaching for yield. Girotti et al. (2021) document a similar pattern in France. Basten and Mariathasan (2018) find qualitatively similar patterns among Swiss banks, based on their levels of excess reserves. However, the Swiss study finds increased book equity as well as risk taking among exposed banks, which is inconsistent with reaching for yield. Their results indicate that banks with excess reserves chose to reduce their reserves and dependence on non-deposit liabilities, while increasing risk. This maps most closely to the opportunity cost of lending channel.

Similarly, the evidence in Bottero et al. (2021) supports the opportunity cost of lending channel in Italy. This paper measures bank exposure via net short-term interbank positions, as well as broader measures of liquidity. The authors find both an expansion of credit supply and an increase in lending to ex-ante riskier and smaller firms, but no increase in ex-post non-performing loans. Further, they argue that Italian banks preserve margins and profitability, in part by raising fees on bank deposits, thus strengthening the argument that opportunity costs drive banks to shift from liquid assets (e.g. interbank loans, securities) into more credit.

Two cross country studies document positive effects on lending. Ulate (2021b) shows that policy rate changes continue to be passed through to loan rates when interest rates are low or negative, potentially driven by the opportunity cost of lending. Lopez et al. (2020) shows that total bank lending as a percentage of bank assets increases, primarily among small and deposit dependent banks. This is viewed by the authors as consistent with reaching for yield, but is more convincingly supported by movements out of reserves that are what we label as the opportunity cost of lending channel.

Numerous studies of market conditions provide support for the argument that bank lending volumes increase even as interest rates are cut into negative territory, based on different sets of European banks, including Jobst and Lin (2016), Turk (2016), and Eisenschmidt and Smets (2019). These papers seem to support the expansionary effects of interest rate cuts in negative territory, which may in part rest on general equilibrium effects. In particular, Altavilla et al. (2018) highlights the positive effects of accommodative monetary policy on loan loss provisions and non-interest income, which mitigate the negative effects from deposit margins.

Taken together, research on bank lending under negative rates can be summarized as showing evidence for five facts. First, there are expansionary effects of negative rates on lending, at least initially. Second, as deposit profitability declines, this affects bank net worth in a way that can lead to either risk bearing or reaching for yield in lending, depending on the context. This affects some banks more than others. Third, excess reserves are increasingly costly under negative rates, and banks react to this steep opportunity cost by shifting their asset mix. Fourth, there could be long run detrimental effects on lending in a negative rates environment. Fifth, and most importantly, the direction in which lending and risk evolve depends not only on bank profitability and other bank channels, but also on how aggregate transmission channels impact the economy. We turn our focus to these aggregate channels in the following section.

4 Aggregate transmission channels

In this section, we explain the aggregate monetary policy transmission channels through which a cut in the policy rate in negative territory affects the real economy. Practically, all of these channels are also active in positive territory (i.e., they are not particular to a negative

interest rate environment). Nevertheless, it is still important to take into consideration that these channels might be active if one wants to study the **overall** effectiveness of a cut in the policy rate in negative territory. Some of these channels could be weaker in negative territory (and some could be stronger), and we point this out when relevant. Along the way, we discuss theoretical and empirical papers that study each channel (if available).

One important reason to analyze and discuss the aggregate transmission channels that could be active in negative territory is that they can shed light on the disparate results that have been obtained by the empirical papers studying negative rates. As set out in the previous section, empirical analyses have covered distinct settings over varied time horizons. The corresponding results could differ in part because the aggregate channels are operational to different degrees. Some examples, discussed in greater detail below, are as follows:

1. Negative rates could transmit differently to mortgage markets depending on the proportion of fixed and adjustable-rate mortgages.
2. Countries where firm borrowing is more dependent on banks (as opposed to the corporate bond market) could experience less benefits from the introduction of negative rates.
3. The signaling channel could be more important the first time that negative rates are implemented, leading to lower effectiveness of subsequent interest rate cuts.
4. In economies where households hold more assets that benefit from cuts in the policy rate, the effectiveness of negative rates could be higher.
5. The exchange rate channel could be more relevant for smaller and more open economies, like Switzerland or Sweden, than for larger economies like the Euro Area.

4.1 Intertemporal substitution

The intertemporal substitution channel has traditionally been a crucial part of the transmission mechanism in theoretical DSGE models. However, estimates of the empirical importance of this channel have traditionally been low (see, e.g. Boivin et al., 2010). Several recent papers emphasizing the importance of heterogeneous agents models (e.g. Kaplan et al., 2018; Auclert, 2019) have also argued that the intertemporal substitution channel might not be as important as representative agent DSGE models assume it to be.[14] A protracted discussion of the strength of the intertemporal substitution channel is beyond the scope of this paper. However, conditional on a given strength for this channel in positive territory, it is is important for the effectiveness of negative rates to understand how and why that strength might change once the policy rate becomes negative.

[14] Even in these heterogeneous agent models, the strength of monetary policy is still proportional to the intertemporal substitution channel, because the initial impulse affecting the economy still stems from this channel. Hence, if the intertemporal substitution channel is weakened under negative rates for any reason, then this would impact monetary policy under representative-agent and heterogeneous-agent models similarly.

The relevant interest rate for the intertemporal substitution channel is the one faced by agents in their Euler equation. If households face the deposit rate, and this rate stays at zero when the policy rate goes negative, then this channel would be inactive in negative territory. This is what happens in papers like Ulate (2021b) or de Groot and Haas (2021), because the deposit rate is the relevant one for the household's Euler equation, and the retail deposit rate does not become negative even after negative nominal policy rates are implemented. If consumers instead face a combination of the deposit rate and the bond rate – which typically follows the policy rate into negative territory – or a combination of the deposit rate and the lending rate, then this channel could still be partially active.[15] If the bank-based lending rate enters the Euler equation of certain agents – usually denoted "borrowers" in models – and this rate increases in negative territory because banks are negatively affected, then it is possible for this channel to even have a contractionary effect on the economy (this is the case in Eggertsson et al., 2019).

