The Convenience of Electronic Payments and Consumer Cash Demand – Causal Evidence from the Staggered Introduction of Contactless Debit Cards*

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Abstract

We provide causal evidence on how the improved convenience of electronic payments affects consumer payment choice and cash demand. We study the staggered introduction of contactless debit cards by a retail bank between 2016-2018. Our analysis is based on account-level data for a random sample of 30'000 bank clients and follows a pre-analysis plan. The timing of access to the contactless payment technology is quasi-random across clients, depending only on the expiry date of the pre-existing debit card. We isolate a "convenience effect" of electronic payments by comparing small-value transactions which are eligible for contactless authentication to large value transactions which are not. On average, consumers increase their use of debit cards for small-value payments in response to receiving a contactless card. Contactless cards increase the frequency of transactions among existing card users but do not cause more consumers to use debit cards. Relative to average consumer cash spending on small-value items, the average increase in debit card use is limited. The impact of contactless cards on cash demand is thus economically small and statistically insignificant.

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

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1. Introduction

Payment cards, electronic banking and mobile payment instruments have expanded consumers' options to pay for everyday goods and services. Inventory theories of cash management and payment choice suggest that transaction fees (higher for card payments) and opportunity costs of cash withdrawals (pecuniary and non-pecuniary) govern consumer choice between these alternative payment instruments (Santomero 1979, Whitesell 1989, Bouhdaoui & Bounie, 2012, Alvarez & Lippi 2017).

The assumption of higher fees for card versus cash payments in inventory models is largely at odds with today's pricing of payment services for consumers. In retail stores or restaurants consumers are rarely charged additional fees for using debit cards (or other electronic payment instruments). Yet, surveys on consumer payment behavior document that cash still accounts for a large share of payment transactions in many advanced economies (e.g. Bundesbank 2018, see also European Central Bank 2020). Near-cashless economies, such as Sweden or Norway are the exception rather than the rule – even after the Pandemic.[2] As a case in point, the most recent Survey of Payment Behavior for Germany – Europe's largest economy - reveals that by Autumn 2020, 60% of payment transactions and 32% of payment value were still conducted in cash (down from 74% and 48% in 2017, respectively).[3]

Evidence based on administrative and survey data suggests that convenience, i.e. broad merchant acceptance and faster execution of transactions, may explain the widespread use of cash, especially for small-value purchases (Klee 2008, Wang & Wolman 2016; SNB, 2018).[4] However, recent innovations to merchant payment infrastructure (NFC payment terminals, self-check-out terminals) and consumer payment instruments (contactless cards, mobile payments, mobile banking) imply that the convenience of electronic payments is increasing at a breathtaking speed. This development could have a sizeable impact on consumer cash demand.

Understanding how the improved convenience of electronic payments affects payment behavior and consumer cash demand is of first-order interest to monetary policy makers for at least two

[2] https://www.economist.com/leaders/2019/08/01/rich-countries-must-start-planning-for-a-cashless-future.

[3] https://www.bundesbank.de/en/publications/reports/studies/payment-behaviour-in-germany-in-2020-858022.

[4] In a summary view of payment surveys in several advanced economies conducted over the past decade, Bagnall et al. (2016) show that cash is mainly used for small value purchases, an observation which still holds with newer data. The Bundesbank (2018) documents that in 2017, 96% of all transactions below 5 euro and 88% of all transactions between 5-20 euro were conducted with cash. In the US, cash use is lower but in 2019 cash was still the most frequently used payment instrument for purchases below 20 US dollar (Greene and Stavins, 2020).

reasons: First, changes in the structure of money demand impact on the welfare costs of inflation (Attanasio et al. 2002, Alvarez and Lippi 2009) and the optimal choice of a nominal anchor (Mishkin 1999). Second, universal access to a risk-free asset and a safe payment system may be undermined if consumers substitute physical central bank cash for electronic commercial bank deposits as their dominant means of payment (Sveriges Riksbank 2017). The latter consideration has led many central banks to contemplate the introduction of central bank digital currencies (Auer et al. 2020).

We provide causal evidence on how the improved convenience of electronic payments affects consumer payment choice and cash demand. We study the most prevalent recent payment innovation – contactless payment cards - in a hitherto cash-dominant economy: Switzerland.[5] Contactless payment cards enhance the convenience of electronic payments for small-value transactions: Below a certain threshold value (40 CHF in Switzerland during our observation period[6]), consumers using a contactless card can "tap and go" rather than having to enter a personal identification number (PIN) to verify their payment.

Identifying a "convenience" effect of contactless cards poses a major empirical challenge. As highlighted by Hyunh et al. (2019) the impact of payment innovations on observed payment choice and cash demand depends on the interplay of consumer and merchant adoption. Due to improved convenience, some consumers who receive a contactless card will plan to use the card more often for small value payments. In anticipation of increased use of contactless payment cards by consumers, merchants may upgrade their payment infrastructure: Some merchants will replace PIN-based terminals with NFC-compatible terminals. Other merchants may introduce card payment terminals for the first time. Importantly, the share of merchants who upgrade their payment infrastructure will determine the observed consumer response to receiving a contactless card.

Several spillover effects are also likely to occur as new payment technologies are adopted: First, consumers who receive a contactless card may increasingly use their payment card for transactions which are beyond the "tap & go" threshold as they no longer carry cash. Second, the upgrade in payment infrastructure may lead to the increasing use of (PIN-based) cards among consumers

[5] 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.

[6] During our whole observation period 2015-2018, the threshold for PIN-exempt transactions was 40 CHF. This threshold has been increased to 80 CHF since April 2020.

without a contactless card. Third, merchants may adapt their payment technology in response to that of neighboring merchants (Crouzet et al., 2020).

Our research design allows us to isolate the "convenience effect" of contactless cards on consumer payment choice and cash demand. Our analysis is based on administrative data for a random sample of 30'000 bank clients. For these clients we observe monthly, account-level information including point of sale payments by debit card as well as cash withdrawals from ATMs and bank branches over the period 2015-2018. We study a quasi-random assignment of contactless cards across a representative consumer sample. Specifically, we exploit the staggered introduction of contactless debit cards by a bank across its entire retail client base. The timing of access to the contactless payment technology depends only on the expiry date of the existing debit card. We group the sampled clients by the year in which they receive 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. After matching the age-structure of these three groups of clients to the age structure of the full sample, the three groups are similar with respect to a broad set of pre-treatment socioeconomic characteristics as well as their pre-treatment trend of payment choice and cash demand. Therefore, we can assign post-treatment differences in payment choice and cash demand causally to the receipt of a contactless card.

We observe – at the account-level - debit card transactions for which contactless card holders can "tap and go" (0 - 40 CHF) as well as transactions for which a PIN-based verification is necessary. By comparing the treatment effect across these different transactions we can isolate the convenience effect of the enhanced card payment technology.

Our analysis follows a pre-analysis plan 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). The use of a pre-analysis plan intends to eliminate biases arising from model selection as well as from the selective reporting of findings and should thus strengthen the credibility of results, in particular for proprietary data (Casey et al. 2012; Coffmann and Niederle, 2015). While pre-analysis plans are common in randomized control trials, they are much less frequent in studies using observational data (Burlig 2018). We are unaware of other papers in monetary economics which employ proprietary, observational data and are based on a pre-analysis plan.

Our hypotheses are informed by inventory theories of money demand which integrate consumer cash management and payment choice (Santomero 1979, Whitesell 1989, Bouhdaoui & Bounie, 2012, Alvarez & Lippi 2017). Within these models, the introduction of contactless cards can be seen as a reduction in the non-pecuniary transaction costs of card versus cash payments - for small value purchases. The reduction in card payment costs arises from the fact that a personal identification number (PIN) no longer needs to be entered at card payment terminals for payments below 40 CHF. This reduces the time (and effort) of paying by card, as consumers can "tap and go". As a consequence, we expect to observe (i) an increase in debit card payments for small-value transactions, (ii) a decrease in the cash share of payments and (iii) a decrease in cash withdrawals.

We test these hypotheses by estimating a difference-in-difference model with staggered adoption (Athey and Imbens 2018). We saturate our empirical model with client and year or location*year fixed effects. We hereby control for varying developments of merchant payment infrastructure in regions populated by the three groups of clients. Our estimated treatment effects can be interpreted as the average effect of receiving a contactless card (as opposed to maintaining a PIN-based card) conditional on the average merchant payment infrastructure during our observation period.

The average treatment effect estimates reveal three main findings. First, access to the contactless payment technology causes a statistically significant increase in the frequency of debit card point of sale transactions (+0.5 transactions per month, 7% of the sample average). The vast majority (89%) of these additional debit card transactions are small-value payments (below 40 CHF), suggesting that it is indeed the enhanced convenience of contactless cards which trigger the observed change in payment behavior. However, the magnitude of the estimated effect on small-value debit card transactions is limited. Payment survey data suggest that – during our observation period - the average Swiss consumer made 50 purchases per month of which 29 (58%) were cash transactions with a value less than 40 CHF. Thus, the estimated effect of the contactless technology represents less than 2% of the total number of small-value cash transactions an average consumer conducts each month. Second, in line with the limited impact on small-value debit card transactions the average effect of contactless cards on consumers' cash share of payments is economically small and statistically insignificant. Third, we find no average effect of contactless cards on cash demand, i.e. the frequency of cash withdrawals, or the average cash withdrawal amount.

Our average treatment effect estimates measure the impact on consumer payment choice and cash demand conditional on the average merchant payment infrastructure during our observation

period. Importantly, the limited impact of contactless cards cannot be explained by a weak adoption of the new technology by merchants. By contrast, aggregate data reveal that by 2018 59% of all payment terminals in Switzerland enabled the contactless technology compared to 26% in 2015. Dynamic treatment effect estimates confirm that the impact of contactless cards on consumer payment behavior increases over time, consistent with increasing merchant adoption.

Does improved convenience lead more consumers to use debit cards (extensive margin effect), or do pre-existing users use their cards more (intensive margin effect)? In a pre-registered test of heterogenous treatment effects we study the impact of contactless cards across consumers with varying pre-treatment payment behavior. One quarter of the clients in our sample paid exclusively by cash before the roll-out of contactless cards, while another quarter relied more on cards than on cash. We find no evidence that improved convenience leads more consumers to use debit cards. The impact of contactless cards on payment choice or cash demand is negligible for consumers, who previously relied only on cash. The impact of contactless debit cards on payment choice is stronger among consumers with an intermediate initial cash-share of payments.

