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FINANCIAL INNOVATION, PAYMENT CHOICE AND CASH DEMAND – CAUSAL EVIDENCE FROM THE STAGGERED INTRODUCTION OF CONTACTLESS DEBIT CARDS

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Financial Innovation, Payment Choice and Cash Demand – Causal Evidence from the Staggered Introduction of Contactless Debit Cards[*]

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Abstract

We examine how an innovation in payment technology impacts on consumer payment choice and cash demand. We study the staggered introduction of contactless debit cards between 2016-2018. The timing of access to the contactless technology is quasi-random across clients, depending only on the expiry date of the existing debit card. Our analysis is based on administrative data for over 21'000 bank clients and follows a pre-analysis plan. Average treatment effects show that the receipt of a contactless card increases the use of debit cards especially for small-value payments. However, we find only a moderate average reduction in the cash share of payments and no reduction of average cash demand. Treatment effects on payment choice are strongest among consumers with an intermediate pre-treatment use of cash. Explorative analyses reveal that effects are largely driven by young consumers in urban locations.

Keywords: Financial innovation, cash, money demand, payment choice, pre-analysis plan.
JEL Codes: E41, G20, O33, D14

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"The only thing useful banks have invented in 20 years is the ATM" — Paul Volcker, 2009

1. Introduction

Over the past decades, the introduction of ATMs, debit and credit cards or online-banking have revolutionized the way consumers pay for goods and services. Understanding how these significant innovations in retail payment technology affect money demand has been of first-order interest to monetary policy makers. First, changes in the structure of money demand impacts on the welfare costs of inflation (Attanasio et al. 2002, Alvarez and Lippi 2009). Second, the stability of money demand impacts on the optimal choice of a nominal anchor, i.e. the targeting of inflation as opposed to monetary aggregates (Mishkin 1999).

While previous innovations in payment technology may have altered the structure of money demand, they did not question the existence of physical central bank issued money, i.e. cash. Today, cash still accounts for a significant share of payment transactions in most advanced economies (Bagnall et al. 2016). However, this may be about to change. Recent innovations of contactless, mobile and instant payments are widely believed to be "game changing" with a higher potential of making cash obsolete.[2] A marked decline in cash demand – as has been observed e.g. in Sweden or Norway – poses two novel and important challenges to central banks[3]: First, most central banks are mandated to guarantee a safe and accessible payment system to consumers and firms. General accessibility to the payment system may be undermined if cash is no longer a universal means of payment. In addition, the overall stability of the payment system may be undermined in the event of a systemic shock to the electronic payment system. Second, in a cashless society, consumers no longer have access to an alternative safe and liquid asset in times of distress to the banking sector. For these reasons, many central banks are today contemplating

[2] The development of private digital currencies is also challenging the role of central bank issued money. A significant decline in money demand due to the use of private digital currencies have major consequences for the conduct of monetary policy, the provision of credit and liquidity to the private sector, financial stability (see e.g. Brunnermeier et al. 2019, Friedman 2000, Schilling and Uhlig 2019, Woodford 2000).

[3] The value share of cash transactions in Sweden declined from about 60% in the year 2000 to about 10% recently. Cash in circulation in percent of nominal GDP has steadily trended downwards from 3% in the year 2000 to less than 2% in 2018 (Engert et al. 2019). Two-thirds of Swedish consumers say that they can manage without cash (Sveriges Riksbank 2017). In many other countries, e.g. Canada, the U.K., Denmark, cash use declined but cash demand remained stable or even increased.

the introduction of electronic cash substitutes, i.e. central bank digital currencies (Bindseil 2020, Brunnermeier and Niepelt 2020).

Are recent digital payment innovations accelerating the move to a cashless society? We provide causal evidence on how an innovation in payment technology impacts on payment choice and cash demand. We study the staggered introduction of contactless debit cards in Switzerland. The timing of access to the contactless technology is quasi-random across clients, depending only on the expiry date of the existing debit card. Our analysis is based on administrative data for over 21'000 bank clients. For these clients we observe account-level information including point of sale (PoS) payments by debit card as well as cash withdrawals from ATMs and bank branches, over the period 2015-2018. We group the sampled clients by the timing of receipt of a contactless debit card: *Early adopters* are clients who received a contactless card at the end of 2016, *Late adopters* are clients who received the card at the end of 2017, and *Non adopters* are clients who did not receive a contactless card until end 2018. These three groups are similar with respect to pre-treatment socioeconomic characteristics as well as their pre-treatment payment and cash withdrawal behavior. Therefore, we can assign post-treatment differences in payment behavior and cash demand to the receipt of a contactless card.

Our focus on the contactless payment technology is well warranted: First, such payments are fast and convenient, especially for small value payments which typically have been the exclusive domain of cash.[4] Second, contactless payments have been growing strongly in almost all developed economies and empirical evidence indicates a concurrent decline in the use of cash (Doyle et al. 2017, Henry et al. 2018).[5] Third, the study of contactless payments is conceptually interesting because this technology lowers consumers' costs of card vis-à-vis cash payments while leaving cash withdrawal costs unchanged. Alvarez and Lippi (2017) suggest that cash may have been resilient to earlier financial innovations, like debit cards, because these innovations have often made both the card and the withdrawal technology more efficient such that relative costs of cash and cards may not have changed much.

[4] We will henceforth refer to Near-Field-Communication debit card payments as contactless payments or as NFC payments, neglecting that such payments are also possible by credit cards or mobile devices as these payments are of low quantitative significance in Switzerland.

[5] In Canada, the share of cash in terms of the number of transactions has decreased from 54% in 2009 to 33% in 2017 (Henry et al. 2018). In Australia, the respective case share has decreased from 69% to 37% within 10 years (Doyle et al. 2017). In both economies, contactless card payments have strongly increased.

Our analysis follows a pre-analysis plan (PAP) which has been registered and time-stamped at https://osf.io/scvbq/ before data delivery. In this plan we have pre-specified the hypotheses, the data cleaning and sample selection, the definition of outcome and explanatory variables, the econometric specification and statistical inference (Olken 2015).[6]

Our hypotheses are derived from Alvarez and Lippi (2017). Their model provides an ideal conceptual framework for our research as it integrates payment instrument choice (cash vs. cards) into an inventory model of cash-management. Within this framework, the introduction of contactless cards can be seen as a reduction in the relative costs of card versus cash payments. As a consequence, contactless cards should on average reduce (i) the cash share of payments, (ii) the frequency of cash withdrawals, and (iii) the average cash withdrawal amount.

We test these hypotheses by estimating a difference-in-difference model with staggered adoption (Athey and Imbens 2018). Our estimates control for client-level and location*year-level fixed effects. They thus account for differences in unobserved transaction costs and payment preferences across consumers as well as time-varying differences in the local payment infrastructure. Our estimates of average treatment effects offer three main findings. First, the receipt of a contactless debit card causes a sizeable increase in the use of debit cards (+8.6%, relative to the sample mean of 79 debit card transactions per year). Second, the contactless payment technology reduces the cash share of payments. However, given that contactless cards mainly increase small value debit card transactions, the impact on overall payment volume is modest (0.6 percentage points (pp) relative to the average cash share of 68%). Our data reveal a downward trend of 2 pp per year in the cash share of payments that is unrelated to the contactless technology. Contactless cards thus add about 30% to this downward trend. This result signifies the importance of causal inference as the decline in the use of cash could be misinterpreted as being mainly caused by concurrent contactless cards. Third, we find no measurable effect of the contactless payment technology on cash demand, i.e. the frequency of cash withdrawals, or the average cash withdrawal amount.

In a (pre-registered) test of heterogenous treatment effects we study the impact of contactless cards across consumers with varying pre-treatment payment behavior. Pre-treatment payment behavior varies strongly in our sample: One-quarter of the sample pays almost exclusively by cash, while

[6] The use of a PAP intends to eliminate biases arising from model selection as well as from the non-reporting of insignificant findings and should thus strengthen the credibility of results, in particular for proprietary data (Casey et al. 2012). While PAPs are common in randomized control trial studies, they are much less frequent in studies using observational data (Burlig 2018). We are unaware of other papers in the monetary economics and finance literature which are based on a PAP.

another quarter pays more by card than by cash. This variation in initial behavior partly reflects differences in local payment infrastructure as well as individual cash preferences related to e.g. budget monitoring, anonymity concerns, or habit. Our results show that the impact of contactless debit cards is particularly strong among consumers with an intermediate initial cash-share of payments.

In an exploratory analysis we study the impact of contactless cards on payment behavior by consumer age and rural vs. urban location. Our findings confirm previous evidence suggesting that younger consumers are more likely to adopt financial technology (see e.g. Yang and Ching 2013). However, we show that contactless cards only exert a strong causal effect on payment behavior among those younger consumers who reside in urban locations. This suggests that technology affinity per se does not drive the adoption of the contactless payment technology. Rather it is likely that local developments in the (contactless) payment infrastructure and / or salience of the new technology among young consumers are responsible for the observed effects on payment choice.

Our paper contributes to the literature on the transaction demand for money (e.g. Baumol 1952, Tobin 1956), as well as to the literature on payment choice (e.g. Whitesell 1989). Recent theoretical approaches account for the interrelatedness of both the transaction demand for money and payment choice (e.g. Alvarez and Lippi 2017). In these models, withdrawal costs, the cost of foregone interest and differences in the costs of using cash or cards jointly determine payment choice and cash demand. The empirical literature on payment choice and cash demand has established significant and persistent heterogeneities in the use of payment instruments across households which cannot be accounted for by observed differences in transaction costs (Schuh and Stavins 2010, Arango et al. 2015, Wang and Wolman 2016, Brancatelli 2019, Stavins 2017). Further models thus emphasize behavioral determinants of payment choice and cash demand, e.g. the role of payment choice for budget control (von Kalckreuth et al. 2014, Ching and Hayashi 2010).

We contribute to this literature in three important ways:

First, in line with the recent theory (Alvarez and Lippi 2017) we empirically test the implications of financial innovation in an inventory model which jointly analyzes payment choice *and* cash demand. By contrast the previous empirical literature mostly analyzes these aspects separately. Here, our analysis complements recent work by Briglevics and Schuh (2014). While those authors examine the dynamic (short-run) sequence of payments our analysis examines the reaction of payment choice and money demand to a change in payment technology.

Second, our research design allows us to provide causal estimates of the impact of payment innovation on payment choice and cash demand. Here, our study builds on previous analyses of payment innovations and money demand. Attanasio et al. (2002), Lippi and Secchi (2009) as well as Alvarez and Lippi (2009) examine how the diffusion of cash withdrawal points (ATMs) impacts on the cash demand of Italian households. More recently, Chen et al. (2017) and Trütsch (2016) use survey data to examine the impact of contactless cards and mobile payments on payment choice and cash demand in Canada and the U.S., respectively.[7] Compared to these papers, our research design allows to better disentangle the causal effect of payment innovation from (unobserved) variation in payment behavior across households and concurrent time trends in overall payment behavior.

Third, the administrative data at hand as well as our pre-analysis plan offer two methodological novelties to the empirical literature on money demand. The bank-account-level data allow us to measure both payment choice and cash demand using precise and reliable indicators at the consumer-level over a significant period of time.[8] The existing empirical literature is based either on survey data (e.g. Borzekowski and Kiser 2008; Koulayev et al. 2016; Schuh and Stavins 2009), payment diary data (e.g. Bagnall et al. 2016; Wakamori and Welte 2017) or grocery store scanner data (Klee 2008, Wang and Wolman, 2016; Brancatelli 2019). None of these sources provide precise measures of the use of cash and cards for payments and on cash demand by the same consumers over a long period of time. Moreover, our pre-analysis plan lends credibility to the empirical results based on this data, as our reported analysis adheres to a pre-specified choice of outcome variables, econometric specifications, and subsample splits.

[7] Bounie and Camara (2019) provide evidence on the real effects of payment innovation by estimating the effects of contactless card acceptance on the profits of French merchants.

[8] Magnac (2017) uses account data to study the effects of ATM withdrawal fees.

2. Research Design, Institutional Background and Hypotheses

2.1. Research Design

We study the staggered introduction of contactless debit cards (Maestro PayPass) by one medium sized bank ("the Bank") in Switzerland over the period 2016-2018.[9] Debit cards at the Bank are valid for three calendar years, expire in December and are automatically replaced two months earlier by new cards. Starting in late 2016 (for calendar year 2017), the Bank replaced conventional debit cards with new debit cards featuring the contactless NFC function. Our research design exploits the fact that the timing of access to this new payment technology depends solely on the expiry date of the previous card, and thus is arguably exogenous from the perspective of an individual bank client.

We observe payment behavior and cash withdrawal behavior from 2015 to 2018 for a random sample of clients who all hold a transaction account and a debit card with the Bank. Our treatment variable captures the timing of receipt of a contactless debit card. The structure of our data is that of panel data with staggered adoption as discussed in Athey and Imbens (2018). As illustrated by Figure 1, clients can be separated into three groups based on the expiry date of their existing debit card. Existing debit cards of *Early adopters* expire at the end of 2016 so that their new contactless card is valid from 2017. *Late adopters* have an expiry date of end 2017 so that their new contactless card is valid from 2018. The existing debit cards of *Non adopters* expire only at the end of 2018, the end of our observation period. We use data from 2015 to conduct balancing tests of outcome variables and covariates as well as to split the sample according to pre-treatment behavior.

--- Insert Figure 1 here ---

2.2. Institutional Background

In Switzerland, as in many other European countries, the payment card system is dominated by debit cards which can be used to withdraw cash from ATMs of any bank as well as to make PoS

[9] Our agreement with the Bank includes its anonymity. The account-level data which we receive were strictly anonymized.

payments.[10] When opening a transaction account, bank clients receive a debit card by default. In addition to a debit card, bank clients can further request a credit card subject to an annual fee.

