AN ANALYTICAL FRAMEWORK FOR THE FORECASTING AND RISK ASSESSMENT OF DEMAND FOR FED CASH SERVICES

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Preface

The Cash Product Office (CPO) at the Federal Reserve Bank of San Francisco (FRBSF) is conducting a long-term strategic planning initiative. Phase I of this initiative has two objectives: (1) to identify "the key uncertainties and risks that could influence the future direction of the Federal Reserve's (Fed's) cash business," and (2) to describe "the potential impact of these uncertainties on the Fed's ability to continue to meet its mission in providing cash services." The CPO has asked the FRBSF Economic Research Department to conduct a quantitative analysis aimed at addressing objective #1. This technical paper provides an identification of the key uncertainties and risks to the Fed's future cash business (i.e., demand for Fed cash services) from an econometric modeling perspective and should serve as a complement to other more qualitative perspectives on this issue that the CPO is bringing to bear. Specifically, the paper aims to answer three questions:

(1) What have been the key determinants of demand for Fed cash services over the past few decades?
(2) What is likely to be the level of demand for Fed cash services over the next decade?
(3) What are the risks to this forecast?

We address these questions first by estimating a "demand system" for Fed cash payments by denomination using historical data on gross cash payments by the Fed and on factors likely to affect Fed cash payments, from Jan. 1974 through Dec. 2009. We then take this fitted model and use it, along with projections of the model's explanatory variables, to generate a baseline projection of Fed cash payments by denomination out to 2020. Our baseline projection implies an 18% increase (1.7% per year) in the aggregate value of gross payments between 2010 and 2020, and a 19% increase (1.8% per year) in the aggregate number of bundles paid out by the Fed. We also use the model to explore alternative simulations, or risk scenarios, for how some of the key explanatory variables may evolve going forward.

1. Introduction

In this paper, we seek to understand what factors have determined the demand for Fed cash services over the last several decades and to then use this understanding as a basis for exploring how demand for cash services may evolve going forward. To begin, we must determine what exactly is the "demand for Fed cash services." The Fed provides two main cash-related services to the public. It provides cash processing services to depository institutions (DIs), including removing and replacing worn-out and counterfeit bills. The demand for this service can be gauged by how much currency the Fed receives from DIs for processing. That demand is likely a function of DIs' cash inventory management practices (and Fed policies/regulations affecting such practices) and the rate at which currency is deteriorating, which may be a function of how frequently cash is used for transactions (the velocity of cash). Second, and perhaps most importantly, the Fed is the nation's sole provider of new currency. The stock of currency in circulation can grow only by the actions of the Fed, paying out more currency to DIs than it receives from them. The Fed increases the stock of currency in circulation in response to increased cash orders by DIs, which in turn are responding to increased demands for cash from the public (households, merchants, etc.).

In a sense, then, the demand for Fed cash services during a particular interval (say, one month) can be measured by the sum of the demand for Fed cash processing, which is revealed by the Fed's gross receipts of cash from DIs, and the demand for increased currency, which is revealed by the change in currency in circulation over the interval. This sum turns out to be simply the gross payments of cash from the Fed to DIs. In other words, gross payments, gross receipts, and the change in currency are linked by the following (approximate) identity:

$$\Delta CIC \approx \text{gross\_payments} - \text{gross\_receipts},$$

where ΔCIC is the change in currency in circulation ($CIC_t - CIC_{t-1}$).[1] That is, the change in currency outstanding is approximately equal to net payments, i.e., gross payments less gross

[1] The true identity is: gross_payments = $(CIC_t - CIC_{t-1}*(1-\delta))$ + gross_receipts, where δ is the rate of currency destruction/loss outside of the Fed. There are also technical issues involving whether cash is stored at a Federal

receipts, which implies that gross payments are the sum of gross receipts and the change in currency:

$$\text{gross\_payments} \approx \text{gross\_receipts} + \Delta\text{CIC}. \tag{1}$$

This relationship demonstrates that modeling and forecasting gross payments involves modeling and forecasting both how much cash the banking sector sends to the Fed to process (i.e., gross receipts) as well as changes in overall cash demand. In its simplest terms, the approach of this paper is to empirically model gross payments, in a reduced form, as a function of observable factors that affect Fed cash receipts and/or (changes in) overall cash demand:

$$\text{gross\_payments} = \text{gross\_receipts}(X,Z) + \Delta\text{CIC}(Y,Z) = f(X,Y,Z).$$ [2]

In other words, there may be factors (X) that only affect the demand for Fed cash processing services (such as Fed processing/shipping fees), factors (Y) that only affect the overall demand for U.S. currency (such as foreign demand for one-hundred dollar notes as a store of value), and factors (Z) that affect both (such as the number of payment transactions in the economy).

More specifically, we first estimate a "demand system" for Fed cash payments by denomination using historical data on gross payments of currency by the Federal Reserve to Depository Institutions (DIs), and on factors likely to have affected Fed cash payments, from January 1974 through December 2009. We show that our estimated demand system fits the historical movements in Fed cash payments – both in aggregate value and in the shares of each denomination – remarkably well in-sample. We also investigate how well it is able to fit the data out-of-sample by estimating the model for the 1974-2001 subsample and then comparing its out-of-sample forecast for 2002-2010 with the observed data for this period. Next, we use the fitted model, estimated over the full historical sample period, along with projections of the explanatory variables in the model, as the basis for a baseline projection of Fed cash payments by denomination out to 2020. Our baseline projection implies an 18% increase (1.7% per year) in the aggregate value of gross payments between 2010 and 2020, and a 19% increase (1.8% per

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Reserve Cash Office or at an external Custodial Inventory site that can cause discrepancies between ΔCIC and net payments.

[2] In future work, it would be valuable to model the determinants of ΔCIC and gross receipts separately and hence predict gross payments as the sum of predicted change in CIC and predicted gross receipts.

year) in the aggregate number of bundles paid out by the Fed. Finally, we use the estimated model to explore alternative simulations, or risk scenarios, for how some of the key explanatory variables may evolve going forward. In particular, we consider four alternative simulations relative to the baseline: (1) faster consumer adoption of payment alternatives to cash, (2) longer-lasting effects of the Fed's recent recirculation polices, and (3) faster foreign economic growth. Simulation (1) is shown to represent moderate downside risks to cash demand over the next decade. Our baseline projection assumes that the negative effects of the Fed's recirculation policies implemented in 2006 on gross volumes are transitory, having no more impact after 2010. Simulation (2) assumes that the estimated negative effects continue through at least 2020. We find that this alternative assumption suggests a major decline in gross cash payments over the next ten years. In simulation (3), we find that faster growth in a couple of key global regions would lead to slightly higher demand for gross payments of one-hundred dollar notes (100s).

It is important to stress that the goal of this paper is not to produce "the" forecast of demand for Fed cash payments over the next ten years, but rather to provide an analytical framework that can be used to identify the key drivers of this demand and to analyze how potential future changes in those drivers may affect cash demand. It should also be noted that our focus is on the long-term outlook for cash demand. This focus implies potentially different empirical approaches than would be the case for short-term forecasting, which tends to be what the forecasting literature in statistics and econometrics is concentrated on. The empirical exercise of this paper can be thought of as akin to the analyses done by the Congressional Budget Office (CBO) in preparing its long-term "Economic Outlook" projections (see CBO 2010). Those projections rely on an empirical model describing how key economic aggregates are affected by each other and by various exogenous drivers, which are estimated with historical data. That model is then used to generate a baseline projection, as well as to consider alternative simulations. As with this paper, the main contribution of the CBO's empirical model is its usefulness in examining the important forces affecting the long-term economic outlook and the key risks to the outlook going forward.

The rest of the paper proceeds as follows. In the next section, we discuss some of the key historical trends and stylized facts regarding cash. In Section 3, we discuss the prior literature on cash demand, which helps guide our choice of explanatory variables to include in the model and highlights other important topics related to cash demand that we do not directly address in this paper. In Section 4, we describe the sources underlying the data we use to estimate the demand system model. Section 5 presents our empirical framework, the results from estimating the model over the full sample period, and an evaluation of the fitted model's out-of-sample forecast accuracy. The baseline and alternative projections based on this empirical model, along with projections of the explanatory variables, are discussed in Section 6. Section 7 offers some concluding remarks. In addition, at the back of the paper, there is a list of references and a glossary of key terms.

Following the paper, there are also three boxes contributed by others that provide detailed discussion and analysis of particular topics related to the paper. These boxes are referred to at various points in the paper. Firstly, Box #1 by Alexander Wolman (Federal Reserve Bank of Richmond) discusses the impacts on cash volumes of changes over time in DIs' cash management practices. Box #2, by Eugene Amromin and Sujit Chakravorti of the Federal Reserve Bank of Chicago, summarizes their cross-country analysis of the impact of debit card use on cash demand by denomination. Box #3 is contributed by Douglas Conover and Lisa Whalen of FRBSF and discusses the effects of the Fed's current recirculation policy on cash volumes.

2. Trends and Stylized Facts

This section of the paper provides background on the notable trends in cash demand over the last four decades.

2.1. Historical Trends

Figure 1 shows the historical trends in the Federal Reserve's cash payments and receipts. Panel A shows the aggregate values of the Fed's gross cash payments and gross cash receipts, as a share of nominal personal consumption expenditures, from January 1974 to December 2010.

Note that the gap between these two in a given month is the change in the value of currency in circulation. From the beginning of our sample period through the mid-1990s, the values of both payments and receipts remained fairly stable at around 7% of PCE; that is, for every 100 dollars of consumption spending in a given month, about 7 dollars in currency were received by the Fed and about 7 dollars were paid out by the Fed. The considerable spike and subsequent drop in late 1999 and early 2000 were the result of Y2K, which we discuss later. Aside from that temporary deviation, gross payments show a slight gradual rise from around 1994 through 2004. Given that this rise is mirrored in the gross receipts series, it appears to be due to an increase in the value of cash sent to the Fed from DIs for recirculation – perhaps due to the changes in sweeps policies instituted around 1995 (discussed in Section 4.1) – rather than changes in overall cash demand. Both payments and receipts fell sharply from 2005 through 2007, perhaps related to increases in cross-shipping fees put in place in 2007 but widely anticipated as early as 2004. (See Boxes #1 and #3 for a discussion of DI cash inventory management practices and the impact of the cross-shipping fees.) After 2007, payments and receipts diverged: receipts continued to fall (perhaps due to continuing adjustment to the cross-shipping fees), while payments spiked in early 2008 and again in 2010, resulting in sharp increases in the growth of currency in circulation. This increase in currency growth may have reflected a flight to safe assets such as cash during the financial crisis and ensuing recession.

Within this aggregate trend, there also exist unique trends for the individual denominations, as shown in Panels B, C, and D of **Figure 1**. These panels show what share of the total value of cash payments is accounted for by each denomination.

The shares of one dollar notes (1s) and five dollar notes (5s) in gross payments fell steadily from (at least) the beginning of the sample period to around 2000, after which they actually grew slightly. This growth over the last decade, albeit slight, may seem surprising given the constant march of inflation over time, which would seem to lower the demand for small denomination notes. Note, however, that inflation should not only shift demand from small denomination notes to higher denomination notes but also from coins to small denomination notes. Basically, inflation pushes demand up the “currency denomination ladder,” beginning with the lowest denomination, pennies.[3] (The potential effects of inflation on total cash payments and denomination mix will be explored in the empirical analysis below.)

The share of ten dollar notes (10s) has fallen dramatically throughout the sample period, going from nearly 28% of the aggregate value of Fed cash payments to just 3% by 2010. The causes of this and other cash payment trends are explored more formally in the analysis below, but one likely culprit is the increasing use and availability of ATMs over this period, which may well have led to substitution away from 10s and toward twenty dollar notes (20s), the denomination most commonly dispensed by ATMs.

The share of 20s in the aggregate value of payments increased sharply from (at least) 1974 to around 1988, as shown in Panel C. During this time, the share of 20s rose from about 47% to about 57%. However, beginning about 1990, the share began to fall. By the end of the sample period, 20s' share of the total value of cash payments was about 42%.

The trends for large denomination currencies are shown in Panel C. In general, the shares of both fifty dollar notes (50s) and 100s increased over the sample period, although the increase has been much more pronounced for 100s than for 50s. At the beginning of the sample period, 50s' share of the total value of cash payments was 5%; this rose to about 10% by the late 1980s, where it has since remained. The share of 100s, on the other hand, continued to rise throughout the sample period, going from below 10% at the start to around 45% by 2010. The increase in Fed payments of 100s relative to other denominations likely in part reflects the important international store-of-value aspect of demand for 100s, which may make 100s more immune to payment substitution trends affecting lower denominations. We will explore the international channel in the empirical analysis below.

Figure 2 shows the analogous historical patterns in terms of numbers of cash bundles.[4] Panel A displays the time series for the aggregate number of cash bundles, per billion dollars of consumption spending. As of 2010, this ratio is about 300, meaning that for each billion dollars of consumption spending in a given month, around 300 bundles (or 300,000 bills) of currency

[3] If in fact the relative decline of small denominations as a share of total payments value is due to inflation, one should observe commensurate declines in the value of coin payments as a share of total payments. We have not investigated coin data, but this might be an interesting area for future research.

[4]A bundle equals 1000 notes.

are received and paid out by the Fed (or 3 bills per $10,000 of consumption spending). Comparing Panel A of Figure 2 to Panel A of Figure 1 shows that while the value of cash payments has held fairly steady as a share of PCE, the number of bills has gradually fallen. This suggests that there must have been a shift in the composition of bills toward higher denominations. This is confirmed by looking at Panels B-E, in which we see that 20s, 50s, and 100s have grown as a share of all bills, while 5s and 10s have fallen and 1s have held steady.

[SEE BOX #1 AT END OF PAPER]

2.2 Seasonal Patterns

Figure 3 displays the seasonal patterns of gross payments by denomination. The panels on the left-hand side are for dollar values, while those on the right-hand side are in terms of bundles. The bars in each figure represent the mean number of bundles paid out (in thousands) by the Federal Reserve for that month across the period of 1974 to 2010, with the exclusion of 1999 and 2000 due to the effects of Y2K.[5]

As shown in the figure, gross payments for all denominations show significant seasonal patterns. Payments are very low in January, following the U.S. holiday season. They then step up somewhat in February and March. In general, payments remain fairly stable during the period of March through August, before dipping back down in September. Then, as the economy heads into the holiday season, demand for cash rises and payments steadily increase through October and November before jumping up in the month of December. Given these strong seasonal patterns in cash demand, we include calendar-month dummies in our estimation models to capture the seasonality of the data.

[5] For further discussion of why years 1999 and 2000 are excluded, see Section 4.2. Also, note that these seasonal patterns would look the same if we detrended the data prior to calculating the seasonal means as long as the trend is assumed to be common over all months.

3. Prior Literature on Cash Demand

3.1 Theoretical Guidance

Theoretical explorations into the fundamental drivers of cash demand almost universally focus on the overall demand for cash by the economy – i.e., currency in circulation rather than gross volumes. Overall cash demand is generally modeled in terms of the inventory management aspect of cash – that is, the decisions by households and businesses (including DIs) regarding how much of their wealth to store in cash versus other stores of value which could be converted to cash (or used directly for payment transactions) as the need arises. This notion is well articulated in Bennett and Lacker (1998):

> *The public's demand for cash services is also fundamentally an inventory management decision regarding how much cash to carry and how much value to store in alternative (highly liquid) financial assets. The willingness to hold and use cash depends on the relative attractiveness of alternative means of storing value and effecting payments, including bank deposits (accessed via checks, ATM and debit cards used at the point of sale, and the ACH), bank lines of credit (accessed via credit cards) and traveler's checks. Eventually, moreover, stored value cards and other electronic cash applications may challenge the effective monopoly notes and coins currently have on small-denomination bearer liabilities. To the extent the public becomes more willing to use electronic cash, the demand for cash services at banks and ultimately at the Federal Reserve will decline.*

The inventory-theoretic model of cash demand dates back at least to Baumol (1952) and Tobin (1956). In the Baumol-Tobin framework, at any given moment agents demand a certain inventory of cash (beyond what they expect to need for purchases at that moment), despite the opportunity cost of not storing that wealth in interest-bearing assets, because converting from those assets into cash involves a fixed cost. This yields a lumpy pattern of cash demand at the household level, whereby households withdraw large amounts of cash on an infrequent basis and then gradually run that inventory down as payment needs arise before restocking their inventory. However, this lumpiness gets smoothed out at the aggregate level given that the times at which households restock their cash inventories are not synchronized. One practical implication of this inventory model for our empirical analysis is that it highlights the potentially important role of the interest rate in affecting cash demand. It should be noted, though, that the interest rate could also affect gross cash volumes by affecting the velocity of cash and therefore the demand for Fed cash processing services. That is, higher interest rates not only incentivize agents to hold less cash but also may lead households to increase the frequency of cash withdrawals which could increase the deterioration rate of physical currency.

The Baumol-Tobin framework has become the standard theoretical foundation for analyses of cash demand. Dotsey (1983), for instance, extends this model to analyze the potential impact on cash demand of innovations and policy-induced changes in cash management practices of depository institutions. Empirically, he finds an important role for these innovations and policies; this finding helps motivate our attempts to control for such change in our empirical model below (for example, by controlling for the effect of policies regarding sweep accounts in the 1990s). See the box below for more discussion on changes in cash management practices at depository institutions. Most recently, Alvarez, et al. (2011) extend the Baumol-Tobin framework to explore the role of money demand in explaining the sluggish response of the aggregate price level to changes in money. It should be pointed out, however, that the concept of "money" in that paper and most of the other papers in this literature is much broader than cash or currency, typically including demand deposits, savings accounts, and money market accounts.

Alvarez and Lippi (2011), on the other hand, extend the Baumol-Tobin inventory-theoretic model to help explain household-level patterns of cash withdrawal. The paper yields the insight that, because holding cash entails foregoing potential interest earnings, changes in the accessibility of cash – for example, from an increase in the number of bank branches or the spread of ATMs – have two conflicting effects on cash demand. On the one hand, making cash more easily accessible reduces the need to hold cash inventories. On the other hand, increased accessibility of cash reduces the relative attractiveness of other stores-of-value/payment types and hence increases cash demand. For instance, consumers may feel less compelled to get a debit or credit card if their bank has an ATM on every corner. Thus, a priori, it is not obvious how the aggregate demand for cash should be affected by the increases in accessibility over time.[6,7]

[6] A similar idea was developed in Whitesell (1989) relating to the countervailing effects of a change in bank withdrawal fees on cash demand.

[7] Increased accessibility of cash could also affect (increase) the velocity of cash. Thus, in terms of equation (1), even if increased accessibility did not increase the overall demand for cash by the economy (that is, ΔCIC), it could

Overall, the theory on cash or money demand suggests a number of factors that potentially affect overall cash demand. In addition to the interest rate and measures of cash accessibility (such as the number of ATMs) mentioned above, the theory also points to important roles for economic conditions (which affect the overall volume of payment transactions in the economy), the availability/popularity of alternative stores-of-value/payment types, and heterogeneous consumer preferences for cash compared to payment alternatives. The heterogeneity in preferences may translate into differences in cash demand (or denomination demand within overall cash) across demographic and socioeconomic groups. For example, higher income individuals with fewer credit constraints may rely more heavily on credit-based payment instruments and may also be more likely to use Internet banking.

3.2 Empirical Guidance

By far the largest area of empirical research relating to cash demand is the study of payment choice – that is, what determines consumers' choices over alternative means of payment. Works in this area include Markose and Loke (2003), Humphrey (2004), Stix (2004), Amromin and Chakravorti (2009), and Schuh, et al. (2010). Amromin and Chakravorti conduct a cross-country panel data study and find strong evidence of consumer substitution away from small-denomination cash in favor of debit cards. They also find that the ATM denomination, which in the United States is the twenty dollar note, is positively impacted by the number of ATMs in a country. (See Box #2 for a detailed summary of their analysis.)

[SEE BOX #2 AT END OF PAPER]

Schuh, et al. (2010) explore the magnitude and welfare consequences of the implicit pecuniary transfer from cash users to credit card users due to merchant fees and reward programs attached to credit cards. Because consumers in general face the same prices whether they pay with a credit card or with cash, despite the fact that credit card use entails an extra cost for the merchant (raising prices for all consumers) and often confers rewards to the card user, cash users

still affect gross receipts, and hence gross payments, if the ensuing increase in velocity leads to cash physically wearing out at a faster pace.

are implicitly subsidizing credit card users.[8] This may help explain why households appear to be increasingly substituting away from cash toward credit and other payment alternatives, as we find in our empirical results below. They also find that the implicit transfer varies by household income level, which helps motivate our inclusion of income distribution measures in our empirical model.

We should also mention that McKinsey Consulting Co. is conducting a study on payment choice. Among other things, this study is conducting surveys of households and businesses to improve the understanding of why consumers choose one payment type over others for different types of transactions. McKinsey is also compiling data on the volume and value of transactions in the United States done by each payment type and by various types of transactions. This builds on the extensive studies documenting payment type use and trends by the Federal Reserve Board (see, for example, Gerdes 2008) and the Survey of Consumer Payment Choice at the Federal Reserve Bank of Boston.

Aside from payment choice, other empirical studies related to cash demand have explored the use of currency data to assess the size of the underground economy (see Porter and Weinbach 2010 and Sprenkle 1993) and the question of how much U.S. currency is held abroad. The seminal work on the latter question is Porter and Judson (1996). Using a variety of methods, they estimate that between 55% and 70% of U.S. currency was held abroad as of 1995, primarily due to large foreign holdings of 100s and (to a lesser extent) 50s. Moreover, they find that the foreign share of U.S. currency increased dramatically from at least 1977 through 1995. They attributed the rise in part to stronger economic growth in the emerging markets that heavily demand U.S. currency compared with U.S. economic growth. Their results underscore the importance of including foreign GDP growth in our empirical model below.

Surprisingly, there has been very little previous work on empirically modeling cash demand. The closest study we are aware of is that of Yoo (2007), which estimates a time-series model of currency outstanding for the Korean won. Unlike our paper, however, that study focuses only on a small set of potential explanatory variables (the interest rate and noncash

[8] Note that debit cards likely fall somewhere in between cash and credit cards in terms of this kind of transfer. Debit cards generally do not have reward programs and many, but not all, merchants charge customers for the use of debit cards for small-value transactions.

payment alternatives) and does not attempt to use this model for forecasting. Another closely related paper is Kohli (1988), which estimates an empirical model of the composition of cash demand across denominations of the Swiss franc.