In an additional (non-registered) test we explore the impact of the contactless payment technology by consumer age and location. Prior to treatment, both the monthly number of debit card transactions and the cash share of payments differ sizably by age. However, within a given age group the use of payment cards and cash use is similar in urban and rural locations, reflecting the well-developed payment infrastructure across the country. Access to the contactless payment technology exerts the strongest causal effect on payment choice for young clients, and especially so in urban areas. These estimates confirm previous evidence highlighting the role of age for the adoption of financial technology (see e.g. Yang and Ching 2013). They also suggest that the payment infrastructure facilitating contactless payments may have adopted faster in urban areas at merchants who are more likely to attract younger consumers.

Our findings contribute to the empirical literature using administrative or survey data to test the predictions of inventory theories of cash management and payment choice (e.g. Baumol 1952, Tobin 1956, Santomero 1979, Whitesell 1989, Alvarez & Lippi 2017). Existing evidence supports key predictions of these models: Consumer choice between card and cash payments vary by transaction size, product characteristics as well as consumer location and income level, confirming a role of (fixed) transaction costs of non-cash payments and the opportunity costs of withdrawing and holding cash (Wang & Wolman 2016, Klee 2008, Borzekowski et al. 2008; Chen et al. 2021; Bouhdaoui & Bounie, 2012). We contribute to this literature in three ways: First, our research

design allows us to identify the role of non-pecuniary transaction costs – i.e. the convenience of payment instruments – for payment choice and cash demand. Here our results suggest that enhanced convenience of electronic payments has a limited impact on consumer choice. Our finding is consistent with the results of Wakamori and Welte (2017) who find that increasing merchant acceptance of electronic payments only marginally affects payment choice.

Second, the administrative data at hand allows us to measure both payment choice and cash demand using precise and reliable indicators at the consumer level over a significant period of time. 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 data sources provides precise measures on payment behavior jointly with information on cash demand by the same consumers over a longer period of time.[7]

Third, our research design allows us to identify the causal impact of payment innovation on consumer 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 ATMs impacts on the cash demand of Italian households. More recently, Chen et al. (2017), Trütsch (2016) and Felt (2020) 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. Compared to these papers, our research design allows to better disentangle the causal effect of payment innovation from concurrent time trends in overall payment behavior.[8]

In a broader context, we contribute to the recent literature which exploits natural experiments to study how innovations in retail financial services impact on consumer behavior. Bachas et al. (2018) study the staggered roll-out of debit cards to low-income bank account holders in Mexico. They document that debit cards lower consumers' transaction costs of accessing bank accounts and increase financial activity.[9] Bachas et al. (2021) document that the receipt of a debit card leads

[7] Agarwal et al. (2019, 2020b) and Magnac (2017) are related to our approach given their use of bank-account level information but differ in focus. Agarwal et al. (2019, 2020b) study how the introduction of a mobile payments technology by a bank in Singapore affected merchants' sales and the growth rate of business creation. Magnac (2017) uses account data to study the effects of ATM withdrawal fees on the behavior of clients of a French bank.

[8] The causal effect of contactless and mobile payments on firm profits is analyzed in Bounie and Camara (2020) for France, in Patnam and Yiao (2020) for India and in Agarwal et al. (2019, 2020b) for Singapore.

[9] Higgens (2020) exploits local variation on the roll-out of these debit cards to examine the impact on supply side card terminal adoption and turnover of merchants.

to a reduction of consumption and an increase in household savings. This finding suggests that card payments in combination with easily available account balance information may help consumers monitor their expenses.[10] Alvarez et al. (2021) exploit the staggered roll-out of debit cards in Mexico to quantify the effect of cash on crime which is one component of their broader assessment of the costs and benefits of restricting cash usage. Jack and Suri (2014) and Suri and Jack (2016) examine how the geographic roll out of mobile money agents in Kenya (M-PESA) impacts on household saving and consumption. Their evidence suggests that access to digital payment services improves household saving as well as inter-household risk management. Agarwal et al. (2020a) study how the forced 2016 demonetization in India affected household consumption and find that consumers spend more after the forced switch to cashless payment instruments. We contribute to this literature by documenting how the improved convenience of electronic payments impacts on payment behavior and cash demand in a high-income economy with a well-developed payment infrastructure.[11]

2. Research Design, Institutional Background and Hypotheses

2.1. Research Design

We study the staggered introduction of contactless debit cards by one retail bank ("the Bank") in Switzerland over the period 2016-2018.[12] 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, 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 exogenous from the perspective of a bank client.

We observe payment behavior and cash withdrawals 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

[10] Several recent studies use experimental methods to explore the impact of savings interventions on household saving and consumption. See the internet appendix to Bachas et al. (2020) for an overview.

[11] Also in an advanced economy, Wright et al. (2017) exploit the geographically staggered switch from cash to non-cash welfare payments in the US to study how crime rates are affected.

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

captures the timing of receipt of a contactless debit card. During our period of observation, contactless debit cards allowed consumers to make purchases below 40 CHF without entering a PIN. For these low-value payments, the consumers could simply "tap and go" at the terminal without further authentication. For purchases above 40 CHF the entry of a PIN was still required to validate the payment.

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 at the end of 2018, the end of our observation period.

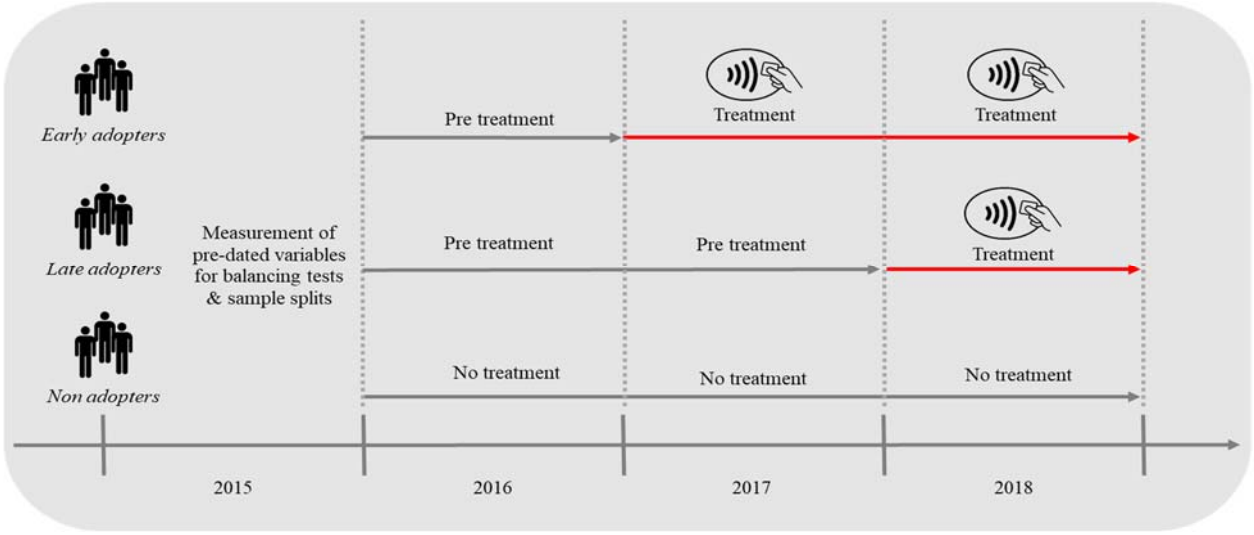

Fig. 1. Research design

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 payments.[13] 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.

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

A representative survey on payment methods confirms that during our observation period the overwhelming majority of PoS payments by Swiss consumers were conducted in cash or by debit card (SNB 2018). By contrast, credit cards[14] are mostly used for online purchases or for specific transactions (e.g. travel expenses). 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 European economies in the pre-Covid period (see Bagnall et al. 2016, European Central Bank 2020), and significantly above that in Australia, Canada or the UK, for example.[15] 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.[16]

During our period of observation, contactless cards enabled Swiss consumers to make purchases below 40 CHF without entering a PIN. Thus the issuing of contactless cards to consumers improved the convenience of card payments for these small value payments. Data from the 2017 SNB payment survey (SNB 2018) suggests that, for the average Swiss consumer, 58% of all transactions (29 out of 50 monthly transactions) were cash transactions with a value of less than 40 CHF. Thus, the potential for contactless cards to impact on payment behavior and cash demand during our observation period is substantial.

The period we study marks the widespread introduction of contactless debit cards in Switzerland. The share of debit cards featuring the contactless technology was 10% at the end of 2015, 28% in 2016, 51% in 2017 and 71% at the end of 2018.[17] 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. In our estimates of average treatment effects we control for time-varying heterogeneities in local payment infrastructure by employing location*year fixed effects. Moreover, we estimate dynamic treatment effects to account for the

[14] The vast majority of credit cards in Switzerland are "delayed debit cards", i.e. card balances have to be paid off in full at the end of the billing period, which is mostly a month.

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

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

[17] Section 2 in the pre-analysis 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).

interplay of innovations of payment instruments and payment infrastructure (Huynh et al. 2019; Crouzet et al. 2020).

2.3. Hypotheses

Our empirical predictions are informed by inventory theories which integrate consumer cash management and payment choice (Santomero 1979, Whitesell 1989, Bouhdaoui & Bounie, 2012, Alvarez & Lippi 2017). Within these models, the introduction of contactless cards can be seen as a reduction in the non-pecuniary transaction costs of card versus cash payments - for small value purchases. The reduction in card payment costs arises from the fact that a personal identification number (PIN) no longer needs to be entered at card payment terminals for payments below 40 CHF. As a consequence, we expect to observe (i) an increase in debit card payments for small-value transactions, (ii) a decrease in the cash share of payments and (iii) a decrease in cash withdrawals.

Based on the above predictions we pre-registered a set of hypotheses in our pre-analysis plan. We test two main hypotheses for the average treatment effect of the introduction of contactless debit cards:

H1: Payment choice: The contactless payment technology reduces the share of cash as a means of payment.