The 2017 survey on payment methods confirms that the overwhelming majority of PoS payments by Swiss consumers are conducted in cash or by debit card (SNB 2018). By contrast, credit cards[11] are mostly used for online purchases or for specific transactions (e.g. travel expenses, durables). According to this survey, 45% of the value and 70% of the volume of consumer transactions in 2017 were paid in cash. This widespread use of cash is similar to that observed in Germany, Italy, Austria and other Euro area economies (see Bagnall et al. 2016, Esselink and Hernández 2017), and significantly above that in Australia, Canada or the UK, for example.[12] It is important to note that the use of cash seems to be governed by a strong cash preference and not by an underdeveloped card infrastructure network. In 2018, Switzerland had 40 PoS terminals per 1,000 inhabitants, which compares with 39 in Australia, 38 in Canada and 41 in the United Kingdom.[13]

The period we study marks the widespread introduction of contactless debit cards in Switzerland. The share of debit cards featuring the NFC technology was 10% at the end of 2015, 28% in 2016, 51% in 2017 and 71% at the end of 2018.[14] While the density of PoS terminals changed little over our sample period, the share of PoS terminals which accepted contactless cards increased from 25% in 2015 to 62% in 2018.[15] In our analysis we control for time-varying heterogeneities in local payment infrastructure by employing location*year fixed effects.

2.3. Hypotheses

We derive our empirical predictions from the theoretical model of Alvarez and Lippi (2017). This model integrates payment instrument choice into an inventory model of money demand. The model thus allows us to make predictions about how the introduction of contactless cards impacts

[10] Bank clients in our sample do not have to pay fees for ATM withdrawals, regardless of whether the withdrawal occurs at an ATM from a different bank.

[11] The vast majority of credit cards are “delayed debit cards”, i.e. card balances have to be paid off in full at the end of the billing period.

[12] The volume share of cash was 37% in Australia 2016 (Doyle et al., 2017) and 33% in Canada in 2017 (Henry et al. 2018).

[13] BIS (CT14B: Number of terminals per inhabitant, https://stats.bis.org/statx/srs/table/CT14b).

[14] Section 2 in the PAP summarizes the dissemination of NFC debit and credit cards and presents evidence on the share of payment instruments. A significant share of credit cards already featured a contactless payment function prior to the beginning of our observation period. However, as mentioned above, credit cards are hardly used for PoS payments in Switzerland (SNB 2018).

[15] Comparable data on contactless terminals are not available for Australia, Canada or the UK.

both on payment choice and cash demand. In the model, consumers can either make payments in cash or with cards. Cash is obtained by ATM withdrawals which can be free or costly, e.g. due to transaction fees or shoe-leather costs. Card payments always involve costs, which can either be transaction fees or the time-cost of transactions relative to cash.[16] In equilibrium, consumers either (i) use cash only or (ii) they act as *cash burners*; i.e. they use cards only when they run out of cash.[17] The model assumes a representative agent, and thus does not explore heterogeneities in payment behavior and cash demand across households. However, it is straightforward to assume that the relative cost of cash versus card payments varies across consumers depending on individual behavioral traits (budget monitoring) or the local payment infrastructure.

Within the Alvarez and Lippi (2017) framework, the introduction of contactless cards can be interpreted as a reduction in the relative costs of card payments, with cash withdrawal costs remaining constant. This implies that for all consumers who initially use cash and cards (i) the cash share of payments should decline, (ii) the average withdrawal amount should decline, (iii) the frequency of (free) ATM withdrawals should remain unaffected,[18] and (iv) the average demand for cash should therefore decline. The model further predicts that some cash-only consumers start using card payments after the introduction of contactless cards.[19] These consumers should hence reduce their number of (costly) cash withdrawals such that their overall number of withdrawals should decline.

Based on the above predictions we establish two main hypotheses for the average treatment effect of the introduction of contactless debit cards:

[16] Studies which measure the time to conduct transactions show that contactless card payments are 10 to 20 seconds below those of PIN-based card payments (Kosse et al. 2017, Polasik et al. 2010). Cash is slightly faster than contactless card payments.

[17] Consumers continue to use cash despite their ownership of cards because they have a certain number of "free" withdrawals whereas card transactions always involve "costs". The model predicts that consumers only use cards when they run out of cash which they previously withdrew at no cost. This prediction is not entirely borne out by empirical evidence. One possible reason for consumers using cards despite the availability of cash is that they want to retain cash for future purchases (c.f. Briglevics and Schuh, 2014 or Huynh et al., 2014).

[18] In this model cash-burning consumers (who use both cash and cards) do not make costly ATM withdrawals as such withdrawals are strictly dominated by cashless payments which are always possible. In the data, we presume that costly ATM withdrawals may exist also for cash-burning consumers as cards are not always accepted which could trigger a costly withdrawal. A reduction in the costs of card payments would not affect the frequency of costly withdrawals if they arise from the non-acceptance of cards.

[19] The threshold costs of withdrawals ($\underline{b}$) decreases. Thus, some consumers should move from cash-only use to cash-card use.

H1: Contactless debit cards and payment choice: The contactless payment technology reduces the use of cash as a means of payment.

H2: Contactless debit cards and cash demand: The contactless payment technology reduces the demand for cash, i.e. the frequency and the average size of cash withdrawals.[20]

For some consumers, the shift in relative costs may not be large enough and hence one might not observe a change in payment choice and cash demand. Such a prediction would be supported by behavioral models which suggest persistent heterogeneities in cash preference, e.g. due to the valuation of anonymity, budget monitoring or habit (e.g. Kahn et al. 2005, von Kalckreuth et al. 2014). Thus, we expect significant heterogeneity in the effect of the introduction of contactless cards on payment choice and cash demand across consumers which is systematically related to consumers' pre-treatment behavior: Consumers who previously only used cash are least likely to react to the payment innovation.

In our test of heterogenous treatment effects we thus predict that the magnitude of the casual effect of contactless cards is systematically related to past payment behavior:

H3: The role of past payment behavior: The impact of the contactless payment technology on cash usage and cash demand differs according to the pre-treatment use of cash. The impact should be stronger for consumers with a low pre-treatment use of cash than for consumers with a high pre-treatment use of cash.

The Alvarez and Lippi (2017) framework suggests that the demand for cash is affected by local payment infrastructure: localities with weak PoS terminal infrastructure and high density of withdrawal opportunities should feature more cash-only consumers.[21] This suggests that a reduction in the relative costs of debit card payments will have heterogenous treatment effects on payment choice and cash demand depending on the locally available payment infrastructure. In our pre-analysis plan we established a hypothesis (H4) that the effect of contactless cards on payment choice and cash demand should be stronger in locations with more PoS terminals and

[20] We focus on the frequency of withdrawals and on the average withdrawal amount as we do not observe average cash balances.

[21] See also Hyunh et al. (2014) or Arango et al. (2015) who find that payment choice decisions and cash holding decisions are affected by the availability of payment terminals.

fewer ATMs. Due to the unavailability of data on the location of PoS terminals we cannot test this hypothesis. [22]

Our conjecture is that access to the contactless payment technology reduces cash demand as consumers increasingly use debit cards for small-value, contactless-eligible payments. [23] In order to shed light on the mechanism behind the effect of the contactless payment technology on payment choice and cash demand we will explore the following auxiliary hypotheses:

H5: The contactless payment technology increases the number of small-value PoS payments (0-20 CHF) relative to all card-based PoS payments.[24]

H6: The contactless payment technology increases the number of medium sized cashless PoS payments which are eligible for the contactless technology (20-40 CHF) relative to medium sized cashless PoS payments which are not eligible for the contactless technology (40-60 CHF).

3. Data and Methodology

3.1. Sample

Our data is based a random sample of retail clients (private individuals only) of the Bank with a transaction account and at least one debit card in 2015.[25] We obtained data on 30,000 randomly drawn clients holding 30,330 accounts and 33,165 debit cards. We apply a series of restrictions to this raw sample (see Appendix A1). First, we restrict our main analysis to the overwhelming majority of clients with one account and one card only (90%=26,934 clients).[26] Second, we

[22] We collect publicly available data on the number of ATMs, population size and settlement area (km^2) for each municipality relevant to our sample. We hand collected information on ATM locations from an ATM locator webpage: https://www.mastercard.ch/de-ch/privatkunden/services-wissenswertes/services/bankomaten-suche.html as per March 2020. As discussed in detail below we define 22 locations of residence for our sample based on the local economic region (MS-region) and municipality size the consumer lives in. The data reveals that the density of the ATM-network varies from 0,29 to 1,02 per 1'000 inhabitants across our 22 locations. This compares well to the national average of 0.84 per 1'000 inhabitants (see section 2.2). Unfortunately, comparable public information on the location of PoS terminals is not available.

[23] In Switzerland contactless payments (without the typing of a PIN code) are possible for amounts up to 40 CHF.

[24] Payment diary survey data suggests that in Switzerland roughly 20% (40%) of all payments feature a value in the range of 0-5 CHF (5-20 CHF) and that more than 90% (80%) of these payments are conducted in cash (SNB 2018).

[25] The PAP details the sampling, e.g. the sample was drawn only among *active* accounts, i.e. accounts with at least 1200 CHF of incoming payments in 2015 and accounts with at least 1200 CHF of cash withdrawals or debit and credit card payments in 2015.

[26] In the PAP, we planned to include accounts with multiple cards in our sample and we described how we will handle the case of accounts with multiple debit cards (and possibly, different expiry dates). In the sample, we found out that

exclude all debit cards which experience irregular changes in the expiry date during our observation period. Irregular changes in expiry dates may occur because a card is lost or stolen or if a client demands a change of his/her card, e.g. because he/she wishes (earlier) access to the contactless technology. This results in 24,021 clients of which 22,504 have complete information on covariates. Finally, we exclude clients whose incoming or outcoming account flows are less than 1,200 CHF or more than 500,000 CHF in any year. The final sample comprises 21,122 clients, of which 8,487 are *Early adopters*, 6,150 are *Late adopters* and 6,485 are *Non adopters*.[27]

We aggregate the account-level data from a monthly to an annual frequency to account for seasonalities in payment behavior and cash demand, e.g. due to festivities or holidays. We thus obtain a balanced panel of client*year data with four observations per client *i* for periods *t= 2015, 2016, 2017, 2018* for a total of 84,488 client*year observations. As illustrated by Figure 1, our main analysis is based on a sample of 63'366 observations for the period 2016-2018. Table A2 presents the definition of all variables used in our analysis. Tables 1 and 2 present pre-treatment summary statistics and balancing tests based on the 2015 data.

3.2. Outcome Variables

As specified in our pre-analysis plan, we study three primary outcome variables which are each measured at the client*year level**.**

Our first outcome variable *Cash ratio* measures the share of annual payments (in CHF value) paid in cash. The value of total payments made in cash is hereby proxied by the total value of cash withdrawals. The total value of non-cash payments is proxied by the sum of PoS debit card payments and total credit card payments from the account.

$$Cash\ ratio\ (\%) = \frac{Value\ in\ CHF\ of\ Cash\ Withdrawals}{Value\ in\ CHF\ of\ [Cash\ withdrawals + Debit\ PoS\ payments + Credit\ card\ payments]}$$

26,923 out of 30,000 accounts (90%) have just one card (see Table A1). Therefore, we focus our analysis on accounts with one card and present robustness checks for accounts with multiple cards.

[27] The separation of clients into the three groups is not fully balanced as there was an irregular renewal of cards by the Bank in 2010 so that some cards were replaced even though they did not expire in that year. As a result, a disproportionate share of clients belongs to the early adopter group (i.e. they received a new card in 2010, in 2013 and in 2016). Importantly, this does not affect the exogeneity of the timing of access to contactless cards. However, it does explain why some covariates (e.g. age) do not fully balance across the groups of *Early, Late, and Non adopters* (see Table 2, Panel B).

We study two measures of cash demand which are central to inventory models. First, we measure the *Cash withdrawal frequency* which captures the total annual number of cash withdrawals from ATMs or from bank branches. Second, we measure the average *Cash withdrawal amount* (in CHF) as:

$$Cash\ withdrawal\ amount = \frac{Value\ in\ CHF\ of\ Cash\ withdrawals\ from\ ATMs\ or\ bank\ branches}{Number\ of\ Cash\ withdrawals\ from\ ATMs\ or\ bank\ branches}$$

The variable $Cash\ ratio$ proxies the value share of PoS payments which are made in cash. *Cash ratio* has the important advantage to be based on a precise measure of cash withdrawals from both ATMs and bank counters, which is difficult to obtain in survey data due to people's limited recall. However, the variable is also subject to measurement error arising from several sources: First, consumers may use other payment methods for PoS payments that are not covered in the denominator of $Cash\ ratio$ (e.g. mobile payments or gift cards). Evidence from payment survey data (SNB 2018) suggests, however, that this is rarely the case for PoS transactions. Second, credit card payments might include non-PoS transactions (e.g. online purchases). Again, payment diary data (SNB, 2018) suggest that this source of measurement error is small relative to the sum of cash, debit and credit transactions. Third, consumers may withdraw cash to conduct non-PoS payments (payment of recurring bills) or to hoard cash. According to SNB (2018) less than 20% of Swiss households report that they withdraw cash to pay bills or to store it. Although this might seem non-negligible, we note that the separation between cash withdrawn for transaction or for hoarding purposes is not straightforward conceptually and practically (i.e. for survey participants) as cash might be stored for ensuing purchases. Our annual aggregation of data alleviates this problem to a large degree.[28] More importantly, our panel data allows us to control for idiosyncratic – time invariant – patterns in the use of credit cards or cash for non-PoS transactions. Finally, we provide robustness tests with several alternative definition of *Cash ratio* (excluding credit cards, including e-banking payments, focusing only in domestic transactions, see Appendix A4).