There also has been some analysis done within the Federal Reserve System on modeling and forecasting the demand for coins. In particular, Stark and Croushore (2004) developed an "Inventory Management and Forecasting" tool principally for the purpose of aiding Federal Reserve Bank coin offices in deciding how much coin to order from the U.S. Mint. In contrast to our study, Stark and Croushore focus on short-term forecasting (over a horizon of two to three months). Their model relies exclusively on the autoregressive properties of coin demand, which tends to produce the best short-term forecasts, rather than modeling its underlying determinants or drivers.[9] As we discuss in Section 5, the autoregressive dynamics of cash demand turn out to add little or no forecasting power for the long-term horizon we consider in this paper.

4. Data for Estimating the Empirical Model

This section describes the construction of the data we used to model and forecast the long-term trends in demand for Fed cash services. As mentioned earlier, while the level of currency in circulation reflects the overall demand for U.S. currency, both domestically and abroad, it is not a good indicator of the demand for Fed cash services. The cash services provided by the Federal Reserve primarily consist of (1) processing received notes from DIs in order to remove from circulation unfit or counterfeit notes and (2) then paying out new or fit used notes in accordance with DIs' order requests. As argued in the introduction, the Fed's gross receipts of cash essentially are determined by DIs' demand for Fed processing of bills, which in turn is driven by the DIs' cash inventory management practices (for example, how much cash to store in their vaults; see Box #1) and the rate of physical deterioration of cash. Though the latter is affected to some extent by the overall demand for cash (more cash transactions may quicken the deterioration of notes), this rate is generally small and stable over time. Hence, the determination of gross receipts is primarily an issue of DI cash management behavior and the

[9] Specifically, Stark and Croushore estimate an ARIMA(14,0) model of the first-difference in seasonally adjusted net payments of coin by denomination.

extent of financial intermediation. Gross payments, on the other hand, will reflect both demand for Fed cash processing services (via receipts) as well as changes in the overall demand for U.S. currency. In this paper, we model the demand for gross payments as a function of variables that potentially affect either demand for Fed cash processing or overall demand for cash. We do not attempt to model these two aspects of payments demand separately, though this would likely be a fruitful area for future research.

Table 1 displays, by denomination, the correlation between gross payments, gross receipts, and the change in currency in circulation (ΔCIC). As shown, receipts and payments are highly correlated across denominations. In fact, the correlation between receipts and payments ranges from 0.85 for 10s to 0.99 for 1s. These high correlations imply that the movements over time in payments are driven primarily by movements in receipts. Changes in the currency stock play a smaller role in determining payments. As Table 1 shows, the correlations between gross payments and the change in CIC are positive but much lower than the correlations between gross payment and gross receipts.

We next discuss the explanatory variables we include in the empirical model. These variables can be set into five broad categories – regulation/policy, significant events, macroeconomic conditions, demographic trends, and technology and consumer preferences – which are discussed in the following subsections.

4.1. Regulation/Policy

We examine three regulatory/policy variables in this study. These variables are used to capture the period-specific time trends of certain regulatory/policy changes that impact the demand for Fed cash processing.

In 1994, the Federal Reserve Board began permitting the use of sweep accounts by commercial banks. "Sweeping" gives commercial banks the ability to, overnight, shift funds out of customer accounts subject to reserve requirements into accounts exempt from reserve requirements and then shift them back the next business day. By allowing banks to reduce their average reserve requirements, this policy change increased DIs' opportunity cost of holding cash, which in turn provided an incentive for DIs to improve their cash inventory management systems. As DIs adopted or purchased new inventory management systems, this likely pushed up Fed cash receipts from DIs during this transition period and may have resulted in a higher new equilibrium level of receipts. Indeed, evidence from Porter and Weinbach (1999), as well as data on sweep accounts from the St. Louis Fed, indicate that sweeping activity remained fairly flat until 1995, at which point it began to steadily increase, at least through 1998, and then leveled off. Therefore, we employ two dummy variables for this regulatory change. One dummy variable is used to capture the change in trend, or the transition period of banks adopting the use of sweeps, and is set to 1 for the period of January 1995 through December 1998. The other dummy variable is used to capture the new equilibrium level of cash, and is set to 1 from January 1999 to December 1999, then lowered by a constant of 0.2 in each following year until it reaches 0 in January 2004, where it remains thereafter.

The other significant regulatory change that occurred during our sample period was the Federal Reserve Currency Recirculation Policy. The policy was introduced to reduce overuse of Federal Reserve Bank currency processing services, brought about, in part, by DIs' use of sweeps and their corresponding efforts to reduce excess cash inventories. This is done via two methods, through a custodial inventory program[10], and by assessing a fee on deposits of cross-shipped currency[11]. The custodial inventory program began to be implemented in mid-2006, while the cross-shipping fees were instituted in mid-2007. See Box #3 for an in-depth discussion of the recirculation policy and its likely impacts on Fed cash receipts. This policy likely resulted in a permanent reduction in the level of cash receipts and, in turn, payments, as financial entities sought to avoid these fees. To capture this policy effect, we include a time trend that starts in July 2006 and ends January 2010. (In Section 6, we will consider an alternative simulation in which this time trend is assumed to be permanent.)

[SEE BOX #3 AT END OF PAPER]

[10] Participating banks are required to hold on their own books one day of average daily payments in ten dollar and twenty notes, representing the amount needed by the depository institution to satisfy normal business needs for those denominations.

[11] Cross-shipping is defined as a depository institution ordering currency of the same denomination within five business days, either prior to or following the deposit of fit currency of said denomination at the Federal Reserve. In the finalized policy, the fee only applies to ten dollar and twenty dollar notes.

4.2. Significant Events

The Y2K phenomenon had an enormous, if temporary, impact on demand for Fed cash payments. In the months leading up to January 1, 2000, households and depository institutions appear to have stockpiled higher denomination currency. This stockpiling may have been due in part to concerns that computer systems, which constitute the electronic backbone of the financial system, would have difficulties on and after January 1. Moreover, DIs were strongly encouraged by the Federal Reserve to build stockpiles in case of unforeseen disruptions. When problems failed to materialize, there was a significant one-time reduction in household and DI cash inventories. This behavior resulted in a significant increase in Federal Reserve cash payments in the months leading up to January 2000, followed by a large decrease in January (and an opposite pattern for Fed cash receipts). To control for this effect we include one dummy variable equal to 1 for the six months leading up to Y2K (July 1999 to December 1999) and another dummy variable equal to 1 for January 2000.

Another significant event that may have affected overall cash demand, and hence the Fed's gross cash payments, is the introduction of the euro in January 1999. It is possible that the introduction of the euro could have led to a decrease in demand for the U.S. dollar if the euro was viewed as a substitute for the dollar as a store of value, especially among foreigners. However, to the extent that such substitution took place it would have caused real depreciation of the dollar and would be reflected in the dollar exchange rate. Since we include the exchange rate as a variable in our model, we do not include a separate dummy or trend corresponding to the euro introduction.

4.3. Macroeconomic Conditions

To account for the effect of national macroeconomic conditions on demand for increased currency in circulation, and hence gross cash payments by the Fed, we include variables for economic growth, growth in consumer spending, inflation, and interest rates. For national economic growth we use the year-over-year percentage change in real GDP, the data for which comes from the Bureau of Economic Analysis and is available on a quarterly basis. Growth in consumer spending comes from growth in real personal consumption expenditures, or PCE.[12] For our measure of inflation, we use the 12-month percentage change in the total PCE price index. Data on PCE and PCE inflation are also provided by the Bureau of Economic Analysis, and are released on a monthly basis. As a proxy for overall interest rates, we use the federal funds effective rate provided by the Federal Reserve Board. This is a monthly series. [13]

We also consider the effect global macroeconomic conditions have on U.S. currency, especially 100s, by introducing variables on foreign economic growth and the U.S. exchange rate. Our data on foreign economic growth comes from the World Bank's World Development Indicators database, which provides, on an annual basis, real GDP growth per capita for seven aggregate region blocs of the globe. These regions are as follows: East Asia and the Pacific, Europe and Central Asia, Latin America and the Caribbean, the Middle East and North Africa, North America, South Asia, and Sub-Saharan Africa. We exclude the region of North America however, because its GDP growth is highly correlated with U.S. real GDP growth. This data is available from 1974 to 2009. To account for the impact the U.S. exchange rate may have on cash demand we include the real trade-weighted exchange value of the U.S. dollar which is provided by the Federal Reserve Board. This series is released monthly, and is available for the entirety of our sample period.

4.4. Demographic Trends

Given the consideration that demographic changes, especially the ongoing aging of the population, within the United States may reshape the public's demand for cash (and hence affect ΔCIC and in turn gross payments), we construct a variable measuring the average age of the

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[12] We use growth rates of GDP and PCE in the model instead of levels because we expect the effect of economic activity on gross payments to come through the change in currency stock (ΔCIC) component rather than the gross receipts component. The change in currency in circulation should be a function of the change in (growth rate of) GDP and/or consumption spending rather than their levels. Nonetheless, in future research, it may be worth exploring whether the levels of economic activity also affect gross payments by affecting the demand for Fed cash processing and hence gross receipts.

[13] At the time of this writing we have data from 1974:Q1 through 2010:Q3 for real GDP; 1974:M1-2010:M11 for PCE inflation; and 1974:M1-2010:M12 for the fed funds rates

population, based on population-by-age data from the Census Bureau. We include the 12-month change in the average age in the empirical model.[14] In addition, as mentioned in Section 3, the national income distribution could affect the overall demand for cash as well as the shares across denominations. To measure changes in the income distribution we include the 12-month change in the U.S. Gini coefficient, which is a statistic summarizing the degree of income inequality and is provided at an annual frequency by the Census Bureau (2009). Relatedly, it is possible that the share of the population that is “unbanked” – that is, that does not have a bank account – would affect the overall demand for cash. However, we were unable to find data on this share over our sample period.

4.5. Technology and Consumer Preferences

Technological advances have presented consumers with an increasing array of payment options as alternatives to cash. While checks have long been an important alternative to cash, ACH, debit cards, and credit cards also have become popular alternatives over the last 20 to 30 years. To assess their impact on cash demand, we compiled data on the volume of transactions conducted using each of these four alternative instruments. Unfortunately, time-series data on these transaction volumes (from the Bank for International Settlements (BIS) as described later in this section) is only available from 1988 onward (at an annual frequency) and, in fact, for most years is based on interpolating between the values in the handful of years in which actual survey data are available. Thus, these data contain very limited time-series variation, which hinders our ability to estimate the effects on cash with much precision. Moreover, they have very different trends in the last ten years of so of our sample period than in the earlier part of the sample; this is especially true for debit cards (the use of which greatly accelerated in the 2000s) and checks (the use of which greatly decelerated in the 2000s). This poses a challenge to our ability to assess, as we do in **Section 5.3**, the out-of-sample (2002-2010) forecast accuracy of the empirical model based on estimating it for the 1974-2001 subsample. Therefore, we use factor analysis to, in essence, obtain a single summary variable capturing the collective time-series movements of

[14] We also explored including population shares by age groups instead of the change in the average age, finding that the age shares individually were not significant.

payment alternatives to cash as a whole.[15] One way to interpret this variable is as reflecting changes in the use of all noncash payment instruments for transactions. Using this variable in our empirical model should allow us to capture the general phenomenon of substitution between cash and other payment instruments, though we cannot say anything about whether different payment instruments have different degrees of substitution with cash; available time-series data are simply insufficient for addressing that question.[16]

As discussed in the previous section, changes over time in households' accessibility to cash may also be important for explaining cash demand. A key variable affecting cash accessibility is the number of ATM terminals in the country, and so we include this variable in our empirical analysis.

The data on both ATMs and transaction volumes by ACH, credit cards, debit cards, and checks comes from the BIS annual report (various years).[17] The data are available on an annual basis from 1988 to 2009. Due to the fact that data for these variables do not go back to 1974, we interact each of them with a dummy variable set to 0 for January 1974 through December 1987 and 1 from January 1988 through the end of the last year of available data. The dummy variable is included in any estimation where we use these variables.

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[15] Factor analysis is a statistical technique that decomposes the joint variation in these four variables into "factors," which are simply linear combinations of the four variables. The first factor is the unique linear combination that accounts for the maximum amount possible of this joint variation. Using this technique, we are able to obtain a single factor that explains 90.6% of the joint variation in these four alternative payment variables over the 1988-2009 time period.

[16] One possible avenue for future research would be to look at noncash payment services provided by the Federal Reserve itself. The Fed competes with the private sector in the markets for electronic wire transfer, ACH, and check processing, and hence has data on transaction volumes of these services handled by the Fed. The challenge, however, for using such data for the purposes of measuring overall transaction volumes for these payment alternatives is separating out movements over time in the Fed's market shares for these services from movements in the overall demand for these services.

[17] In the 2000 release the BIS noted in regard to the volume of checks that "Statistics reported in prior years may have been overestimated and are currently under review." The 2001 release included revised values for 1997 to 2000, but nothing for the period of 1988 to 1996. As such, we used data published by the Federal Reserve Board (used by the BIS for its calculations as well) to interpolate the values for the period of 1988 to 1996. Furthermore, the preliminary release for 2009 currently lacks values for some variables used in our analysis. We use values reported in the 2010 Federal Reserve Payments Study for 2009 and interpolate values between 2006 and 2009 to maintain consistency.

5. An Empirical Model of Cash Demand from 1974-2010

In this section we set out to develop an empirical model of demand for Fed cash payments that can achieve two goals: first, aid our understanding of what factors historically have been important determinants of this demand, and second, provide the basis for making baseline and alternative projections out to 2020. This involves three steps:

1. Develop an empirical model that can be estimated.
2. Estimate the model for the full sample period for which data are available, which is 1974-2010. Analyze the resulting coefficients and the in-sample fit of the model.
3. Evaluate the likely forecast accuracy of the model (over a 9-10 year horizon) by estimating it for a subsample period, 1974-2001, and then comparing this fitted model's out-of-sample predictions for 2002-2010 with actual data from 2002-2010.

5.1. Empirical Framework

As we discussed in the introduction, the demand for Fed cash payments is derived from changes in the overall demand for U.S. currency as well as demand for Fed cash processing and storage. The demand for cash processing and storage is determined in large part by DI cash inventory management practices, which are affected by observable Federal Reserve regulatory policies. Modeling the overall demand for U.S. currency, however, is less straightforward. In thinking about how to best model overall cash demand, it is instructive to consider how economists empirically model the demand for other differentiated goods, such as automobiles. However, instead of differing by make and model, cash differs by denomination. In other words, while certain factors affect all denominations in common, other factors may affect some denominations more than others because different denominations are imperfect substitutes for each other.

Economists traditionally have modeled demand for differentiated goods using a so-called demand system. Prominent developments of empirical demand systems are Stone (1954) and

Deaton and Muellbauer (1980). These systems simultaneously model aggregate demand (expenditures) as well as the expenditures shares for each type of good within the aggregate. In its simplest form, aggregate demand is modeled as a function of aggregate income and the aggregate price level. Each type's share of the aggregate is modeled as a function of relative prices (among the types) and possibly aggregate income as well. Recognizing cash as a differentiated good suggests that cash demand can and should be modeled in the same way. Thus, the empirical model we present in this section is a system of equations consisting of an aggregate gross payments equation and an equation for each denomination's share of the total value of payments. While we do not observe explicit "prices" for aggregate cash or for different denominations, the implicit price of cash can be thought of as a function of factors that affect the attractiveness of cash relative to noncash alternatives. The interest rate is an example of such a factor because higher interest rates make cash less attractive relative to interest-bearing alternatives such as payment types drawing from bank accounts (e.g., checks, debit cards, and ACH). Similarly, the relative prices of one denomination with respect to other denominations are functions of factors affecting the relative attractiveness of that denomination. For example, the widespread diffusion of ATMs lowers the cost (relative price) of accessing 20s compared with other denominations. Thus, we include the number of ATMs in the nation as an important explanatory variable in our analysis.

An alternative modeling approach is to simply estimate the demand (volume of payments) for each denomination individually, without separately modeling the aggregate. This model has the disadvantage that it does not transparently reveal the impact of variables on the aggregate value of cash. It is also more difficult to impose cross-equation restrictions or constraints on this model, leading to more parameters to be estimated and consequently less precision in their estimation. Nonetheless, the results from estimating such a model are provided in **Appendix Table 1**. Note that the results are qualitatively similar to those presented here.

Before proceeding, it is worth discussing why we chose to estimate the empirical model for gross payments in terms of dollar values rather than numbers of bundles (i.e., bills). The primary reason is that changes in the overall demand for cash, which, as discussed earlier, in part determines gross payments, are fundamentally determined by the aggregate value of the spending desired by the economy. That is, what matters to consumers (or businesses) when contemplating how to pay for a given purchase is the value of that transaction. Given that value, they then decide whether to use cash or another payment method to complete the transaction. The number of bills required for the transaction is of little concern to the consumer. Nonetheless, it is quite straightforward to back out the implied number of notes from any of our in-sample or out-of-sample forecasts based on values. For a given denomination, the number of notes is obviously just the predicted dollar value of gross payments for that denomination divided by the denomination's unit value. Aggregate numbers of notes can then be measured by adding up across denominations. Below, we present our aggregate results both in terms of values and numbers of bundles.

Based on discussion with CPO staff and others, and a review of the economic literature on cash demand, we have identified the following broad set of factors, or "blocks," that are potentially important determinants of demand for Fed cash services:

R: Regulation/policy (e.g., cross-shipping fees)

Y: Domestic macroeconomic variables (e.g., real U.S. GDP growth, PCE growth, interest rates, and inflation)

I: International macroeconomic variables (e.g., exchange rates and foreign GDP growth)

M: Demographic trends (e.g., average age of the population; measures of the income distribution)

P: Technology and consumer tastes (e.g., alternative payment systems such as debit and checks).

Among the variables in these blocks, some we include only in the aggregate payment equation, some we include only in one or more of the denomination share equations, and some we include in both. For each variable, this decision is guided by whether that variable is likely to affect the relative demand for cash services in general, the demand for any given denomination relative to others, or both. Formally, the system of equations we estimate can be written as follows. We first estimate a single aggregate equation:

$$\ln C_t = \alpha + \mathbf{R}_t \beta^R + \mathbf{Y}_t \beta^Y + \mathbf{I}_t \beta^I + \mathbf{M}_t \beta^M + \mathbf{P}_t \beta^P + \varepsilon_t \tag{1a}$$

where C_t is the aggregate value of gross payments (over the six denominations, ones, fives, tens, twenties, fifties, and hundreds) at time *t*. Then we estimate separate equations for each denomination's share of the total:

$$\ln\left(C_{dt}/C_{t}\right)=\alpha_{d}+\mathbf{R}_{t}\beta_{d}^{R}+\mathbf{Y}_{t}\beta_{d}^{Y}+\mathbf{I}_{t}\beta_{d}^{I}+\mathbf{M}_{t}\beta_{d}^{M}+\mathbf{P}_{t}\beta_{d}^{P}+\varepsilon_{dt} \tag{1b}$$

for d = 1, 5, 10, 20, 50, and 100.[18] We exclude two dollar bills and denominations above $100 from the analysis because they account for a negligible share of total payments, either by value or by number of bills.

Again, note that not all variables need enter every equation, meaning that we will constrain some of the parameters above to be zero prior to estimation. This imposes some parsimony and structure on the system that helps us more precisely estimate the parameters that are truly of interest. It also helps avoid misleading or spurious results. For example, the Fed's recirculation policy involved cross-shipping fees for ten and twenty dollar notes. Therefore, we include the recirculation policy variable in the aggregate payments equation as well as the shares equations for 10s and 20s, but we exclude it from the other denominations' share equations.[19] Similarly, macroeconomic variables such as GDP growth, interest rates, and inflation should impact overall cash demand but there is no reason to think they should have any significant effect on demand for one denomination versus another.

5.2. Model estimation

We estimate the linear demand system expressed in equations (1a) to (1b) above using ordinary least squares (OLS) regression for equation (1a) and seemingly unrelated regression (SUR) estimation for the six share equations of (1b). We have also experimented with

[18] We model the aggregate and shares in logarithmic terms to ensure that all predicted values will be positive. However, this has the disadvantage that it is then not possible to enforce the linear constraint that the denomination shares add up to 1 and hence not possible to constrain coefficients on a given variable in (1b) to add up to zero across the denomination shares.

[19] Note that it is possible that the recirculation policy could have had an indirect effect on other denominations by altering DIs' inventory management practices, as discussed in Box #3 below, however our prior is that any indirect effect would be too small to estimate precisely with this model.

estimating the system of share equations using vector auto-regression (VAR) (augmented with the exogenous explanatory variables). Relative to SUR, the VAR estimation additionally estimates the effect of lagged values of a given denomination as well as the other denominations on that denomination's current value. VAR models are frequently used in short- to medium-term forecasting exercises. However, in our long-term forecasting context, the autoregressive terms in the model are of very little value. Recall that one objective of the paper is to project cash demand out to 2020. Given that we have monthly data, a 10-year ahead forecast requires forecasting 120 months in the future. The autoregressiveness of payments over recent months offers virtually no forecastability so far into the future. Therefore, we opt to use SUR instead. SUR estimation differs from OLS estimation only in that it exploits cross-equation correlations in the residuals to achieve greater precision (lower standard errors) of the parameter estimates.

Before proceeding with the model estimation, it is important to evaluate the stationarity of the dependent variables in the model. In particular, aggregate payments as well as some denomination shares are likely to have a unit root (i.e., a permanent trend). If this is not accounted for, the fact that some of the explanatory variables also have a unit root could cause spurious correlations. One way to handle this is to simply include a linear (or higher-order) time trend as an additional explanatory variable. **Table 2** shows the results of a unit root test, known as the augmented Dickey-Fuller (ADF) test, on $\ln(C_t)$ and $\ln(C_{dt}/C_t)$, for each denomination, both with and without a linear time trend. The displayed p-value for the ADF statistic indicates the probabililty of the null hypothesis that the variable (possibly after controlling for time trend) is nonstationary (i.e., has a unit root). After controlling for a time trend, the p-values are virtually zero, indicating that including these dependent variables in a model with time trends should yield consistent estimates. In the estimates we present in this section, we have included a quadratic time trend (time and time squared) in the aggregate equation as well as each share equation.