H2: Cash demand: The contactless payment technology reduces the demand for cash, i.e. the frequency and the average size of cash withdrawals.[18]

In order to shed light on the convenience effect of contactless debit card transactions as a mechanism we test the following auxiliary hypothesis:

H3: Debit card transactions: The contactless payment technology increases the number of debit card PoS payments which are eligible for the contactless technology (0-40 CHF) relative to PoS payments which are not eligible for the contactless technology (above 40 CHF).[19]

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

[19] In our pre-analysis plan we split this hypothesis into separate hypotheses comparing small transactions (0-20 CHF), medium sized transactions (20-40 CHF) which are eligible for contactless payment, medium sized transactions (40-CHF) which are eligible for contactless payment, and other transactions. For reasons of exposition we summarize

In a pre-registered test of heterogenous treatment effects we examine whether the casual effect of contactless cards is systematically related to past payment behavior. In particular we are interested in whether the enhanced convenience of electronic payments leads more consumers to use debit cards at the point of sale - or whether it primarily leads existing users of debit cards to use their cards more often. We conjecture that the extensive margin effect is weaker than the intensive margin effect. This prediction is supported by behavioral models which suggest persistent heterogeneities in cash preferences, e.g. due to the valuation of anonymity, budget monitoring or habit (e.g. Kahn et al. 2005, van der Cruijsen et al. 2017, von Kalckreuth et al. 2014).

H4: The role of past payment behavior: The impact of the contactless payment technology on payment choice and cash demand differs according to the pre-treatment use of cash. The impact should be smaller for consumers with a high pre-treatment use of cash than for consumers with a low pre-treatment use of cash.

The observed impact of payment innovation on consumer payment choice and cash demand should be strongly affected by merchant payment infrastructure (Huynh et al. 2019; Crouzet et al. 2020). In our pre-analysis plan we established a corresponding hypothesis that the effect of contactless cards on payment choice and cash demand should be stronger in locations with more PoS terminals and fewer ATMs. Due to the unavailability of data on the location of PoS terminals we were unable to test this hypothesis.[20] As an alternative, in section 5.2 we report on (non-registered) tests by client age and location.

these hypotheses in H3. Our empirical analysis in section 4.1 reports and compares estimates for all pre-registered transaction sizes.

[20] 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 section 6.2 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.

3. Data and Methodology

3.1. Sample

Our data is based on a random sample of retail clients (private individuals only) of the Bank with a transaction account and at least one debit card in 2015.[21] 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 Internet Appendix 1). First, we restrict our main analysis to the clients with one account and one card only with the Bank (90%=26'934 clients).[22]

Second, we 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. However, an irregular change in expiry dates may also occur if a client demands a change of his/her card, e.g. because he/she wishes (earlier) access to the contactless technology. To rule out selection into adoption of the contactless technology we thus drop 2'913 clients with irregular changes of card expiry dates. This leaves us with 24'021 clients of which 22'504 have complete information on covariates.

Due to the administrative nature of our data, we do not observe whether a client has accounts at other banks which are used for regular payments. In order to limit our sample to accounts which are actively used for regular payments (only) we exclude clients whose incoming or outcoming account flows are less than 1'200 CHF or more than 500'000 CHF in any year of our observation period. This sample comprises 21'122 clients.

Even though clients were drawn randomly, a disproportionate share of clients belongs to the early adopter group (i.e. they received a new card in 2016). Consultations with the Bank revealed that this data pattern is driven by a synchronous renewal of a large number of cards by the Bank in 2010. While this legacy effect does not affect the exogeneity of the timing of access to contactless cards from 2016 onwards, it is associated with an imbalance in the age-structure across treatment groups. As client age is likely to affect the development of consumer behavior during our

[21] The pre-analysis plan details the sampling, i.e. the sample was drawn only among *active* accounts, i.e. accounts with at least 1'200 CHF of incoming payments in 2015 and accounts with at least 1'200 CHF of cash withdrawals or debit and credit card payments in 2015.

[22] In the pre-analysis plan, 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 26'923 out of 30'000 accounts (90%) have just one card (see Internet Appendix 1). Therefore, we focus our analysis on accounts with one card and present robustness checks for accounts with multiple cards.

observation period, we pre-processed the data set such that the age structure for each treatment group matches the age structure of the overall sample. This is done by randomly selecting (without replacement) the maximum number of clients from each of six age classes such that the three groups are balanced with respect to these six age classes. This pre-processing stage reduces the number of clients in the sample to 16'779, of which 7'471 are *Early adopters*, 4'803 are *Late adopters* and 4'505 are *Non adopters.* This pre-processing procedure was not registered in the pre-analysis plan as our initial quality checks on the data were conducted on a blinded sample without treatment information. For transparency, we document the main results for the unprocessed sample in the Internet Appendix.[23]

As specified in our pre-analysis plan, 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 16'779 clients. Our main analysis for the period 2016-2018 is thus based on a sample of 50'337 client*year observations.

In addition to our main analysis conducted on client*year observations we present descriptive evidence and robustness tests based on client*year-quarter observations. The year-quarter data allow for a more precise inspection of pre-treatment parallel trends of our outcome variables. They also allow for a more detailed analysis of dynamic treatment effects.

3.2. Outcome Variables

As specified in the pre-analysis plan, we study three primary outcome variables**.** The variable *Cash ratio* measures the share of out-of-pocket expenditures (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.

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

[23] Overall, the average treatment effects are weaker or more often insignificant with the processed sample than with the unprocessed sample. This is intuitively clear given that the treatment effect rests on a comparison of the group of *Early adopters* with the group of *Non adopters*. The pre-processing disproportionally eliminates younger respondents in the *Early adopters* group which are more likely to react to financial innovation and older respondents in the *Non adopters* group which are less likely to react to financial innovation.

We study two measures of cash demand which are central to inventory models. The variable *Cash withdrawal frequency* captures the average monthly number of cash withdrawals from ATMs and bank branches. We additionally measure the average size of each withdrawal transaction with the variable *Cash withdrawal amount* (in CHF):

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

All three of our main outcome variables are potentially subject to measurement error. 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 or non-response. 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 our sample of consumers. 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 pay 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.[24] 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 definitions of *Cash ratio* (excluding credit cards, including e-banking payments, focusing only on domestic transactions, see Internet Appendix).

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

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

make withdrawals to hoard cash. However, again SNB (2018) report that the vast majority of surveyed households 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 which would imply that we do not observe a consumer's 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). We limit our analysis to accounts which are regularly used for payments. Moreover, 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 isolate the convenience effect of contactless payment cards we study auxiliary outcome variables which capture the average monthly number 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 non-PIN contactless payments (up to 40 CHF).

Table 1 presents descriptive statistics for all outcome variables. The table documents the importance of cash as a means of payment in our sample. The median *Cash ratio* is 74%, while the interquartile range spans 46%-95%. Thus, only about 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.[25] The median of *Cash withdrawal frequency* is 3 transactions per month while the median *Cash withdrawal amount* is 338 CHF, implying that the average consumer in our sample makes 1 cash withdrawal roughly every 10 days and withdraws an amount equal to about 34 CHF per day. A closer look at the data (see the Internet Appendix for details) reveals that almost all cash withdrawals are made from ATMs (median 2.8 per month). The median size of withdrawals from ATMs (272 CHF) is significantly lower than that from bank branches (1650 CHF).

[25] 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 the Internet Appendix).

Table 1. Outcome variables

	mean	min	p25	p50	p75	max	n
Main Outcome Variables							
Cash ratio (%)	68.2	0.0	46.3	73.7	94.8	100	50,169
Cash withdrawal frequency (per month)	3.7	0.0	1.6	3.0	5.0	43	50,337
Cash withdrawal amount (CHF)	614	16	189	338	662	35'000	49,667
Auxiliary Outcome Variables (frequency per month)							
Debit PoS transactions	6.5	0.0	0.5	3.6	9.7	105	50,337
Debit PoS transactions (0-20 CHF)	1.9	0.0	0.0	0.3	1.8	89	50,337
Debit PoS transactions (20-40 CHF)	1.5	0.0	0.0	0.6	2.1	24	50,337
Debit PoS transactions (40-60 CHF)	1.0	0.0	0.0	0.5	1.5	13	50,337
Debit PoS transactions (60-100 CHF)	1.1	0.0	0.1	0.6	1.7	17	50,337
Debit PoS transactions (100+ CHF)	1.1	0.0	0.1	0.6	1.4	19	50,337

Note: The table presents descriptive statistics for our main and auxiliary outcome variables. Observations are at the client*year level for 16'779 clients and for the years 2016, 2017, 2018. Variable definitions are presented in Appendix A.

During our period of analysis, the median number of *Debit PoS transactions* per month is 3.6, while the interquartile range spans from 0.5 to 10 transactions per month. These descriptive statistics confirm the presence of pronounced heterogeneities in payment behavior that have also been noted in prior studies using survey data (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) and Baker et al. (2021). 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 compare three relevant groups of clients in our sample (see Figure 1). *Early adopters* are those clients who receive access to the contactless payment technology at the end of 2016. For these clients we have adoption date $a_i = 2017$. *Late adopters* are those clients who receive access to the contactless payment technology at the end of 2017. For these clients we have $a_i = 2018$. *Non adopters* do not receive access to 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 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 average 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 administrative data provides us with a broad set of socioeconomic and account-level covariates which allow us to verify the assumption of randomized adoption. Table 2 presents summary statistics and balancing tests for all covariates as measured per December 2015. As discussed above we pre-process the sample to assure that the age-structure of the three groups is balanced with that of the full sample. All other socioeconomic covariates are also well balanced. While some t-tests indicate statistically significant differences for some covariates between some treatment groups, the magnitude of these differences is negligible. We thus argue that our data largely meet the assumptions of randomized adoption.