The variables $Cash\ withdrawal\ frequency$ and $Cash\ withdrawal\ amount$ both proxy for the transaction demand for cash. Both variables are also subject to measurement error if consumers make withdrawals to hoard cash. SNB (2018) report that the vast majority of surveyed households

[28] The fact that cash withdrawals might also contain hoarding can also be seen as an advantage as central banks are interested in the overall demand for cash (transaction balances, precautionary balances, hoarding, etc.).

withdraw cash to make PoS payments. And, our panel data allows us to control for idiosyncratic, time invariant, patterns in cash hoarding with client-level fixed-effects.

Note that all three of our outcome variables might additionally be subject to measurement error as they may not capture all cash, debit card and credit card transactions of the households in question. In particular, this could arise if households use other current accounts (of the Bank or another bank) to conduct cash withdrawals and PoS payments we will not observe their entire payment behavior and cash demand. Survey data suggests that less than half of all Swiss households hold transaction accounts at multiple banks (Brown et al. 2020). Our account-level fixed effects also allow us to control for time-invariant variation in the use of accounts in our sample for transaction purposes.

To examine the mechanism by which the contactless payment technology affects cash use and cash demand we study six auxiliary outcome variables. These measure the frequency of *Debit PoS transactions* in total as well as by transaction size (0-20 CHF: 20-40 CHF; 40-60 CHF; 60-100 CHF; more than 100 CHF). While we do observe debit card transactions by size, we do not observe whether a debit card payment employed the contactless (NFC) technology. However, the use of the contactless feature can be inferred indirectly by separately analyzing debit card payments according to their eligibility for no PIN contactless payments (up to 40 CHF).

--- Insert Table 1 about here ---

Panel A of Table 1 presents descriptive statistics for all outcome variables based on pre-treatment (2015) observations. The table documents the importance of cash as a means of payment in our sample. The median *Cash ratio* is 78%, while the interquartile range spans 52%-96%. Thus, only one quarter of the consumers in our sample pay more with cards than they do with cash, while another quarter pay almost exclusively in cash.[29] The median of *Cash withdrawal frequency* is 39 while that of *Cash withdrawal amount* is 344 CHF, implying that the average consumer in our sample makes less than 1 cash withdrawal per week and withdraws an amount equal to roughly 258 CHF per week. A closer look at the data reveals that median number of withdrawals from ATMs (36) by far outweighs that from bank branches withdrawals (1). By contrast the median size

[29] The ratio is higher than in SNB (2018), because the latter study includes payments via bank transfer in the denominator. If we include bank transfer payments that are conducted via e-banking, we obtain a cash share of 51% (see the robustness tests in Appendix A4).

of withdrawals from ATMs (270 CHF) is significantly lower than that from bank branches (1625 CHF). The median number of *Debit PoS transactions* is 36 in 2015, while the interquartile range spans from 6 to 95. Thus, the average consumer in our sample uses the debit card only 3 times per month, while one quarter of our sample use the debit card at most every second month. The average consumer in our sample rarely uses the debit card for small-value transactions: The median number of debit transactions below 20 CHF is only 2 (!) per year in 2015. These descriptive statistics confirm the presence of pronounced heterogeneities in payment behavior that have also been noted in other studies (e.g. Attanasio et al 2002, Bagnall et al. 2016, Koulayev et al. 2016).

3.3. Methodology

The structure of our data is that of *panel data with staggered adoption* as discussed in Athey and Imbens (2018). Defining $t \in \{2016, 2017, 2018\}$ as our observation periods and $a \in \{2017, 2018\}$ as the possible adoption dates during this observation period we can identify three relevant groups of clients in our sample (see Figure 1): *Early adopters* are those clients who have a debit card which expired at end 2016 and thus adopt the contactless payment technology as per the beginning of 2017. For these clients we have adoption date $a_i = 2017$. *Late adopters* are those clients who have a debit card which expired at end 2017 and thus adopt the contactless payment technology at the beginning of 2018. For these clients we have $a_i = 2018$. *Non adopters* are those clients who have a debit card which expires at end 2018 and thus do not adopt the contactless payment technology during our observation period. In line with the notation of Athey and Imbens (2018) these clients have $a_i = \infty$.

We define $Y_{i,t}(a)$ as the potential outcome (cash use or cash demand) of client *i* in period *t* conditional on the adoption date *a*. We can define $\tau_{t;a,a'} = E\left[Y_{i,t}(a)\right] - E\left[Y_{i,t}(a')\right]$ as the treatment effect of adopting the technology in period a instead of period a' on outcome in period *t*. In this framework, the treatment effect of adoption may depend on (i) which pair of adoption dates we are comparing (a, a') and (ii) the period for which we are measuring outcomes (t).

Given our empirical setting, there are three separate treatment effects of particular interest:

- Early adoption vs. Non adoption on outcomes in 2017: $\tau_{t=2017;a=2017,a'=\infty}$
- Early adoption vs. Non adoption on outcomes in 2018: $\tau_{t=2018;a=2017,a'=\infty}$

- Late adoption vs. Non adoption on outcomes in 2018: $\tau_{t=2018;a=2018,a'=\infty}$

One may also be interested in the effect of early adoption vs. later adoption on outcomes in 2018: $\tau_{t=2018;a=2017,a'=2018}$. This can be calculated from $\tau_{t=2018;a=2017,a'=\infty}$ - $\tau_{t=2018;a=2018,a'=\infty}$.

Following Athey and Imbens (2018) we will consider a difference-in-difference (DiD) estimand τ estimated by the following regression:

[1] $$Y_{i,t} = \beta_i + \beta_t + \tau \cdot A_{i,t} + \varepsilon_{i,t}$$

where $Y_{i,t} \in \{Cash\ ratio_{i,t}, Cash\ withdrawal\ frequency_{i,t}, Cash\ withdrawal\ amount_{i,t}\}$ and $t \in \{2016, 2017, 2018\}$. In this regression β_i , β_t are client and year fixed effects respectively. $A_{i,t}$ is set to 1 for all accounts *i* in period *t* which have already adopted the technology, i.e. $a_i \leq t$ (and 0 otherwise). Athey and Imbens (2018) show that under the assumption of random assignment of adoption and no anticipation effects the DiD estimator $\hat{\tau}$ is a weighted average of the three causal treatment effects of interest listed above ($\tau_{t=2017;a=2017,a'=\infty}$; $\tau_{t=2018;a=2017,a'=\infty}$; $\tau_{t=2018;a=2018,a'=\infty}$).

Our observation of pre-adoption realizations ($t < a_i$) of the outcome variables allow us to verify the assumption of no anticipation. In particular we can compare the $Y_{i,t} \in \{Cash\ ratio_{i,t}, Cash\ withdrawal\ frequency_{i,t}, Cash\ withdrawal\ amount_{i,t}\}$ by adoption date $a_i \in \{2017, 2018, \infty\}$ for the period $t \in \{2015\}$. Panel B of Table 1 presents summary statistics for all outcome variables by treatment groups. The table displays similar pre-treatment payment behavior and cash demand across the three groups.

Our administrative data provides us with a broad set of socioeconomic and account-level covariates measured as per December 2015 (see Appendix A2, Panel B for details). Table 2 (Panel B) presents balancing tests for all covariates which allow us to verify the assumption of randomized adoption. While t-tests indicate statistically significant differences for some covariates across the treatment groups, the magnitude of these differences is negligible for most variables. We thus argue that our data largely meet the assumptions of randomized adoption as well as no anticipation.

--- Insert Table 2 about here ---

Our DiD estimator $\hat{\tau}$ provides us with a measure of the "average" effect of contactless debit cards on subsequent payment and cash holding behavior during our observation period. However, as discussed above this estimator is a weighted average of three separate treatment effects: $\tau_{t=2017;a=2017,a'=\infty}$, $\tau_{t=2018;a=2017,a'=\infty}$ and $\tau_{t=2018;a=2018,a'=\infty}$.[30]

To better understand the dynamics of this treatment effect we will explore the heterogeneity of the three individual treatment effects by running the following regression:

[2] $$Y_{i,t} = \beta_i + \beta_t + \tau_{2017,2017} \cdot A_{2017,2017} + \tau_{2017,2018} \cdot A_{2017,2018} + \tau_{2018,2018} \cdot A_{2018,2018} + \varepsilon_{i,t}$$

where $Y_{i,t} \in \{Cash\ ratio_{i,t}, Casg\ withdrawal\ frequency_{i,t}, Cash\ withdrawal\ amount_{i,t}\}$ and $t \in \{2016, 2017, 2018\}$. In this regression β_i , β_t are again individual and time fixed effects respectively. $A_{2017,2017}$ is set to 1 for all observations in period $t \in \{2017\}$ of clients who adopted the technology in 2017 (and 0 otherwise). $A_{2017,2018}$ is set to 1 for all observations in period $t \in \{2018\}$ of clients who adopted the technology in 2017 (and 0 otherwise). $A_{2018,2018}$ is set to 1 for all observations in period $t \in \{2018\}$ of clients who adopted the technology in 2018 (and 0 otherwise).

3.4. Inference

Our null-hypotheses suggest no effect of the contactless payment technology on the outcome variables *Cash ratio*, *Cash withdrawal frequency* and *Cash withdrawal amount*. Our statistical inference is therefore based on two-sided tests of the DiD estimators $\hat{\tau}$ in regression equations [1] and [2]. The DiD estimation of the treatment variable τ is based on data at the client*year level which includes multiple pre-treatment and post-treatment observations per account. We therefore account for potential serial correlation in the outcome variable and its effect on the standard error of our estimate for the treatment variable $\hat{\tau}$ (see Bertrand et al. 2004). We do so by adjusting standard errors for clustering at the client-level.

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[30] Athey and Imbens (2018) show that two key assumptions are required for these treatment effects to be homogenous $(\tau = \tau_{t;\, a,a'} \forall t, a, a')$. The first assumption is history invariance, i.e. the treatment effect for period *t* is independent of adoption period *a*, i.e. $Y_{i,t}(1) = Y_{i,t}(a)\ \forall\ \alpha \leq t$. The second assumption is constant treatment effect over time, i.e. the treatment effect of adoption period α is identical for all subsequent periods, i.e. $Y_{i,t}(a) - Y_{i,t}(\infty) = Y_{i,t'}(a) - Y_{i,t'}(\infty)\ \forall\ t, t' \geq \alpha$. In our setting neither of these assumptions are likely to hold as it is very likely that the treatment effect of contactless debit cards on payment behavior and cash demand is dynamic within subject.

We account for multiple hypothesis testing (three primary outcome variables) by adjusting our inference tests according to the Bonferroni method (see Olken, 2015). Thus, to reject either of our null-hypotheses at the 5% level we require the estimated coefficient of our treatment variables $\hat{\tau}$ in equations [1] and [2] to be significant at a level of $p<0.0167$.

4. Average Treatment Effects

4.1. Debit Card PoS Transactions

Panel A of Figure 2 depicts the average number of debit card, PoS transactions by treatment group over the period 2015 - 2018. The figure documents an increase in the number of debit card transactions for all groups during our period of interest. The increase for the group of *Non adopters* documents that even without access to the contactless payment technology there is a strong upward trend in the use of debit cards for PoS transactions. The average number of transactions per year increases for this group by 7.5% in 2016, 6.3% in 2017 and 8.4% in 2018. By comparison, however, the growth rate for debit card PoS transactions of *Early adopters* increases after they receive a contactless card (at the end of 2016) from 10.5% in 2016 to 14.2% in 2017 and 14.8% in 2018. Similarly, the growth rate for debit card PoS transactions of *Late adopters* increases after they receive a contactless card (at the end of 2017) from 9.1% in 2016 and 8.2% in 2017 to 17.9% in 2018. Panel B of Figure 2 shows that these effects are even more pronounced for transactions with a value below 20 CHF (see Appendix A3 for larger transaction amounts).

--- Insert Figure 2 about here ---

Our visual inspection in Figure 2 suggests a strong causal effect of the contactless payment technology on the use of debit cards for PoS payments. This finding is confirmed by the regression estimates presented in Table 3. The column 1 results show that the use of debit cards increases by 6.8 transactions on average per year after the receipt of a contactless card. [31] This average treatment

[31] Note that we apply standard critical values for parameter tests in Table 3, because the dependent variable does not belong to the group of primary outcome variables.

effect amounts to an 8.6% increase relative to the sample mean of 79 transactions. The bulk of this increase occurs for small transaction values: 4.9 transactions per year for amounts below 20 CHF (column 2) and 1.1 transactions per year for amounts between 20 and 40 CHF (column 3). In relation to the baseline sample mean, the increase declines from 21% for transactions up to 20 CHF to 6.1% for transactions between 20 and 40 CHF.

As we observe debit card transactions by amounts, we can test whether contactless cards trigger increases in (contactless) debit card payments also for amounts above 40 CHF still requiring the introduction of the PIN. Such effects would arise if consumers start to more frequently use their debit card through comfort-with technology effects or learning, for example. The results of Table 3, columns (4-6) suggest that these spillover effects are present for payment amounts beyond 40 CHF, although they are considerably weaker than for smaller payment amounts. For example, the relative increase in card use is just 1.8% for transactions larger than 100 CHF (relative to the sample mean).[32] Overall, the Table 3 results confirm our auxiliary hypotheses: The receipt of a contactless debit card increases the number of small-value debit card transactions relative to all such transactions (Hypothesis 5). Also, the receipt of a contactless card increases the number of medium-sized debit card transactions which are eligible for the contactless technology relative to medium transactions for which a PIN has to be entered (Hypothesis 6)

--- Insert Table 3 about here ---

4.2. Payment choice and cash demand

Access to the contactless payment technology increases the use of debit cards for PoS payments. But to what extent does this payment innovation decrease the cash share of payments and cash demand? Figure 3 illustrates the impact of the contactless payment technology on our primary outcome variables; the *Cash ratio*, the *Cash withdrawal frequency*, and the *Cash withdrawal amount*. The figure provides two key insights. First, we observe a significant trend decline in the cash ratio and the number of cash withdrawals from 2015 to 2018, while there is no change in the

[32] The quantitative impact on the number of payments should not be mistaken with the impact on cash use as a small increase of higher value payments may have a bigger effect on cash use than a larger increase of small value payments. In fact, a back-of-the-envelope calculation shows that the increase in debit card payments up to 40 CHF exerts a similar decrease in cash use as the increase in debit card payments of more than 40 CHF.

average size of cash withdrawals. Second, while there does appear to be a steeper decline of the *Cash ratio* for *Early adopters* and *Late adopters* than for *Non adopters*, the effect seems less substantial than observed in Figure 2 for debit card transactions.