Even though the intertemporal substitution channel is a non-financial channel, if the relevant interest rate in the household's Euler equation is influenced by any bank-based interest rates, then the strength of this channel in low and negative territory will depend on the banking channels that we have discussed in previous sections. Hence, we could describe the intertemporal substitution channel as an aggregate channel whose strength during times of low and negative nominal interest rates can be substantially influenced by bank channels. While this influence could also be present during normal times, it is unlikely to be as critical for the functioning of the channel. This is because bank competition is more likely to affect the pass-through from the policy rate to the deposit rate during times of low or negative rates.[16]

Another way in which households' intertemporal decisions may influence the economy in a negative-rates environment is through mortgage borrowing and refinancing. Recent papers (e.g. Wong, 2016) have pointed to the importance of mortgage refinancing for the transmission of monetary policy. This channel could continue to be active in negative territory if the mortgage rate falls with a cut in the policy rate in negative territory. Whether this occurs depends on the banking structure of the economy, and more generally on the characteristics of the mortgage market. Additionally, what matters for this channel are mortgage rates, which are essentially a long-term object, and hence depend on the pass-through of the short-term negative nominal policy rate to longer term rates.[17]

[15] Rognlie (2016) discusses the stimulative effects that arise from intertemporal substitution when the deposit rate becomes negative in a model without banks. These are similar to the effects in positive territory.

[16] To see an example of this, take the model of Ulate (2021b). There, a cut in the policy rate from 3 to 2.5% would result in a 50 basis point cut in the Euler-equation interest rate regardless of whether banks have monopoly power or not. In contrast, a cut in the policy rate from 50 basis points to zero has a 50 basis point impact on the Euler-equation interest rate if banks are in perfect competition but no impact whatsoever if banks are in monopolistic competition. This means that bank market structure is more relevant for the intertemporal substitution channel when rates are low than in normal times. Something relatively similar would occur in Balloch and Koby (2019).

[17] This depends, among other things, on the signaling channel, which we discuss later on.

As discussed in Section 3.2, Eggertsson et al. (2019) and Amzallag et al. (2019) show that pass-through to mortgage rates is low or negative (i.e. mortgage rates increase) after a cut in the policy rate in Sweden and Italy, respectively. By contrast, Schelling and Towbin (2020) find that mortgage spreads in Switzerland decreased following the introduction of negative rates. As emphasized by Amzallag et al. (2019), both the extent of pass-through and the types of consumer loans offered by banks in a negative-rate environment is likely to depend substantially on the pre-existing share of fixed versus adjustable-rate mortgages. In their data, Italian banks not only charge higher rates on fixed-rate mortgages after the implementation of negative rates, but also shift to originating more adjustable rate mortgages in the negative rate environment.

In all three mortgage papers mentioned above, the discussion focuses on a bank-based mortgage rate, which indicates that, like the standard intertemporal substitution channel, the mortgage refinancing channel is also an aggregate transmission channel that is heavily influenced by bank-based mechanisms. More research is likely to be needed to properly assess whether this channel is still operational in negative territory, and to what degree.

4.2 Investment

The investment channel is similar to the intertemporal substitution channel in that we need to determine the appropriate interest rate that firms face in order to assess how this channel is affected in negative territory. One possibility is that the relevant rate for this channel is a bank-based lending rate. If the bank lending rate falls, private firms can invest more, and this can stimulate the economy. This is one of the crucial mechanisms in Ulate (2021b). On the other hand, if the lending rate increases after a cut in the policy rate in negative territory because banks are negatively affected, private firms invest less and this results in a contractionary impetus. This is what occurs when the policy rate falls below the reversal rate in the model of Brunnermeier and Koby (2018). Of course, the behavior of the bank lending rate will be affected by the bank-based channels described in previous sections. In this sense, the investment channel, like the intertemporal substitution channel, is an aggregate transmission channel that is heavily influenced by banking channels.

It is also possible that the relevant rate for the investment channel is not just a bank lending rate, but is instead a combination of a bank-based lending rate (for bank-dependent firms) and a corporate bond rate (for firms that borrow in the bond market). In this case, even if banks do not lower their lending rate, the investment of firms that can borrow directly in the bond market can still increase when the policy rate becomes negative. This is because the policy rate is typically transmitted one-for-one to bond rates, even in negative territory. This mechanism is present in Brunnermeier and Koby (2018), where there are two types of firms, bank dependent ones and non bank-dependent ones. A related but slightly different mechanism is present in Balloch and Koby (2019), where firms borrow both from banks and the bond market.

It is even possible that corporate deposit rates are relevant for this channel, as firms with large accumulations of cash might be more likely to invest this cash if they start to face negative corporate deposit rates. Empirical evidence about the relevance of this mechanism is reported in Altavilla et al. (2021).

4.3 Signaling

Another important channel for the transmission of negative rates to the aggregate economy is the signaling channel. This channel is related to forward guidance. It refers to the ability of negative policy rates to signal a prolonged environment of low rates. This signaling can occur even if certain current-period interest rates – like the bank deposit rate – do not move in response to cuts in the policy rate in negative territory. While this channel might be present when a cut in the policy rate occurs in positive territory – where the policy rate and the deposit rate usually co-move – it is likely to gain importance in negative territory, where only future deposit rates can react to a current movement in the policy rate. In essence, even if the bank deposit rate cannot react in the current period to a cut in the policy rate, the cut can signal lower policy rates in the future, perhaps even signaling the willingness of the central bank to stay in negative territory for a longer period. This can lower bank deposit rates in future periods relative to what would have been their value before the cut.