Another important estimation issue is how to handle the obvious seasonality of the payments data. One approach would be to seasonally adjust the payments data ex ante and then use seasonally adjusted data as the dependent variables in the model estimation. However, this has been shown to potentially lead to biased coefficient estimates of the model's parameters if the seasonal factors are correlated with the explanatory variables. It is likely that some of our explanatory variables (for example, PCE) have a seasonal pattern, so this is indeed a concern.

The generally recommended alternative approach is to include seasonal indicators – in our case, calendar-month dummies – as additional explanatory variables in the model.

Finally, an additional complication in implementing the model estimation with our data is that while our dependent variables are monthly, many (though not all) of the RHS variables are at quarterly or annual frequencies. We have converted the quarterly and annual variables to monthly via linear interpolation. It should be noted, however, that the true underlying time aggregation of these variables suggests that their standard errors may be biased downward.

The results of the model estimation, over the full sample period of January 1974 through December 2009, are shown in **Table 3**. The statistical significance of each coefficient is indicated by asterisks: one asterisk denotes significance at the 90% level, two denotes significance at the 95% level, and three denotes significance at the 99% level. As indicated in the table, the aggregate equation includes only the following subset of variables (the data sources for these variables is described in **Section 4** above):

- the logarithm of the number of ATMs in the United States;
- our measure of noncash payment alternatives (described in **Section 4** above), which begins in 1988;
- a dummy variable equal to 0 prior to 1988 and 1 from 1988 onward (this is necessary because data for the ATM and payment alternative variables are missing prior to 1988);
- a dummy variable for the initial implementation of sweeps, set to 1 for the period of January 1995 through December 1998 ("sweeps_1995");
- a step-function variable to capture the transition to a new post-sweeps equilibrium level of gross payments, set to 1 from January 1999 to December 1999, then lowered by a constant of 0.2 in each following year until it reaches 0 in January 2004, at which it remains thereafter ("sweeps_1999");
- a recirculation policy time trend ("Fed 2007"), which begins in July 2006 and ends with January 2010;
- macroeconomic variables – real GDP growth, real PCE growth, the fed funds rate, and the inflation rate (12-month growth rate in the PCE price index);
- a dummy variable equal to 1 for each of the six months leading up to Y2K ("Y2K1999") and 0 otherwise;
- a dummy variable equal to 1 in January 2000 and 0 otherwise ("Y2K2000");

- a quadratic time trend (time and time squared);
- and a dummy variable for each calendar month to absorb seasonal patterns.

In selected denomination shares equations, we also include the 12-month change in the Gini coefficient (a measure of income inequality), the 12-month change in the average age of the population, the number of ATMs, the noncash payment alternatives variable, the 1988-on dummy, the recirculation policy time trend, the broad dollar real exchange rate, real GDP growth by global region, the Y2K dummies, and a quadratic time trend.

Beginning with the demographic and socioeconomic variables, we find that changes in income inequality, which we assume to only affect relative shares, not aggregate cash payments, have little effect on denomination shares except 50s, for which increases in the Gini coefficient are found to have a negative effect. The coefficients on the change in the average age of the population suggest that increases in the average age increase the relative demand for small denominations and decrease the relative demand for higher denominations. It is possible that this result reflects greater adoption of new payment methods and substitution away from small-denomination cash by younger individuals.

Turning to technology/consumer-choice variables, we find that the diffusion of ATMs has had a positive and significant effect on aggregate cash payments. The coefficient of 0.206 implies that each 10% increase in the number of ATMs in the United States has been associated with a 2.06% increase in the aggregate value of gross cash payments from the Fed. As expected, ATMs also have had a positive and statistically significant effect on the relative share of 20s in gross payments, but a negative and significant effect on the shares of other denominations (aside from 100s, for which we constrain the effect to be zero).

The payment alternatives variable is found to have a negative and significant coefficient in the aggregate equation, implying that an increase in the use of payment alternatives has led to a decline in the demand for Fed cash services, which we interpret as a due to a decline in the overall demand for cash. Across denominations, payment alternatives appear to have led to a shift in cash composition away from 20s and toward 10s and 100s. In other words, while the increasing availability of alternative payment methods to cash has hurt overall cash demand, it has hurt 20s relatively more than other denominations and has hurt 10s and 100s relatively less than other denominations. The shares of other denominations appear to be unaffected by payment alternatives. The positive effect of payment alternatives on the relative share of 100s likely reflects the fact that demand for 100s may be derived more from their store of value attribute than their means of payment attribute, so while consumers substitute away from cash in general, they substitute more away from smaller denominations than away from 100s. The finding that 10s' share goes up is more difficult to explain but could be related to ATM-induced substitution between 10s and 20s. That is, increasing payment alternatives to cash could have slowed the ongoing substitution away from 10s and toward 20s that was occurring thanks to the spread of ATMs. Future research might explore the interactions between ATM diffusion and the advance of alternative payment means and their joint impact on cash demand.

The changes in reserve requirements starting around 1995 that allowed sweeps increased DIs' incentives to minimize vault cash (because of its opportunity cost from foregone interest earnings). Data on sweeps from Porter and Weinbach (1999) and from the St. Louis Fed suggest that there was a transition toward the increasing use of sweeps between 1995 and 1998 before stabilizing at a new permanent equilibrium. We find that demand for aggregate cash payments fell during the 1995-1998 sweeps-adoption period and that the trend in payments slowed during the transition period (assumed to be 1999-2004) to a new post-sweeps equilibrium. This result runs counter to the hypothesis that sweeps caused DIs to increase the frequency of cash deposits and orders with the Fed, leading to higher Fed cash receipts and payments. It is possible, however, that the ability to use sweeps accelerated the adoption of cash inventory management software and systems, which led to DIs lowering excess cash inventories and increasing their own internal cash recirculation, leading to lower demand from DIs for Fed cash processing.

As expected, we also find that the 2007 Fed recirculation policy appears to have lowered the demand for aggregate gross cash payments and, within the aggregate, to have disproportionately lowered the demand for 10s and 20s.

Somewhat surprisingly, we find no statistically significant impact of the macroeconomic variables on aggregate gross payments. The lack of evidence for an effect of GDP or PCE growth could be due to multicollinearity – that is, GDP growth and PCE growth may be so highly correlated that neither effect can be separately identified. Another possibility is that their effects could be delayed; future research might explore this possibility by experimenting with distributed-lag specifications for these variables. Also, as mentioned earlier, though theory suggests that it is the growth rate of economic activity that should affect gross payments (via the change in currency in circulation), future research might explore whether the levels of these macroeconomic variables affect gross payments.

The non-effect of the inflation rate could be explained by the potentially offsetting effects of inflation on cash demand. On the one hand, higher prices mean more cash (by value) is required to conduct the same amount of real consumption spending, leading to higher overall demand for cash. On the other hand, inflation implies a ongoing loss of the real value of cash holding, reducing demand for cash as a store of value. The lack of negative effect on cash from the interest rate could be due to two offsetting effects: higher interest rates imply a higher opportunity cost of holding cash, leading to lower cash demand, but also could increase the frequency of cash withdrawals and the velocity of cash, leading to higher demand for Fed cash processing. Another possibility is that the increasing accessibility of cash from interest-bearing deposit accounts, via ATMs, has greatly reduced the interest rate sensivity of cash demand.

We find that the growth in real GDP in other regions of the world significantly affects the demand for 100s. Specifically, growth in Latin America and the Caribbean is found to increase demand for 100s – likely because currencies in many countries in this region are pegged to the dollar and, in addition, many institutions and households in this region rely on U.S. one-hundred dollar notes as a store of value rather than domestic currencies. Conversely, growth in Europe and Central Asia tends to reduce demand for 100s, perhaps because growth in that region increases demand for Euro notes relative to the dollar. We also find that growth in the exchange rate between the dollar and a broad basket of foreign currencies (growth in this variable represents dollar appreciation) is associated with increased demand for 100s, though it is possible that the causality here runs from increased demand for 100s (for any reason) causing dollar appreciation.

Y2K clearly had a large, temporary impact on cash demand. The coefficients on the Y2K dummies indicate that aggregate cash payments increased an average of 12% in each of the six months leading up to January 2000 and then dropped by nearly 50% during January 2000. In results not shown here, we have found that the opposite pattern holds if we analyze Fed cash receipts instead of payments (i.e., Fed receipts of cash fell in the months leading up to Y2K and then jumped sharply in January 2000). Presumably, these patterns reflect stockpiling of cash by households and DIs in the months leading up to Y2K, followed by increased cash withdrawals by households from DIs and in turn higher requests for cash payments by DIs from the Fed (and lower receipts of cash by the Fed) in January 2000.

Finally, we find that, after controlling for these factors, cash still has a significant time trend.[20] The coefficients on time and time squared indicate that unobserved factors have tended to push aggregate cash payments upward but at a slowing pace. That is, the growth rate of demand for gross cash payments by the Fed, net of observable factors, is found to be positive but declining over time. The implied peak is found to be far in the future, so that the estimated quadratic time trend (alone) suggests positive growth in aggregate cash payment far beyond the sample period. (We discuss projections based on the time trend alone versus explanatory variables alone in **Section 6**.)

We find that the time trend terms are not only statistically significant for aggregate cash demand, but are also important for explaining relative denomination shares. Overall, the explanatory variables in the model, including the time trends and seasonal dummies, explain a very high fraction of the variance in aggregate cash payments and shares of payments value by denomination. The R^2 for the aggregate demand equation is 0.99, while the R^2s across the shares equations are all above 0.91, except 20s for which the R^2 is 0.76.[21]

5.3. Out-of-Sample Accuracy

In this subsection, we evaluate the out-of-sample forecast accuracy of the above empirical model by first estimating the model over the subsample period 1974-2001 and then comparing the model's out-of-sample forecast from 2002-2010 with the actual data over this latter period.[22] In evaluating such long-term forecasts, it is useful to keep in mind that there are

[20] In fact, for aggregate payments and payments of 1s, 5s, 10s, and 50s, the quadratic time trend alone can explain more of the dependent variable's variation than can the explanatory variables. In other words, for these dependent variables, the R^2 from a model containing only the quadratic time trend and a constant is higher than the R^2 from a model containing only the other explanatory variables (both models include the month dummies). On the other hand, the time trend terms are less important than the explanatory variables for explaining the variation over time in gross payments of 20s and 100s.

[21] The importance of ATMs for the relative demand for 20s could explain the lower fit of the model for this denomination. Recall that the data on number of ATMs did not start until 1988. Therefore, a key variable for explaining the movements of 20s is unobserved for roughly half of the sample period, reducing the explanatory power of the model for 20s.

[22] We estimate the model through 2001 instead of 2000 (which would have allowed for a 10-year ahead forecast, comparable to the 10-year ahead forecast through 2020 presented in the next section) in order to avoid any end-of-

two broad sources of forecast error: (1) model uncertainty and (2) factor uncertainty, i.e., uncertainty about the future of explanatory variables. Within model uncertainty, there is parameter uncertainty (reflected in the coefficient standard errors) and specification uncertainty, i.e., uncertainty over the functional forms used in the model, the variables that are included, and the constraints that are imposed. Model uncertainty can be minimized by following sound economic theory and making appropriate modeling assumptions, as we have attempted to do in this paper.

Uncertainty about the future of the factors that drive cash demand, however, obviously is beyond our control and is inherent to the challenge of forecasting. Factor uncertainty, in fact, is especially important when thinking about out-of-sample forecasting of the 2001-2010 period because of the major impact of the Fed recirculation policy, which appears to have greatly reduced cash volumes from 2007-2010, and the nearly concurrent financial crisis and deep recession. Our model estimated over the 1974-2001 period obviously cannot control for the potential negative impacts of these future events, and so projections based on that estimated model miss on the upside over the 2007-2010 period. As an attempt to remove this forecast error due to the 2007-2010 trend-shift (which we have interpreted as due to the recirculation policy but would also pick up any effect of the crisis and recession) and thus focus on the model's general forecast error, we have added back this trend-shift, estimated from the full sample, onto the out-of-sample forecast obtained from the 1974-2001 estimated model.

The panels in **Figure 4** show the results of using our fitted empirical model, estimated over the subsample period of January 1974 – December 2001 (with the exception of the 2007 trend-shift), to obtain both in-sample and out-of-sample predicted values of cash demand. The vertical line in each figure indicates the end of the in-sample period (December 2001). The red line in each figure shows the actual data. The blue line shows the model's predicted values. All data are displayed in log form to ease interpretations (a straight line in log values means a constant growth rate). Panel A shows the aggregate value of gross cash payments and Panel B shows the aggregate number of bundles of gross cash payments (computed by aggregating over the predicted number of bundles for each denomination. Panels C-G show gross cash payments

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sample complications due to Y2K. Estimating the model through 2001 allows us to control for the unusual pattern of cash demand around January 2000.

by denomination.[23] Note that the by-denomination figures look exactly the same whether they are in terms of dollar values or in terms of number of bundles. The units displayed on the vertical axis for Panels C-G are in terms of the logarithm of the dollar values, but transforming these units into the logarithm of number of bundles simply involves subtracting off a denomination-specific constant.[24]

As one can see, the model does an excellent job of explaining the data in-sample, including the pronounced seasonal patterns. This is just a visual confirmation of what we learned from the high R^2s reported in the previous subsection. The bigger challenge, of course, is fitting the data out-of-sample. The model does a fairly good job of predicting the 2002-2010 evolution of aggregate gross payments, both in terms of dollar values and number of bundles. Across denominations, the out-of-sample forecasts are most accurate for 10s, 50s, and 100s. For 1s and 20s, the model misses on the upside for the 2006-2010 period (despite our incorporation of the 2007-2010 trend-shift). For 5s, the model misses on the downside for the same period. For 50s and for aggregate payments, the model tends to miss on the upside in later years.

6. Baseline and Alternative Projections of Cash Demand Through 2020

In this section, we describe how we use our fitted model of demand for Fed cash payments, estimated over the full sample period of January 1974 – December 2009, to obtain baseline and alternative projections of cash demand out to 2020. The specification of that model was discussed above, in **Section 5.1**, and the estimation results were presented in **Section 5.2**. The baseline projection gives our best guess as to how payments will evolve over the next ten years based on our estimated model and our best guess as to how the model's explanatory variables will evolve over this time frame. Of course, as noted earlier with regard to factor uncertainty, there is great uncertainty and debate surrounding how these explanatory variables will evolve and, moreover, there likely will be future technologies and policies that affect cash demand that cannot be included in our present model. The baseline projections should be thought of as a benchmark or starting point from which to evaluate alternative risk scenarios.

[23] The predicted log of cash payments for a given denomination is calculated by taking the model's prediction for the log of the denomination's share of aggregate payments value and adding to it the model's prediction for the log of aggregate payments value.

[24] That is, the log(# of bundles) = log(dollar value) – log(denomination's unit value*1000).

The utility of our empirical model lies as much (or more) in its ability to provide a well-defined analytical framework within which to consider the impact of alternative scenarios as it is in its ability to make accurate forecasts so far into the future.[25]

6.1. Baseline Projections

To construct our baseline projections of cash demand, we must obtain projections of how the explanatory variables will evolve in the future. For most variables, the available historical data currently runs through the end of 2009. Thus, we must project these variables from January 2010 through December 2020. For real GDP growth and PCE inflation, we use the projections given by the Congressional Budget Office (CBO) in its report, "Budget and Economic Outlook: Fiscal Years 2011 to 2021," which provides, at an annual frequency, estimates of growth in GDP and PCE inflation through 2020 (see CBO 2011). To maintain consistency with the data used during our sample period, we assign the annual value of GDP imputed from the CBO estimates as the December value in a particular year, and interpolate a monthly series. Similarly, for PCE inflation, we treat the annual value as the December value and interpolate a monthly series.

Projections on the average age of the population are based on projected population shares by age from the Census Bureau's 2008 national population projections. The estimates on population provided are at an annual frequency through July 1, 2050, so for our purposes we treat each annual value as the July value for that year and interpolate a monthly series from 2010 through the end of 2020.

[25] There are, of course, other methodologies for long-term forecasting than the approach we have taken in this paper. One common approach in the field of statistics is known as "direct forecasting." Loosely speaking, this approach involves regressing the dependent variable(s) of interest on explanatory variables lagged the number of periods in the forecast horizon, and then using that fitted model to obtain predictions of the dependent variable over the forecast horizon. In our context, this amounts to replacing the contemporaneous values of the explanatory variables in our model with the values of these variables 120 months earlier. The out-of-sample predicted values of cash demand (i.e., aggregate payments and the denomination shares) for months up through December 2020 can then be obtained based only on the available historical data on the explanatory variables. The advantage of this approach is that it does not require any assumption about how the explanatory variables will evolve in the future. The disadvantage is that it does not lend itself to evaluating alternative risk scenarios, which inherently involve alternative assumptions about the future evolution of key explanatory variables. Therefore, we present here only projections based on our estimated empirical model. Nonetheless, we have generated cash demand forecasts using this approach (they are available from the authors upon request) and found that the forecasts are qualitatively similar to our baseline projections.

As outside projections for our other explanatory variables are not provided by reliable sources, we construct our own estimates in the following manner. For our variables on the Gini coefficient, the number of ATMs, and the factor variable summarizing the trends in noncash payment alternatives, we assume that each will continue to grow at its 2001-2009 (linear) trend through 2020. One should think about the ATMs projection and the payment alternatives projection as proxying for the larger concepts of cash accessibility and the attractiveness of all cash alternatives, respectively. Hence, while the spread of ATMs is likely to slow in the decade to come, other technologies may compensate such that the overall accessibility to cash may continue to grow at roughly the same pace as over the past decade. Similarly, though check and perhaps credit card use may have already peaked and begun declining, and debit cards may soon reach their saturation point, the availability and attractiveness of payment alternatives to cash, especially with new technologies such as mobile payments, is as likely as not to continue as the same pace as the last ten years.

For our variables on international growth rates, the fed funds rate, and PCE growth, we think it unlikely that they will stay at their current rates for another ten years. For example, it seems unreasonable to think that the fed funds rate will remain near 0 over the next ten years given the likelihood of U.S. economic recovery. For these variables, we take the average value over the period of January 2001 and December 2009 and assign this value for the period of 2010 to 2020.

As mentioned earlier, our baseline projections assume that the Fed recirculation policy led to a temporary trend shift in cash payments (aggregate and by denomination) from 2007 to 2010. An alternative hypothesis would be that this trend shift is permanent. We explore that hypothesis as an alternative simulation below.

Our baseline projections of aggregate cash payments and shares by denomination are shown in the panels of **Figure 5**. The baseline projection for the aggregate value of cash payments (Panel A) shows a slight increase over the 2011-2020 forecast horizon.[26] The exact percentage of the projected decline is given by the difference between the log of predicted aggregate payments value (the blue line) in December 2020 and that in December 2010

[26] Note that while we only have data through 2009 for the explanatory variables, we have data on cash payments through 2010. Therefore, though we refer to the forecast period as 2011-2020, our projections are actually over the period 2010-2020.

(multiplied by 100). The result is a cumulative increase of 18.2%, which represents an average annual increase of 1.7%. In terms of dollar amounts, the projected increase is $9.3 billion in monthly Fed cash payments (from $62.9 billion in December 2010 to $74.3 billion by December 2020). Panel B shows the baseline projection in terms of number of bundles. The projected increase in bundles is slightly higher, at 19.0% (1.8% per year), than the increase in dollar values. Among denominations, gross payments of 1s and 5s are projected to increase, gross payments of 20s, 50s, and 100s are projected to stay roughly flat, and 10s are projected to decline. The sharpest projected decline is for 10s and 100s.

To get a sense of what is driving each of these projections, we have decomposed these projections into the contribution from the quadratic time trend alone – which reflects any unobserved or omitted factors that have historically affected cash demand – and the contribution from the other explanatory variables alone.[27] The results of the time-trend-alone ("time_fit") and explanatory-variables-alone ("ev_fit") projections, alongside the baseline projections, are provided in **Figure 6**. For aggregate values and aggregate bundles, the baseline projection is being pulled in opposite directions by the time trend and the explanatory variables. The time trend is pushing the baseline projections up strongly while the explanatory variables are pushing the projections downward. A similar dynamic is at work for the projections for 1s, 5s, 20s and 50s. For 10s, again the explanatory variables are pushing the projection down but in the estimated model for 10s, the explanatory variables have much more explanatory power than the time trend and hence more influence on the projections, so the explanatory variables strongly push down the baseline projection. For 100s, there is very little difference between the projection based only on the explanatory variables and that based only on the time trend.

The expected continued rise in the use of noncash payment alternatives appears to explain much of the downward influence coming from the explanatory variables for aggregate cash payments. For 10s, ATM-induced substitution away from 10s toward 20s is also important.

6.2. Alternative Simulations – Examples

[27] For the projection based on the time trend alone, we set all explanatory variables equal to their last historical data point (2009:M12) for all future periods. For the projection based on the explanatory variables alone, we set "time" and time squared equal to 2009:M12 for all future periods.

We present three alternative projections, or "simulations," to illustrate how the model can be useful for evaluating potential scenarios for, or risks to, cash demand going forward. The alternatives described here are but examples of possible scenarios that could be explored.

The first alternative simulation is depicted in **Figure 7**. In this simulation, we consider the downside risk to cash demand due to the possibility that the use of noncash payment types grows faster than in our baseline projection. Recall that our baseline projection assumes that the principal factor, summarizing the volume of transactions of alternative payment types (checks, credit cards, debit cards, and ACH), grows at the same trend rate as it did during 2001-2009. In this alternative simulation, we assume this factor grows at double that rate. This simulation can be thought of as representing an increased pace of adoption of existing payment alternatives to cash and/or the diffusion of new or emerging payment alternatives such as mobile payments.

As one would expect, we find that such an acceleration in alternative payment type use effects lower aggregate cash demand over the forecast horizon. The negative effect is spread across all denominations except 100s, which are largely unaffected.

The second alternative simulation is shown in **Figure 8**. Here, we assume that the negative trend-shift we estimate for the 2007-2010 period, which we ascribe to the Fed recirculation policy, is actually a permanent effect. That is, we assume that the negative effect of the Fed recirculation policy on the trend (growth rate) of gross receipts, and hence gross payments, is permanent, rather than ending in 2010 as our baseline projection assumes. Another interpretation of this assumption is that the negative 2007-2010 trend-shift was caused by some other permanent phenomenon rather than the recirculation policy. One could also use this alternative simulation to consider the impacts of extensions or expansions, say to other denominations beyond 10s and 20s, to the current recirculation policy. We find that this alternative simulation entails sharp declines in aggregate cash payments and sharp declines in all denominations.