--- Insert Figure 3 about here ---

Table 4 presents our estimates of the average treatment effect of the contactless payment technology on cash use and cash demand. The column 1 results indicate that contactless cards cause a decline in the *Cash ratio* by -0.6 pp per year. This amounts to an average annual treatment effect of -0.9% relative to the mean cash ratio of 68.1% in our sample for the period 2016-2018. This modest decrease fits well to the Table 3 results on debit card payments. Although the causal increase in debit card transactions is substantial, the overall number and value of such transactions is low. This implies that even a significant increase in the number of debit card transactions leads only to a small decline in the cash share of payments. The column (1) regression results also reveal a trend decrease in the cash ratio of -1.5 pp from 2016 to 2017 and -2 pp from 2017 to 2018. Thus, the causal effect of contactless cards per year is less than one-third of the annual trend. Columns (3) and (5) of Table 4 summarize the findings regarding cash demand. We find no significant effect of contactless cards on the *Cash withdrawal frequency* or *Cash withdrawal amount*.

Our main estimates in columns (1, 3, 5) of Table 4 are based on the regression specification in equation [1] including client and year fixed effects. This specification accounts for any time-invariant heterogeneity in the access to local payment infrastructure across households. As the timing of access to contactless cards is largely orthogonal to household characteristics, including the place of residence (see Table 2), it is very unlikely that our estimates are biased by unobserved heterogeneity in the development of local payment infrastructure. This is confirmed by our estimates in columns (2, 4, 6) of Table 4. There we additionally include location*year fixed effects to account for time-varying heterogeneity in local payment infrastructure.[33] Our estimates of the causal effect of contactless cards on the *Cash ratio*, *Cash withdrawal frequency*, and *Cash withdrawal amount* are unaffected.

[33] For reasons of data-protection we do not observe the exact zip-code / municipality of clients. See section 5 for a detailed discussion of how we define location based on available information on region of residence and municipality size.

--- Insert Table 4 about here ---

As discussed in section 3.3 on methodology, the average treatment effect estimates presented in Table 4 are a weighted average of three distinct treatment effects; the treatment effect on *Early adopters* in 2017, the treatment effect on *Early adopters* in 2018, and the treatment effect on *Late adopters* in 2018. In Table 5 we present separate estimates of these three treatment effects based on regression equation [2]. The results confirm our main findings from Table 4: While contactless cards impact on the *Cash ratio* we find no treatment effect at all on *Cash withdrawal frequency* or *Cash withdrawal amount*. Interestingly, Table 5 shows that the average treatment effect of contactless cards on the *Cash ratio* is largely driven by the impact on *Early adopters* and *Late adopters* in 2018. By contrast the impact on *Early adopters* in 2017 is small and statistically insignificant. It appears that the initial impact of contactless debit cards on *Early adopters* was muted - either due to lack of salience of the new payment technology or a lack in access to corresponding payment infrastructure. To sum up, the average treatment effects confirm Hypothesis 1 as a negative impact of contactless debit cards on *Cash ratio* indicates a reduced use of cash as a means of payment. By contrast, we do not find evidence for our second hypothesis, that the contactless payment technology reduces the demand for cash as *Cash withdrawal frequency* and *Cash withdrawal amount* remain unaffected.

--- Insert Table 5 about here ---

5. Heterogenous Treatment Effects

Given that Table 4 and 5 document an average treatment effect for *Cash ratio* only, we focus our analysis of heterogenous treatment effects on this outcome variable. Theory suggests that cross-sectional differences in payment behavior across households may result due to transaction costs (Alvarez and Lippi 2017) as well as persistent differences in cash preferences due to budget monitoring (von Kalckreuth et. al. 2014), habit (van der Cruijsen et al. 2017) or preferences towards anonymity (Kahn et al. 2005). As a consequence, we hypothesize that the impact of contactless payment technology on cash use and cash demand will be related to pre-treatment

payment behavior. In particular, Hypothesis 3 suggests a stronger effect of contactless cards among those consumers who already frequently use non-cash payment technologies.[34]

We split our sample into four groups which correspond to four quartiles of the pre-treatment *Cash ratio,* as measured in 2015. Note from Table 1 (Panel B) that this pre-treatment level of cash use is all but identical across our three treatment groups (*Early adopters*, *Late adopters*, *Non adopters*). We expect that the treatment effect of contactless cards on the *Cash ratio* should be smaller for consumers with a higher pre-treatment cash use. As predicted, the groups of consumers with the highest pre-treatment cash use (columns 3 and 4 in Table 6) reveal the lowest (relative) treatment effect. In these groups contactless cards lead to a statistically insignificant reduction of the *Cash ratio* by 0.35 pp, compared to a pre-treatment level of more than 78%. Interestingly, the group of consumers who used cards most intensively before treatment (column 1) also reveal a low and insignificant treatment effect. In this group, contactless cards lead to a reduction of the *Cash ratio* by only 0.17 pp, compared to a pre-treatment level of 35%. This insignificant treatment effect may indicate either demand-side saturation effects or supply side constraints.

Table 6 (column 2) documents a sizeable and significant treatment effect of contactless cards for the group with an intermediate pre-treatment cash ratio. In this group, contactless cards reduce the cash ratio by 1.3 pp per year compared to an average pre-treatment cash ratio of 60%. This finding suggests contactless cards may have the largest impact on card vs. cash payments among those clients who initially make regular, but few card payments. A closer look at the frequency of debit card payments for this group of clients supports this conjecture. In unreported regressions we replicate our Table 3 analysis only for this group of clients. In this group the average number of debit transactions increases from 94 in 2016 to 119 in 2018. The average treatment effect of contactless cards is estimated to be 9 transactions per year in this subsample. In line with the Table 3 findings, this treatment effect is mainly driven by debit card payments for small value transactions (below 20 CHF), where contactless cards lead to an increase by 6.3 transactions per year.

--- Insert Table 6 about here ---

[34] As noted in section 2.3. we cannot test Hypothesis 4 from our pre-analysis plan due to a lack of data on locations of PoS terminals.

In Table 7 we present an explorative (not pre-registered) subsample analysis. Here we examine whether the treatment effect of contactless debit cards on *Cash ratio* differs by location (urban vs. rural) and age of consumers. Survey evidence shows that the payment behavior of consumers within Switzerland varies cross-sectionally both by age and location (SNB 2018). There are many reasons why this may be the case: Local payment infrastructure (PoS terminals vs. ATMs) and thus relative transaction costs of cards vs. cash for the same type of purchases may differ between urban and rural areas. Individual consumption behavior (types of goods and services purchased, timing of purchases) may differ by age group, so that differences in payment infrastructure across types of purchases would lead to differences in observed payment behavior. Differences in behavioral traits (budget monitoring), habits as well as network effects may also affect payment behavior across locations and age groups. If payment behavior differs cross-sectionally by location and age-group it is also plausible that we could see a heterogenous impact of a change in payment technology on this behavior. Young and urban consumers may be more likely to adopt the contactless payment technology than older consumers in rural areas.

Based on our administrative data we split our sample by three, similarly sized age groups: less than 35 years old, 35-55 years and above 55 years. We also split our sample, by whether the client resides in an urban or rural area. For reasons of data-protection we do not observe the zip-code of clients. We do, however, observe the local economic region (MS-region) as well as the size (number of inhabitants) of the municipality in which the client resides (0-5'000; 5'001-10'000; 10'001-20'000; 20'001-50'000; more than 50'000). Crossing this information, we can distinguish 22 locations based on a combination of the local economic region and the size of the municipality within that region that the client resides in. We collect publicly available data on population size and settlement area (km^2) for each municipality relevant to our sample. Aggregating this information for each location we obtain a measure of population density per region.[35] We categorize locations with a population density of more (less) than 3'000 inhabitants per km^2 as urban (rural).

Table 7 presents our subsample estimates for the impact of contactless cards on *Cash ratio* by age and location. The results are striking. First, we observe that the cash share of payments depends strongly on client age, but hardly on client location. In urban locations the mean *Cash ratio* varies

[35] The data reveals that the population density varies from just under 1'500 inhabitants per km^2 to just over 4'500 inhabitants per km^2. The median population density is just under 3'000 inhabitants per km^2.

from 58% for consumers below 35 years to 66% for 35-55 year olds and 78% for clients above 55 years. The mean cash share of payments is almost identical by age group for clients in rural areas. Second, younger consumers exhibit a stronger trend decline in the cash share of payments than older consumers. And again the time trend per age-group is independent of urban vs. rural location. Consumers aged below 35 years display a decline in the *Cash ratio* by 3-4 pp per year in 2017 and 2018 compared to 2016. The trend decline for 35-55 year olds is 1-2 pp per year while it is roughly half a percentage point per year for clients above 55 years. Third, the causal impact of contactless cards on the *Cash ratio* is large and statistically significant only for young consumers in urban areas (column 1). In this subsample, the receipt of a contactless card reduces the *Cash ratio* by 1.25 pp per year. This effect is sizeable as it amounts to 2% of the subsample mean and more than one-third of the annual trend decline. By comparison, the estimate of the causal effect of contactless cards is smaller and statistically insignificant for young consumers in rural areas (column 4) as well as for older consumers (columns 2-3, 5-6).

What could explain that a substantial causal effect of contactless cards on payment choice is limited to young urban consumers? Previous studies suggest that young consumers are more likely to adopt new (financial) technologies due to lower resistance and greater ability to learn new technologies and a longer time horizon (see e.g. Yang and Ching, 2013). However, if affinity to new technology were the driving force in our case, we should observe a similar effect for all young consumers. After all, young consumers in rural areas display not only an identical level for the *Cash ratio* but also an identical time-trend as young consumers in urban areas. For the same reason, it seems unlikely that general changes in local payment infrastructure (e.g. self-checkouts in grocery stores) are the driver of our results. One potential driver may, however, be changes in payment infrastructure which are specific to contactless cards, i.e. the faster dissemination of NFC enabled terminals in urban areas. A further potential driver is a heightened awareness of the new payment technology and potential network effects among young urban consumers.

--- Insert Table 7 about here ---

6. Robustness tests

In accordance with our pre-analysis plan, we conduct a series of robustness tests. First, we replicate our main analysis from Table 4 applying alternative definitions of our primary outcome variables. The definitions and summary statistics of these alternative outcome variables as well as the corresponding regression results are provided in Appendix A4. We first alter our definition of *Cash ratio* to (i) omit credit card payments, (ii) include e-banking payments and (iii) focus only on domestic card transactions. These adjustments have no effect on the causal effect of contactless cards on cash use, qualitatively (Panel A, columns 1-3). We further alter our measures of *Cash withdrawal frequency* and *Cash withdrawal amount* to focus on ATM withdrawals only (columns 4-5) and on domestic transactions only (columns 6-7). Again, our baseline results of Table 4 are confirmed.

Second, we replicate regression equation [1] measuring the outcome variables not by calendar year, but from the month of November to the following month of October. This robustness test accounts for the fact that replacement debit cards are sent to clients 2 months prior to the expiry of their old card and can be used immediately after receipt. Appendix A5 presents regression estimates which confirm our baseline results from Table 4.

Third, we replicate our subsample analysis of Table 6 employing an alternative definition of pre-treatment payment behavior. Specifically, we separate clients according to their pre-treatment number of debit card transactions below 20 CHF. Again, our results are confirmed (see Appendix A6).

Next, we report on a placebo test to disentangle the effect of a new payment card per se from the effect of receiving a payment card with a contactless function. To this end we exploit the fact that our control group (*Non adopters*) receive a new payment card at the end of 2015 (valid from beginning 2016) but this card does not yet feature the contactless technology (see Figure 1). Our placebo test therefore compares the payment behavior of *Non adopters* to early and *Late adopters* over the period 2015:01 to 2016:12.

[4] $$Y_{i,t} = \beta_i + \beta_t + \tau_{placebo} \cdot New\ card_{i,2016} + \varepsilon_{i,t}$$

where

$$Y_{i,t}\begin{Bmatrix} Debit\ card\ use_{i,t}, Cash\ ratio_{i,t}, Cash\ withdrawal\ frequency_{i,t}, \\ Cash\ withdrawal\ amount_{i,t} \end{Bmatrix} \text{ and } t \in \{2015, 2016\}.$$

In this regression β_i , β_t are individual and time fixed effects respectively. $New\ card_{i,2016}$ is set to 1 for all individuals *i* of *Non adopters* in year 2016 (and 0 otherwise). Table A7 summarize the respective findings for the number of debit card transactions and the results suggest that *Non adopters* decrease rather than increase their use of debit cards after receipt of a new card. The respective results for our primary outcome variables are shown in Table A8. Reassuringly, the estimate of *New card* is insignificant in all specifications.

Finally, we replicate our analysis with a sample of clients which hold multiple debit cards. In this sample, we define treatment at the card level and not at the account level because expiry dates of cards might differ. Therefore, we can only conduct the analysis for the number of debit card transactions but cannot compute *Cash ratio* or withdrawal variables, which would require aggregation at the account level. Moreover, the number of observations (cards) in this sample is just 1,412 which limits the statistical power of our analysis. The respective results in Appendix A9 confirm, nevertheless, that small value card transactions strongly increase after the receipt of a contactless card.