This channel is explained and emphasized in de Groot and Haas (2021), and it is also present in Ulate (2021b). The mechanism is related to the persistence parameter in the Taylor rule. With high persistence, negative policy rates today signal lower policy rates in the future, and this can put downward pressure on future deposit rates. In both de Groot and Haas (2021) and Ulate (2021b), a higher persistence parameter in the Taylor rule leads to a greater overall efficiency of negative rates. This channel is also related to the "forward guidance" aspect of negative rates described by Sims and Wu (2021). Additionally, Wu and Xia (2020) examine how market expectations and the yield curve react to negative rates.

This channel might be particularly pronounced the first time that negative nominal interest rates are implemented in an economy, because prolonged periods with negative rates suddenly become a lot more likely. This matters when interpreting the out-of-sample relevance of empirical studies. It is possible that the first cuts into negative territory are more potent than future ones. Studies that calibrate using first-round experiments might overestimate the effectiveness of negative rates if they do not take this into consideration.

4.4 Household wealth effects

A cut in the policy rate can drive up the prices of stocks, bonds, and/or housing held by private agents, and this can increase consumer spending. While this channel is present both

in positive and negative territory, its importance could be amplified in negative territory due to convexity. That is, the increase in the price of a long-lived asset should be higher when the interest rate is cut from 0.1% to zero percent than when it is cut from three percent to 2.9%.[18]

Empirical estimates of the magnitude of this channel in normal territory have yielded mixed results (c.f., Chodorow-Reich et al., 2019; Cloyne et al., 2020; Di Maggio et al., 2020). Specific to negative rates, Bräuning and Wu (2017) find that European stock and bond prices increase after a cut in the policy rate in negative territory. They do not study whether this induces additional household spending, but it is natural to assume that wealth effects would be present to some extent.

Theoretically, this channel would arise automatically in DSGE models where households held long-term bonds, equities, or housing. To date, the most prominent theoretical papers studying negative rates (e.g. Brunnermeier and Koby, 2018; Ulate, 2021b; Eggertsson et al., 2019) do not include these features. Consequently, this channel has not been emphasized in the negative rates literature, but could still have aggregate effects.

4.5 Exchange rates

Another relevant aggregate channel for the transmission of monetary policy is the exchange rate. This channel was explicitly described as an important aspect of the decision to implement negative nominal interest rates in some countries, like Switzerland and Denmark (see, among others, Swiss National Bank, 2016; Rohde, 2015).

When a cut in the policy rate transmits to other relevant rates, like money market rates, bond rates and retail deposit rates, it makes it less attractive to invest in domestic assets, possibly leading to a depreciation of the home currency. A depreciation, in turn, could have stimulative effects through the usual trade mechanisms. Whether this channel is still active in negative territory depends on whether the relevant rates at which foreign and domestic agents invest their money in the home country move with the policy rate in negative territory. Since foreign agents are likely to invest their money in bonds, equities, or the money market (as opposed to retail deposits), a cut in the policy rate is likely to lead to a depreciation even in negative territory. This channel is expected to be more important in small open economies like Switzerland, Sweden, or Denmark than in large economies like the Euro Area.

Empirical papers like Thornton and Vasilakis (2019), Arteta et al. (2016), Khayat (2018), and Bräuning and Wu (2017) have all found support for this mechanism. Additionally, most of them find that the depreciation generated by a cut in the policy rate in negative territory is larger than the one that would be generated if the same cut had occurred in positive territory. In terms of higher order moments, Hameed and Rose (2016) find that the volatility of

[18]This difference in the magnitude of the asset price change for a given change in the interest rate is absent if the model is log-linearized.

the exchange rate is not impacted by a move into negative rates, while Viswanath (2020) finds that CIP deviations widen around negative rate announcements. On the theoretical front, this channel has been explored in specific settings, but not fully incorporated into the general equilibrium assessments of the effectiveness of negative rates.[19]

4.6 Others

There are other effects of negative nominal interest rates that do not fit neatly into any category, and additional variables that are likely to be impacted by negative rates, but that are not necessarily "transmission channels" by which negative rates impact the economy. In this section, we discuss three such topics: cash subsidies, inequality, and productivity.

Cash subsidies can be an important aspect in models where money demand does not explode as the policy rate crosses zero percent and where cash usage is an important consideration. This is the case in the model of Rognlie (2016), where negative rates inefficiently subsidize paper currency. The subsidy arises because when rates are negative, the nominal return on cash (zero) exceeds the return on other short-term assets.[20] In this setting, negative rates have a stimulative effect through intertemporal substitution, but they have a negative welfare impact because the cash subsidy distorts households' saving behavior.[21] Starting from a zero percent nominal rate, the stimulative effect of cutting the policy rate in a recession dominates the negative effects of the subsidy, because the costs of distortions are second order. However, as rates become more negative, the cost of inefficiently subsidizing cash can dominate.

Negative nominal interest rates could also impact inequality. While this idea has generally been under-explored, Moser et al. (2020) studies the wage and employment effects of changes in labor demand due to a firm-level credit supply shock originating from negative rates. The authors find that non-financial firms which have relationships with banks that are more exposed to the ECB's negative rate policy (due to having higher deposit-to-asset ratios, as in the exposure studies discussed in Section 3) see a relative reduction in credit. Furthermore, this lower credit leads to lower firm-level average wages and employment. This has different effects on different worker groups within firms: lower-paid workers are more likely to be fired and higher-paid workers are more likely to receive wage cuts. Wages also decline by more

[19] Amador et al. (2017) develop an international macro model to study the cost of balance sheet policies that help the central bank achieve its exchange rate target when it is constrained by the ZLB, but do not examine negative rate policies explicitly. Cavallino and Sandri (2019) explore how the interaction between capital flows and domestic collateral constraints in emerging economies can undermine the transmission of monetary policy by giving rise to an open-economy effective lower bound akin to a reversal rate. Ruprecht (2020) studies the impact of negative rates on exchange rates in a monetarist model with two countries and finds that the impact of going negative on the exchange rate depends on initial conditions (specifically, the ratio between the money market rate and the rate on reserves for the domestic currency relative to the foreign currency).