Table 2. Covariate variables

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

	mean	min	p25	p50	p75	max	n
Client-level Variables							
Age: 35 or younger	0.3	0	0	0	1	1	16,779
Age: 36-55	0.4	0	0	0	1	1	16,779
Age: 56 or older	0.3	0	0	0	1	1	16,779
Male	0.51	0	0	1	1	1	16,779
Nationality Swiss	0.71	0	0	1	1	1	16,779
Size municipality	2.63	1	2	2	3	5	16,779
Income	2.61	1	1	2	4	6	16,779
Wealth	2.02	1	1	2	3	6	16,779
Savings account	0.53	0	0	1	1	1	16,779
Retirement account	0.22	0	0	0	0	1	16,779
Custody account	0.19	0	0	0	0	1	16,779
Mortgage	0.07	0	0	0	0	1	16,779
Ebanking	0.53	0	0	1	1	1	16,779
Account-level Variables							
Account opening year	1998	1972	1990	2000	2008	2014	16,779
Direct debiting	0.55	0	0	1	1	1	16,779
Standing order Ebanking	0.15	0	0	0	0	1	16,779
Standing order paper	0.36	0	0	0	1	1	16,779
Ebanking payments	1,619	0	0	0	2,524	36,312	16,779
Transfers	326	0	0	0	25	29,279	16,779
Incoming payments	4,907	100	2,362	4,449	6,389	38,562	16,779
Outgoing payments	5,392	107	2,577	4,706	6,871	41,619	16,779
Account balance	3.41	1	1	3	6	6	16,779

Note: 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 A. In Panel B, *, **, *** denote significance of T-tests at the 0.1, 0.05 and 0.01-level.

Panel B. Sample means by treatment group (Pre-treatment = 2015)

	Early adopters	Late Adopters	Non adopters	T-tests		
	[1]	[2]	[3]	[1 vs. 2]	[1 vs. 3]	[2 vs. 3]
Client-level Variables						
Age: 35 or younger	0.30	0.30	0.30			
Age: 36-55	0.40	0.40	0.40			
Age: 56 or older	0.30	0.30	0.30			
Male	0.51	0.52	0.50			*
Nationality Swiss	0.71	0.71	0.71			
Size municipality	2.64	2.63	2.62			
Income	2.61	2.64	2.59			
Wealth	2.06	1.98	2.02	***	*	
Savings account	0.54	0.53	0.51		**	
Retirement account	0.22	0.22	0.22			
Custody account	0.19	0.18	0.20	*		**
Mortgage	0.07	0.08	0.07			
Ebanking	0.53	0.54	0.53			
Account-level Variables						
Account opening year	1998	1999	1998	***		***
Direct debiting	0.55	0.56	0.54			
Standing order Ebanking	0.15	0.16	0.15			**
Standing order paper	0.35	0.36	0.37		**	
Ebanking payments	1,618	1,641	1,595			
Transfers	316	332	337			
Incoming payments	4,893	4,923	4,915			
Outgoing payments	5,369	5,436	5,385			
Account balance	3.46	3.34	3.39	***	**	

Our observation of pre-adoption realizations ($t < a_i$) of the outcome variables allow us to verify the assumption of no anticipation. Specifically, we can examine whether the outcome variables exhibit parallel trends by treatment group in the pre-adoption phase. Figures 2 and 3 provide a visual inspection of the parallel-trends assumption for our outcome variables using quarterly breakdowns of our data. *Early adopters* receive a contactless card in 2016q4. To rule out anticipation by the early adopters we therefore compare the trend of our outcome variables to that of the non-adoption group over the period 2016q1-2016q3. *Late adopters* receive a contactless card in 2017q4. To rule out anticipation by this group of clients we therefore compare the trend of our outcome variables to that of the non-adoption group over the period 2016q1-2017q3. Both comparisons support the assumption of no anticipation.

Panel A. Transactions with a value of at most 40 CHF (no PIN required for contactless)

Panel B. Transactions with a value of more than 40 CHF (PIN required for contactless)

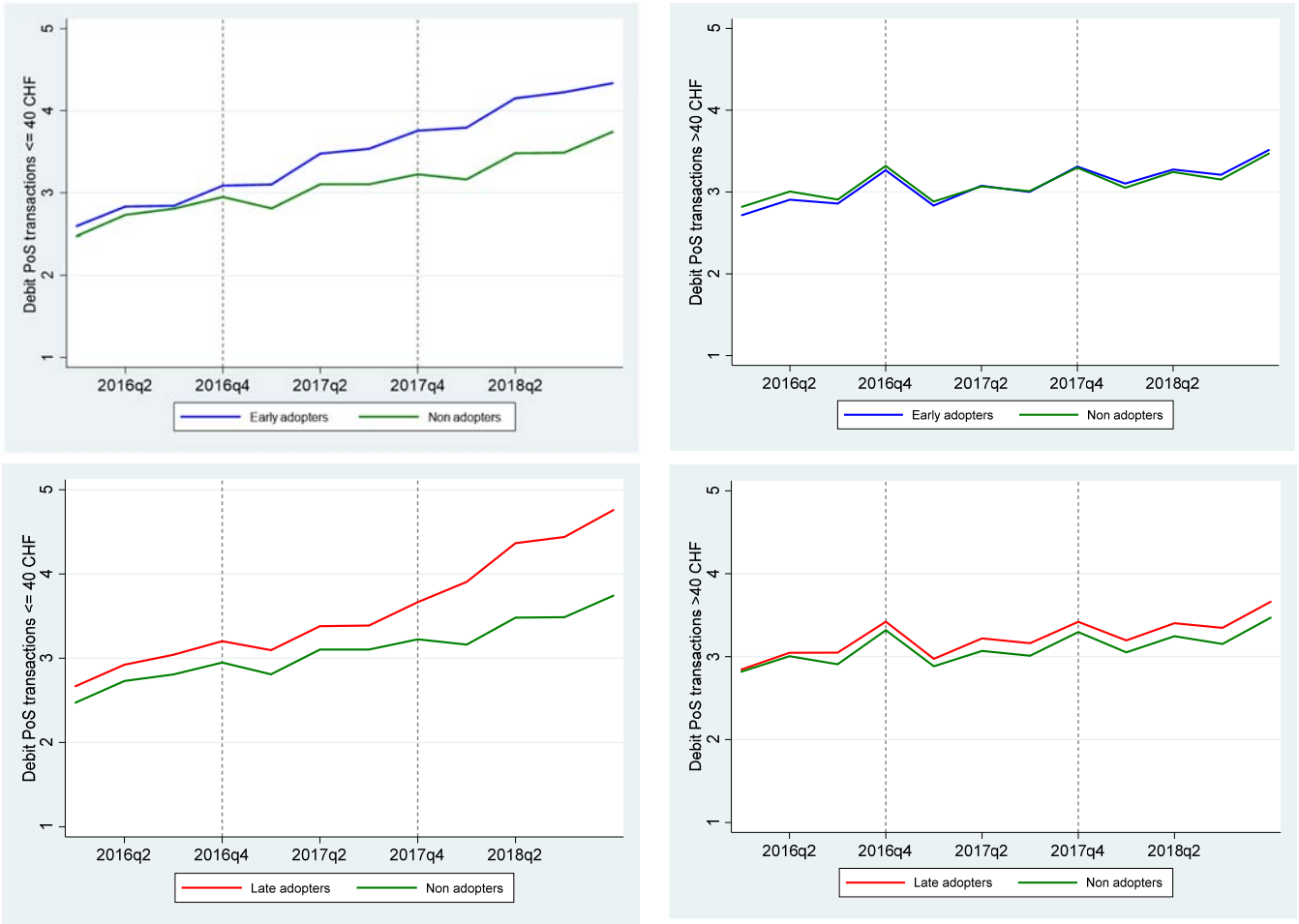

Fig. 2. Debit card PoS transactions. This figure displays the monthly average number of Point of Sale (PoS) transactions conducted by debit card per client and year-quarter by treatment group. Panel A displays the number of transactions with a value of at most 40 CHF. Panel B displays the number of transactions with a value of more than 40 CHF. Appendix A presents definitions of all variables. Table 1 presents summary statistics.

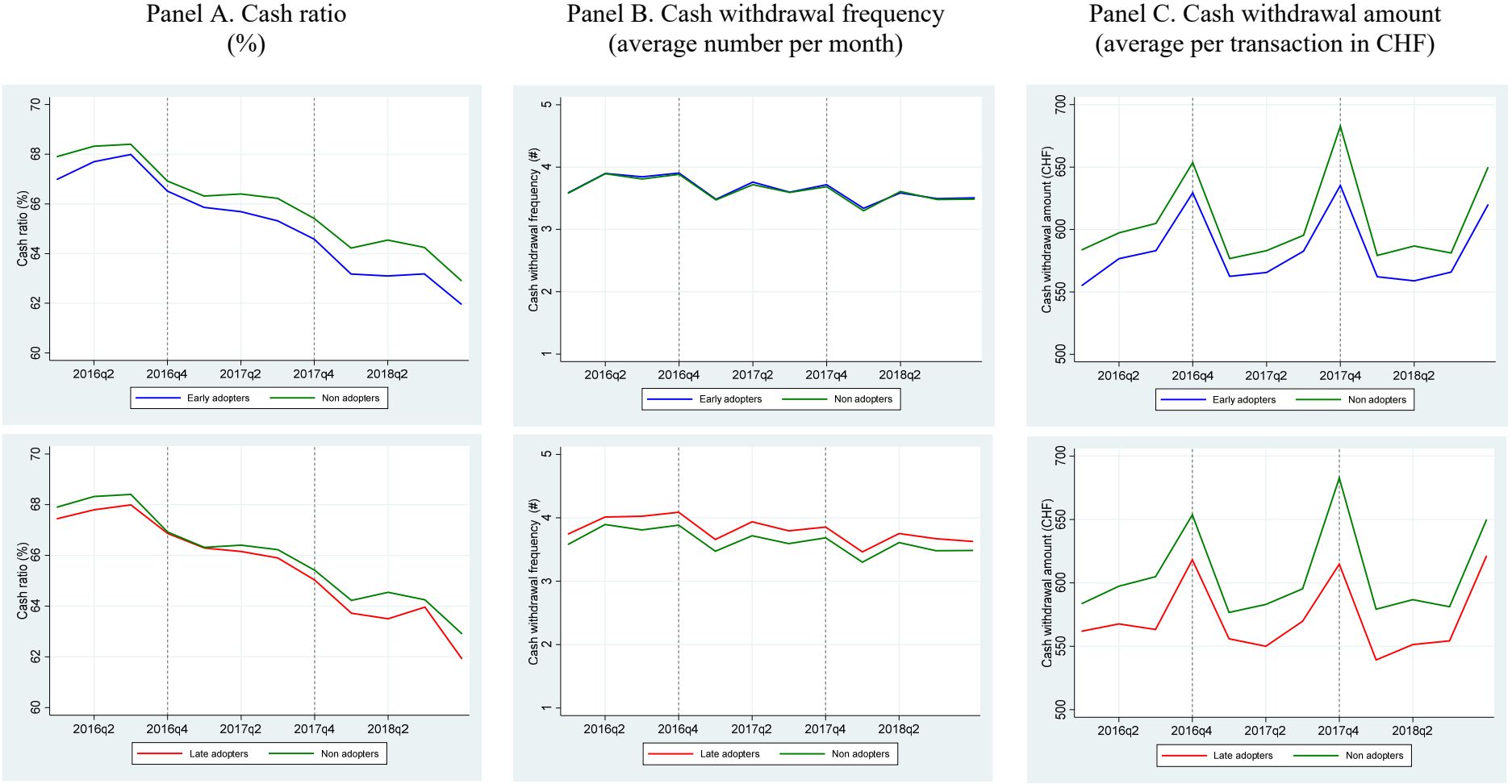

Fig. 3. Payment choice and cash demand. This figure displays the payment choice and cash demand per client and year-quarter by treatment group. Panel A displays the cash ratio of payments in %. Panel B displays the average monthly number of cash withdrawals. Panel C displays the average size of cash withdrawals in CHF. Appendix A presents definitions of all variables. Table 1 presents summary statistics.