7. Discussion

We study the causal effect of a payment technology innovation on payment choice and cash demand. We examine the staggered introduction of contactless debit cards in Switzerland over the period 2016-2018. We thus focus on an economy with a high level of financial development and a well-established payment infrastructure. Yet, like in many other European economies, Swiss consumers are strikingly cash intensive in their payment behavior. Studying how financial innovation affects payment behavior and money demand in cash intensive, advanced economies is important. The future use of cash as opposed to electronic private money, and hence the future design of the monetary system, will arguably be strongly influenced by these economies.[36]

Our analysis is based on account-level, administrative data for over 21,000 retail bank clients. The date at which these clients receive a contactless debit card the first time depends only on the expiry

[36] As a case in point, the Euro area, Japan and Switzerland account for roughly 40% of world currency in circulation. The card-intensive economies Australia, Canada, the UK, Sweden and Norway account for about 4% (own calculations). Even if we abstract from currency which is circulating abroad, the quantitative difference is large.

date of their previous card. Our results show that the introduction of contactless debit cards causes a strong increase in the use of debit cards at PoS. The impact on the cash-share of payments is weaker as the level of debit card payments is initially low and most additional debit cards payments are of small value. We find no effect of contactless cards on cash demand as measured by the frequency and average size of cash withdrawals.

Overall, our results document statistically significant effects of payment innovation on payment choice, but the economic magnitude of these effects are small. By comparison, our data reveal a strong decline in the use of cash which in descriptive analyses may be confused for a causal impact of recent payment innovations. This highlights the importance of disentangling causal effects of payment innovations from overarching trends in payment behavior

While the average treatment effect of contactless cards is underwhelming, our subsample analyses reveal substantial and informative heterogeneities across households: the impact of contactless cards is strongest among consumers with an intermediate cash share of payments. By contrast, the impact is negligible among extensive margin "cash lovers". Explorative analyses reveal that the impact of contactless cards on payment choice is largely driven by young consumers, but only those in urban locations. The latter finding suggests that recent payment innovations may accelerate the trend towards cashless transactions among technology affine consumers in locations with dense networks for cashless payments. By contrast, digital payment innovations may not trigger a widespread jump to a cashless society – at least in presently cash-intensive advanced economies.

Our findings speak to – and qualify – recent inventory theories of money demand which jointly model payment choice and cash demand (Alvarez and Lippi, 2017). First, our data reveal that a financial innovation may impact differently on payment choice and cash demand. While payment choice reacts to payment innovations, the frequency and average amount of cash withdrawals does not. In cash-intensive economies, even a strong increase in cashless payments - especially for small value transactions – has a limited impact on aggregate cash demand. We suspect that this low sensitivity of cash demand is related to the exceptionally low interest rates. Second, our results reveal significant and persistent heterogeneities in payment choice across consumers which can hardly be explained by variation in local payment infrastructure and corresponding transaction costs. Thus, it appears that habit and / or behavioral motives may exert a stronger impact on payment choice and cash demand than is typically assumed in inventory models.

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Figure 1. Research Design

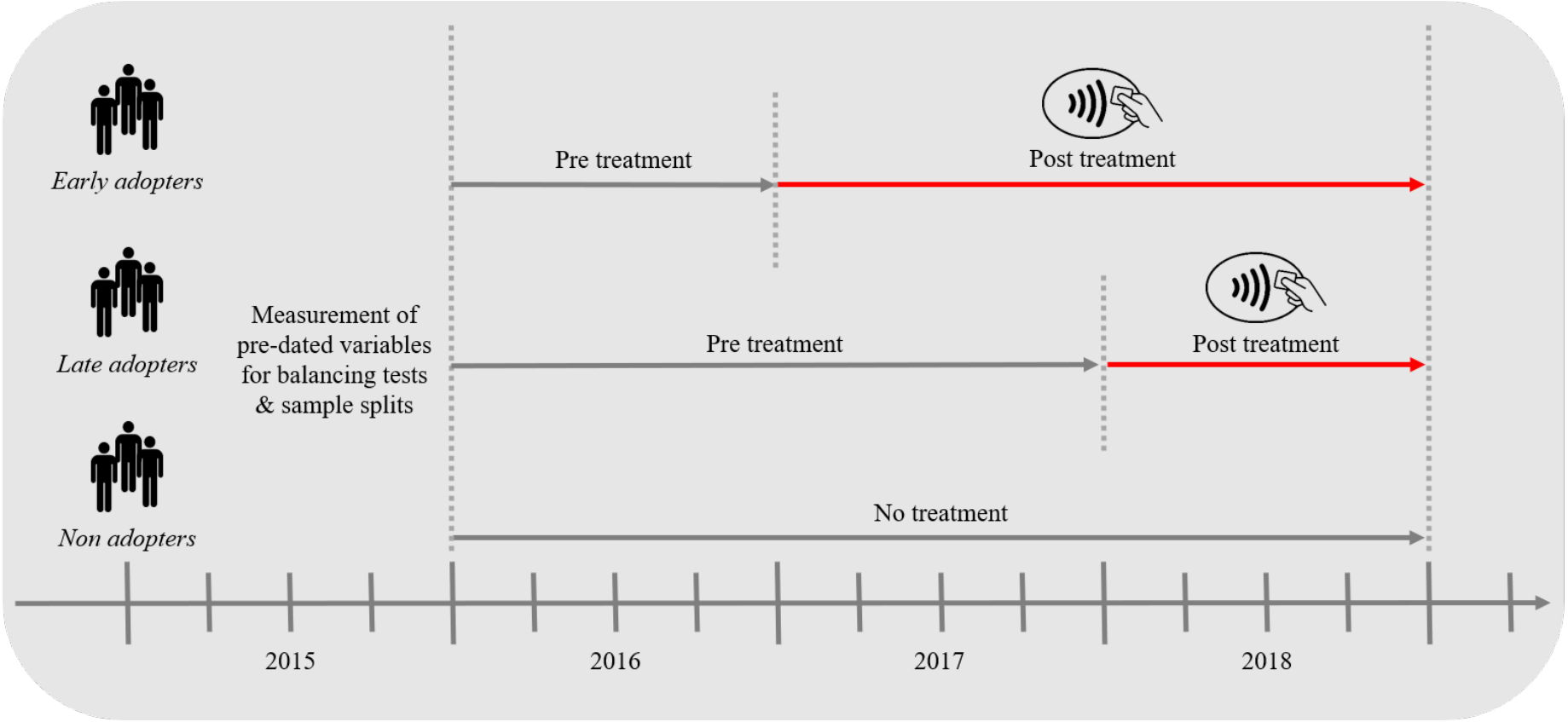
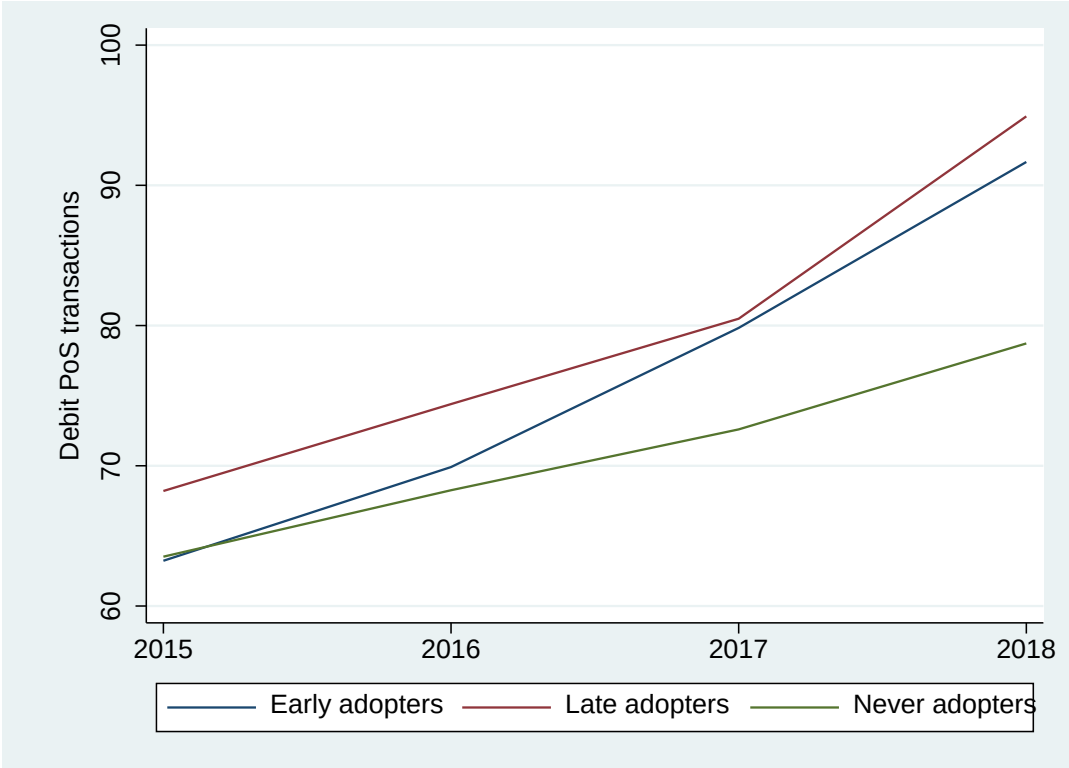


Figure 2. Debit Card PoS Transactions

This figure displays the average number of Point of Sale (PoS) transactions conducted by debit card per client and year by treatment group. Panel A displays the total number of PoS debit card transactions. Panel B displays the number of transactions with a value of at most 20 CHF. Appendix A2 presents definitions of all variables. Table 1 presents pre-treatment (2015) summary statistics.

Panel A- Total number of transactions



Panel B. Transactions below 20 CHF only

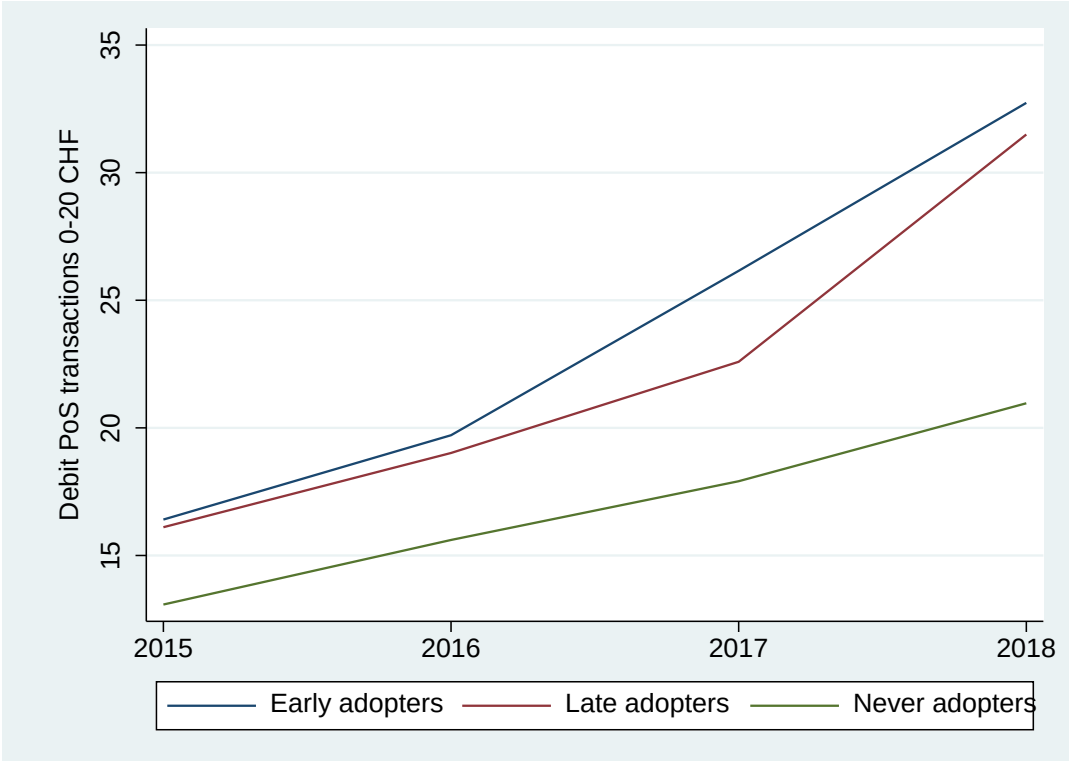
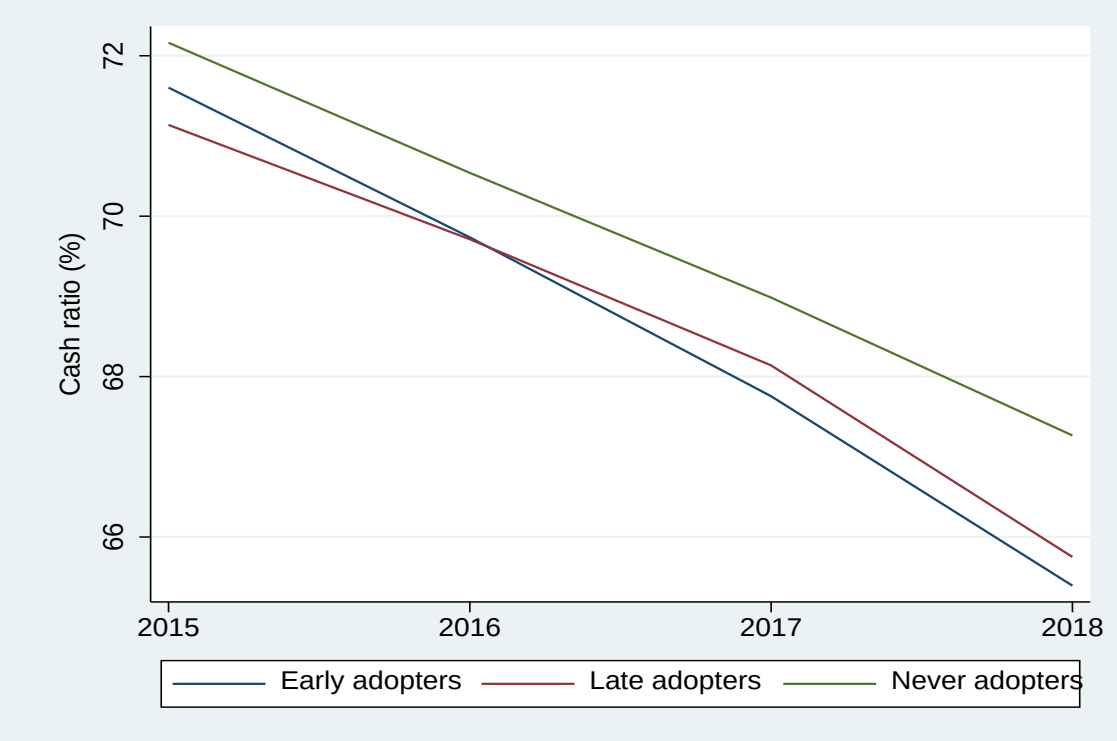