[20] In other words, there is a deviation from the so-called "Friedman rule".

[21] Households directly face the negative policy rate in their Euler equation because there is no banking-sector intermediation in the model.

at ex-ante higher-paying firms. Consequently, according to this paper the implementation of negative rates can be understood to decrease wage inequality within and between firms.

After a move towards negative rates, wealth and income inequality can also be affected directly due to the impact on asset prices (e.g., house, equity, or bond prices) or interest rates. As inequality has risen significantly in recent decades, several research papers have considered the distributional effects of monetary policy (c.f., Amberg et al., 2021; Andersen et al., 2021). To the extent that households have different balance sheets, it is natural to expect that heterogeneous asset price changes may lead to unequal changes in wealth, and could impact inequality. To the best of our knowledge, how much this happens when rates are specifically negative has not been previously studied.

There is a budding literature that studies the impacts of low interest rates on firm productivity, investment, and market concentration. In these papers, the relevant interest rate is usually the long-term real interest rate and not the nominal policy rate. This means that this issue is not directly related to negative nominal interest rates. Nevertheless, for completeness, we mention below some relevant papers in this area.

Liu et al. (2019) find that lower long-term rates can trigger a stronger investment response by market leaders (relative to less productive firms, deemed market followers) leading to more concentrated markets, higher profits, and lower aggregate productivity growth. Importantly, the authors assume that followers cannot "leap-frog" and catch the market leader quickly. Instead, this takes several steps. When leap-frogging is allowed, low interest rates can, instead, promote investment, R&D, and growth. This has been shown in Chikis et al. (2021), who propose and estimate a general model than can nest Liu et al. (2019). They find that their estimated model leads to a significant chance of leap-frogging. As a consequence, in the model of Chikis et al. (2021), lower discount rates actually increase investment and the growth rate.

4.7 Taking stock

In this section, we have analyzed the aggregate transmission channels through which a cut in the policy rate in negative territory affects the macroeconomy. Table 5 serves to summarize the main results discussed so far. The first column indicates the name of the relevant channel, and the second describes whether the effect is stimulative, contractionary, or ambiguous as rates become negative. The intertemporal substitution and investment channels have ambiguous effects on the economy, because they depend on what happens to relevant bank-based interest rates. On the other hand, the signaling, wealth effects, and exchange rate channels are likely to have stimulative effects after a cut in the policy rate in negative territory.

In terms of comparing the magnitude of a given channel in negative territory with its magnitude in positive territory there are also important differences between channels. The third column in Table 5 indicates if the effect of the channel is weaker than in positive territory,

Table 5: Aggregate transmission channels

Channel	Direction of effect as rates become negative	Weaker than positive territory	Stronger than positive territory
Intertemporal substitution	+/-	✓	
Investment	+/-	✓	
Signaling	+		✓
Wealth effects	+		✓
Exchange rates	+		

Notes: This table summarizes the aggregate transmission channels through which negative nominal interest rates affect the macroeconomy, and whether those channels are likely to be weaker or stronger than in positive territory. A green plus sign denotes stimulative effects, a red negative sign denotes contractionary effects, and an orange plus/minus sign denotes that the effect is ambiguous.

and the fourth indicates if the effect is stronger than in positive territory. The intertemporal substitution and investment channels are likely to be weaker in negative territory, because they depend on the pass-through to bank-based interest rates (which is likely to be at least somewhat impaired). As argued above, the signaling and wealth effects channels are likely to be stronger than in positive territory. Finally, the exchange rate channel seems likely to have similar effectiveness in positive and negative territory.

5 General equilibrium models

To assess the combined effect of negative rates on overall outcomes through bank and aggregate transmission channels, general equilibrium analysis is required. While the empirical papers on negative rates have mainly studied the effects of a cut in the policy rate on bank variables, aggregate channels are crucial for assessing the overall effects on the real economy.

Several theoretical general equilibrium models with both bank and aggregate transmission channels have been proposed to estimate the overall effectiveness of negative rates at stimulating the economy. So far, the results in these studies have spanned a considerable range. Certain papers, like Eggertsson et al. (2019), find that negative rates are not effective at stimulating the economy, and can even be harmful. In contrast, papers like Ulate (2021b), de Groot and Haas (2021), and Onofri et al. (2021) find that, even though a cut in the policy rate in negative territory is less effective than one in positive territory, cuts in negative territory still preserve a significant amount of their effectiveness and can thus stimulate the economy.

The aforementioned general equilibrium models use different combinations of the banking and aggregate transmission channels that have been described in previous sections to obtain an estimate of the effectiveness of a cut in the policy rate in negative territory. In this section, we discuss which channels are included in each model, and assess what differences bear the most

responsibility for discrepancies between the papers' conclusions. First, we discuss how the papers differ in the channels that affect bank profitability. Second, we talk about how they differ in terms of lending channels that operate through profits. Third, we consider what lending channels not mediated by profitability are included in which models. Finally, we describe how the papers differ in terms of the aggregate transmission channels that are active. As we discuss below, lending channels not mediated by profitability have been some of the main points of contention among these papers.