Our final alternative simulation involves assuming strong growth in the key foreign economies we find to be important for demand for 100s, namely East Asia and Latin America. These variables only affect the equation for 100s and hence have no impact, by construction, on aggregate cash payments or payments of other denominations. In this simulation, we assume that GDP growth in those two regions is three times what it was in the 2001-2009 period (and what is assumed in the baseline). The results are shown in **Figure 9**. Even with this large shock to foreign growth, we find little impact on the gross payments of 100s, suggesting that while foreign growth may have a statistically significant effect on 100s, the effect is not quantitatively (or economically) important.

7. Conclusion and Areas for Future Research

In this paper, we estimated a demand system for Fed cash payments, across denominations, using historical data on gross cash payments from the Fed and on various explanatory variables from January 1974 through December 2009. We then used that estimated model as the basis for a baseline projection and alternative simulations of gross payments by denomination out to 2020. Our baseline projection implies an 18% increase (1.7% per year) in the aggregate value of payments between 2010 and 2020 and a 19% increase (1.8% per year) in the aggregate number of cash bundles paid out. Our alternative simulations explore the risk to demand for Fed cash payments over the decade to come of faster-than-expected consumer adoption of noncash payment instruments, persistent effects of the Fed's recent changes to its recirculation policy, and faster-than-expected foreign economic growth. Faster-than expected substitution away from cash toward other payment types implies a moderate downside risk to demand for Fed cash payments, while persistence in the impact of the Fed's recirculation policy implies a major downside risk. Faster-than-expected foreign economic growth, on the other hand, has a modest effect on the demand for 100s.

We see the principal contribution of this paper as providing an analytical framework for understanding the historical movements in demand for Fed cash payments and for considering its future direction. In future research, the empirical analysis presented in this paper could likely be improved along a number of dimensions. First, using geographic variation in cash demand (across Federal Reserve cash offices) may well allow for more precise estimation of the impacts of the explanatory factors on demand for Fed cash services. In addition, a longer historical analysis, using alternative data, would likely be fruitful. Third, it is possible that the market concentration of the financial sector has an impact on the demand by DIs for Fed cash processing because a larger, more integrated bank may result in consolidating cash depositors and cash orderers under a single roof, such that the net demand for cash processing by the bank may be reduced. Thus, including a variable in the model for financial market concentration may be useful. Similarly, the composition of the financial sector, such as credit unions' share of the sector, could impact the demand for Fed cash services.

The empirical specification of the model might also be improved. In particular, the model currently relies heavily on the monthly variation and quarterly variation in the data to estimate the effects of the explanatory variables. It is quite possible that some, if not most, of the explanatory variables have lagged or delayed effects on Fed cash payments. For example, perhaps PCE growth affects the public's demand for increased currency in circulation immediately but institutional frictions cause a delay of one or more months before this increased demand shows up in the form of higher cash orders by DIs. Future research might explore either moving the estimation to lower frequency data, such as annual, or including lags of certain variables in the model.

Fifth, the ability of the model to estimate and forecast the substitution between cash and other payment alternatives is greatly hampered by the sparsity of data on the use of payment alternatives. Future improvements in data collection or availability of new historical data sources (such as from credit and debit card providers) would allow for a more accurate model of the demand for Fed cash services. Lastly, as mentioned earlier, separately modeling the overall demand for cash by the public from the demand for cash processing by DIs would likely improve the understanding of the channels by which each explanatory variable affects the Fed's gross cash payments.

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Glossary of Key Terms

Payments – Federal Reserve notes, both new and processed, paid directly from the Federal Reserve office or cash depot to depository institutions, government agencies, and over the counter during the month.

Receipts – Federal Reserve notes received for processing from depository institutions, government agencies, and over the counter.

Currency in Circulation (CIC) – Federal Reserve notes in circulation, both domestically and abroad.

Depository Institutions – Financial institutions that make loans and obtain their funds mainly through deposits from the public; including commercial banks, savings and loan associations, savings banks, and credit unions.

Extended Custodial Inventory (ECI) – Offsite holdings of the Federal Reserve's cash assets at designated Depository Institutions' facilities (separate from the DIs' own cash holdings).

Real Gross Domestic Product (real GDP) – a measure of the total value of goods and services produced by labor and property located in the United States adjusted for price changes.

Personal Consumption Expenditure (PCE) – a component of GDP, it consists of the actual and imputed expenditures of consumers on goods and services; it accounts for roughly two -thirds of GDP. The other components of GDP are gross private domestic investment, net exports, and government consumption expenditures and gross investment.

PCE Inflation – Measured as the year-over-year change in the monthly price index for PCE.

	Table 1. Correlations between measures of cash		
	Receipt and Payment	Receipt and ΔCIC	Payment and ΔCIC
$1's	0.9889	0.003	0.0664
$5's	0.9721	-0.0323	0.1097
$10's	0.8452	-0.2004	0.3373
$20's	0.9808	-0.0689	0.1312
$50's	0.9406	-0.1315	0.1039
$100's	0.9571	0.0997	0.2499

Table 2. p-value of Augmented Dickey-Fuller Unit Root tests

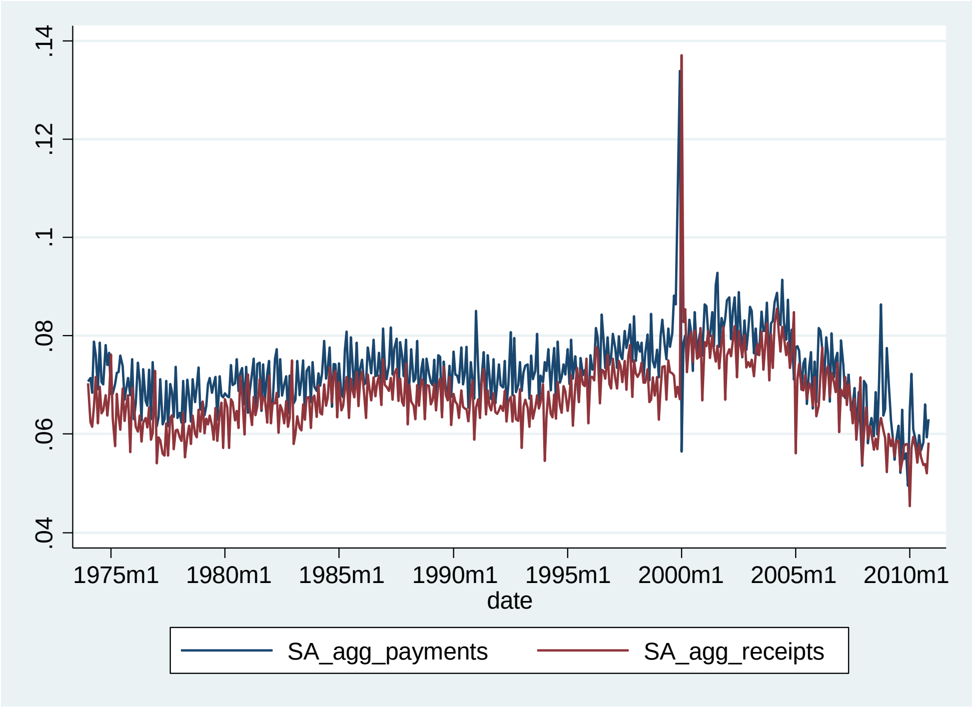
	All Denominations	$1's	$5's	$10's	$20's	$50's	$100's
$\text{Log}(C_{dt})$	0.01	0	0	0	0.0075	0.005	0.0851
$\text{Log}(C_{dt} / C_t)$	--	0.0033	0.2544	0.69	0.0037	0	0.2395
$\text{Log}(C_{dt})$, with trend		0	0	0	0	0	0
$\text{Log}(C_{dt} / C_t)$, with trend	--	0	0	0	0	0	0

Table 3. Demand System Regression Results

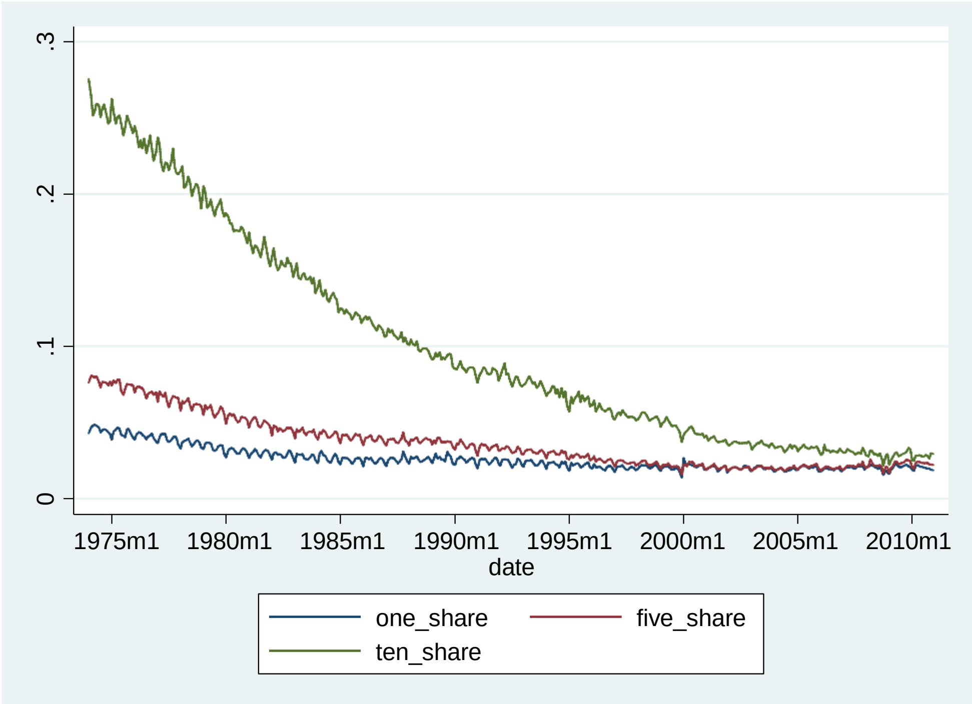
	Aggregate	$1's	$5's	$10's	$20's	$50's	$100's
Demographic							
Gini	--	-0.142	-0.097	0.053	-0.432	-2.992***	--
Average Age	--	0.811***	0.145	1.334***	-0.910***	-1.859***	--
Technology							
ATMs	0.206***	-0.063*	-0.319***	-0.301***	0.155***	-0.090***	--
PCF of non-cash payments	-0.174***	-0.006	-0.015	0.052*	-0.143***	-0.051	0.351***
i88	-1.224***	0.396**	1.400***	1.336***	-0.924***	0.241	1.212***
Regulatory/Policy							
Sweeps 1995	-0.042***	--	--	--	--	--	--
Sweeps 1999	-0.042***	--	--	--	--	--	--
Recirculation Policy	-0.007***	--	--	-0.001***	-0.001***	--	--
Macroeconomic: National							
Real GDP growth	-0.09	--	--	--	--	--	--
Fed Fund	0.002	--	--	--	--	--	--
Real PCE growth	-0.483	--	--	--	--	--	--
PCE inflation growth	0.046	--	--	--	--	--	--
Macroeconomic: International							
Exch. Rate Growth	--	--	--	--	--	--	0.118**
Growth in Per Capita RGDP							
East Asia & Pacific	--	--	--	--	--	--	0.337
Europe & Central Asia	--	--	--	--	--	--	-0.832**
Latin America & Caribbean	--	--	--	--	--	--	0.501**
Middle East & North Africa	--	--	--	--	--	--	-0.305
South Asia	--	--	--	--	--	--	-0.186
Sub-Saharan Africa	--	--	--	--	--	--	-0.08
Y2k 1999	0.122***	-0.127***	-0.109***	-0.024	-0.073***	0.131***	0.149***
Y2k 2000	-0.472***	0.261***	0.027	-0.078	0.038	-0.176***	0.011
Time	0.012***	-0.007***	-0.011***	-0.007***	0.001***	0.006***	0.009***
Time^2	-0.00001***	0.00001***	0.00001***	0.000003***	-0.000002**	-0.00001***	-0.00001***
R^2	0.9906	0.9102	0.9798	0.9956	0.7646	0.9205	0.9483

Note: Regressions include monthly dummy variables to capture the seasonal trends in payments. Due to space constraints their coefficients are not included above.

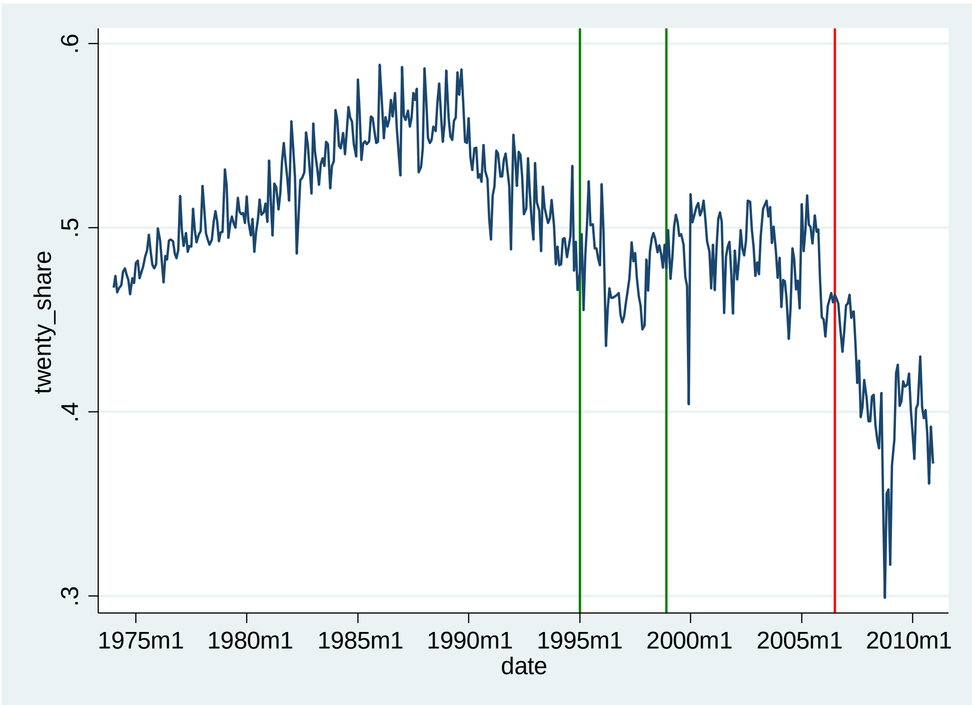
Figure 1. Historical Trends in Fed Cash Payments
Panel A. Aggregate Value of Cash Payments and Receipts
(as Share of Nominal PCE)
(seasonally adjusted)



Panel B. Denomination Shares of Aggregate Payments Value – 1s, 5s and 10s



Panel C. Denomination Shares of Aggregate Payments Value – 20s



Note: Green lines denote approximate period of increased bank adoption of sweep accounts. Red line denotes the start of Fed recirculation policy.

Panel D. Denomination Shares of Aggregate Payments Value – 50s and 100s

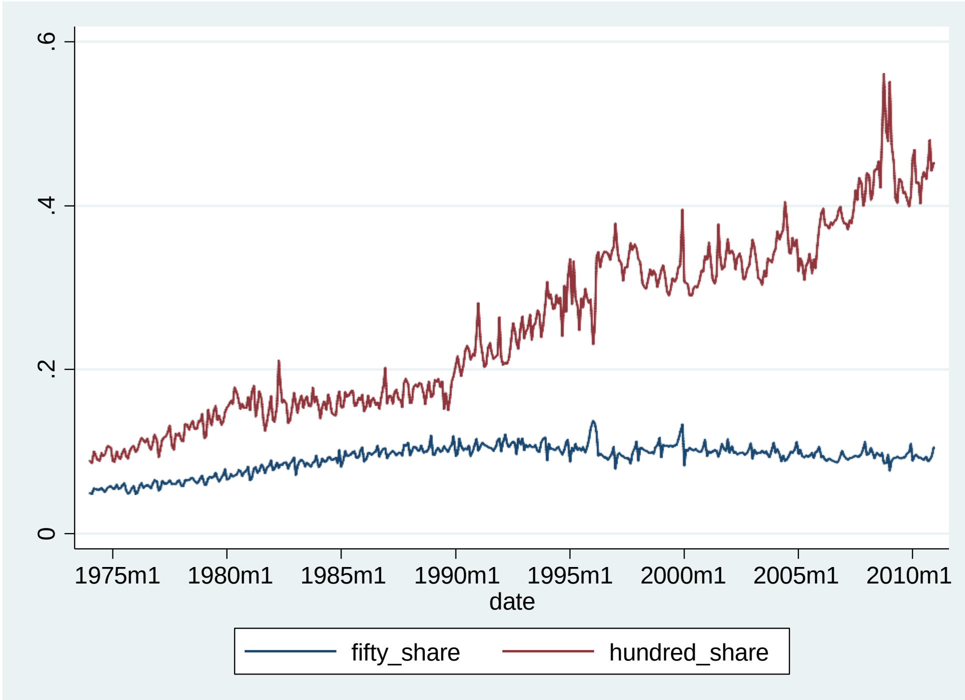
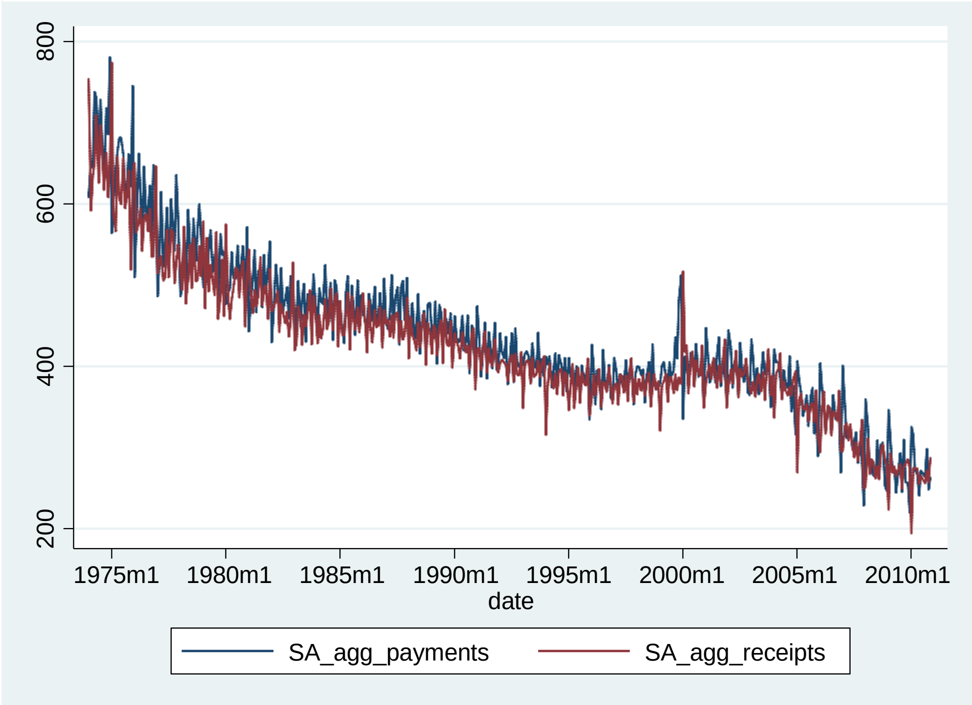
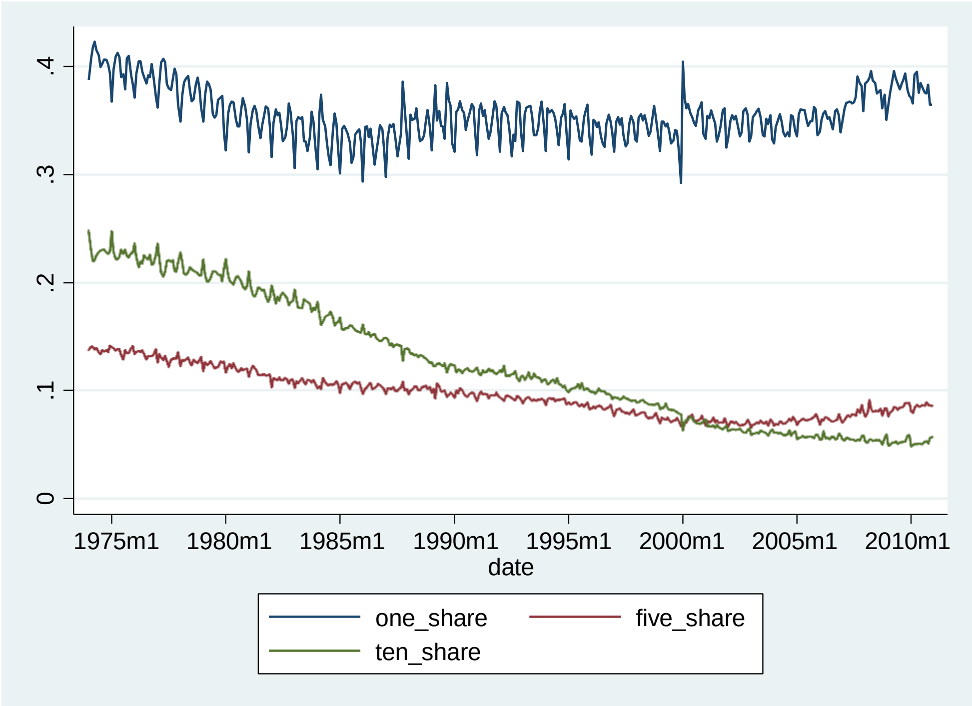