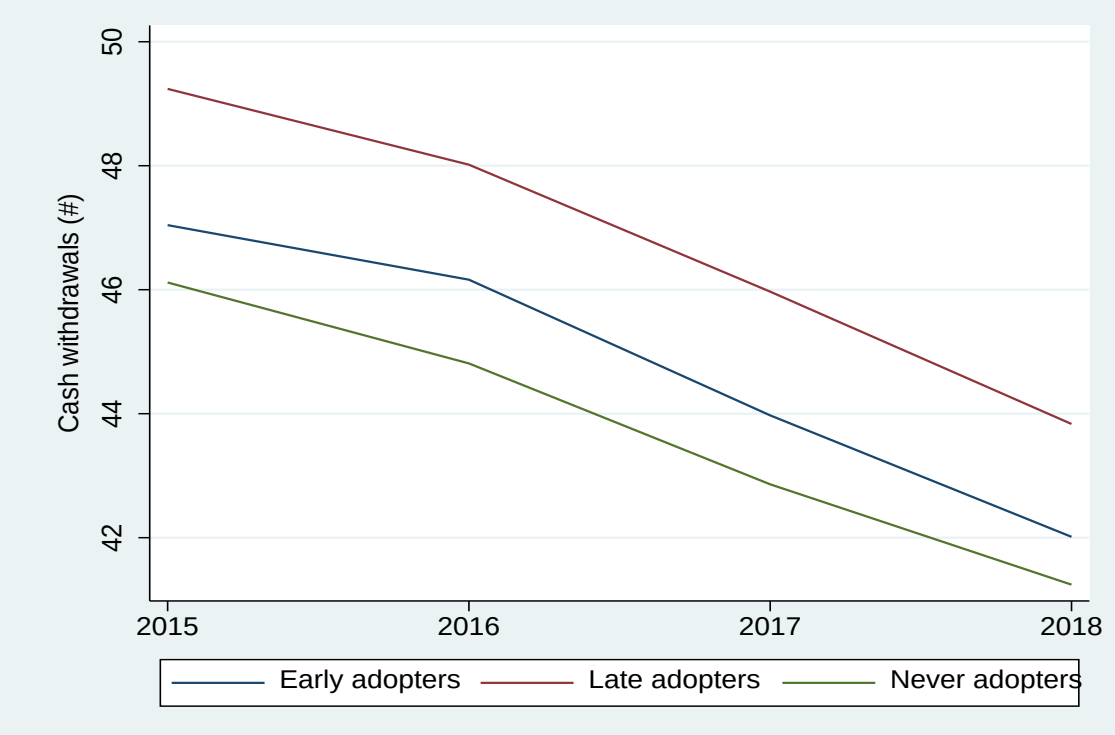
Figure 3. Payment choice and Cash demand

This figure displays the payment choice and cash demand per client and year by treatment group. Panel A displays the cash ratio of payments in %. Panel B displays the number of cash withdrawals. Panel C displays the average size of cash withdrawals in CHF. Appendix A2 presents definitions of all variables. Table 1 presents pre-treatment (2015) summary statistics.

Panel A- Cash ratio (%)



Panel B. Cash withdrawal frequency



Panel C. Cash withdrawal amount

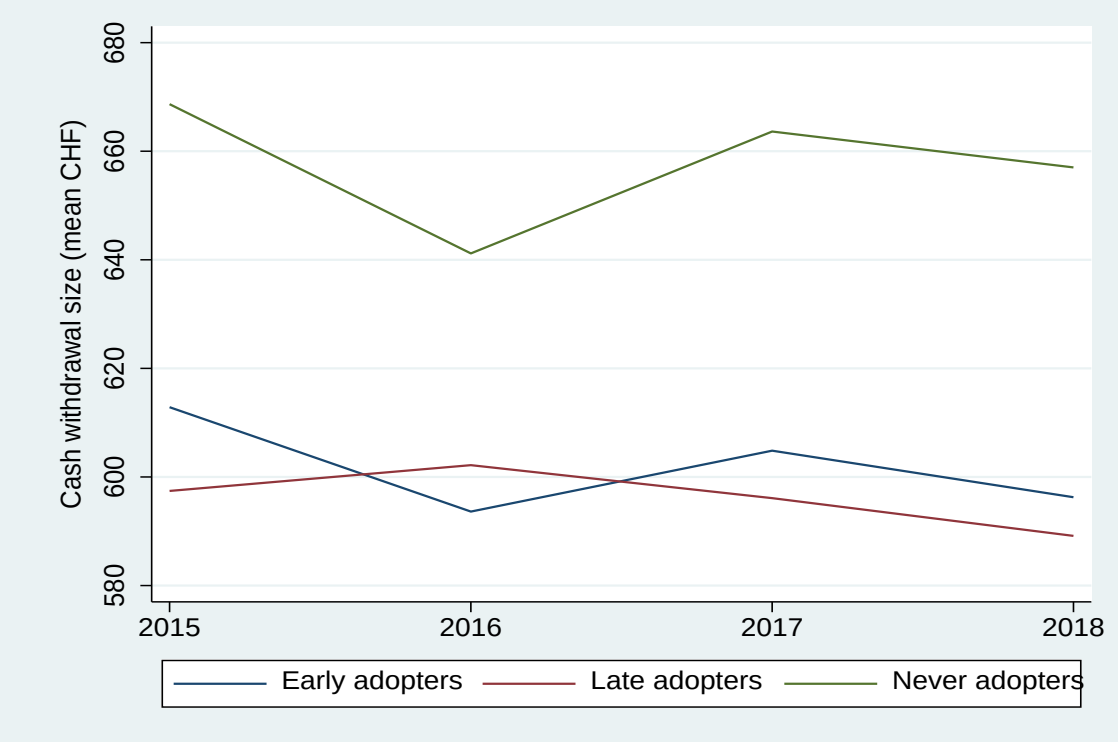


Table 1. Outcome Variables

The table presents descriptive statistics for our main and auxiliary outcome variables as measured in 2015 (pre-treatment). Panel A displays detailed summary statistics for all variables. Panel B displays comparisons of sample means by treatment group. Variable definitions are presented in Appendix Table A2.

Panel A. Summary Statistics (Pre-treatment = 2015)

	mean	min	p25	p50	p75	max	n
Main Outcome Variables							
Cash ratio (%)	71.6	0	52	78	96	100	21'122
Cash withdrawal frequency	47.4	0	20	39	64	594	21'122
Cash withdrawal amount	625	20	189	344	677	25'000	20'992
Auxillary Outcome Variables							
Debit PoS transactions	64.8	0	6	36	95	909	21'122
Debit PoS transactions (0-20 CHF)	15.3	0	0	2	15	633	21'122
Debit PoS transactions (20-40 CHF)	14.4	0	0	5	19	288	21'122
Debit PoS transactions (40-60 CHF)	10.7	0	0	5	15	178	21'122
Debit PoS transactions (60-100 CHF)	12.3	0	1	6	18	278	21'122
Debit PoS transactions (>100 CHF)	12.1	0	1	6	16	195	21'122

Panel B. Sample Means by Treatment Group (Pre-treatment = 2015)

* (**) indicate significance levels of T-tests at the 5%-level (1%-level), respectively.

	Early adopters	Late Adopters	Non adopters	T-tests		
	[1]	[2]	[3]	[1 vs. 2]	[1 vs. 3]	[2 vs. 3]
Main Outcome Variables						
Cash ratio (%)	71.6	71.1	72.2			*
Cash withdrawal frequency	47.0	49.2	46.1	**	**	
Cash withdrawal amount	613	597	669		**	**
Auxillary Outcome Variables						
Debit PoS transactions	63.2	68.2	63.5	**		**
Debit PoS transactions (0-20 CHF)	16.4	16.1	13.1		**	**
Debit PoS transactions (20-40 CHF)	13.9	15.1	14.4	**		
Debit PoS transactions (40-60 CHF)	10.1	11.3	10.9	**	**	
Debit PoS transactions (60-100 CHF)	11.5	13.0	12.7	**	**	
Debit PoS transactions (>100 CHF)	11.3	12.8	12.5	**	**	

Table 2. Covariate Variables

The table presents descriptive statistics for our client-level and account-level covariates as measured in 2015 (pre-treatment). Panel A displays detailed summary statistics for all variables. Panel B displays comparisons of sample means by treatment group. Variable definitions are presented in Appendix Table A2.

Panel A. Summary Statistics (Pre-treatment = 2015)

	mean	min	p25	p50	p75	max	n
Client-level Variables							
Age	3.52	1	2	4	5	6	21'122
Male	0.51	0	0	1	1	1	21'122
Nationality Swiss	0.71	0	0	1	1	1	21'122
Size municipality	2.63	1	2	2	3	5	21'122
Income	2.62	1	1	2	4	6	21'122
Wealth	2.02	1	1	2	3	6	21'122
Retirement account	0.53	0	0	1	1	1	21'122
Savings account	0.22	0	0	0	0	1	21'122
Custody account	0.19	0	0	0	0	1	21'122
Mortgage	0.07	0	0	0	0	1	21'122
Ebanking	0.54	0	0	1	1	1	21'122
Account-level Variables							
Account opening year	1998	1972	1990	2000	2008	2014	21'122
Direct debiting	0.55	0	0	1	1	1	21'122
Standing order Ebanking	0.15	0	0	0	0	1	21'122
Standing order paper	0.36	0	0	0	1	1	21'122
Ebanking payments	19'335	0	0	0	30'227	435'745	21'122
Transfers	3'938	0	0	0	400	420'000	21'122
Incoming payments	58'663	1'200	28'413	53'169	76'518	471'408	21'122
Outgoing payments	64'466	1'206	30'862	56'377	82'371	499'429	21'122
Account balance	3.4	1	1	3	6	6	21'122

Panel B. Sample Means by Treatment Group (Pre-treatment = 2015)

* (**) indicate significance levels of T-tests at the 5%-level (1%-level), respectively.

	Early adopters	Late Adopters	Non adopters	T-tests		
	[1]	[2]	[3]	[1 vs. 2]	[1 vs. 3]	[2 vs. 3]
Client-level Variables						
Age	3.41	3.49	3.68	**	**	**
Male	0.51	0.53	0.50			**
Nationality Swiss	0.72	0.70	0.71	**	*	
Size municipality	2.64	2.64	2.61			
Income	2.53	2.71	2.64	**	**	*
Wealth	2.03	1.98	2.05	*		**
Retirement account	0.54	0.53	0.52		*	
Savings account	0.21	0.23	0.23	**	**	
Custody account	0.19	0.18	0.21		**	**
Mortgage	0.07	0.07	0.08			
Ebanking	0.54	0.55	0.52		**	**
Account-level Variables						
Account opening year	1998	1999	1997	**	**	**
Direct debiting	0.54	0.56	0.55	**		
Standing order Ebanking	0.15	0.17	0.15	**		**
Standing order paper	0.35	0.36	0.38		**	
Ebanking payments	18'493	20'428	19'401	**		
Transfers	3'632	4'293	4'000	**		
Incoming payments	56'351	60'366	60'073	**	**	
Outgoing payments	61'858	66'614	65'842	**	**	
Account balance	3.42	3.34	3.42	*		*

Table 3. Debit PoS transactions

The table shows the results of an OLS regression. The dependent variables measure the number of debit PoS transactions per client and year. In column (1) the dependent variable covers all transactions, in columns (2-6) the dependent variable covers transactions of specific values only (0-20 CHF, 20-40 CHF, 40-60 CHF, 60-100 CHF, 100+ CHF). Each regression includes 3 annual observations (2016, 2017, 2018) for 21'122 clients. The explanatory variable *Contacless* is 1 for early adopters in years 2017 and 2018 and for late adopters in year 2018. All regressions include client fixed effects. Robust standard errors are reported in parentheses. *, **,*** denote significance at the 0.05, 0.01, and 0.001-level.

	(1)	(2)	(3)	(4)	(5)	(6)
		Debit card PoS transactions by transaction value				
Outcome variable	All	below 20 CHF	20-40 CHF	40-60 CHF	60 - 100 CHF	above 100 CHF
Contactless	6.786***	4.888***	1.092***	0.322***	0.242**	0.241**
	(0.506)	(0.316)	(0.140)	(0.087)	(0.091)	(0.087)
Year = 2017	4.365***	2.371***	1.061***	0.221***	0.638***	0.074
	(0.323)	(0.186)	(0.096)	(0.063)	(0.065)	(0.064)
Year = 2018	13.227***	7.122***	3.033***	0.797***	1.593***	0.681***
	(0.493)	(0.288)	(0.142)	(0.090)	(0.094)	(0.090)
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Clients	21'122	21'122	21'122	21'122	21'122	21'122
Client * Year observations	63'366	63'366	63'366	63'366	63'366	63'366
Mean of dependent variable	79.05	23.20	17.85	11.97	13.30	12.73
Method	OLS	OLS	OLS	OLS	OLS	OLS

Table 4. Payment choice and cash demand: Average treatment effect

The table shows the results of an OLS regression. The dependent variables measure payment choice and cash demand per client and year. In columns (1-2) the dependent variable is *Cash ratio* , in columns (3-4) *Cash withdrawals frequency* , in columns (5-6) *Cash withdrawal amount* . Appendix A2 presents definitions of each variable. Each regression includes 3 annual observations (2016, 2017, 2018) per client. The explanatory variable *Contactless* is 1 for early adopters in years 2017 and 2018 and for late adopters in year 2018. All regressions include client fixed effects. Columns (1,3,5) include year fixed effects. Columns (2,4,6) include year*location fixed effects. We distinguish 22 locations based on a combination of the local economic region (MS-region) and the size of the municipality within that region that the client resides in. Robust standard errors are reported in parentheses. *, **,*** denote significance at the 0.017, 0.01, and 0.001-level.