3.4. Inference

In line with our pre-analysis plan our statistical inference is based on two-sided tests of the estimators $\hat{\tau}$ in regression equation [1]. 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 client. 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) by adjusting standard errors for clustering at the client-level. Our analysis features three main outcome variables: *Cash ratio*, *Cash withdrawal frequency* and *Cash withdrawal amount*. We account for multiple hypothesis testing 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 main treatment variables $\hat{\tau}$ in equation [1] to be significant at a level of $p<0.0167$. For our analysis of auxiliary outcome variables we apply non-adjusted inference tests.

4. Average Treatment Effects

4.1. Debit Card Point of Sale (PoS)Transactions

Figure 2 depicts the average monthly number of debit card PoS transactions by treatment group over the analysis period 2016-2018. We present the data by year-quarter rather than by year to allow a visual inspection of pre-adoption parallel trends and dynamic treatment effects. In Panel A (Panel B) of the figure we split the data by whether the transaction value was below (above) 40 CHF, the threshold below which consumers may "tap and go" with a contactless card. In both panels we present separate figures comparing early adopters and late adopters vs. non-adopters respectively.

Figure 2, Panel A documents a trend increase in the number of low-value debit card transactions for all bank clients 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 small-value PoS transactions. The average number of transactions per month increases for this group from 2.5 in 2016q1 to 3.7 in 2018q4 (+51%).

The increase for the group of early adopters (late adopters) over the same period amounts to +67% (+78%), suggesting a causal impact of contactless cards on payment choice. Importantly, Panel A documents no difference in the growth of debit card use in the pre-adoption period, followed by an acceleration after the adoption of contactless cards. The group of early adopters displays a slightly weaker increase (+10%) than the group of non-adopters (+13%) during their pre-adoption period 2016q-2016q3. Post-adoption, 2016q4-2018q4, transactions increase by 40% for the early adopters compared to 20% for the non-adopters. Similarly, the group of late adopters displays an almost identical increase (+27%) as the group of non-adopters (+25%) during their pre-adoption period 2016q1-2017q3. Post-adoption, 2017q4-2018q4, transactions increase by a further 30% for the late adopters compared to only 16% for the non-adopters.

Panel B of Figure 2 replicates our visual inspection of debit card use for transactions with a value exceeding 40 CHF. For these transactions consumers are required to enter a PIN even if they have a contactless card. If it is the enhanced convenience of contactless cards (as opposed to PIN-based cards) which drives the treatment effect on debit card use, we would expect to see a much weaker effect for these large-value transactions then for the small-value transactions displayed in Panel A. This is the case. Over the period 2016q4-2018q4 transactions increase by 8% for the early adopters compared to 5% for the non-adopters. Similarly, over the period 2017q4-2018q4 transactions increase by 7% for the late adopters compared to 5% for the non-adopters.

Our visual inspection in Figure 2 suggests a strong causal effect on debit card PoS transactions only for the small-value payments for which contactless cards feature enhanced convenience. This finding is confirmed by the regression estimates presented in Table 3. The column 1 results show that after the receipt of a contactless card, the average monthly number of debit card transactions increases by an additional 0.47 transactions. This average treatment effect amounts to an 7.1% increase relative to the sample mean of 6.53 transactions per month. The bulk of this increase occurs for small transaction values: 0.42 monthly transactions on average for amounts below 40 CHF (columns 2-3). The estimates reported in Table 3 columns (4-6) confirm that spillover effects to larger value payments are small in economic magnitude and only borderline significant.

Table 3. Debit card PoS transactions

	(1)	(2)	(3)	(4)	(5)	(6)
		Debit PoS transactions by transaction value				
Outcome variable	All	below 20 CHF	20-40 CHF	40-60 CHF	60-100 CHF	above 100 CHF
Contactless	0.465***	0.347***	0.067***	0.019*	0.015	0.017*
	[0.047]	[0.030]	[0.013]	[0.008]	[0.009]	[0.008]
Year = 2017	0.377***	0.212***	0.091***	0.017***	0.051***	0.006
	[0.032]	[0.019]	[0.009]	[0.006]	[0.006]	[0.006]
Year = 2018	1.131***	0.611***	0.259***	0.066***	0.138***	0.058***
	[0.048]	[0.029]	[0.014]	[0.009]	[0.009]	[0.009]
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Clients	16,779	16,779	16,779	16,779	16,779	16,779
Client*Year observations	50,337	50,337	50,337	50,337	50,337	50,337
Mean of dependent variable	6.53	1.93	1.47	0.98	1.10	1.05
Method	OLS	OLS	OLS	OLS	OLS	OLS

Note: The table shows the results of OLS regressions. The dependent variables measure the average number of debit card PoS transactions per month for each client. In column (1) the dependent variable covers all debit card 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 16'779 clients. 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 brackets. *, **, *** denote significance at the 0.1, 0.05, and 0.01-level.

4.2. Cash use and cash demand

The results in the previous section confirm our auxiliary hypothesis: Consumer access to the contactless payment technology increases the use of debit cards for small value PoS transactions. The impact on the overall cash share of payments and cash demand will, however, depend on (i) the magnitude to which debit card transactions replace small-value cash transactions and (ii) the relevance of small-value purchases for total consumer spending.

The administrative data we use in this study does not allow us to observe how consumers use the cash that they withdraw from ATM's and bank branches. We therefore use payment diary data elicited for a representative sample of the Swiss population during our observation period (SNB 2018) to gauge the magnitude of the increase in small-value debit card transactions. That data suggests that Swiss consumers conduct 1.65 transactions per day, or roughly 50 transactions per month. Cash payments below 40 CHF account for an estimated 58% (29 per month) of these total transactions. Moreover, cash payments below 40 CHF account for roughly 40% of the total cash volume spent by the average consumer. Payment diary data thus reveals that a major shift in small-value payments from cash to debit card could have a large impact on the cash-share of payments and cash demand. However, gauged against this payment behavior of the average Swiss consumer, the causal effect of contactless cards on the use of debit cards for small-value payments is limited. Our estimates suggest an average increase in debit card transactions below 40 CHF of less than 0.5 transactions per month. This is less than 2% of the total number of small-value cash transactions an average consumer conducts each month.

We can also gauge the magnitude of our estimated effect compared to total consumer spending by payment instrument in our sample: Our data reveals that in 2016 on average a consumer in our sample spent 2'121 CHF per month on non-recurring transactions, of which 402 CHF were paid by debit card, 107 CHF were paid by credit card and 1612 CHF were settled by cash. This implies an average cash ratio of 76.0% in 2016.[26] Based on our Table 3 estimates we calculate an average treatment effect of 11 CHF in additional monthly debit card payments caused by the contactless technology. Consider that the increase in debit card payments of 11 CHF were fully offset by a decrease in cash withdrawals, without an increase in overall spending. This would imply a change in the cash ratio to 75.5% or a decrease of a mere 0.5 percentage points. Likewise, the average

[26] Note that this value deviates from the sample mean of individual cash ratios as shown in Table 1 (as the ratio of means differs from the mean of ratios).

monthly volume of cash withdrawals would decrease by 11 CHF from 1612 CHF, i.e. a mere 0.7%. These back-of-the-envelope calculations suggest that while the convenience of contactless cards may have caused an increase in the frequency of small-value debit card transactions, their impact on the cash share of payments and average cash demand is likely to be very small.

Figure 3 illustrates the impact of the contactless payment technology on our primary outcome variables: *Cash ratio* (Panel A), *Cash withdrawal frequency* (Panel B), and *Cash withdrawal amount* (Panel C). Again, we use quarterly data to visually examine the pre-adoption parallel trends assumption and the dynamics of post-adoption treatment effects. Panel A of Figure 3 reveals a significant trend decline in the cash ratio during our observation period. The cash ratio of non-adopters declines by 5 percentage points from 67.9 in 2016q1 to 62.9% in 2018q4. The group of early adopters (-5 pp) and late adopters (-5.5 pp) display a similar decline of the cash ratio over the same period. Panel B of Figure 3 documents a slight decline in the *Cash withdrawal frequency* for all three groups of clients. However, again there is no visible treatment effect of contactless card adoption for early adopters (from 2016q4) or for late adopters (from 2017q4). Panel C displays significant seasonalities in the average *Cash withdrawal amount* during our period of analysis, however no observable trend change.

Table 4 presents our estimates of the average treatment effect of the contactless payment technology for the three main outcome variables. The table confirms that the causal effect of contactless cards on cash use and cash demand is negligible. The column (1) results indicate that after receiving a contactless card the *Cash ratio* of a client declines by -0.3 pp, but this decline is statistically not significantly different from zero. By comparison, the column (1) regression results confirm a significant trend decrease in the cash ratio of -1.6 pp from 2016 to 2017 and -2.1 pp from 2017 to 2018. Columns (3) and (5) of Table 4 present our estimates of the impact of contactless cards on cash demand. We find neither a statistically significant treatment effect on the monthly *Cash withdrawal frequency* nor on average *Cash withdrawal amount*. In accordance with the declining trend in the cash ratio, the estimates reveal a declining time trend in the number of monthly withdrawals, but not in the *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.[27] Our estimates of the causal effect of contactless cards on the *Cash ratio*, *Cash withdrawal frequency*, and *Cash withdrawal amount* are unaffected.