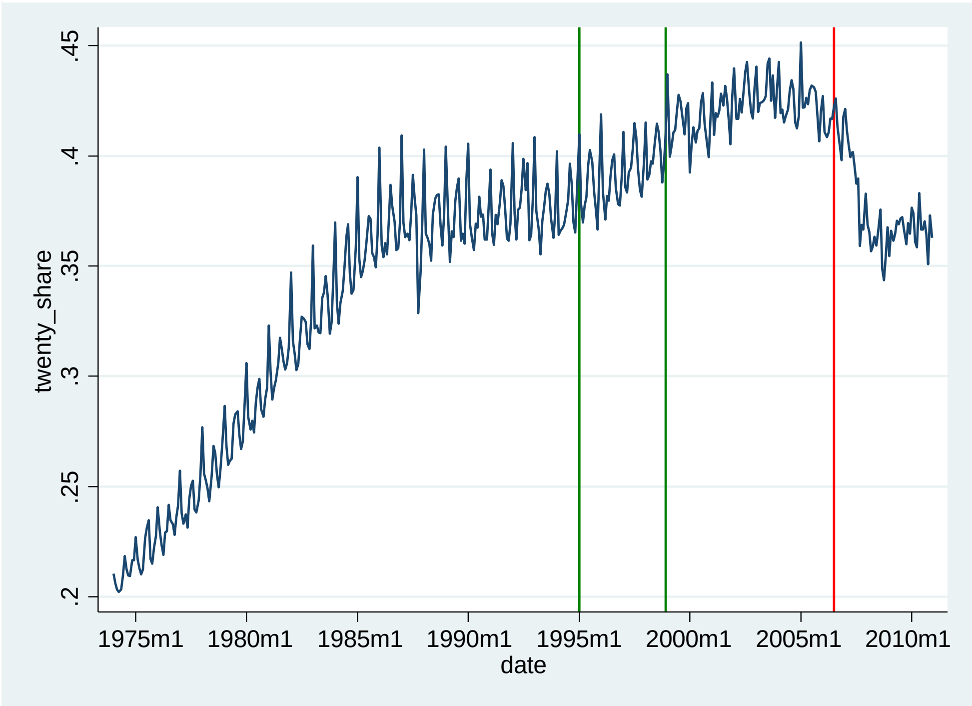
Figure 2. Historical Trends in Fed Cash Payments
Panel A. Aggregate Bundles of Cash Payments and Receipts
(as Share of Nominal PCE, billions)
(seasonally adjusted)



Panel B. Denomination Shares of Aggregate Payment Bundles – 1s, 5s and 10s



Panel C. Denomination Shares of Aggregate Payment Bundles– 20s



Panel D. Denomination Shares of Aggregate Payment Bundles – 50s and 100s

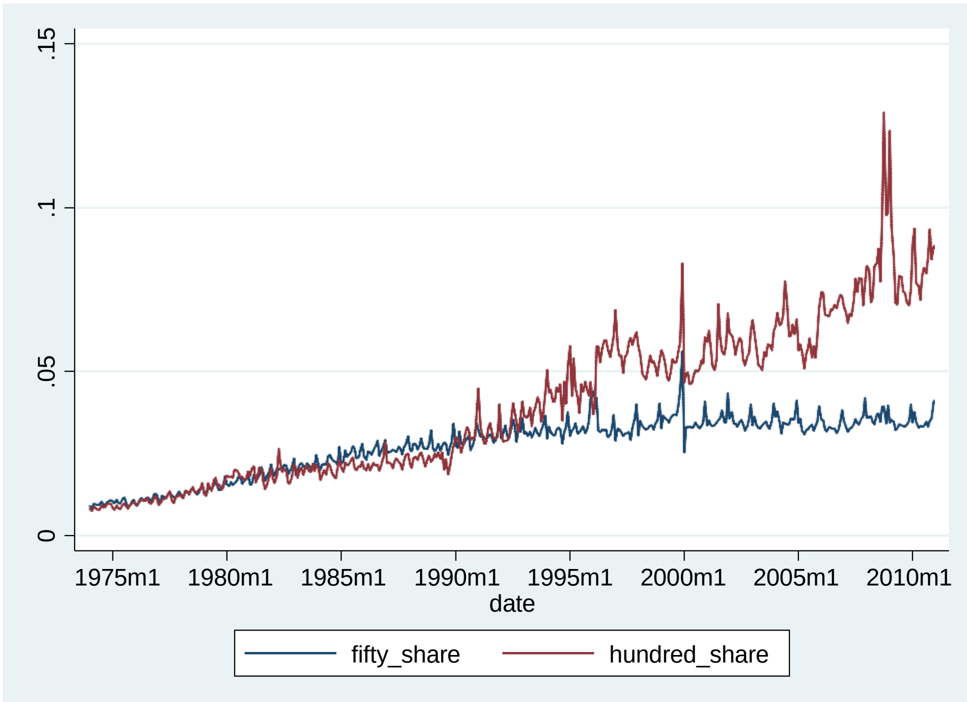
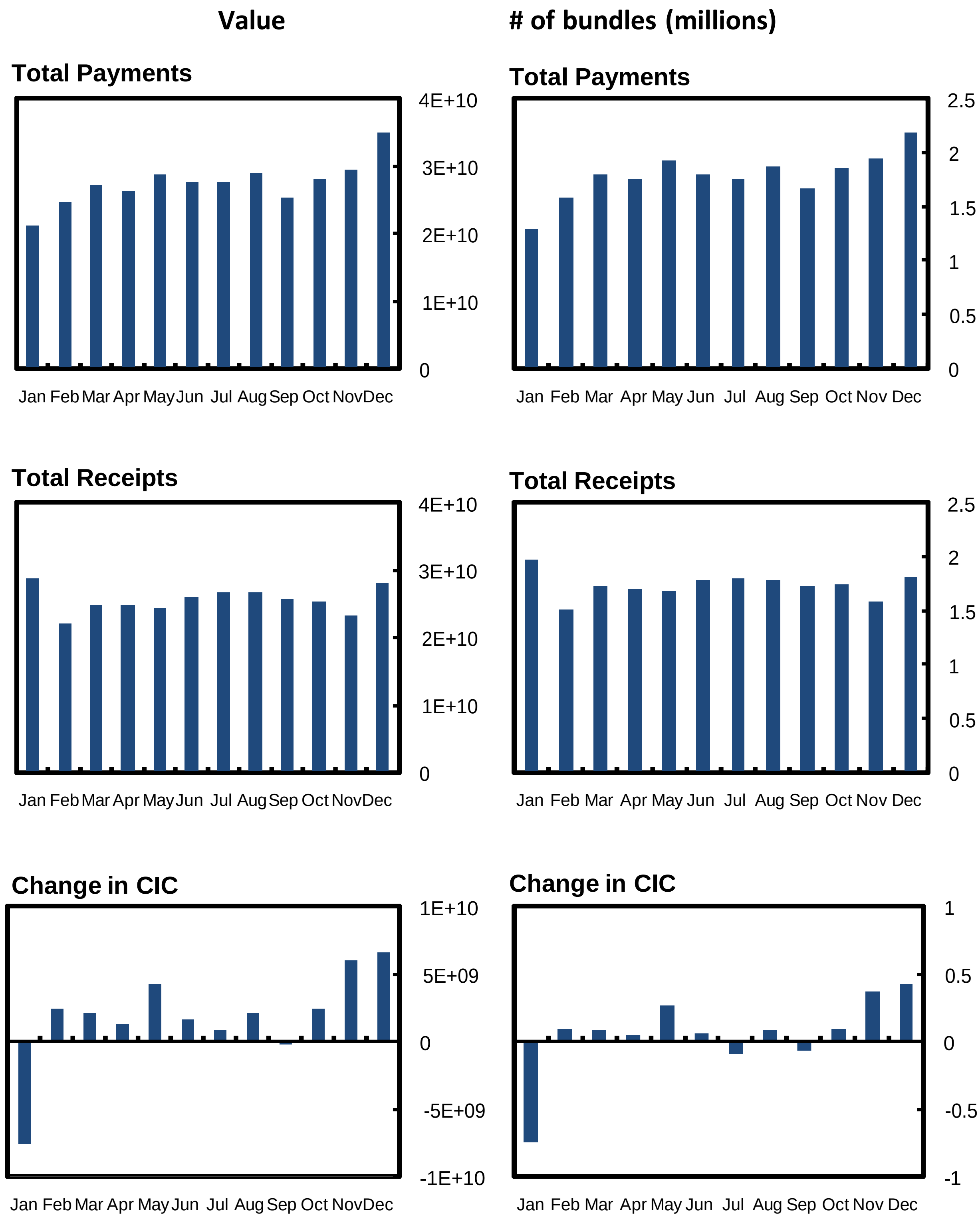
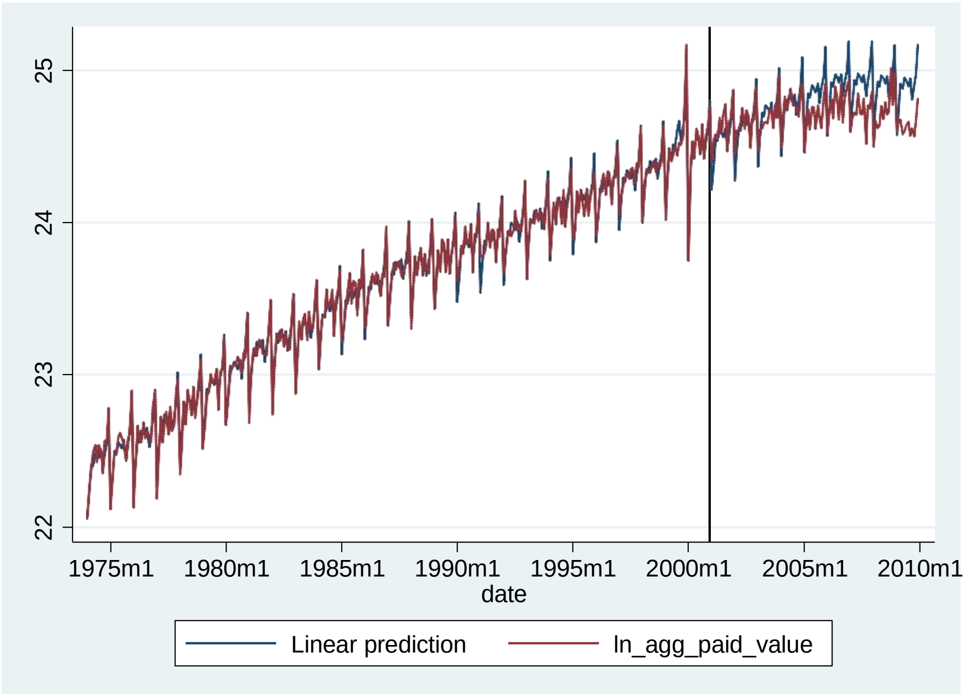


Figure 3. Monthly means 1974-2010*

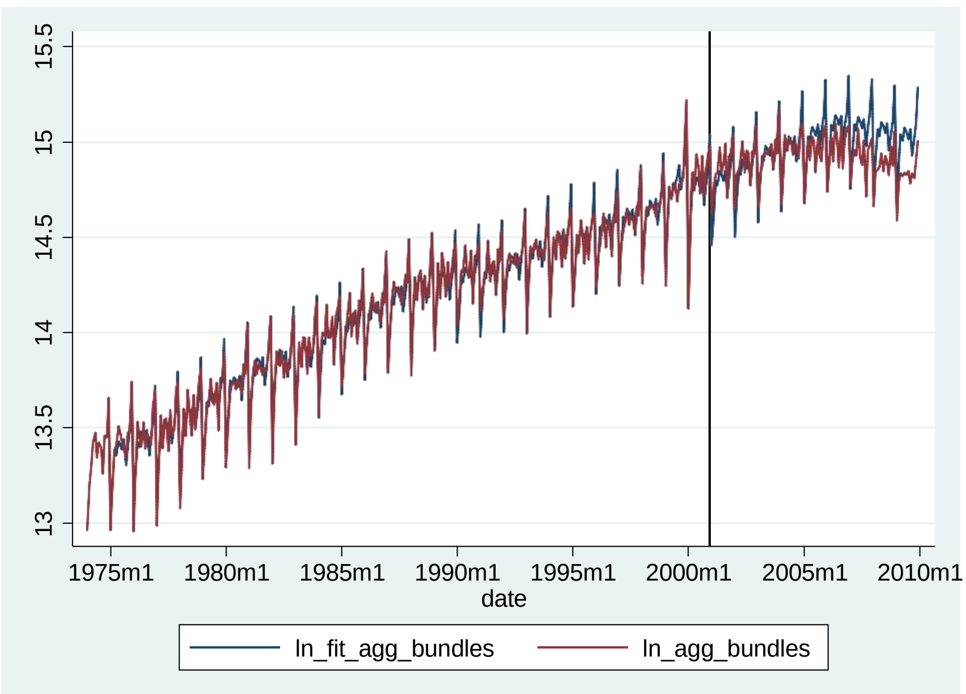


* The years 1999 and 2000 are excluded from the payment and receipt calculation due the the pronounced transitory effect of the Y2K event. The change in CIC figures include data from 1980 on.

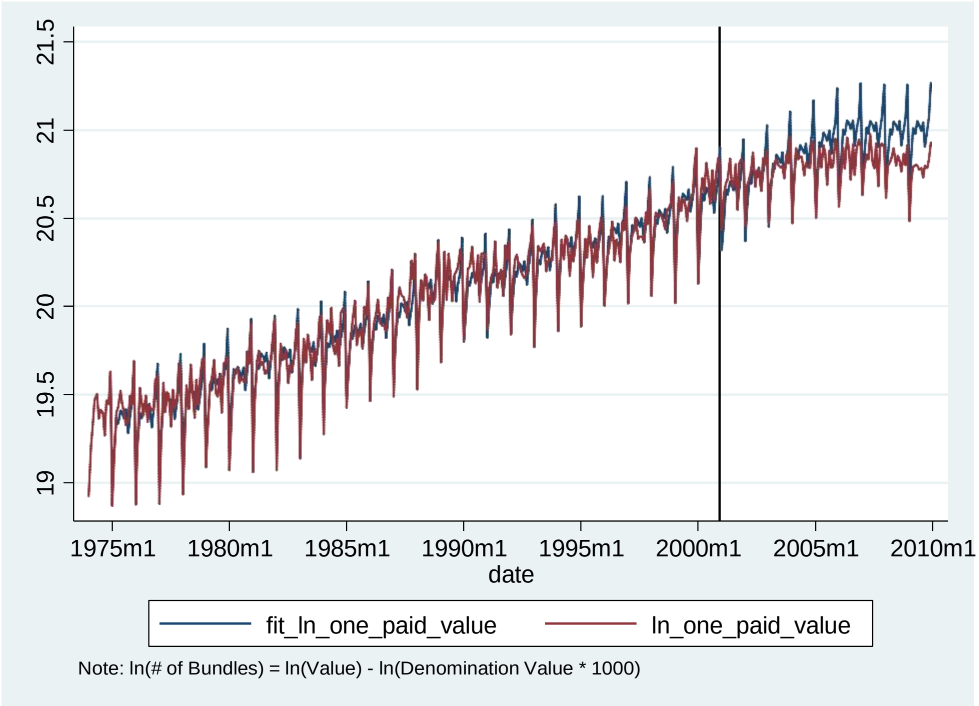
Figure 4. In-Sample (1974-2001) and Out-of-Sample Forecasts
Panel A. Aggregate Value of Cash Payments (in logs)



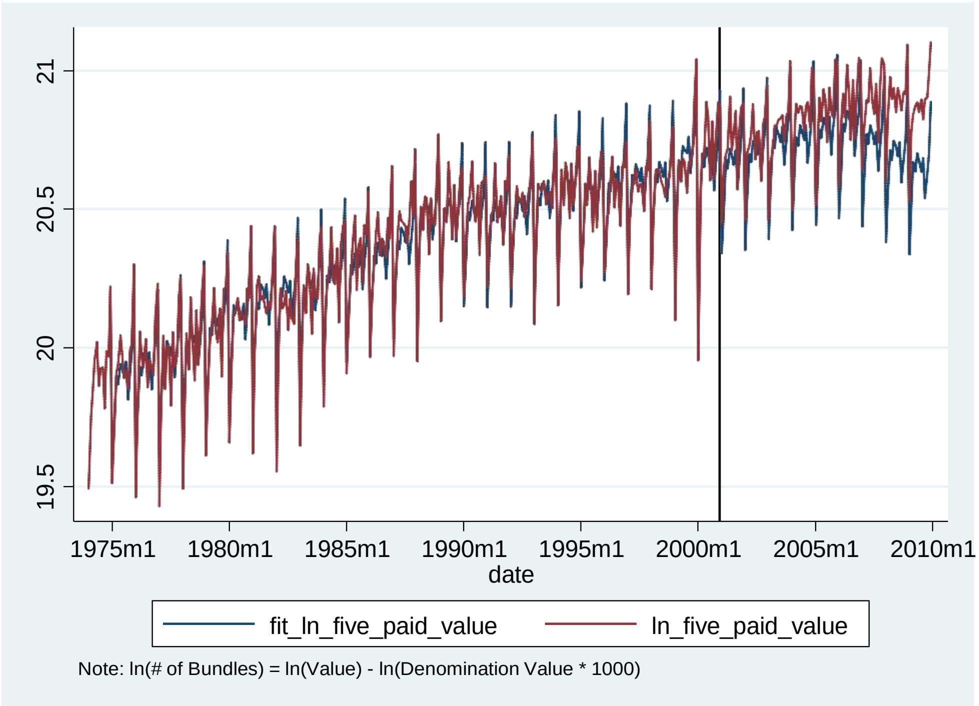
Panel B. Aggregate Number of Bundles (in logs)



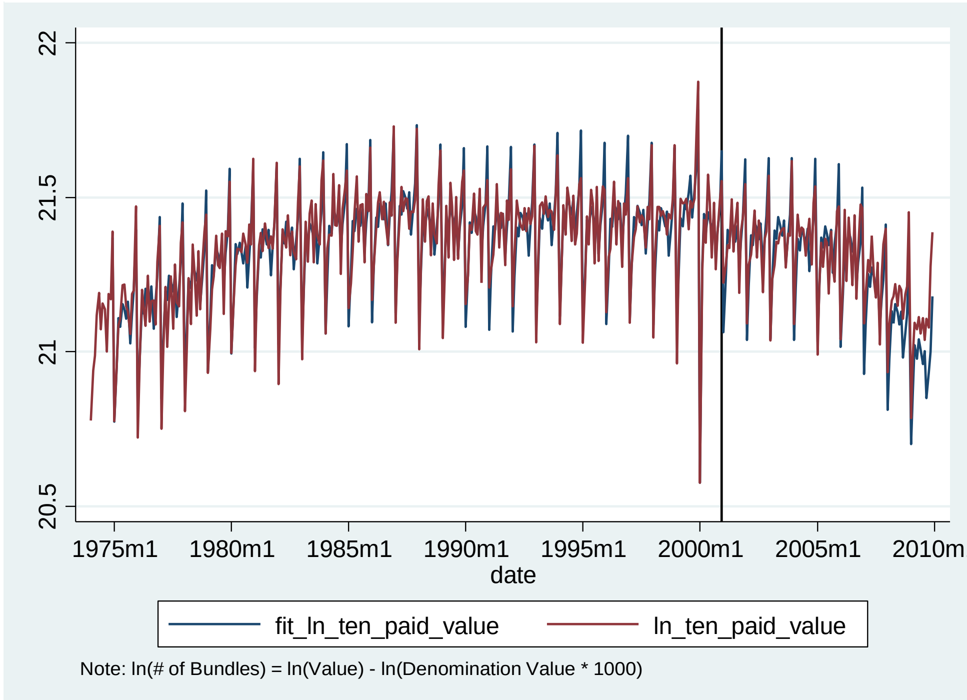
Panel C. Payments Value by Denomination (in logs) – 1s



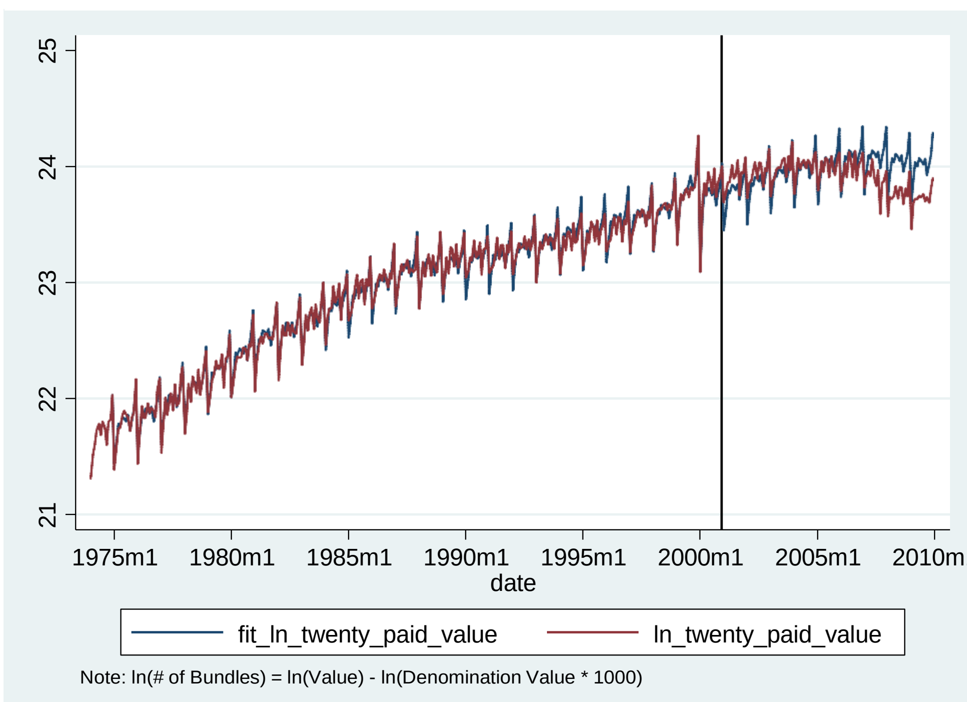
Panel D. Payments Value by Denomination (in logs) – 5s