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome variable	Cash ratio (%)		Cash withdrawal frequency		Cash withdrawal amount	
Contactless	-0.581***	-0.574***	-0.362	-0.346	-1.138	-0.944
	(0.144)	(0.144)	(0.169)	(0.169)	(7.602)	(7.685)
Year = 2017	-1.496***		-1.929***		8.943	
	(0.104)		(0.122)		(5.611)	
Year = 2018	-3.518***		-3.729***		4.262	
	(0.143)		(0.168)		(7.081)	
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	Yes	No	Yes	No	Yes
Clients	21'112	21'112	21'122	21'122	21'047	21'047
Client * Year observations	63'169	63'169	63'366	63'366	62'544	62'544
Mean of dependent variable	68.10	68.10	44.27	44.27	614.62	614.62
Method	OLS	OLS	OLS	OLS	OLS	OLS

Table 5. Payment choice and cash demand: Dynamic treatment effect

The table shows the results of an OLS regression. The dependent variables measure payment choice and cash demand per client and year. In columns (1-2) the dependent variable is *Cash ratio* , in columns (3-4) *Cash withdrawal frequency* , in columns (5-6) *Cash withdrawal amount* . Appendix A2 presents definitions of each variable. Each regression includes 3 annual observations (2016, 2017, 2018) per client. The explanatory variables are Early adopter in 2017, Early adopter in 2018 and Late adopter in 2018. In addition we report the estimate for Late adopter in 2017 as an anticipation / placebo effect. All regressions include client fixed effects. Columns (1,3,5) include year fixed effects, columns (2,4,6) include year*location fixed effects. We distinguish 22 locations based on a combination of the local economic region (MS-region) and the size of the municipality within that region that the client resides in. Robust standard errors are reported in parentheses. *, **, *** denote significance at the 0.017, 0.01, and 0.001-level.

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome variable	Cash ratio (%)		Cash withdrawal frequency		Cash withdrawals amount	
Early adopter, 2017	-0.46	-0.451	-0.239	-0.221	-9.911	-10.44
	(0.214)	-0.215	(0.241)	(0.241)	(12.553)	-12.645
Early adopter, 2018	-1.128***	-1.124***	-0.58	-0.552	-8.63	-9.204
	-0.257	(0.257)	(0.306)	(0.306)	(12.073)	-12.198
Late adopter, 2017	0.006	0.001	-0.098	-0.079	-27.064	-28.113
	(0.225)	(0.225)	(0.265)	(0.265)	(12.111)	-12.116
Late adopter, 2018	-0.709**	-0.710**	-0.614	-0.58	-19.981	-20.045
	(0.271)	(0.271)	(0.339)	(0.339)	(12.545)	-12.536
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	No	Yes	No	Yes	No
Year*Location fixed effects	No	Yes	No	Yes	No	Yes
Clients	21'112	21'112	21'122	21'122	21'047	21'047
Client * Year observations	63'169	63'169	63'366	63'366	62'544	62'544
Mean of dependent variable	68.10	68.10	44.27	44.27	614.62	614.62
Method	OLS	OLS	OLS	OLS	OLS	OLS

Table 6. Payment choice: By pre-treatment payment behavior

The table shows the results of an OLS regression for subsamples of clients based on their pre-treatment payment behavior. We split clients by quartile of *Cash ratio* (%) in 2015. The dependent variable is *Cash ratio* (%) in all columns. Appendix A2 presents definitions of each variable. Each regression includes 3 annual observations (2016, 2017, 2018) per client. The explanatory variable *Contactless* is 1 for early adopters in years 2017 and 2018 and for late adopters in year 2018. All regressions include client fixed effects. Robust standard errors are reported in parentheses. *, **, *** denote significance at the 0.017, 0.01 and 0.001-level.

	(1)	(2)	(3)	(4)
Outcome variable	Cash ratio (%)			
Cash ratio (%) in 2015 (subsample):	[0-52%]	(52%-78%]	(78%-96%]	(96%-100%]
Contactless	-0.172	-1.292***	-0.347	-0.343
	(0.333)	(0.326)	(0.276)	(0.191)
Year = 2017	-0.620*	-1.973***	-2.296***	-1.144***
	(0.244)	(0.240)	(0.202)	(0.129)
Year = 2018	-2.226***	-4.775***	-5.061***	-2.102***
	(0.329)	(0.325)	(0.289)	(0.183)
Client fixed effects	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	No	No	No
Clients	5'278	5'278	5'280	5'276
Client * Year observations	15'801	15'805	15'820	15'743
Mean of dependent variable	35.56	59.60	81.07	96.24
Method	OLS	OLS	OLS	OLS

Table 7. Payment choice: By client location and age-group

This table shows the results of an OLS regression for subsamples of clients based on the population-density of their residential location and the clients age. We distinguish urban locations (columns 1-3) from rural locations, whereby locations of residence are categorized as urban (rural) if they have above (below) 3'000 inhabitants per km2 settlement area. The dependent variable is *Cash ratio* in all columns. Appendix A2 presents definitions of each variable. Each regression includes 3 annual observations (2016, 2017, 2018) per client. The explanatory variable *Contactless* is 1 for early adopters in years 2017 and 2018 and for late adopters in year 2018. All regressions include client fixed effects. Robust standard errors are reported in parentheses. *, **, *** denote significance at the 0.017, 0.01, and 0.001-level.

	(1)	(2)	-3	(4)	-5	(6)
Outcome variable	Cash ratio (%)					
Location	Urban			Rural		
Client age (years)	below 35	35-55	above 55	below 35	35-55	above 55
Contactless	-1.246**	-0.717	0.092	-0.390	-0.333	0.365**
	(0.411)	(0.303)	(0.348)	(0.396)	(0.307)	(0.364)
Year = 2017	-3.085***	-0.858***	-0.643*	-3.244***	-1.308***	-0.549***
	(0.301)	(0.217)	(0.259)	(0.300)	(0.217)	(0.265)
Year = 2018	-7.139***	-2.720***	-1.198***	-7.137***	-2.961***	-1.164***
	(0.428)	(0.294)	(0.346)	(0.411)	(0.305)	(0.347)
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	No	No	No	No	No
Clients	3'041	4'033	3'262	3'323	4'417	3'036
Client * Year observations	9'105	12'085	9'738	9'958	13'214	9'069
Mean of dependent variable	58.44	66.22	77.73	61.86	66.97	78.45
Method	OLS	OLS	OLS	OLS	OLS	OLS

Apppendix A1. Sample composition

Raw data sample	
Clients:	30'000
Accounts:	30'330
Debit cards:	33'165

Main sample (1 account, 1 card)		**Robustness sample (1 account, multiple cards)****		
Single account /single card:	26'934	Single account / multiple cards:	2'735	(5470 accounts)
with regular expiry date	24'021	with regular expiry date	2'582	(5164 accounts)
with account opened before 2015:	23'957	with account opened before 2015	2'576	(5152 accounts)
non-missing covariates:	22'504	non-missing covariates:	1'485	(2970 accounts)
No outlier turnover*:	21'122	No outlier turnover*:	1'396	(2792 accounts)
		Multiple expiry dates	706	(1412 accounts)
Final sample, # clients:	**21'122**	**Final sample, # clients:**	**706**	**(1412 accounts)**

* Outlier turnovers are defined as incoming /outgoing account flows below 1200 CHF or exceeding 500'000 CHF in any year.
** Our robustness sample includes only clients with 1 account and 2 debit cards. We drop 6 clients with 1 account and 3 debit cards.

Appendix A2. Definition of Variables

Panel A. Outcome variables

Main outcome variables

Variable	Definition	Unit	Range
Cash ratio	Cash withdrawals (ATM & Branch in CHF) / [Cash withdrawals (ATM & Branch in CHF) + Debit PoS transactions (in CHF) + Credit Card transactions (in CHF)], annual	%	[0,100]
Cash withdrawal frequency	Number of cash withdrawals (ATM & Branch), annual	number	>=0
Cash withdrawal amount	Cash withdrawals (ATM & Branch) in CHF / Cash withdrawals frequency	CHF	>0

Auxillary outcome variables

Variable	Definition	Unit	Range
Debit PoS transactions	Number of PoS transactions by debit card, annual		
Debit PoS transactions (0-20 CHF)	Number of PoS transactions with volume of (0,20] CHF by debit card, annual	number	>=0
Debit PoS transactions (20-40 CHF)	Number of PoS transactions with volume of (20,40] CHF by debit card, annual	number	>=0
Debit PoS transactions (40-60 CHF)	Number of PoS transactions with volume of (40,60] CHF by debit card, annual	number	>=0
Debit PoS transactions (60-100 CHF)	Number of PoS transactions with volume of (60,100] CHF by debit card, annual	number	>=0
Debit PoS transactions (>100 CHF)	Number of PoS transactions with volume of >100 CHF by debit card, annual	number	>=0

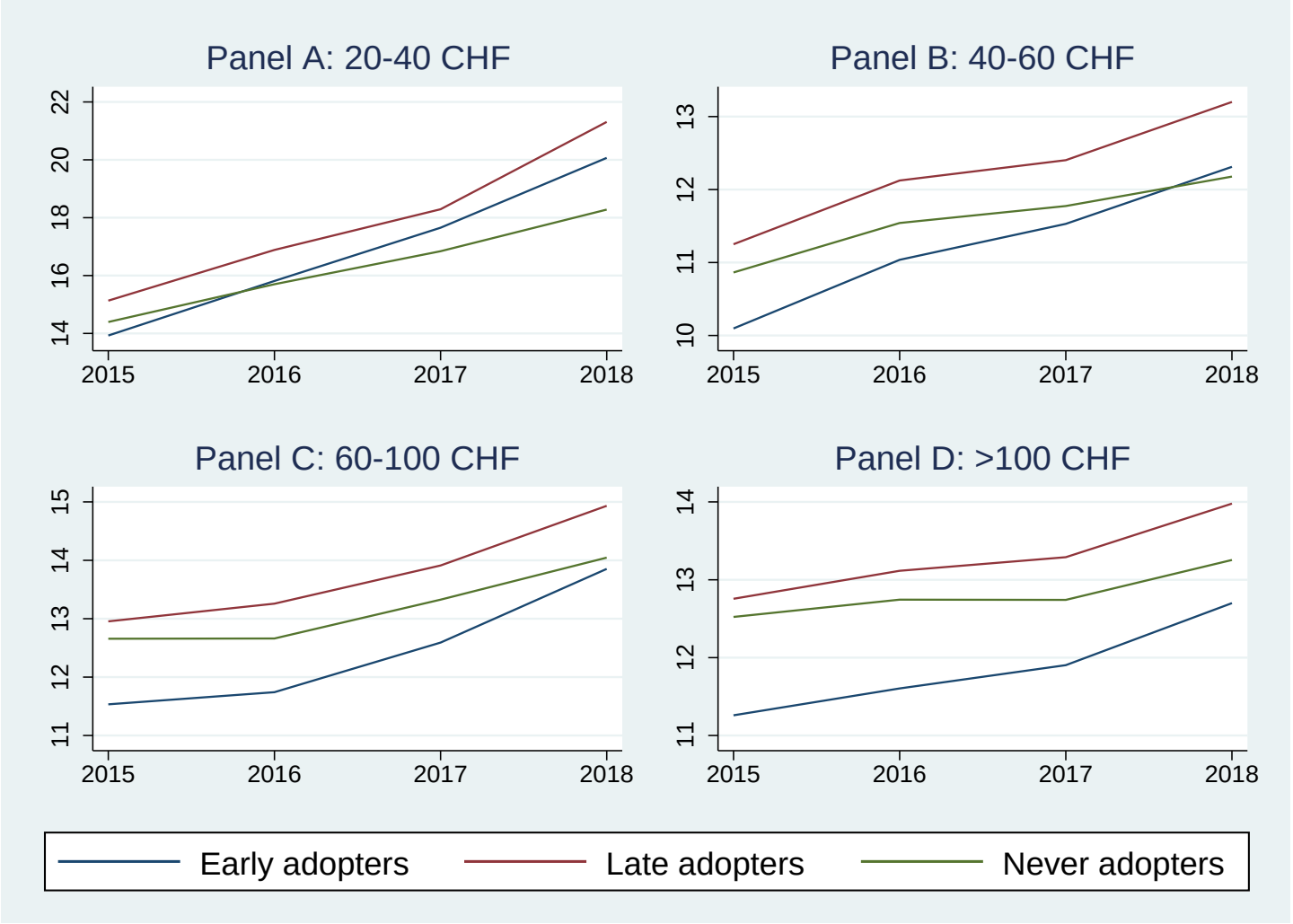
Panel B. Covariates

Client-level variables		
Variable	Definition	Unit
Age	Age of client in years: 1=25 or younger; 2=26-35; 3=36-45; 4=46-55; 5=56-65; 6= 66 and older	[1;..;6]
Male	Gender of client: 1=male; 0=female.	[0;1]
Nationality Swiss	Nationality of client 1=Swiss; 0=other nationality	[0;1]
Size municipality	Population of municipality in which client resides. 1= (0,5'000] ; 2=(5'000-10'000]; 3=(10'000-20'000]; 4=(20'000-50'000]; 5= more than 50'000	[1;..;5]
Income	Monthly income of client in CHF as estimated by the Bank in December 2015. 1 = [0,3'000]; 2= (1'000, 2'500]; 3= (2'500, 5'000]; 4= (5'000, 7'500]; 5= (7'500. 10'000]; 6= >10'000	[1;..;6]
Wealth	Total financial assets under management of the client with the Bank in December 2015 in CHF. 1 = [0,10'000]; 2= (10'000, 50'000]; 3= (50'000, 100'000]; 4= (100'000, 250'000]; 5= (250'000, 1'000'000]; 6=more than 1'000'000.	[1;..;6]
Retirement account	Dummy variable = 1 if client has a voluntary retirement savings account with the Bank, 0=otherwise	%
Savings account	Dummy variable = 1 if client has an ordinary savings account with the Bank, 0=otherwise	number
Custody account	Dummy variable = 1 if client has a custody account for securities with the Bank, 0=otherwise	
Mortgage	Dummy variable = 1 if client has a mortgage with the Bank, 0=otherwise	
E-banking	Dummy variable = 1 if client has an Ebanking contract with the Bank, 0=otherwise	