[27] For reasons of data-protection we do not observe the exact zip-code or municipality of clients. See section 6.2 for a detailed discussion of how we define location based on available information on region of residence and municipality size.

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

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome variable	Cash ratio (%)		Cash withdrawal frequency		Cash withdrawal amount	
Contactless	-0.303	-0.295	-0.013	-0.012	4.73	5.059
	[0.163]	[0.163]	[0.016]	[0.016]	[8.467]	[8.587]
Year = 2017	-1.662***		-0.162***		1.289	
	[0.122]		[0.012]		[6.220]	
Year = 2018	-3.735***		-0.321***		-6.198	
	[0.168]		[0.016]		[7.728]	
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	Yes	No	Yes	No	Yes
Clients	16,769	16,769	16,779	16,779	16,718	16,718
Client*Year observations	50,169	50,169	50,337	50,337	49,667	49,667
Mean of dependent variable	68.2	68.2	3.68	3.68	614	614
Method	OLS	OLS	OLS	OLS	OLS	OLS

Note: The table shows the results of OLS regressions. 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 A 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 brackets. *, **,*** denote significance at the 0.05, 0.0167, and 0.01-level.

5. Dynamic Treatment Effects

The impact of payment innovation on observed consumer behavior depends on adoption of the innovation by both consumers and merchants. Our average treatment effects reported in section 4 estimate the response of consumers to receiving a contactless debit card (rather than maintaining a PIN-based card) conditional on the average merchant payment infrastructure. As illustrated in section 3, the electronic payment infrastructure in Switzerland was well developed during our observation period. However, the specific payment infrastructure relevant to facilitating contactless payments evolved substantially: The share of NFC compatible payment terminals more than doubled between 2015 (26%) and 2018 (59%).

To examine the dynamics of our 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 $Y_{i,t} \in \{Cash\ ratio_{i,t}, Cash\ withdrawal\ frequency_{i,t}, Cash\ withdrawal\ amount_{i,t}\}$ 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). [28]

[28] In Section 8.2 we report a (non-registered) robustness check in which we examine dynamic treatment effects based on quarterly data.

Table 5. Dynamic treatment effect

Panel A. Debit PoS transactions (transactions per month)

	(1)	(2)	(3)	(4)	(5)	(6)
		Debit PoS transactions by transaction value				
Outcome variable	All	below 20 CHF	20-40 CHF	40-60 CHF	60-100 CHF	above 100 CHF
Early adopter, 2017	0.376***	0.267***	0.042*	0.025*	0.016	0.026*
	[0.063]	[0.038]	[0.018]	[0.012]	[0.012]	[0.012]
Early adopter, 2018	0.682***	0.463***	0.096***	0.039**	0.039*	0.045***
	[0.091]	[0.056]	[0.024]	[0.015]	[0.016]	[0.015]
Late adopter, 2017	0.155*	0.082*	0.022	0.019	0.010	0.022
	[0.068]	[0.039]	[0.020]	[0.013]	[0.013]	[0.013]
Late adopter, 2018	0.774***	0.554***	0.126***	0.035*	0.027	0.032
	[0.107]	[0.066]	[0.028]	[0.017]	[0.018]	[0.017]
Year = 2017	0.372***	0.224***	0.096***	0.009	0.048***	-0.004
	[0.047]	[0.027]	[0.014]	[0.009]	[0.010]	[0.009]
Year = 2018	0.946***	0.500***	0.229***	0.052***	0.124***	0.041***
	[0.068]	[0.040]	[0.019]	[0.012]	[0.013]	[0.012]
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Clients	16,779	16,779	16,779	16,779	16,779	16,779
Client*Year observations	50,337	50,337	50,337	50,337	50,337	50,337
Mean of dependent variable	6.53	1.93	1.47	0.98	1.10	1.05
Method	OLS	OLS	OLS	OLS	OLS	OLS

Note: The table shows the results of OLS regressions with the treatment effect separated by year. The dependent variable in Panel A is Debit PoS transactions, i.e. the average number of debit card PoS transactions per month for each client. In column (1) the dependent variable covers all debit card 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). The dependent variables in Panel B are the Cash ratio, the Cash withdrawal frequency and the Cash withdrawal amount. Appendix A 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. Robust standard errors are reported in brackets. In Panel A, *, **, *** denote significance at the 0.1, 0.05, and 0.01-level. In Panel B, *, **, *** denote significance at the 0.05, 0.0167, and 0.01-level.

Panel B. Payment choice and cash demand

Outcome variable	(1) Cash ratio (%)	(2) Cash withdrawal frequency (#)	(3) Cash withdrawals amount (CHF)
Early adopter, 2017	-0.193	0.006	-0.028
	[0.243]	[0.023]	[13.278]
Early adopter, 2018	-0.426	-0.004	2.688
	[0.295]	[0.029]	[13.059]
Late adopter, 2017	-0.015	0.018	-16.434
	[0.263]	[0.026]	[13.143]
Late adopter, 2018	-0.471	-0.016	-8.393
	[0.321]	[0.033]	[13.786]
Year = 2017	-1.707***	-0.175***	8.116
	[0.190]	[0.018]	[9.198]
Year = 2018	-3.632***	-0.324***	-1.531
	[0.230]	[0.022]	[9.857]
Client fixed effects	Yes	Yes	Yes
Year*Location fixed effects	No	No	No
Clients	16,769	16,779	16,718
Client*Year observations	50'169	50'337	49'667
Mean of dependent variable	68.2	3.7	614
Method	OLS	OLS	OLS

Table 5, Panel A reveals a time-varying treatment effect on the frequency of small-value debit card transactions. The estimated effects for early adopters in 2018 and late adopters in 2018 is substantially larger than that for early adopters in 2017 (columns 2-3). This supports the conjecture that increasing merchant adoption of NFC compatible payment infrastructure during our observation period impacted on the payment choice of those consumers who were able to use this more convenient electronic payment technology.

In Table 5 Panel B, the estimated treatment effect for the *Cash ratio* is also larger in magnitude for early adopters in 2018 and late adopters in 2018 than for early adopters in 2017 (column 1). However, all effects remain statistically insignificant. The estimated treatment effects for *Cash withdrawal frequency* and *Cash withdrawal amount* (columns 2-3) reveal no systematic (dynamic) pattern.

6. Heterogenous Treatment Effects

6.1. Pre-treatment payment behavior

Does enhanced convenience of contactless cards lead more consumers to use debit cards at the point of sale? Or do only existing debit card users increase the frequency with which they use their cards? Theory and evidence suggest that cross-sectional differences in payment behavior across households may partly result due to persistent differences in cash preferences, e.g. for reasons of budget monitoring (von Kalckreuth et. al. 2014), habit (van der Cruijsen et al. 2017) or preferences towards anonymity (Kahn et al. 2005). Our hypothesis 4 therefore suggests a stronger effect of contactless cards for consumers who already use debit cards at the point of sale compared to cash-only consumers.

We split our sample into four groups which correspond to four quartiles of the pre-treatment *Cash ratio,* as measured in 2015. Table 6, Panel A shows a strong and significant treatment effect on the number of monthly debit card transactions for those clients who used debit cards already before receiving a contactless card (columns 1, 2 and 3). In contrast, we find that consumers who relied predominantly on cash in 2015 do not increase their number of card payments after receipt of a contactless card (column 4). We confirm our conjecture that the enhanced convenience of electronic payments provided by contactless debit cards does not lead more consumers to use these cards (extensive margin effect).

The estimated annual increase in the number of monthly debit card transactions is 0.49 for clients with a pre-treatment cash ratio between 78% and 96%, 0.6 for clients with a pre-treatment cash ratio between 52% and 78% and 0.65 for clients with a pre-treatment cash ratio between 0% and 52%. Relative to the mean number of monthly debit card transactions, the intensive margin treatment effect is thus strongest for clients with an low, but positive pre-treatment use of debit cards (column 3).

Table 6, Panel B reports the heterogenous treatment effect estimates for the *Cash ratio.* A sizeable and significant treatment effect of contactless cards is only found for the group with an intermediate pre-treatment cash ratio (column 2). In this group, contactless cards reduce the cash ratio by 0.74 pp compared to an average pre-treatment cash ratio of 59.8%. Panels C and D of Table 6 summarize our estimates for the cash withdrawal frequency and the average cash withdrawal amount. The results show that the modest increase in card use does not cause significant changes in cash demand.

Overall, the Table 6 results confirm strong persistence in payment behavior at the extensive margin. Cash-only consumers hardly change their payment behavior in reaction to the availability of more convenient electronic payment instruments.

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

Panel A. Debit PoS transactions (transactions per month)

	(1)	(2)	(3)	(4)
Outcome variable	Debit PoS transactions			
Cash ratio (%) in 2015 (quartiles):	[0-52%]	(52%-78%]	(78%-96%]	(96%-100%]
Contactless	0.652***	0.609***	0.490***	0.065
	[0.114]	[0.115]	[0.087]	[0.044]
Year = 2017	0.226***	0.534***	0.492***	0.272***
	[0.081]	[0.076]	[0.056]	[0.033]
Year = 2018	1.096***	1.588***	1.310***	0.552***
	[0.119]	[0.118]	[0.087]	[0.047]
Client fixed effects	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	No	No	No
Clients	4,195	4,195	4,195	4,194
Client*Year observations	12,585	12,585	12,585	12,582
Mean of dependent variable	11.5	8.7	5.0	0.9
Method	OLS	OLS	OLS	OLS

Note: The table shows the results of OLS regressions for subsamples of clients based on their pre-treatment payment behavior. We split clients by quartile of Cash ratio (%) in 2015. The dependent variable in Panel A is Debit PoS transactions, in Panel B the Cash ratio, in Panel C the Cash withdrawal frequency and in Panel D the Cash withdrawal amount. Appendix A 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 brackets. In Panel A, *, **, *** denote significance at the 0.1, 0.05, and 0.01-level. In Panel B, C and D, *, **, *** denote significance at the 0.05, 0.0167, and 0.01-level.