Table 6 offers a graphical classification of the papers discussed, summarizing the channels that they incorporate and in which direction these channels operate. Green is used to depict positive outcomes, red is used to depict negative outcomes, and orange is used to depict ambiguous outcomes that depend on the level of the policy rate or other relevant aspects of the calibration. As a general point, when a paper contains both a small illustrative model and a calibrated general equilibrium model, the discussion in this section refers to the general equilibrium model using the baseline calibration. It is also worth noting that we will discuss some papers that do not specifically analyze negative nominal interest rates, but that instead analyze a low rate environment where the policy rate is close to zero, specifically: Balloch and Koby (2019), Wang (2019), and Kumhof and Wang (2020).[22] In Table 6, an asterisk is used to denote the papers that do not explicitly analyze negative nominal interest rates.

In terms of bank profitability, most prominent papers in this literature (e.g., Ulate, 2021a; Brunnermeier and Koby, 2018; Balloch and Koby, 2019; de Groot and Haas, 2021; Eggertsson et al., 2019; Wang, 2019, etc.), include a deposit margin channel that hurts bank profitability after negative rates are implemented. In some papers, this occurs because deposit rates are assumed to be constrained at zero, while in others it happens because the pass-through of the policy rate to the deposit rate becomes low or negligible as the policy rate becomes negative.

There is more dispersion in the treatment of capital gains. In papers like Ulate (2021b) and Brunnermeier and Koby (2018), a capital gains channel benefits banks as rates become negative. In Balloch and Koby (2019) there are no capital gains, because the authors aim to capture long-run considerations. In Eggertsson et al. (2019), banks can suffer capital gains or losses when negative rates are implemented, depending on how the exogenous pass-through to external financing compares to the pass-through to other liquid assets. Changing business models have not been incorporated in theoretical negative-rates papers, while general equilibrium effects in banking are sometimes present, but have typically not been emphasized because they operate through a combination of other channels.

Regarding lending channels that operate through profits, existing papers are somewhat more consistent. Reaching for yield effects have generally not been considered, even though

[22] Wang (2019) contains both a short-run and a long-run model. In this section, we refer mainly to the short-run model. The long-run model has implications that are somewhat similar to the ones in Balloch and Koby (2019), which exclusively deals with long-run issues.

Table 6: Classification of Theoretical Negative Rates Papers

Category	Channel	Rognl	Ulate	BruKo	GroHa	OnoEA	Wang*	EggEA	BaKo*	KuWa*
Bank profitability	Deposit margin		↓	↓	↓	↓	↓	↓	↓	↓
	Capital gains		↑	↑	↑	↑	↑	○		
	GE effects		↑		↑	↑	↑			
	Changing business models									
Bank lending mediated by profits	Risk bearing		↓	↓				↓	↓	
	Balance sheet constraints				↑	○	○			
	Reaching for yield									
Bank lending not mediated by profits	Opportunity cost of lending		↑	↑						
	Funding rate					↑	↑			
	Deposit supply						○			↓
Aggregate channels	Intertemporal substitution	↑		↑		↑	↑	↓		
	Investment		↑	○	↑	○			↓	↓
	Signaling		↑	↑	↑	↑				
	Wealth effects									
	Exchange rate									
Overall:		↑	↑	↑	↑	↑		↓		

Notes: This table contains a classification of the theoretical negative-rates papers according to the channels that they incorporate. White means not active, green means active and positive, red means active and negative, orange means ambiguous. In order of appearance from left to right, the papers analyzed are Rognlie (2016); Ulate (2021b); Brunnermeier and Koby (2018); de Groot and Haas (2021); Onofri et al. (2021); Wang (2019); Eggertsson et al. (2019); Balloch and Koby (2019); Kumhof and Wang (2020). Papers denoted with an asterisk do not actually analyze negative nominal interest rates per se, but analyze the effects of low rates that are close to zero. The "overall" row refers to whether a cut in the policy rate during a recession starting from a zero policy rate is stimulative for output. No overall result is displayed for the papers with an asterisk, because they do not actually analyze negative nominal interest rates.

they feature prominently in the empirical literature. By contrast, most theoretical papers have incorporated either a risk bearing or balance sheet channel that constrains lending if profits decrease. However, since in several of the papers the direction of profits is ambiguous, it is unclear in which direction the risk bearing and balance sheet channels go. In some papers, like Ulate (2021b), Balloch and Koby (2019), and Eggertsson et al. (2019), the baseline calibration indicates that bank profits fall, constraining the lending ability of banks through the risk bearing channel. In Brunnermeier and Koby (2018), the overall effect on bank profitability depends on the level of the interest rate, and this can lead to an increase or decrease in bank lending via the risk bearing channel. In de Groot and Haas (2021) and Onofri et al. (2021), the models follow Gertler and Karadi (2011), so it is the balance sheet channel that relates profitability to lending. In particular, banks in the model of de Groot and Haas (2021) end up with higher equity after negative rates are implemented (due to a strong capital-gains channel), which means they can obtain more deposits from households and intermediate more loans.

Differences in how lending channels not mediated by profits operate across theoretical negative rates papers have generated a substantial amount of the differences across these papers. In theoretical models with monopoly power like Ulate (2021b) and Brunnermeier and Koby (2018), banks hold excess reserves. This links the opportunity cost of making a loan to the rate on excess reserves and leads to a fall in the loan rate after negative rates are implemented, stimulating lending. In papers without excess reserves stemming from monopoly

power, the funding rate determines the lending rate. If the funding rate is stuck at zero, like in Eggertsson et al. (2019) or de Groot and Haas (2021), then the lending rate does not fall when negative rates are implemented. In Onofri et al. (2021), banks can fund themselves using bank bonds that follow the policy rate into negative territory, which allows the funding rate, and hence the lending rate, to fall. Finally, the deposit supply channel plays an important role in papers like Wang (2019) or Kumhof and Wang (2020).