Account-level variables (measured in 2015)		
Variable	Definition	Unit
Account opening year	Year in which account was opened	Year
Direct debiting	Dummy variable = 1 if client uses direct debiting with this account, 0=otherwise	[0;1]
Standing order Ebanking	Dummy variable = 1 if client uses Ebanking standing orders with this account, 0=otherwise	[0;1]
Standing order paper	Dummy variable = 1 if client uses ordinary standing orders with this account, 0=otherwise	[0;1]
Ebanking payments	Volume of outgoing Ebanking transactions in CHF, 2015	CHF
Transfers	Volume of outgoing account transfers in CHF, 2015	CHF
Incoming payments	Total volume of incoming payments in CHF, 2015	CHF
Outgoing payments	Total volume of outgoing payments in CHF, 2015	CHF
Account balance	Account balance in CHF as per end December 2015. 1 = [0,1'000]; 2= (1'000, 2'500]; 3= (2'500, 5'000]; 4= (5'000, 7'500]; 5= (7'500. 10'000]; 6=more than 10'000	[1;..;6]

Appendix A3 Debit Card PoS Transactions

The figure displays the average number of Point of Sale (PoS) transactions conducted by debit card per client and year by treatment group. Panel A displays the number of transactions with a value of (20-40] CHF. Panel B displays the number of transactions with a value of (40-60] CHF. Panel C displays the number of transactions with a value of (60-100] CHF. Panel A displays the number of transactions with a value of >100 CHF.



Appendix A4. Payment choice and cash demand: Alternative outcome variables

Panel A. Average treatment effect estimates

Panel A shows the results of OLS regressions, where the dependent variables are alternative indicators of payment choice and cash demand per client. Panel B presents definitions of each variable. Panel C presents (pre-treatment) summary statistics for each variable. Each regression includes 3 annual observations (2016, 2017, 2018) per client. The explanatory variable *Contactless* is 1 for early adopters in years 2017 and 2018 and for late adopters in year 2018. All regressions include client fixed effects. Robust standard errors are reported in parentheses. *, **, *** denote significance at the 0.017, 0.01 and 0.001-level.

Outcome variable	(1) Cash ratio without credit (%)	(2) Cash ratio with Ebanking (%)	(3) Cash ratio - domestic (%)	(4) Cash withdrawal frequency - ATM	(5) Cash withdrawals amount - ATM	(6) Cash withdrawal number - domestic	(7) Cash withdrawal amount - domestic
Contactless	-0.514***	-0.427**	-0.550***	-0.420*	-0.188	-0.367	-1.908
	(0.143)	(0.143)	(0.154)	(0.168)	(1.906)	(0.155)	(8.043)
Year = 2017	-1.192***	-2.251***	-1.322***	-1.736***	3.927**	-1.871***	7.537
	(0.104)	(0.103)	(0.112)	(0.121)	(1.369)	(0.112)	(6.149)
Year = 2018	-2.944***	-4.778***	-3.234***	-3.354***	8.072***	-3.532***	3.281
	(0.142)	(0.148)	(0.153)	(0.167)	(1.970)	(0.156)	(7.466)
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region*Year fixed effects	No	No	No	No	No	No	No
Clients	21'096	21'118	21'079	21'122	20'341	21'122	21'000
Client * Year observations	63'036	63'289	62'911	63'366	59'810	63'366	62'172
Mean of dependent variable	71.60	50.70	70.30	41.17	360.96	38.80	638.00
Method	OLS	OLS	OLS	OLS	OLS	OLS	OLS

Panel B. Alternative outcome variables - Definitions

Variable	Definition	Unit	Range
Cash ratio without credit	Cash withdrawals (ATM & Branch, value) / [Cash withdrawals (ATM & Branch, value) + Debit PoS transactions (value) + Credit Card transactions (value)], annual	%	[0,100]
Cash ratio with ebanking	Cash withdrawals (ATM & Branch, value) / [Cash withdrawals (ATM & Branch, value) + Debit PoS transactions (value) + Credit Card transactions (value)+ Ebanking transactions (value)], annual	%	[0,100]
Cash ratio - domestic	*Cash ratio without credit* , calculated based on transactions in CHF in Switzerland only	%	[0,100]
Cash withdrawal frequency - ATM	Number of ATM withdrawals, annual	number	>=0
Cash withdrawal amount - ATM	ATM withdrawals (value) / Cash withdrawals - number	CHF	>0
Cash withdrawal frequency - domestic	*Cash withdrawals CHF - number* , calculated based on transactions in CHF in Switzerland only	number	>=0
Cash withdrawal amount - domestic	*Cash withdrawals - average size* , calculated based on transactions in CHF in Switzerland only	CHF	>0

Panel C. Summary Statistics (Pre-treatment = 2015)

	mean	min	p25	p50	p75	max	n
Cash ratio without credit	74.5	0	57	81	97	100	21'094
Cash ratio with Ebanking	55.5	0	20	56	93	100	21'122
Cash ratio - domestic	73.3	0	55	81	97	100	21'076
Cash withdrawal frequency - ATM	44.0	0	17	36	62	592	21'122
Cash withdrawal amount - ATM	358.5	20	163	270	438	5'000	20'031
Cash withdrawal frequency - domestic	42.0	0	17	34	57	594	21'122
Cash withdrawal amount - domestic	645.5	20	181	339	700	25'000	20'907

Appendix A5. Payment choice and cash demand: Alternative treatment period definition

The table shows the results of robustness tests with an alternative definition of treatment periods. In our main analysis we define treatment periods by calendar year (January - December). In this robustness test we define treatment periods from November to the following year October. This accounts for the fact that new debit cards are typically issued at end of October of the previous year. The dependent variables measure payment choice and cash demand per client and year. Appendix A2 presents definitions of each variable. Each regression includes 3 annual observations (2016, 2017, 2018) per client. The explanatory variable *Contactless* is 1 for early adopters in years 2017 and 2018 and for late adopters in year 2018. All regressions include client and year fixed effects. Robust standard errors are reported in parentheses. *, ** denote significance at the 0.017, and 0.001-level.

Outcome variable	(1) Cash ratio (%)	(3) Cash withdrawal frequency	(5) Cash withdrawal amount (CHF)
Contactless	-0.471***	-0.279	-13.932
	(0.142)	(0.170)	(13.151)
Year = 2017	-1.533***	-1.815***	29.663
	(0.105)	(0.124)	(17.312)
Year = 2018	-3.370***	-3.705***	24.213
	(0.143)	(0.171)	(15.391)
Client fixed effects	Yes	Yes	Yes
Region*Year fixed effects	No	No	No
Clients	20'928	20'934	20'861
Client * Year observations	62'634	62'802	62'058
Mean of dependent variable	68.70	44.90	621.60
Method	OLS	OLS	OLS

Table A6. Payment choice: By pre-treatment payment behavior

The table shows the results of an OLS regression for subsamples of clients based on their pre-treatment payment behavior. We split clients by quartile of PoS debit transactions (below 20 CHF) in 2015. The dependent variable is *Cash ratio* (%) in all columns. Appendix A2 presents definitions of each variable. Each regression includes 3 annual observations (2016, 2017, 2018) per client. The explanatory variable *Contactless* is 1 for early adopters in years 2017 and 2018 and for late adopters in year 2018. All regressions include client fixed effects. Robust standard errors are reported in parentheses. *, **, *** denote significance at the 0.017, 0.01 and 0.001-level.

	(1)	(2)	(3)	(4)
Outcome variable	Cash ratio (%)			
PoS debit transactions (below 20 CHF) in 2015 (subsample):	[0]	(1-2]	(3-15]	(16-633]
Contactless	-0.398	-0.286	-0.374	-0.931**
	(0.226)	(0.410)	(0.294)	(0.292)
Year = 2017	-0.885***	-1.717***	-1.505***	-2.395***
	(0.166)	(0.300)	(0.206)	(0.215)
Year = 2018	-1.851***	-3.954***	-4.109***	-5.368***
	(0.220)	(0.409)	(0.290)	(0.301)
Client fixed effects	Yes	Yes	Yes	Yes
Region*Year fixed effects	No	No	No	No
Clients	5278	3022	5287	5068
Client * Year observations	7'735	9'048	15'849	15'193
Mean of dependent variable	1.5	5.1	16.3	74.4
Method	OLS	OLS	OLS	OLS

Appendix A7. Debit PoS transactions - Placebo Test

The table shows the results of a placebo test with observations from year 2015 and 2016 only. The dependent variables measure the number of debit PoS transactions per client and year. Appendix A2 presents definitions of each variable. The explanatory variable *New card* is 1 for all cards which expire at end 2015 and thus receive a new card (albeit one without a contactless function) for 2016. All regressions include client and year fixed effects. Robust standard errors are reported in parentheses. *, **,*** denote significance at the 0.05, 0.01, and 0.001-level.

	(1)	(2)	(3)	(4)	(5)	(6)
		Debit card transactions by transaction value				
Outcome variable	All	below 20 CHF	20-40CHF	40-60 CHF	60 - 100 CHF	above 100 CHF
New card	-1.740***	-0.608*	-0.524***	-0.235*	-0.245*	-0.129
	(0.508)	(0.271)	(0.157)	(0.110)	(0.112)	(0.113)
Year = 2016	6.478***	3.138***	1.829***	0.913***	0.248***	0.351***
	(0.307)	(0.173)	(0.091)	(0.060)	(0.063)	(0.062)
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Clients	21'122	21'122	21'122	21'122	21'122	21'122
Card * Year observations	42'244	42'244	42'244	42'244	42'244	42'244
Mean of dependent variable	67.70	16.80	15.30	11.10	12.40	12.20
Method	OLS	OLS	OLS	OLS	OLS	OLS

Appendix A8. Payment choice and cash demand: Placebo test

The table shows the results of a placebo test with observations from year 2015 and 2016 only. The dependent variables measure payment choice and cash demand per client and year. Appendix A2 presents definitions of each variable.The explanatory variable *New card* is 1 for all cards which expire at end 2015 and thus are replaced with a new card (albeit one without a contactless function) for 2016. All regressions include client and year fixed effects. Robust standard errors are reported in parentheses. *, ** denote significance at the 0.017, and 0.001-level.

Outcome variable	(1) Cash ratio (%)	(3) Cash withdrawals frequency (#)	(5) Cash withdrawal amount (CHF)
New card	0.06	-0.282	-16.65
	(0.188)	(0.226)	(9.809)
Year = 2016	-1.673***	-1.024***	-3.877
	(0.105)	(0.134)	(5.079)
Client fixed effects	Yes	Yes	Yes
Region*Year fixed effects	No	No	No
Clients	21'122	21'122	21'052
Client * Year observations	42'193	42'244	41'896
Mean of dependent variable	70.80	46.80	618.10
Method	OLS	OLS	OLS

Appendix A9. Debit PoS transactions - Multiple card holders

This table shows the results of OLS regressions for the sample of clients with one account and two debit cards in 2015. The dependent variables measure the number of debit PoS transactions per card and year. In column (1) the dependent variable covers all transactions, in columns (2-6) the dependent variable covers transactions of specific values only (0-20 CHF, 20-40 CHF, 40-60 CHF, 60-100 CHF, 100+ CHF). Each regression includes 3 annual observations (2016, 2017, 2018) per card. The explanatory variable *Contactless* is defined at the card level. It is 1 for cards replaced in years 2017 and 2018. All regressions include card fixed effects. Robust standard errors are reported in parentheses. *, **,*** denote significance at the 0.05, 0.01, and 0.001-level respectively

	(1)	(2)	(3)	(4)	(5)	(6)
		Debit card transactions by transaction value				
Outcome variable	All	below 20 CHF	20-40CHF	40-60 CHF	60 - 100 CHF	above 100 CHF
Contactless	2.291	1.376*	-0.112	0.028	0.412	0.588
	(1.516)	(0.696)	(0.457)	(0.339)	(0.383)	(0.361)
Year = 2017	1.355	1.591***	0.850*	-0.319	-0.271	-0.497
	(1.066)	(0.417)	(0.337)	(0.258)	(0.279)	(0.264)
Year = 2018	5.820***	4.469***	2.187***	-0.388	0.065	-0.513
	(1.624)	(0.705)	(0.495)	(0.367)	(0.399)	(0.385)
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Clients	706	706	706	706	706	706
Cards	1'412	1'412	1'412	1'412	1'412	1'412
Card * Year observations	4236	4236	4236	4236	4236	4236
Mean of dependent variable	81.50	13.90	18.20	13.90	17.00	18.40
Method	OLS	OLS	OLS	OLS	OLS	OLS