Panel B. Cash ratio (%)

	(1)	(2)	(3)	(4)
Outcome variable	Cash ratio (%)			
Cash ratio (%) in 2015 (quartiles):	[0-52%]	(52%-78%]	(78%-96%]	(96%-100%]
Contactless	-0.010	-0.742*	-0.127	-0.240
	[0.379]	[0.364]	[0.312]	[0.225]
Year = 2017	-0.748***	-2.262***	-2.412***	-1.265***
	[0.290]	[0.274]	[0.234]	[0.157]
Year = 2018	-2.326***	-5.195***	-5.145***	-2.326***
	[0.390]	[0.371]	[0.332]	[0.227]
Client fixed effects	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	No	No	No
Clients	4,192	4,193	4,194	4,190
Client*Year observations	12,549	12,556	12,562	12,502
Mean of dependent variable	35.9	59.8	81.3	96.1
Method	OLS	OLS	OLS	OLS

Panel C. Cash withdrawal frequency (transactions per month)

	(1)	(2)	(3)	(4)
Outcome variable	Cash withdrawal frequency			
Cash ratio (%) in 2015 (quartiles):	[0-52%]	(52%-78%]	(78%-96%]	(96%-100%]
Contactless	-0.006	-0.045	0.015	-0.007
	[0.025]	[0.033]	[0.037]	[0.030]
Year = 2017	-0.129***	-0.221***	-0.241***	-0.059***
	[0.019]	[0.026]	[0.028]	[0.022]
Year = 2018	-0.262***	-0.430***	-0.454***	-0.144***
	[0.026]	[0.035]	[0.039]	[0.029]
Client fixed effects	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	No	No	No
Clients	4,195	4,195	4,195	4,194
Client*Year observations	12,585	12,585	12,585	12,582
Mean of dependent variable	2.7	3.9	4.6	3.5
Method	OLS	OLS	OLS	OLS

Panel D. Cash withdrawal amount (CHF per withdrawal)

	(1)	(2)	(3)	(4)
Outcome variable	Cash Withdrawal Amount (CHF)			
Cash ratio (%) in 2015 (quartiles):	[0-52%]	(52%-78%]	(78%-96%]	(96%-100%]
Contactless	18.834	-3.571	11.073	-7.191
	[18.568]	[11.934]	[14.771]	[21.126]
Year = 2017	-9.210	8.412	6.033	-0.410
	[13.234]	[10.045]	[10.943]	[14.932]
Year = 2018	-14.336	4.405	-12.227	-2.850
	[12.635]	[12.185]	[14.891]	[20.222]
Client fixed effects	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	No	No	No
Clients	4,152	4,189	4,190	4,187
Client*Year observations	12,186	12,491	12,519	12,471
Mean of dependent variable	324.1	367.7	599.4	1160.1
Method	OLS	OLS	OLS	OLS

6.2. Age and location

In Table 7 we present an explorative (not pre-registered) subsample analysis along two important dimensions: the age and location of consumers. Survey evidence from numerous countries shows that the payment behavior of consumers varies cross-sectionally by age (e.g. Arango et al. 2015, SNB 2018). Young consumers are thought of being more likely to adopt and use new (financial) technologies due to lower resistance and greater ability to learn new technologies and their longer time horizon (see e.g. Yang and Ching, 2013).

The impact of contactless cards on payment behavior is likely to depend strongly on pre-existing local payment infrastructure (PoS terminals vs. ATMs) and how merchants adapt to contactless payment instruments (NFC payment terminals, self-check outs). Treatment effects could thus differ between urban and rural locations if contactless-enabled terminals are installed at a greater pace in urban locations than in rural locations. Furthermore, the effect of age and location could interact if the payment infrastructure differs between merchants at specific (urban) locations.

Based on our administrative data we split our sample by three 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.[29] 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 by age and location. Subsample averages confirm that the use of debit cards (Panel A) as well as the cash share of payments (Panel B) depends strongly on client age. Consumers of each age group conduct more

[29] 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.

debit card transactions in urban areas, while the cash share of payments is hardly affected by urban vs. rural location. Younger consumers exhibit a much stronger trend increase in the number of debit card transactions and a stronger trend decline in the cash share of payments than older consumers. Conditional on the age-group, the time trend in payment behavior appears independent of urban vs. rural locations.

Table 7, Panel A presents our subsample estimates for the impact of contactless cards on the number of monthly *Debit PoS transactions*. The results are striking. For young urban clients the receipt of a contactless card increases the monthly number of debit card transactions by 1.4 transactions, or by 12% relative to an average of 11 debit card transactions per month. For middle-aged urban clients, the increase is 0.4 card transactions per month (5% relative to the mean of 7.4 transactions per month). There is no significant change in the use of debit cards following the receipt of a contactless card for clients above 55 years. Treatment effects are similar between urban and rural areas for middle-aged and older clients. By contrast, for young clients (below 35 years) living in rural areas the treatment effect is only half the size (0.65 transactions per month) of that for young clients living in urban areas.

Table 7, Panel B presents our subsample estimates for the impact of contactless cards on cash use. We find that the causal impact of contactless cards on the *Cash ratio* is 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 1.3 pp. This effect is sizeable as it amounts to 2.2% 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). Table 7, Panels C and D presents our subsample estimates for the impact of contactless cards on cash withdrawals. We find no significant treatment effects.

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

Panel A. Debit PoS transactions (transactions per month)

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome variable	Debit PoS transactions					
Location	Urban			Rural		
Client age (years)	below 35	35-55	above 55	below 35	35-55	above 55
Contactless	1.352***	0.362***	0.128	0.652***	0.331***	0.068
	[0.189]	[0.096]	[0.071]	[0.158]	[0.077]	[0.059]
Year = 2017	1.034***	0.177***	-0.025	1.014***	0.142***	0.061
	[0.132]	[0.064]	[0.050]	[0.104]	[0.054]	[0.042]
Year = 2018	2.647***	0.847***	0.177*	2.506***	0.643***	0.221***
	[0.191]	[0.100]	[0.080]	[0.162]	[0.078]	[0.061]
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	No	No	No	No	No
Clients	2,418	3,204	2,585	2,640	3,511	2,421
Client*Year observations	7,254	9,612	7,755	7,920	10,533	7,263
Mean of dependent variable	11.0	7.4	3.4	8.4	6.1	2.9
Method	OLS	OLS	OLS	OLS	OLS	OLS

Notes: This table shows the results of a OLS regressions 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 in Panel A is Debit PoS transactions, in Panel B the Cash ratio, in Panel C the Cash withdrawal frequency and in Panel D the Cash withdrawal amount. Appendix A 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 brackets. In Panel A, *, **, *** denote significance at the 0.1, 0.05, and 0.01-level. In Panel B, C and D, *, **, *** denote significance at the 0.05, 0.0167, and 0.01-level.

Panel B. Cash ratio (%)

	(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	-1.289***	-0.334	0.042	-0.327	-0.134	0.155
	[0.462]	[0.335]	[0.397]	[0.447]	[0.350]	[0.418]
Year = 2017	-3.061***	-1.193***	-0.601*	-3.321***	-1.388***	-0.604
	[0.333]	[0.252]	[0.304]	[0.340]	[0.262]	[0.317]
Year = 2018	-6.908***	-3.138***	-1.039**	-7.447***	-3.107***	-1.073**
	[0.476]	[0.335]	[0.409]	[0.461]	[0.365]	[0.424]
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	No	No	No	No	No
Clients	2,418	3,202	2,582	2,638	3,509	2,420
Client*Year observations	7,243	9,594	7,709	7,905	10,495	7,223
Mean of dependent variable	58.3	66.6	78.1	62.3	66.9	78.4
Method	OLS	OLS	OLS	OLS	OLS	OLS

Panel C. Cash withdrawal frequency (transactions per month)

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome variable	Cash withdrawal frequency					
Location		Urban			Rural	
Client age (years)	below 35	35-55	above 55	below 35	35-55	above 55
Contactless	-0.024	0.003	0.015	-0.062	-0.034	0.030
	[0.056]	[0.034]	[0.029]	[0.051]	[0.031]	[0.027]
Year = 2017	-0.285***	-0.147***	-0.126***	-0.176***	-0.143***	-0.107***
	[0.042]	[0.026]	[0.022]	[0.038]	[0.023]	[0.020]
Year = 2018	-0.617***	-0.281***	-0.218***	-0.457***	-0.230***	-0.170***
	[0.056]	[0.036]	[0.030]	[0.052]	[0.031]	[0.029]
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	No	No	No	No	No
Clients	2,418	3,204	2,585	2,640	3,511	2,421
Client*Year observations	7,254	9,612	7,755	7,920	10,533	7,263
Mean of dependent variable	4.6	3.9	2.9	4.3	3.6	2.7
Method	OLS	OLS	OLS	OLS	OLS	OLS

Panel D. Cash withdrawal amount (CHF per withdrawal)

	(1)	(2)	(3)	(4)	(5)	(6)
Outcome variable	Cash withdrawal amount (CHF)					
Location		Urban			Rural	
Client age (years)	below 35	35-55	above 55	below 35	35-55	above 55
Contactless	1.599	12.356	5.145	-2.533	-7.354	23.578
	[8.710]	[20.751]	[26.496]	[9.543]	[22.385]	[26.065]
Year = 2017	2.727	10.877	22.898	5.708	-11.442	-22.928
	[6.521]	[14.034]	[19.657]	[6.085]	[15.442]	[22.335]
Year = 2018	13.099	-13.22	7.121	8.507	-19.85	-27.56
	[10.408]	[18.037]	[25.105]	[8.836]	[16.094]	[29.267]
Client fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year*Location fixed effects	No	No	No	No	No	No
Clients	2,414	3,192	2,570	2,637	3,495	2,410
Client*Year observations	7,201	9,477	7,609	7,878	10,378	7,124
Mean of dependent variable	308.8	613.7	908.8	341.0	616.4	909.2
Method	OLS	OLS	OLS	OLS	OLS	OLS

What could explain that the causal effect of contactless cards on payment choice is strongest among young urban consumers? Differences in the average local payment infrastructure are unlikely to be the main driver: If urban areas would differ from rural areas with respect to the average payment infrastructure, we should see an increase in cashless payments by all urban bank clients which receive a contactless card, both young and old. Technology-affinity of young consumers alone can also hardly explain our results as this would imply a significant treatment effect for young consumers both in urban and rural locations. A plausible explanation is that developments in the contactless payment infrastructure were specific to stores/locations which are

frequented more by young urban consumers. As argued by Hyunh et al. (2019) the impact of payment innovations on observed consumer behavior depend crucially on interplay of consumer and merchant adoption. If merchants who serve young, urban consumers anticipate a stronger adoption of contactless payments by their consumer base, it would be rational for them to adjust their payment infrastructure more quickly.[30] Our data does not allow us to test this conjecture as we do not observe payment behavior at the customer*merchant level.