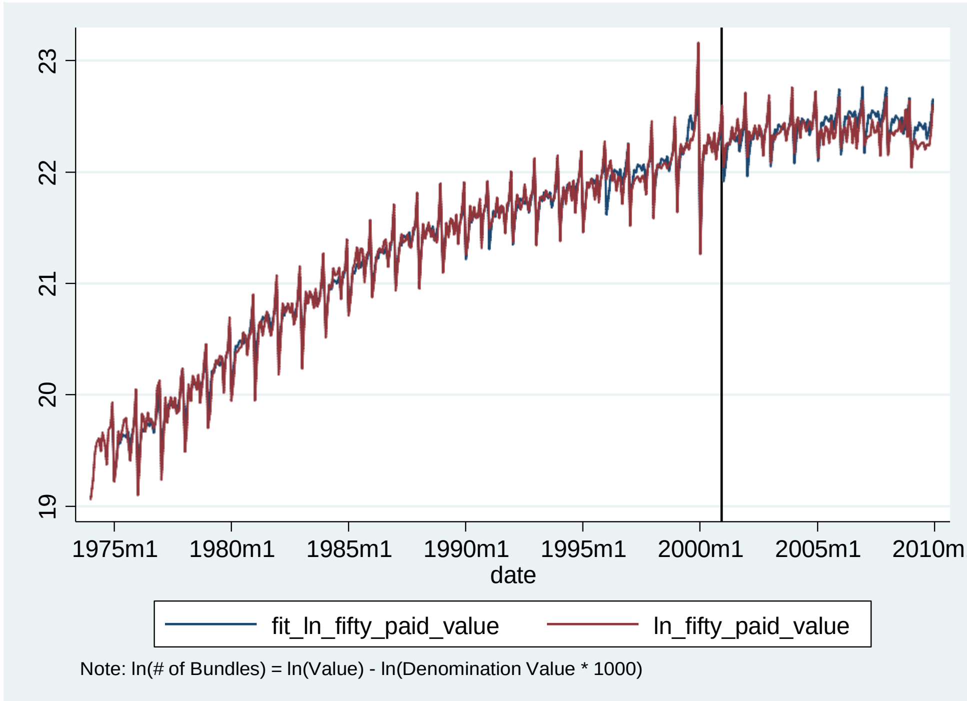
Panel D. Payments Value by Denomination (in logs) – 10s



Panel E. Payments Value by Denomination (in logs) – 20s



Panel F. Payments Value by Denomination (in logs) – 50s



Panel G. Payments Value by Denomination (in logs) – 100s

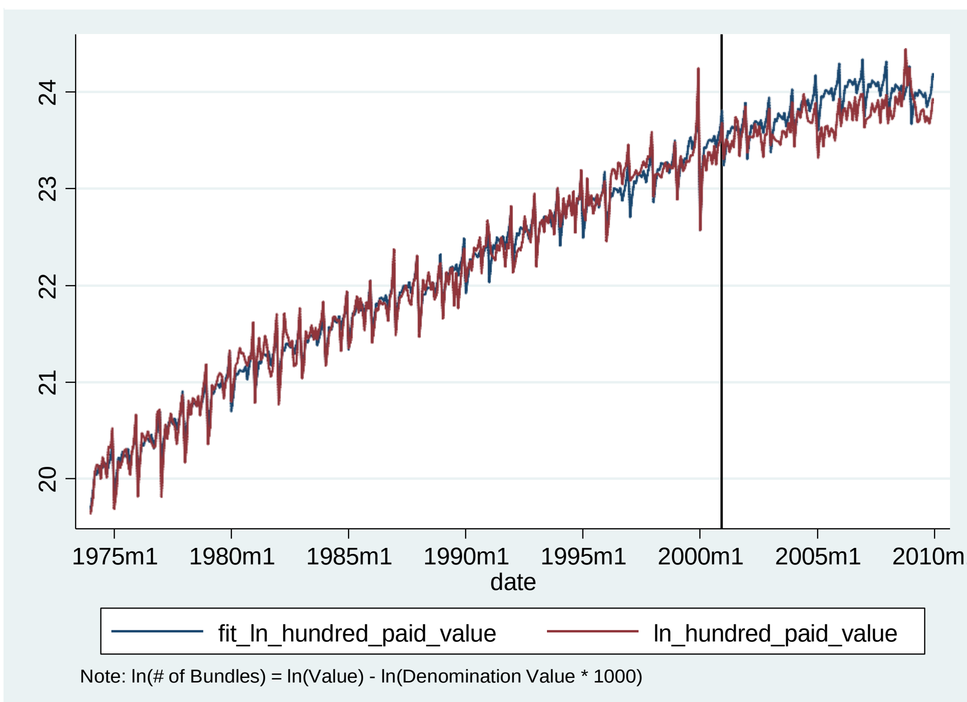
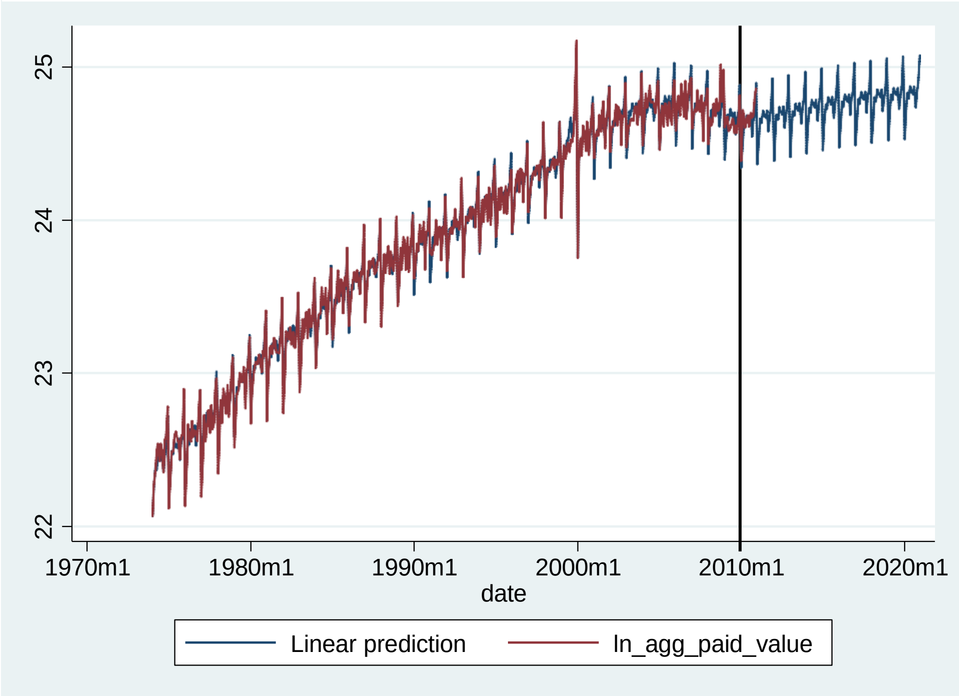
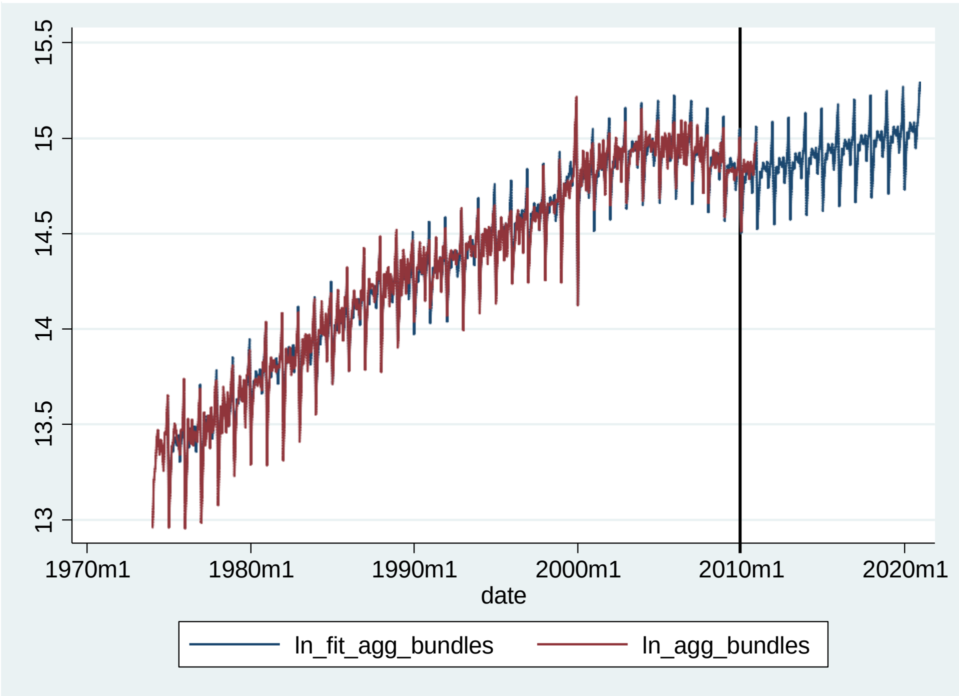


Figure 5. Baseline Projections of Cash Demand 2010-2020

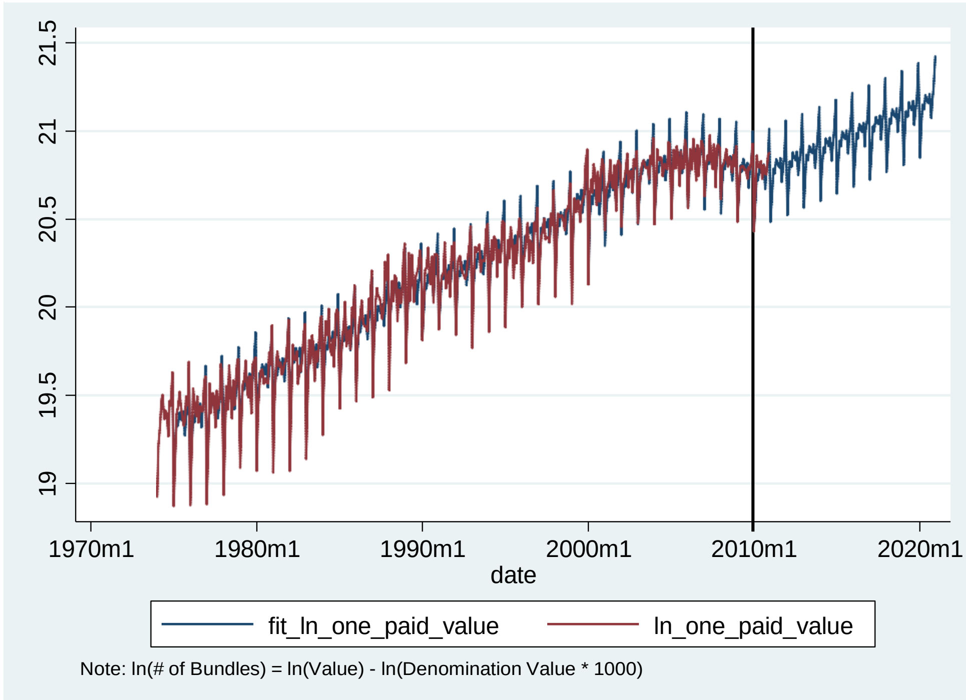
Panel A. Aggregate Value of Cash Payments (in logs)



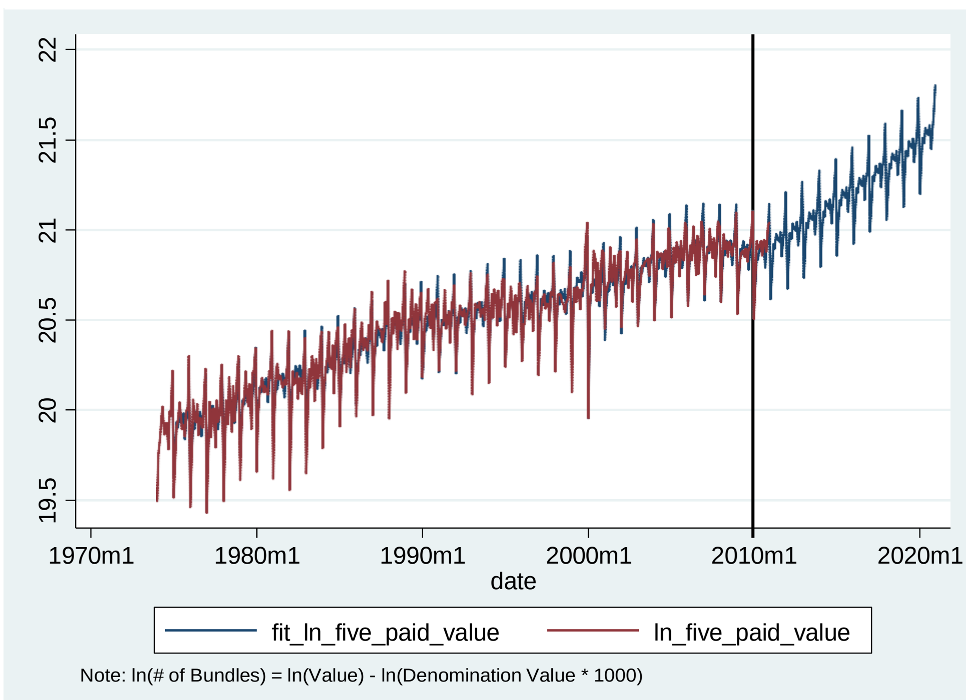
Panel B. Aggregate Number of Bundles (in logs)



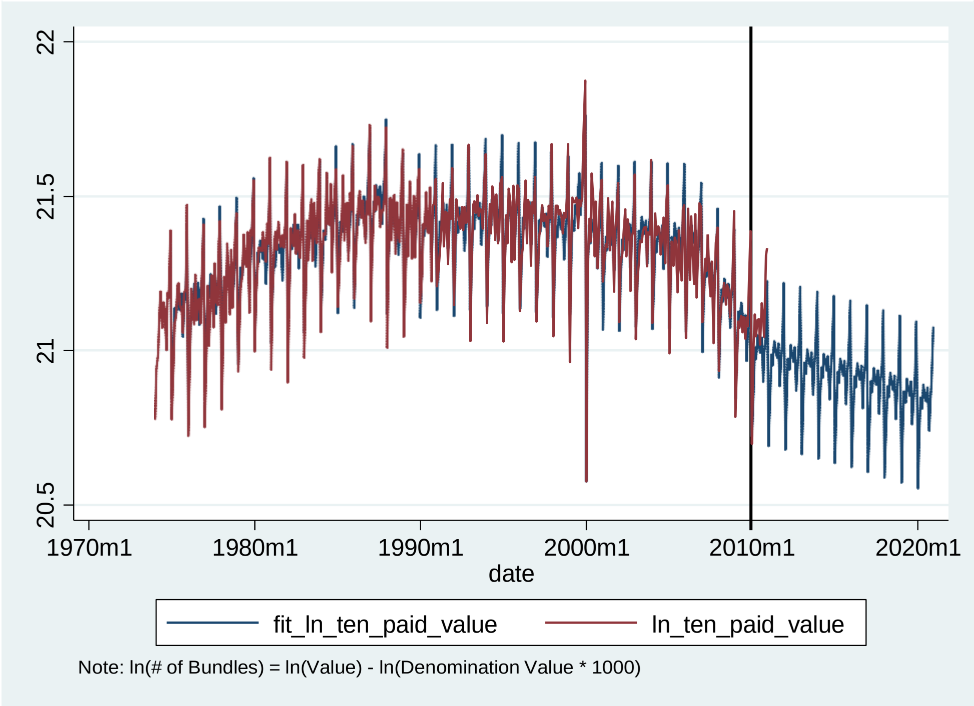
Panel B. Payments Value by Denomination (in logs) – 1s



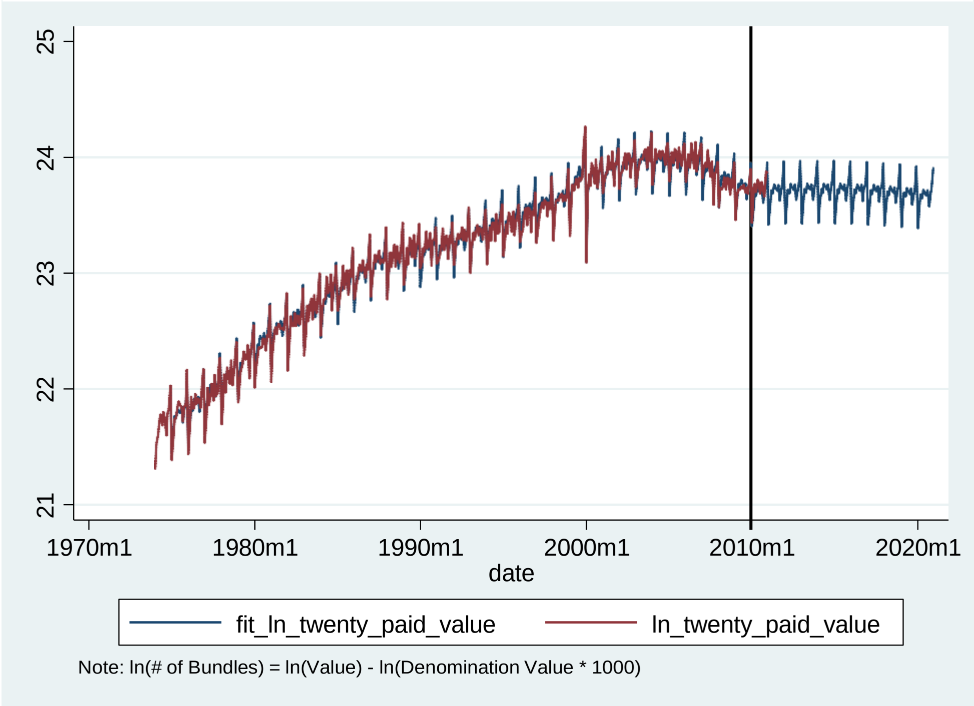
Panel C. Payments Value by Denomination (in logs) – 5s



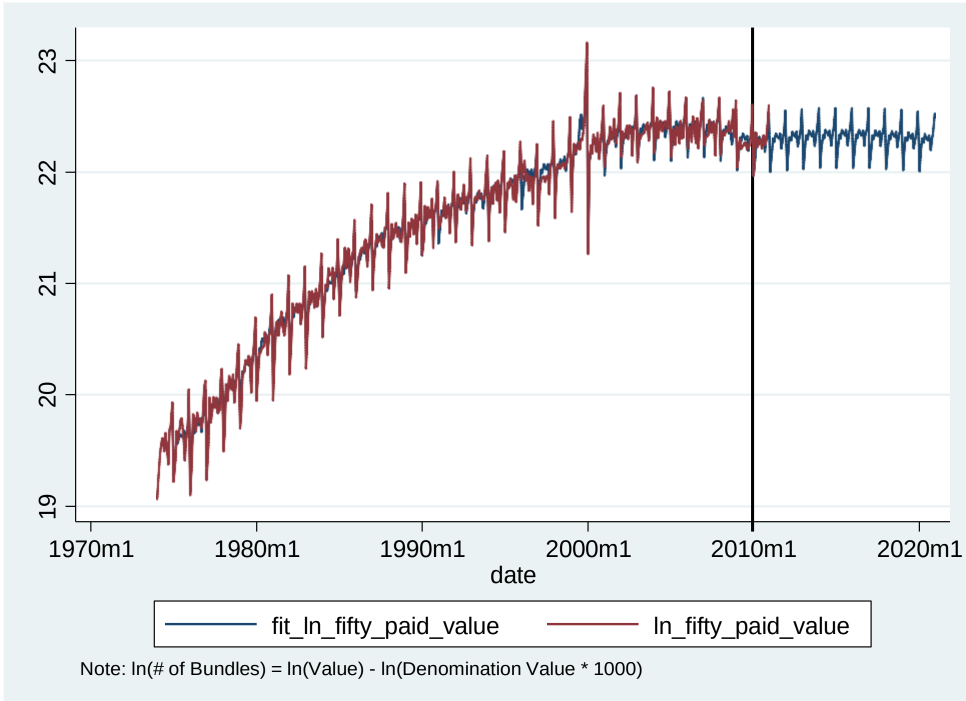
Panel D. Payments Value by Denomination (in logs) – 10s