Negative-rates papers have also differed in their assumptions regarding aggregate transmission channels. In Eggertsson et al. (2019), negative rates can only affect the economy to the extent that banks change their lending rates and this leads borrowers to spend more or less via the intertemporal substitution channel. None of the investment, signaling, wealth-effects or exchange-rate channels are present. Since in the main calibration, banks are negatively affected and less able to lend, the intertemporal substitution channel has a contractionary effect on the economy. By contrast, the intertemporal substitution channel stimulates the economy in other papers. In Rognlie (2016) there are no banks, and the policy rate directly affects the Euler-equation interest rate, so negative rates lead to more contemporary consumption and stimulate the economy. In Onofri et al. (2021), households can not only invest in deposits, whose rate cannot fall below zero, but also in shares of investment funds, whose return can be negative, restoring the stimulative impact of the intertemporal substitution channel.

Beyond the intertemporal substitution channel, many negative-rates papers incorporate capital in the production function of firms, and therefore allow for effects via the investment channel. In papers like Ulate (2021b) and de Groot and Haas (2021), the bank-based lending rate falls after negative rates are implemented, and firms then invest more. In Brunnermeier and Koby (2018) or Onofri et al. (2021) this can also occur, but it depends on whether banks are positively or negatively affected by negative rates. By contrast, in Balloch and Koby (2019) or Kumhof and Wang (2020), the bank-based lending rate increases when close-to-zero rates are implemented, and this negatively impacts the economy. In both Brunnermeier and Koby (2018) and Balloch and Koby (2019), firms can borrow from non-bank sources, which introduces the possibility that a fall in the policy rate stimulates investment even if the bank-based lending rate does not move (or even increases).[23]

The third channel that has been prominently incorporated in theoretical negative rates papers is the signaling channel. This is the main element featured in de Groot and Haas (2021), and it is more generally present in models that use Taylor rules with a smoothing coefficient, such as Ulate (2021b), Brunnermeier and Koby (2018), and Onofri et al. (2021). Other channels related to wealth effects and exchange rates have generally not been incorporated in theoretical negative-rates models but are realistic and, if considered, are likely to increase the effectiveness of negative rates (especially because these channels are not likely to be impaired in negative

[23]However, this does not finally materialize in Balloch and Koby (2019) because the real rate does not change when negative nominal interest rates are implemented.

territory).

There are also some important differences across papers regarding the type of shock that generates the impetus for lower policy rates. This is important, because the effects of a monetary policy shock in these models – that are not necessarily log-linearized – depend on the state of the economy. Therefore, the type of shock hitting the economy is a relevant consideration for lending, output, and – most importantly – the welfare implications of negative rates. To see why this is the case, note that if a non-monetary shock generates a recession that requires an expansionary monetary policy environment, lowering the policy rate into negative territory could benefit the economy. By contrast, if a monetary policy shock puts the economy in close-to-negative territory, a further lowering of the policy rate is not likely to improve welfare.[24]

In Ulate (2021b), the recession analyzed is generated by a capital efficiency shock that has long-lived consequences. In de Groot and Haas (2021), Eggertsson et al. (2019), and Onofri et al. (2021), either risk-premium or discount-rate shocks generate relatively brief recessions. In Brunnermeier and Koby (2018), Wang (2019), and Kumhof and Wang (2020) a monetary policy shock hits the economy. In Balloch and Koby (2019) there is a change in the inflation target that generates a different required nominal rate to maintain a constant real interest rate. Finally, in Rognlie (2016) there is an unspecified shock that leads the economy to have a negative natural real rate, and hence also a negative nominal rate (steady state inflation is zero).

In summary, theoretical general-equilibrium negative rates papers have differed in various ways. In terms of bank profitability they have generally incorporated a negative deposit margin channel, a positive capital gains channel, and sometimes positive general equilibrium effects. On balance, most have found detrimental effects for banks but a minority has found beneficial ones. Since the balance of effects on bank profitability is theoretically ambiguous, the effects on bank lending through profits are also theoretically ambiguous (albeit mostly negative). The effects on bank lending not mediated by profits are one of the main points of contention. Papers incorporating excess reserves and monopoly power (i.e., Ulate, 2021b; Brunnermeier and Koby, 2018) or those that "reactivate" the funding rate channel (i.e., Onofri et al., 2021) have found greater efficiency. Finally, regarding aggregate transmission channels, the intertemporal substitution and signaling channels have typically been found to be stimulative, the investment channel has been mixed, and the remaining channels have not been incorporated yet.

Overall, the majority of the theoretical negative rates papers (specifically, Ulate, 2021b; Brunnermeier and Koby, 2018; Rognlie, 2016; de Groot and Haas, 2021; Onofri et al., 2021) find that a temporary policy rate cut into negative territory to fight a recession can be effective. Specifically, we mean by this that a cut in the policy rate starting from a level of zero percent – pursued temporarily to fight a recession – has stimulative effects. Eggertsson et al. (2019) is the exception that finds such a cut to be contractionary. Importantly, even the papers that find

[24] This is formally true if the model under consideration has the feature that the steady state policy rate maximizes welfare in the absence of shocks.

stimulative effects starting from a policy rate level of zero percent, indicate that this effectiveness can wane or even reverse as rates become more negative or more time is spent in negative territory. Taken together, this evidence implies that negative rates are a valuable tool that central banks should not discard outright, but also that they need to be deployed carefully. It is important to notice that most theoretical papers reach the cautiously positive conclusion described above even though they do not incorporate some aggregate transmission channels that are likely to increase the effectiveness of negative rates (e.g., exchange-rate and wealth-effects channels) and even though they mostly include the negative effects on bank profitability that have been documented by the empirical negative-rates literature.