7. Do contactless cards increase consumer spending?

Our analysis so far has focused on how the convenience of electronic payments affects how consumers pay for goods and services. In this section, we briefly discuss an explorative (not pre-registered) analysis of how contactless cards affect the level of consumer spending. Agarwal et al. (2020a) study whether the demonetization event of 2016 in India affected consumers spending. That paper exploits the cross-consumer variation in cash dependence prior to demonetization and shows that the forced switch from cash to digital payments lead to a substantial increase in consumer spending. Agarwal et al. (2020a) conjecture that the lower salience of digital payments is driving their result: "When households 'tap and go' using cards or mobile payments, it is easy for them to become complacent and over-spend" (ibid, p. 26).

Our data allows us to analyze how the availability of 'tap and go' payments affects spending levels of consumers in an advanced economy with a well-developed payment infrastructure. Figure 4 depicts the monthly average of non-recurrent spending as measured by the total of cash withdrawals, debit card PoS payments and credit card payments by year-quarter and by treatment group.

Figure 4 reveals that the three client groups are very similar with respect to the level and the seasonal pattern of spending before receipt of a contactless card.[31] Importantly, there appears to be no significant impact on the level of consumer spending after the receipt of a contactless card. This finding suggests that the availability of a 'tap and go' payment instrument does not affect the total level of consumption of the average consumer in an advanced economy like Switzerland. In

[30] Another potential explanation is that young urban clients differ from young rural clients in our sample with respect to income or education. The income channel is unlikely, however, as the amount of monthly cash withdrawals is very similar between the two groups.

[31] Discernible effects are rather small, i.e. in the range of 50 CHF.

non-reported analyses we find no effect of contactless cards on the level of spending even for those consumers who show the strongest treatment effect for payment choice.

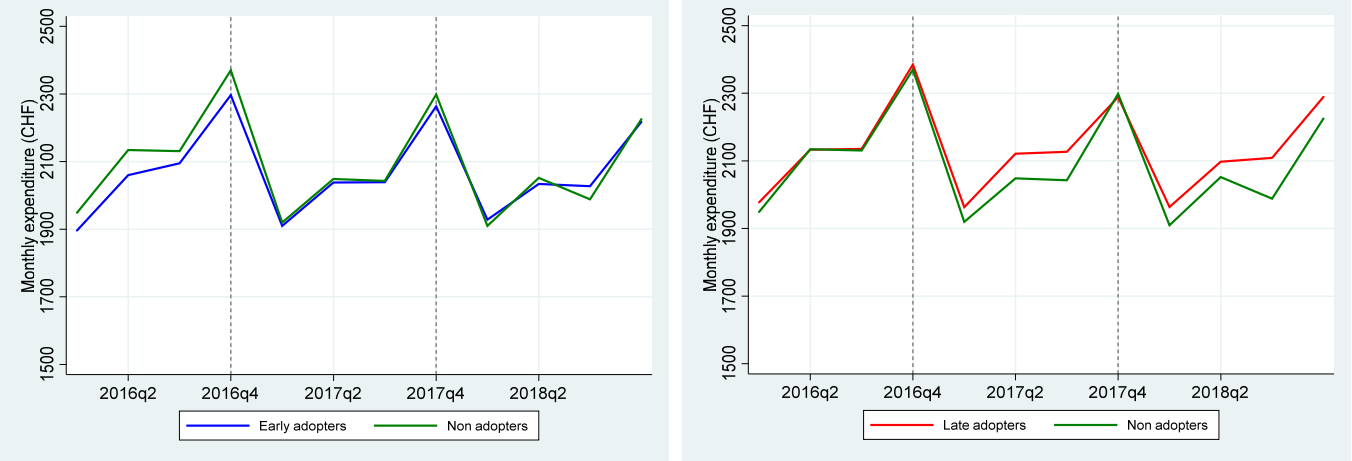

Fig. 4. Monthly expenditure. This figure displays the average monthly expenditure (in CHF) as measured by the sum of cash withdrawals and debit card and credit card PoS payments per client and year-quarter by treatment group.

8. Robustness tests

8.1. Pre-specified tests

In accordance with our pre-analysis plan, we conduct a series of robustness tests.

First, we replicate our Table 4 analysis 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 Internet Appendix 2. 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 do not affect the insignificance of the causal effect of contactless cards on the cash ratio of payments (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). Our Table 4 results are confirmed.

Second, we replicate the equation [1] regression 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 two months prior to the expiry

of their old card and can be used immediately after receipt. Internet Appendix 3 presents regression estimates which confirm our 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 40 CHF instead of pre-treatment *Cash ratio*. Our Table 6 results are confirmed (see Internet Appendix 4).

Next, 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 as 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 results presented in Internet Appendix 5 confirm that small-value debit card transactions increase after the receipt of a contactless card.

Finally, 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 2). Our placebo test therefore compares the payment behavior of *Non adopters* to *Early adopters* 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). Internet Appendix 6, Panel A presents the respective findings for the number of debit card transactions. The respective results for our primary outcome variables of payment choice and cash demand are shown in Internet Appendix 6, Panel B. Reassuringly, the estimate of *New card* is insignificant in all specifications of both panels.

8.2. Additional tests

We report three additional robustness tests which were not pre-specified in the pre-analysis plan. Internet Appendix 7 replicates our main analyses on the sample of clients which are not balanced by age-structure. As reported in section 3.3 , our treatment and control groups are not well balanced with regard to the age-structure of the clients, who are younger in the group of early adopters and late adopters than in the non-adopter group. Note that our heterogenous treatment effect analysis in Table 7 documents a much stronger treatment effect among young clients than among other older client groups. As the unbalanced sample comprises of more young clients in the treated groups, the estimated treatment effects are somewhat larger in this sample than in the age-structure balanced sample.

Next we replicate our main analysis with a sample including clients who experience irregular card renewals. 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. As discussed in section 3.3 our main analysis is based on a sample from which we exclude all debit cards with irregular changes in expiry dates in order to rule out endogenous access to the contactless technology. However, this implies that we may exclude a disproportionate share of "card-loving" clients from the late and non-adopter groups. In Internet Appendix 8, we replicate our analysis of debit card PoS payments (Panel A) as well as payment choice and cash demand (Panel B). Our point estimates for the causal effect of contactless cards are hardly affected.

Our final robustness test replicates the dynamic treatment effect analysis in section 5 with quarterly rather than annual data. For ease of exposition, we present the respective regression results in a graphical form. Panel A of Internet Appendix 9 displays results regarding the number of monthly debit card transactions and shows point estimates and confidence intervals of the treatment effects by quarter. *Early adopters* increase their use of debit cards after they receive a contactless card. The figure shows that the effect is somewhat stronger in the second year than in the first year after treatment. Panel B, C and D report this test for our main dependent variables *Cash ratio, Cash withdrawal frequency* and *Cash withdrawal amount*. The findings from the dynamic analyses are all in line with the findings from the annual data.

9. Discussion

We study the causal effect of an increase in the convenience of electronic payments on consumer 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 have been strikingly cash intensive in their payment behavior, in particular prior to the Covid-19 pandemic. 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.[32]

Our results suggest that consumer access to contactless debit cards leads to an increase in the use of debit cards for small-value payments. However, this increase is surprisingly weak relative to the number of small value cash payments of the average Swiss consumer (less than 2%). As a consequence, the impact of contactless cards on the cash share of payments and cash demand is negligible.

While the average treatment effect of contactless cards is underwhelming, our subsample analyses reveal substantial heterogeneities across households: The increase in convenience of debit card payments does not lead more consumers to use debit cards at the point of sale: the impact is negligible among extensive margin "cash lovers". By contrast consumers who already use their debit card at the point of sale, use it more often (for small value payments) when these transactions become more convenient. Explorative analyses reveal that the impact of contactless cards on payment choice is largely driven by young, urban consumers. These results suggest that while improvements in the convenience of card payments may not trigger a jump to a cashless society, they are bound to increase the heterogeneity in payment behavior among socioeconomic groups.

Our findings speak to – and qualify – inventory theories which jointly model payment choice and cash management. In particular, our results suggest that non-monetary transaction costs of electronic payments (time, effort) are not the main driver behind pervasive cash payments. If this

[32] As a case in point, the cash-intensive economies 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 only about 4% (own calculations). Even if we abstract from currency which is circulating abroad, the quantitative difference remains large.

were the case, the improved convenience of electronic payments through contactless cards should trigger a larger reduction in cash payments for small-value transactions.

One explanation for our findings may be that we are analyzing the impact of this particular payment innovation at an early stage in a process which depends on the dynamic interplay between consumers and merchants. We document that the treatment effect of contactless cards on debit card use does increase over time, consistent with the increased merchant adoption of NFC compatible payment terminals. An alternative explanation would be that the pervasive use of cash is dominated by consumer preferences for budget control , anonymity or pure habit. The strong increase of the use of cashless payments during the Covid-19 pandemic could thus be seen as an exogenous shock which shifted relative costs and benefits of cash use enough to impact on money demand (e.g. Alvarez and Argente 2020).

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Appendix A. 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) average per month	number	>=0
Cash withdrawal amount	Cash withdrawals (ATM & Branch) in CHF / Cash withdrawals frequency, average per year	CHF	>0

Auxiliary outcome variables

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

Appendix A. Definition of variables

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]
Savings account	Dummy variable = 1 if client has an ordinary savings account with the Bank, 0=otherwise	[0;1]
Retirement account	Dummy variable = 1 if client has a voluntary retirement savings account with the Bank, 0=otherwise	[0;1]
Custody account	Dummy variable = 1 if client has a custody account for securities with the Bank, 0=otherwise	[0;1]
Mortgage	Dummy variable = 1 if client has a mortgage with the Bank, 0=otherwise	[0;1]
E-banking	Dummy variable = 1 if client has an Ebanking contract with the Bank, 0=otherwise	[0;1]

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]