Panel E. Payments Value by Denomination (in logs) – 20s



Panel F. Payments Value by Denomination (in logs) – 50s



Panel G. Payments Value by Denomination (in logs) – 100s

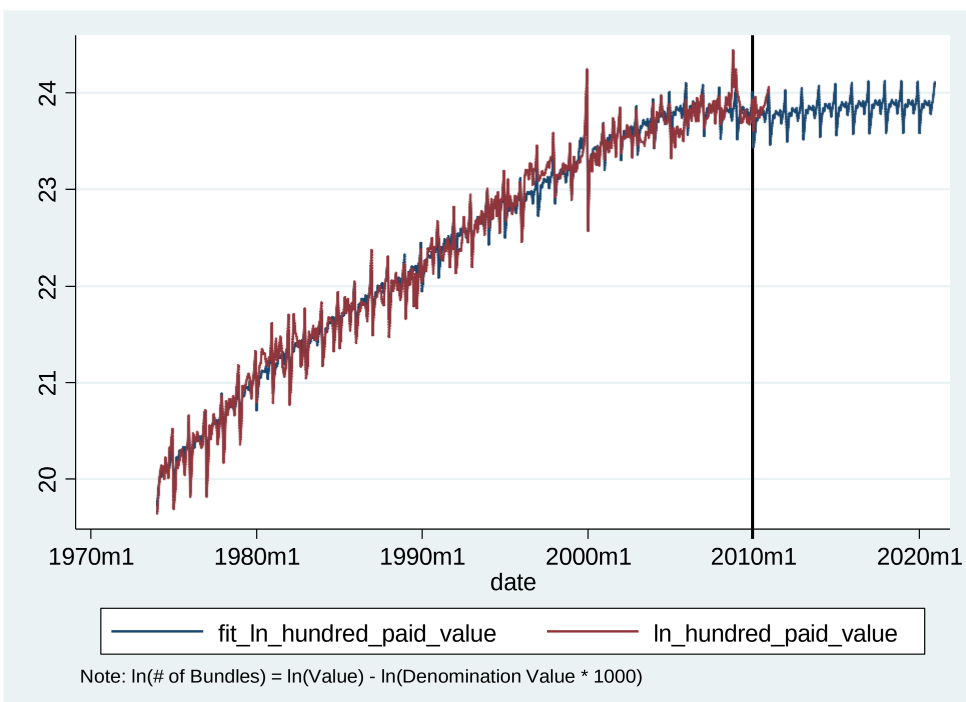
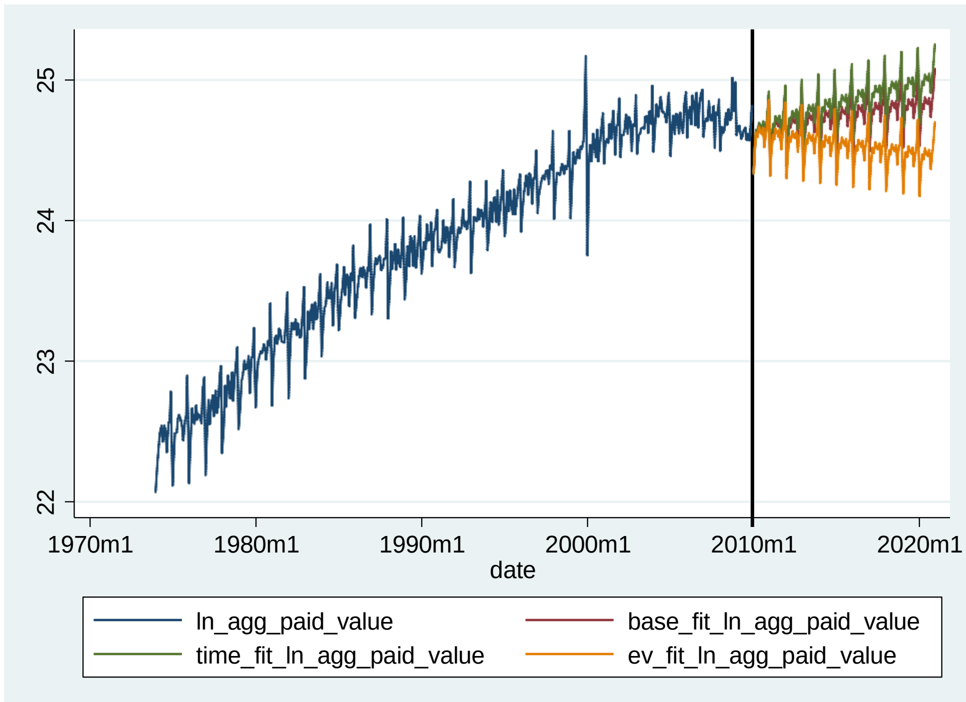
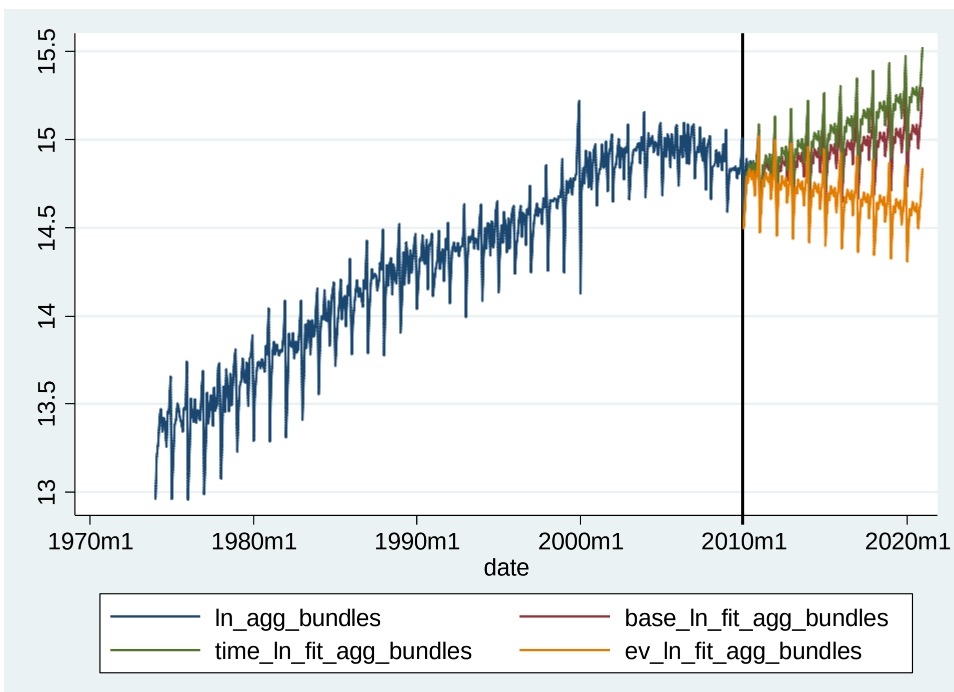


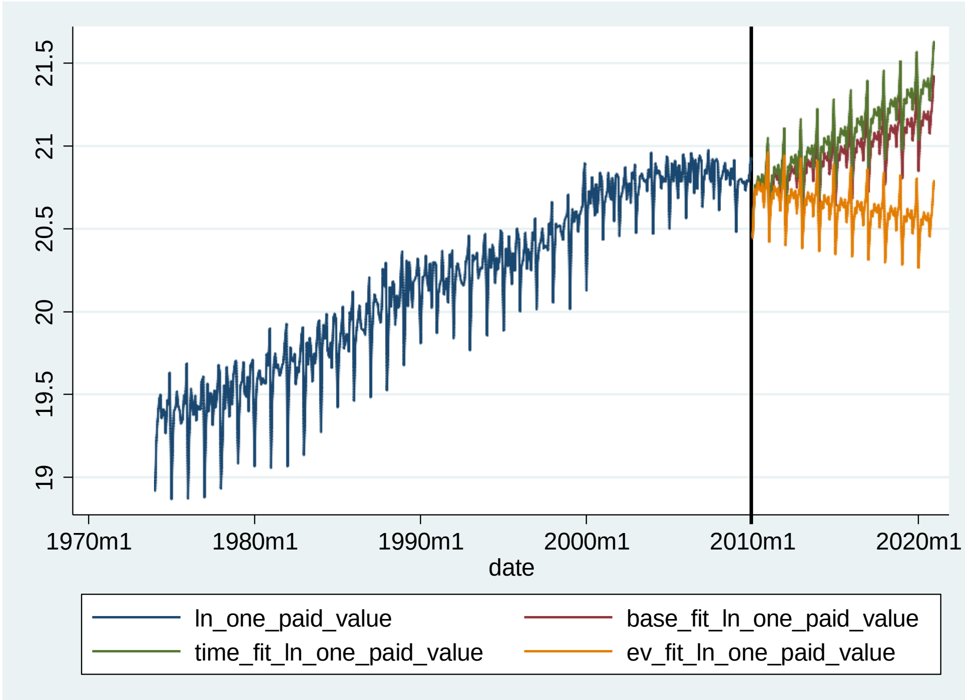
Figure 6. Baseline Projections of Cash Demand 2010-2020
Including results for only time trend effects and constant time trends
Panel A. Aggregate Value of Cash Payments (in logs)



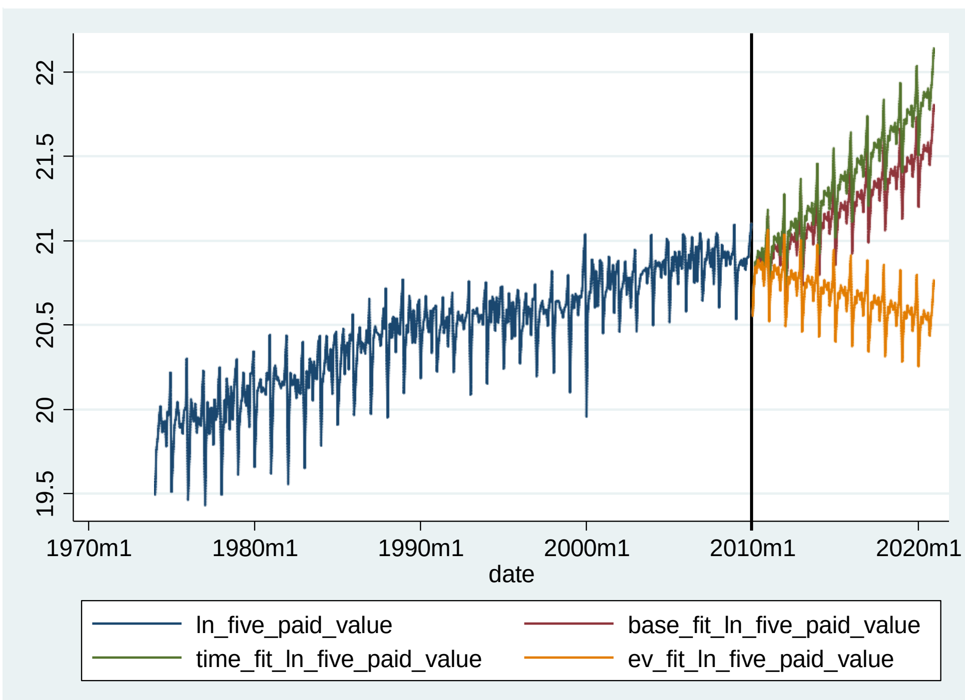
Panel B. Aggregate Number of Bundles (in logs)



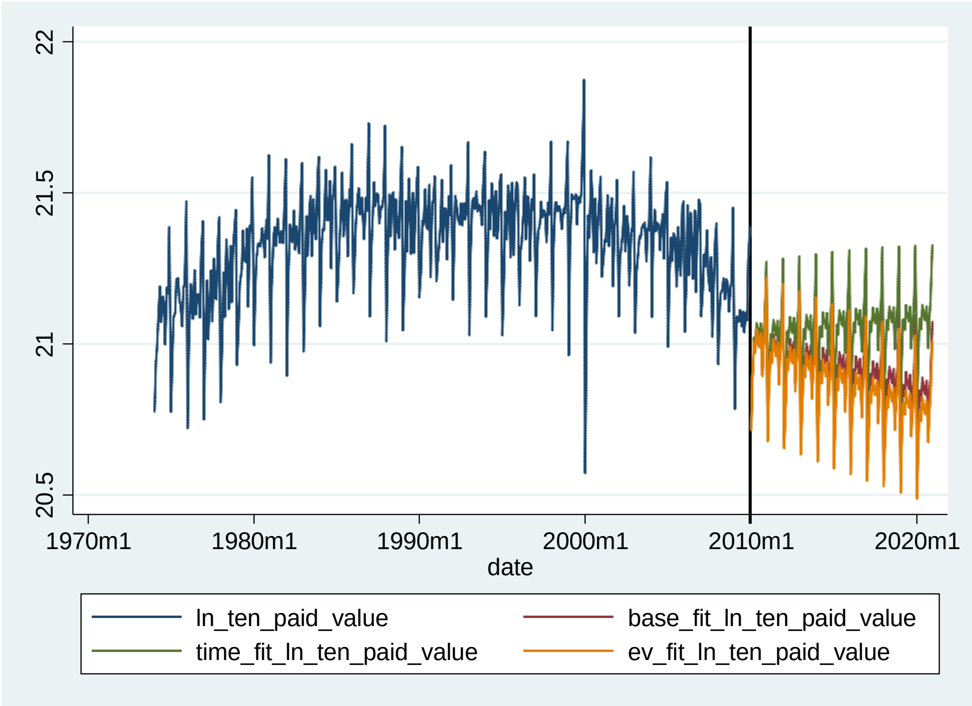
Panel C. Payments Value by Denomination (in logs) – 1s



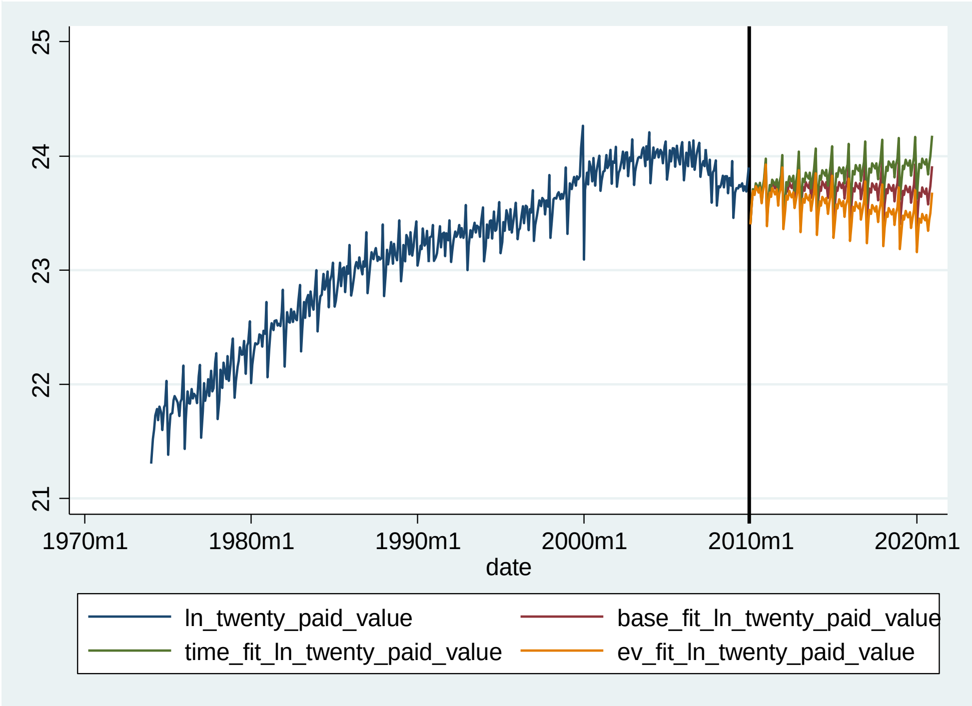
Panel D. Payments Value by Denomination (in logs) – 5s



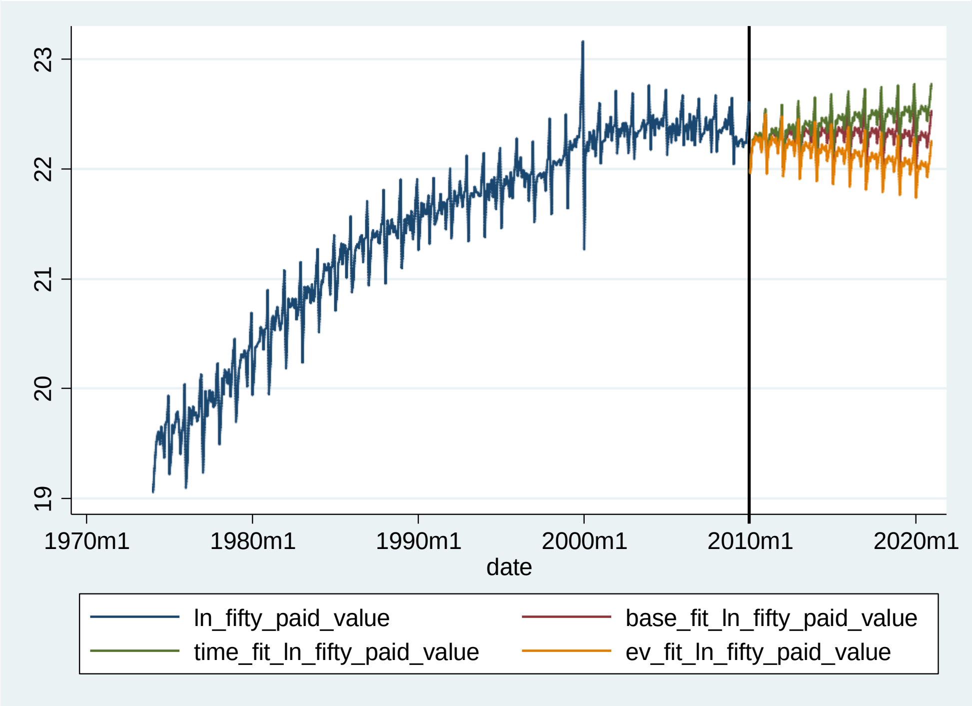
Panel E. Payments Value by Denomination (in logs) – 10s



Panel F. Payments Value by Denomination (in logs) – 20s



Panel G. Payments Value by Denomination (in logs) – 50s



Panel H. Payments Value by Denomination (in logs) – 100s

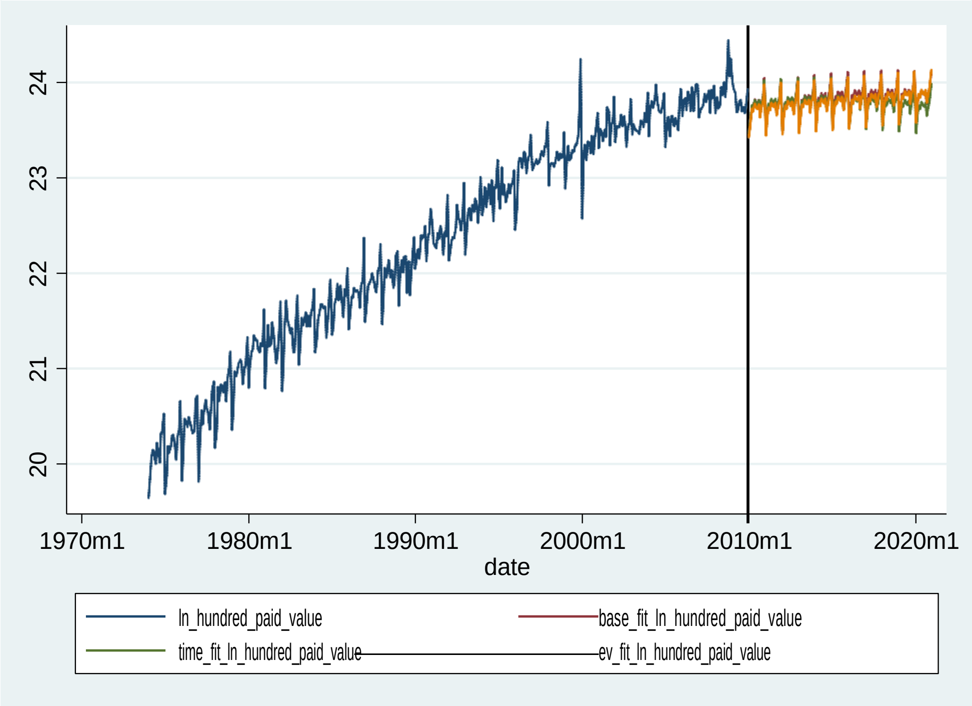
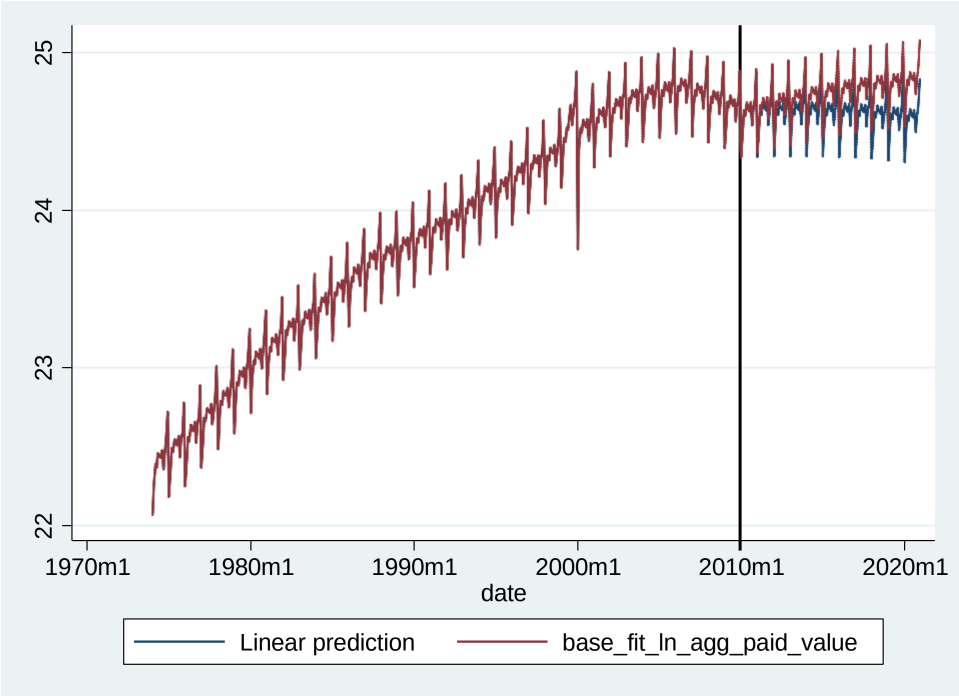
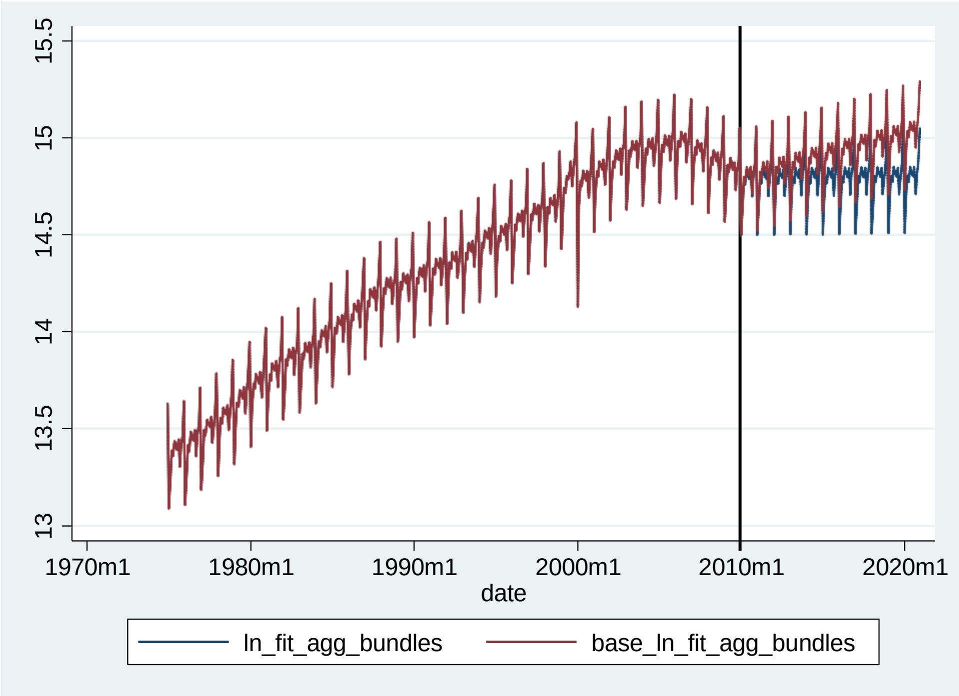