It is important to note that things labeled "channels" in other papers can be seen as a combination of simpler channels in the framework that we have developed in this paper. For example, what is called the "contractionary bank net worth channel" in Ulate (2021b) is a combination of what in this paper we have called the deposit margin channel of bank profitability, the risk bearing channel of bank lending mediated through profits, and the investment channel. Similarly, the "bank lending channel" described in Eggertsson et al. (2019) is a combination of what in this paper we have called the deposit margin and capital gains channels, the risk bearing channel, and the intertemporal substitution channel. In this paper, we opted to be as granular as possible in our classification of channels so we could more easily categorize the empirical and theoretical papers within a unified framework.

An ideal theoretical general equilibrium model of negative rates would incorporate a realistic banking sector with monopoly power (which has been widely documented) and excess reserves that captures most of the aforementioned banking channels and calibrates them from the data. Similarly, such a model would incorporate all the aggregate transmission channels mentioned in Section 4 in realistic ways. Such a model would be rich enough to allow for beneficial or detrimental negative rates depending on parameter values and the state of the economy. Incorporating underexplored channels like the exchange-rate and wealth-effects channels would probably increase the effectiveness of negative rates in such a model. Similarly, "reactivating" the intertemporal substitution channel by allowing households to save in non-deposit instruments, or the investment channel by allowing firms to borrow from non-bank sources, would also increase the effectiveness of negative rates (as in Onofri et al., 2021).

6 Other issues

For completeness, we now briefly discuss some theoretical papers that have not been previously mentioned, but nevertheless contain additional observations or contributions relating to negative rates. We also discuss some practical issues regarding the implementation of negative rates that we think are important to keep in mind. These practical issues include the

persistence of low-rate environments and central banks' long-run objectives, reserve remuneration, interactions with unconventional monetary policy, and financial system fragility.

On the theory side, Stettler (2020) uses loss aversion to explain the observed transmission pattern of near-zero policy rates to deposit rates. Loss aversion refers to a household's higher sensitivity to losses than to gains. In the model put forth in that paper, two banks that compete for deposits and value them for their future revenue potential – originating from deposit stickiness – could endogenously maintain their deposit rates at zero even after the policy rate goes negative. Since loss aversion could be more pronounced among individuals with less market experience, this suggests that the extent of the deposit margin channel may be tied to country-level measures of financial sophistication. It also provides a specific microfoundation for the deposit rate setting behavior of banks beyond market power, which if accurate could imply different calibration strategies in quantitative models and ultimately different estimates of the effectiveness of negative rates.

Tractability and calibration remain challenges in mapping empirical data to general equilibrium settings. To this end, Ulate (2021a) introduces two models in which one can obtain non-unitary pass-through from the policy rate to loans and deposit rates – even before negative rates are implemented – without having to assume a finite number of banks. Models that obtain non-unitary pass-through while assuming a finite number of banks are more common, e.g. Drechsler et al. (2017), Wang et al. (2019), Kurlat (2019), or Balloch and Koby (2019). The models in Ulate (2021a) instead deliver non-unitary pass-through while assuming a continuum of banks, which is a feature that can allow models to remain tractable and sidesteps the need to calibrate the "number of banks" in the economy.

As we have highlighted previously, one important consideration when assessing the effectiveness of negative rates is whether they are implemented as a temporary or permanent measure. As a temporary expansionary measure taken by a central bank to fight a transitory shock, interest rates are expected to revert to a higher level after some time. In contrast, if nominal interest rates fall in response to declines in the long-run real interest rate, or lower inflation, the nominal policy rate may be expected to remain low in the long run, and perhaps permanently. As a low or negative interest rate environment persists, the expansionary effects of interest rate cuts may be more limited, for two potential reasons. First, prices are flexible in the long run, so monetary policy (including negative rates) stops having stimulative effects. Second, the capital gains that banks experience after a cut in the policy rate are transitory.

The effects of permanently lower interest rates have implications for central banks' long run objectives, in particular the optimal rate of inflation, because different inflation levels directly correspond to different levels of the nominal rate for a given real rate. Presumably, the real interest rate is outside of the control of the monetary authority. Hence, in the long run, the optimal inflation target is intrinsically linked to the effects of different nominal rates. If lower steady state nominal rates are harmful for the economy, perhaps a higher inflation target is

warranted, as shown in Wang (2019) and Balloch and Koby (2019).

There are other relevant considerations impacting the effectiveness of NNIR. Central banks can establish an exemption threshold below which reserves at not charged. This can change commercial bank behavior, by modifying the marginal rate on reserves, while cushioning the impact on bank profitability. Balloch and Koby (2019) theoretically examine this policy and find that it can mitigate some of the negative effects of deposit margin compression on bank profitability. Most central banks with a negative policy rate have implemented some form of reserve tiering policies. Empirically, Fuster et al. (2021) and Altavilla et al. (2022) also emphasize reserve tiering. In related theoretical work, Boutros and Witmer (2020) point out that if there is a tiered remuneration system for reserves where thresholds are allowed to vary with the cash withdrawals of commercial banks (for example, as implemented in Switzerland), the rate on reserves can be effectively divorced from the yield on cash. This is relevant because it indicates that the central bank might be able to lower the rate on reserves below the physical lower bound – at least temporarily – to fight a recession.

More broadly, the interactions between negative rates and other unconventional monetary policies remains an important topic. In this spirit, Sims and Wu (2021) study three different types of unconventional monetary policies – quantitative easing, forward guidance, and negative rates – in a unified framework. The authors emphasize that quantitative easing, by leading to a larger central bank balance sheet, could make negative rates less effective because commercial banks are more severely affected. These findings are echoed by de Groot and Haas (2021) and Bittner et al. (2021). By contrast, Girotti et al. (2021) study the interaction between quantitative easing policies and negative rates empirically, and argue that there might be complementarities between them (likely driven by the opportunity cost of lending channel).

Finally, there are ancillary concerns regarding the impact that negative interest rates may have on financial system functioning and fragility. Darracq et al. (2020) uses a Gertler and Karadi (2011)-style framework to analyze the interaction of negative rates with macro-prudential policies. In this framework, maintaining macro-prudential policy in normal times that increases bank capitalization can lower the reversal rate, giving the central bank more room to use negative rates in recessions. This highlights a concern that is implicit to the overall detrimental bank-profitability effects found in empirical and general equilibrium work: negative rates may lead banks to fail. Consequently, the balance of monetary and financial stability objectives involves careful consideration.

One particular concern for the implementation of negative rates in the U.S. is the prominence of money market funds in short term funding markets. A roughly five trillion dollar asset class in the U.S., money market funds are a critical source of savings and funding, as well as short-term cash management. The design of money market funds aims to provide both stability and liquidity, a notion that was called into question in both 2008 and 2020. Historically, money market funds have been viewed as retaining at least nominal $1.00 net asset values (NAVs),

and money market investors are generally considered to be very averse to losses. Reforms introduced in the U.S. during 2016 moved some funds to "floating" net asset values, and allowed funds greater flexibility in charging fees or delaying redemptions via "gates." These changes are now being reviewed in light of the incentives they appeared to provide in early 2020 to redeem even earlier than other investors. In Europe, money market funds initially dealt with the impact of negative rates through share cancellations while maintaining stable NAVs, and then shifted to floating NAVs following a regulatory ruling in 2018. The latest proposed changes to the functioning of U.S. money market funds discussed in SEC (2021), already incorporate some provisions in case negative rates are implemented, including guidance for affected funds to convert from stable NAVs to floating NAVs. It remains to be seen whether U.S. investors would adapt similarly to changes in the functioning of money market funds brought about by the potential implementation of negative nominal interest rates.

As mentioned in the introduction, retaining a clear view of the three concepts of zero, effective, and physical lower bounds remains crucially important. Brandao-Marques et al. (2021), for instance, use the term effective lower bound to refer to the threshold at which there would be a switch to cash. Given the nomenclature introduced in this paper, we find it more appropriate to call this threshold the physical lower bound. Other papers use the term effective lower bound but ultimately assume its level is zero without any justification. Making clear distinctions between zero, effective, and physical lower bounds should be encouraged, unless there is a strong empirical argument that their levels coincide. While this coincidence is theoretically possible, for the reasons explained in this paper, our view is that it is unlikely. We believe the effective lower bound is likely to be below zero in most advanced economies, with the physical lower bound further below.

7 Conclusion

In this paper, we have considered the many channels through which negative nominal interest rates affect banks in theory, studied to what extent there is empirical evidence in support of these channels, analyzed what additional aggregate transmission channels may influence outcomes, and discussed how this all adds up in general equilibrium. Some broad conclusions can be drawn, and there are several areas in which improvement is certainly needed and where we see scope for future work.

On bank profitability, the effects of negative interest rates are theoretically ambiguous but empirical studies generally find that the impact is negative. This is mainly due to declining deposit margins, which quantitatively seem to outweigh the positive impact of capital gains, general equilibrium effects, and changing business models. Capital gains and general equilibrium effects are likely to benefit banks mostly in the short run, and the scope for banks to

increase their profitability through adjustments in their business model seems to be limited in practice. Consequently, the overall effect of negative interest rates on profitability appears to worsen over time, as deposit margins remain compressed.

Yet, bank lending does appear to increase in the short run in response to monetary accommodation, even when interest rates are in negative territory. This appears to be driven by the opportunity cost of lending channel, in which loan rates are driven down directly by the lower return earned on excess liquidity, as well as by reaching for yield, in which banks seek out riskier asset mixes to earn higher returns. Evidence suggests this is neither a universal outcome, nor one that can be relied on over protracted periods of negative nominal interest rates. Several papers highlight the potential for the expansionary effects to diminish over time, or potentially even to reverse due to the eventual relative strength of the risk-bearing channel or balance-sheet constraints.

Aggregate transmission channels are central to understanding the overall effectiveness of negative rates, and sometimes to interpreting the empirical results on bank profitability and lending. Traditional channels considered in modeling the effectiveness of monetary policy – intertemporal substitution, investment, and the signaling channel – all remain relevant in negative rates environments, although the latter is exclusively expected to be stronger in negative than positive territory. Both the intertemporal substitution and investment channels may weaken in negative territory. Household wealth effects and exchange rates are both potentially important areas through which negative rates may have a particularly positive impact, but have yet to be incorporated in general equilibrium analysis.

The main conclusions drawn so far from general equilibrium models of the effectiveness of negative nominal interest rates have been – for the most part – positive. By combining various subsets of the aforementioned channels, and with varied calibrations and shocks, most papers find that there are still significant benefits to interest rate cuts in negative territory, in that they can stimulate the economy. This is in spite of excluding several channels that are likely to provide additional expansionary effects, which is encouraging. Yet, it is generally acknowledged that effectiveness can wane or even reverse as rates become more negative, or more time is spent in negative territory. Overall, this implies not only that negative rates are a valuable tool, but also that care should be taken in their implementation.

Several areas of work related to the theoretical basis for deposit spreads and the practical implications of negative rates for central bank policy have been explored. We see these as important topics that should remain in the focus of researchers. There is also room, we believe, for improvement along several margins. For empirical work, there could be better identification of specific channels, in particular as further data becomes available on ex-post measures of risk. On the theoretical side, many channels that exist are not yet incorporated into general equilibrium models, and it remains to be seen to what extent they affect the estimates of the overall effectiveness of negative nominal interest rates, and the design of optimal policy.

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