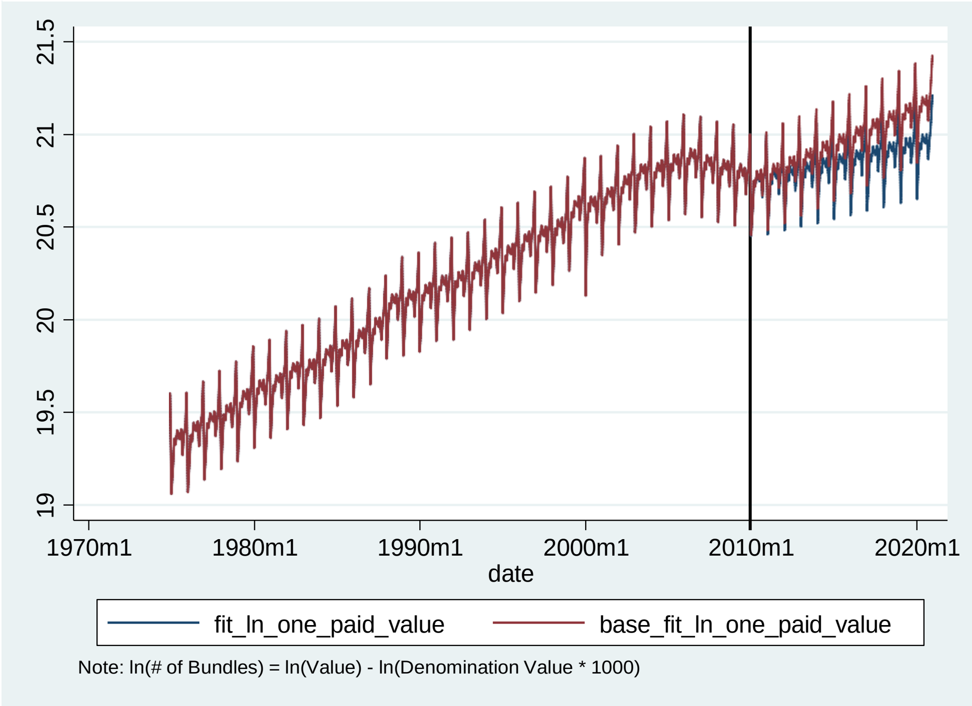
Figure 7. Alternative Simulation of Cash Demand 2010-2020:
"Greater substitution to payment alternatives"
Panel A. Aggregate Value of Cash Payments (in logs)



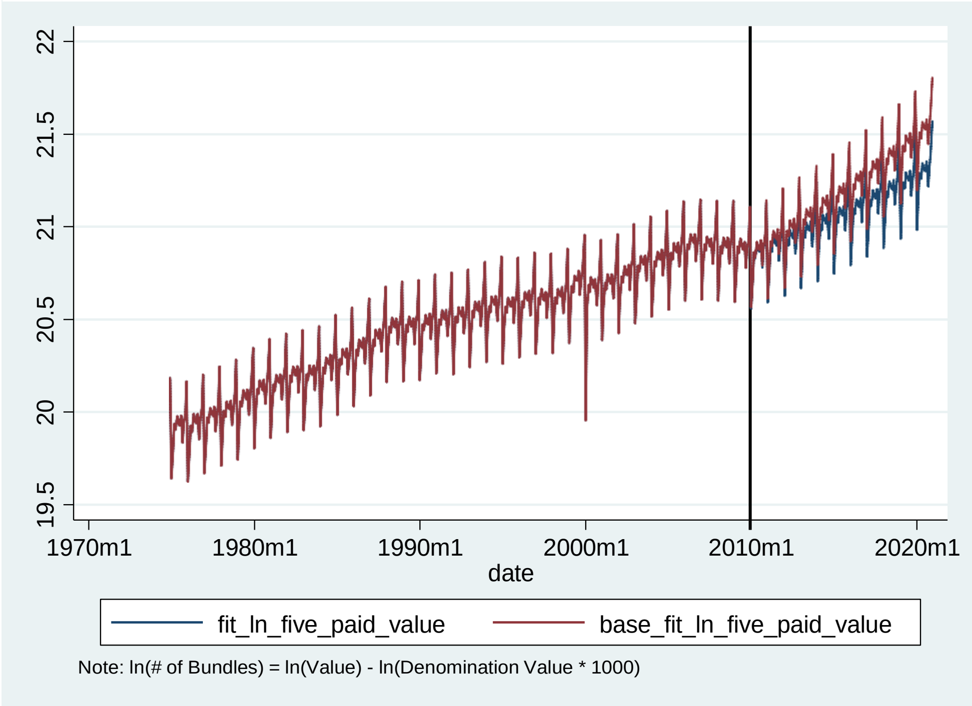
Panel B. Aggregate Number of Bundles (in logs)



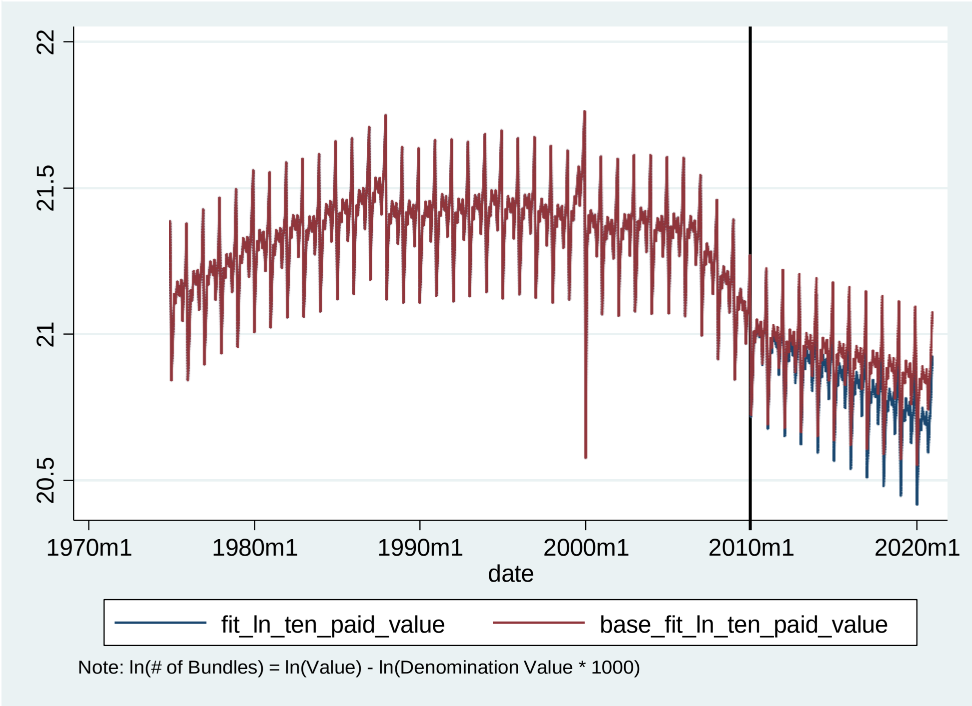
Panel C. Payments Value by Denomination (in logs) – 1s



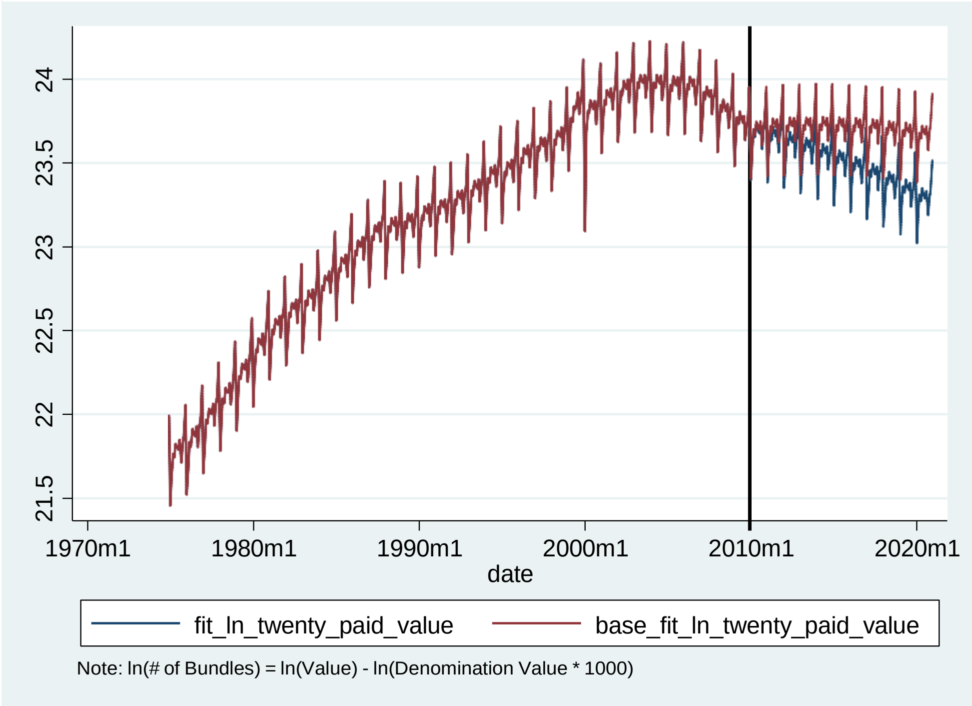
Panel D. Payments Value by Denomination (in logs) – 5s



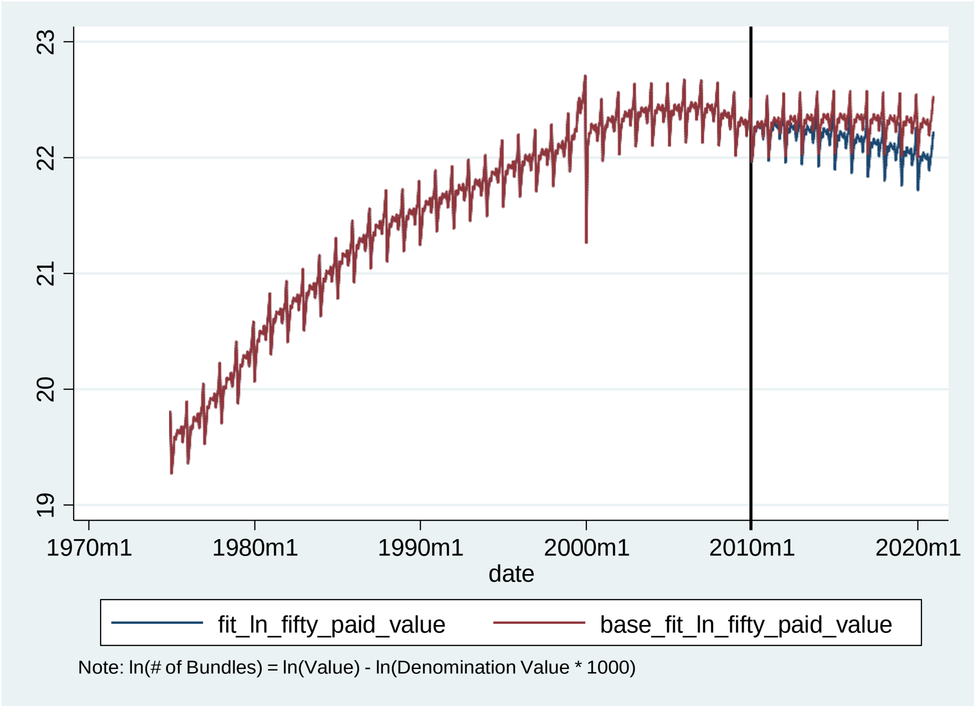
Panel E. Payments Value by Denomination (in logs) – 10s



Panel F. Payments Value by Denomination (in logs) – 20s



Panel G. Payments Value by Denomination (in logs) – 50s



Panel H. Payments Value by Denomination (in logs) – 100s

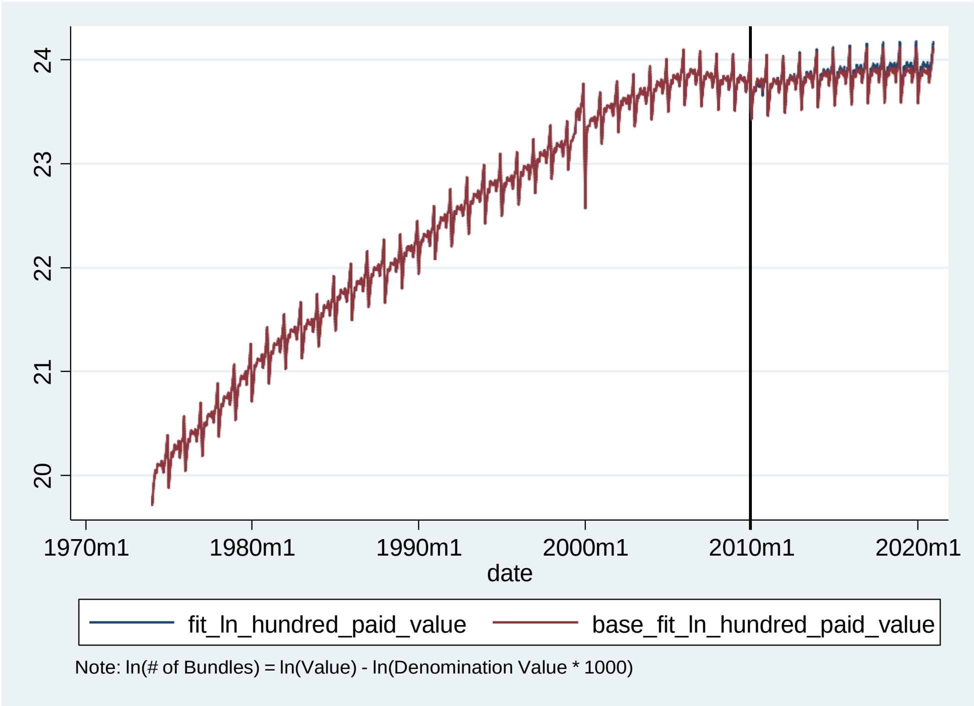
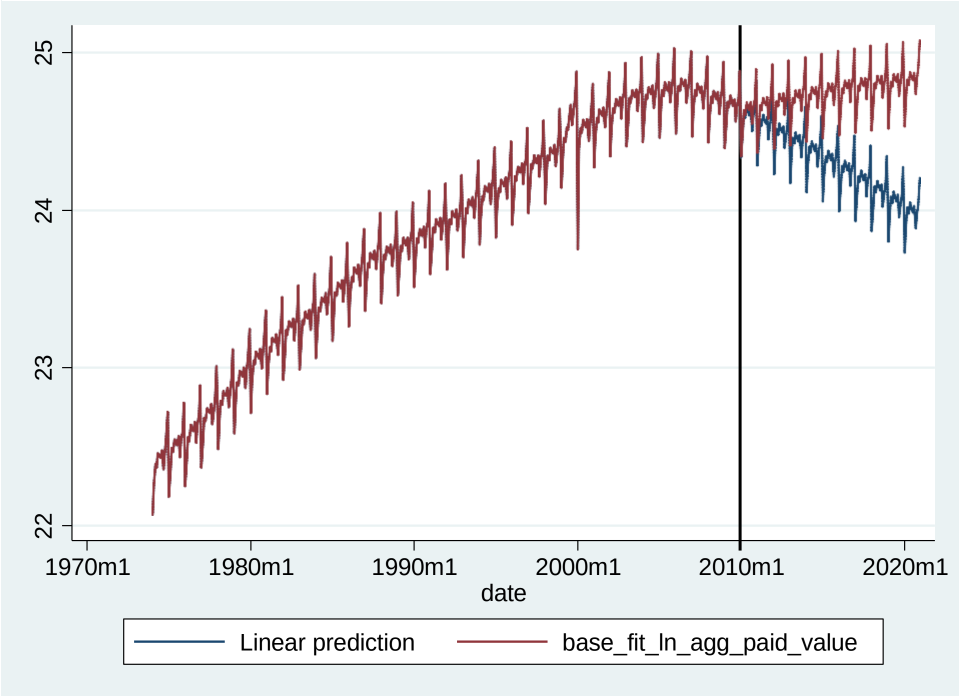
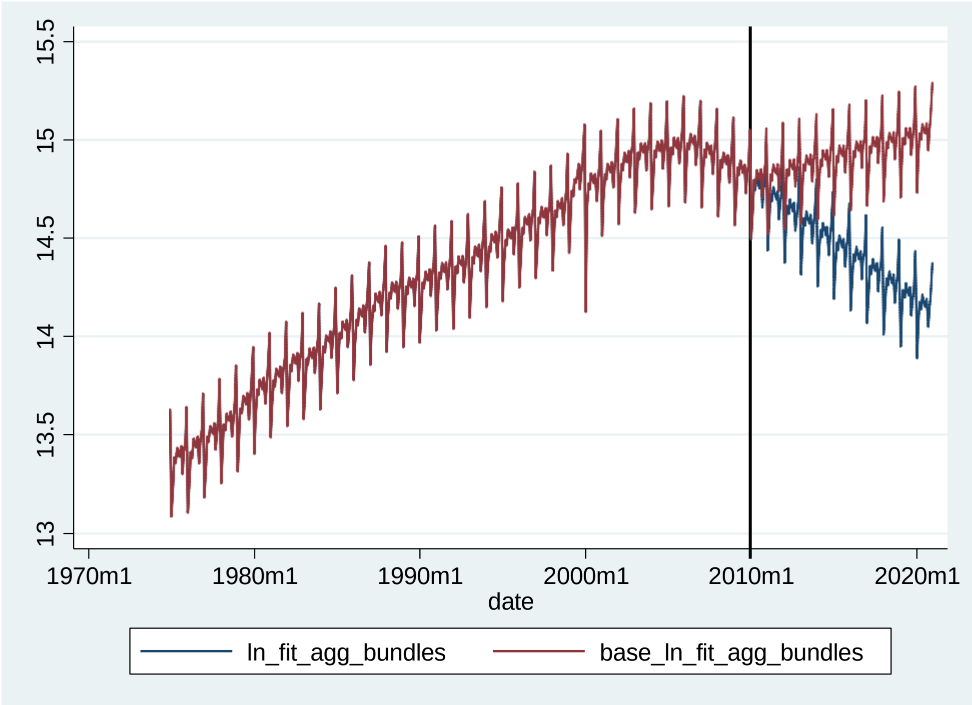


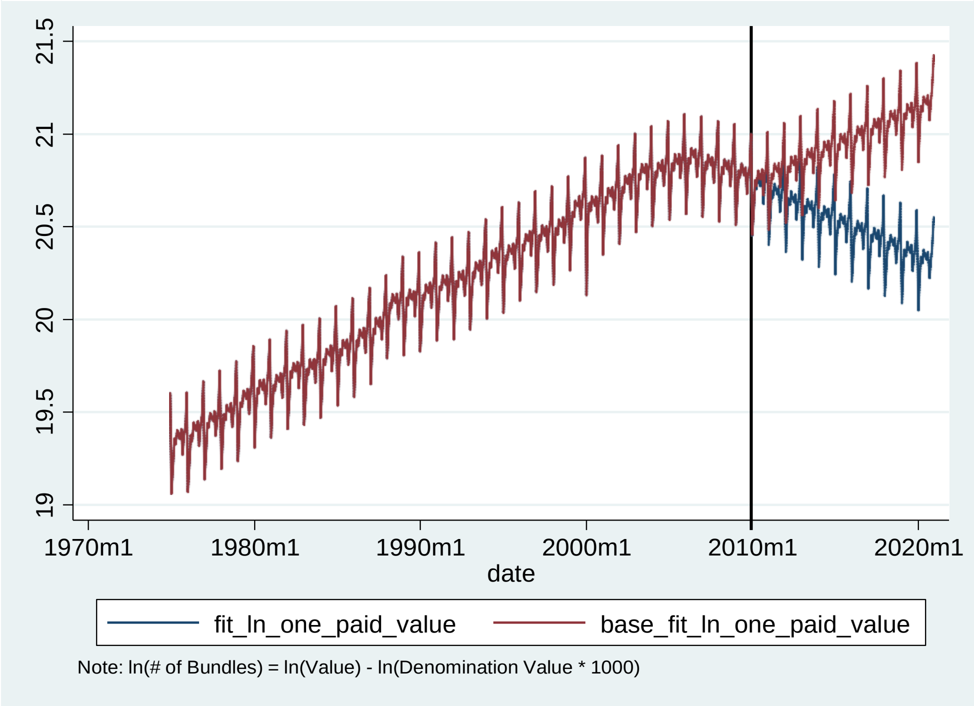
Figure 8. Alternative Simulation of Cash Demand 2010-2020:
"Permanent Recirculation Policy Trend"
Panel A. Aggregate Value of Cash Payments (in logs)



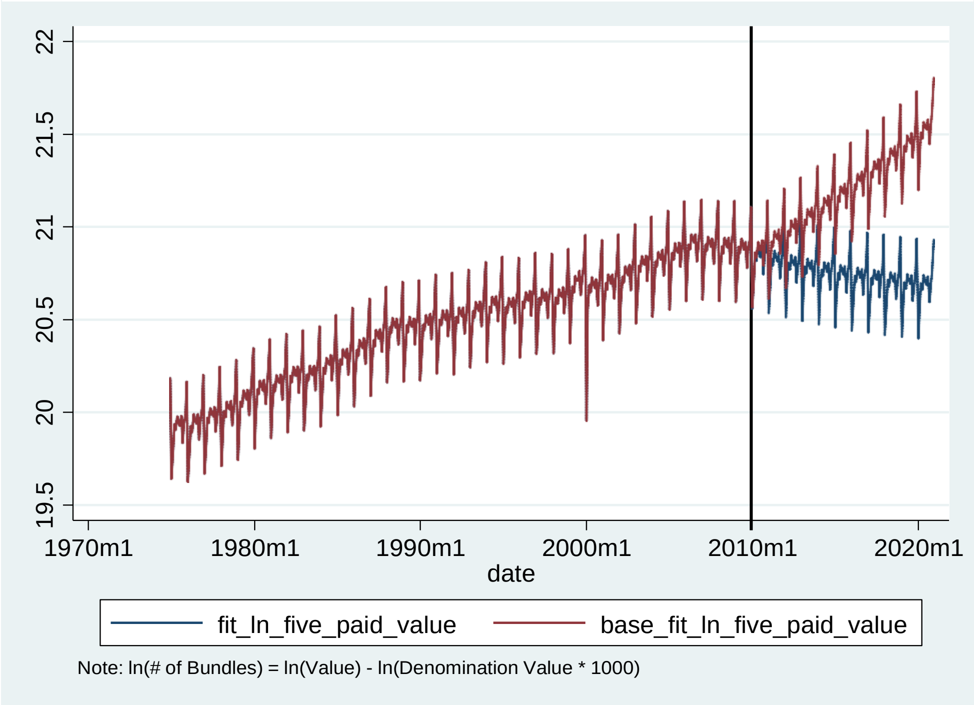
Panel B. Aggregate Number of Bundles (in logs)



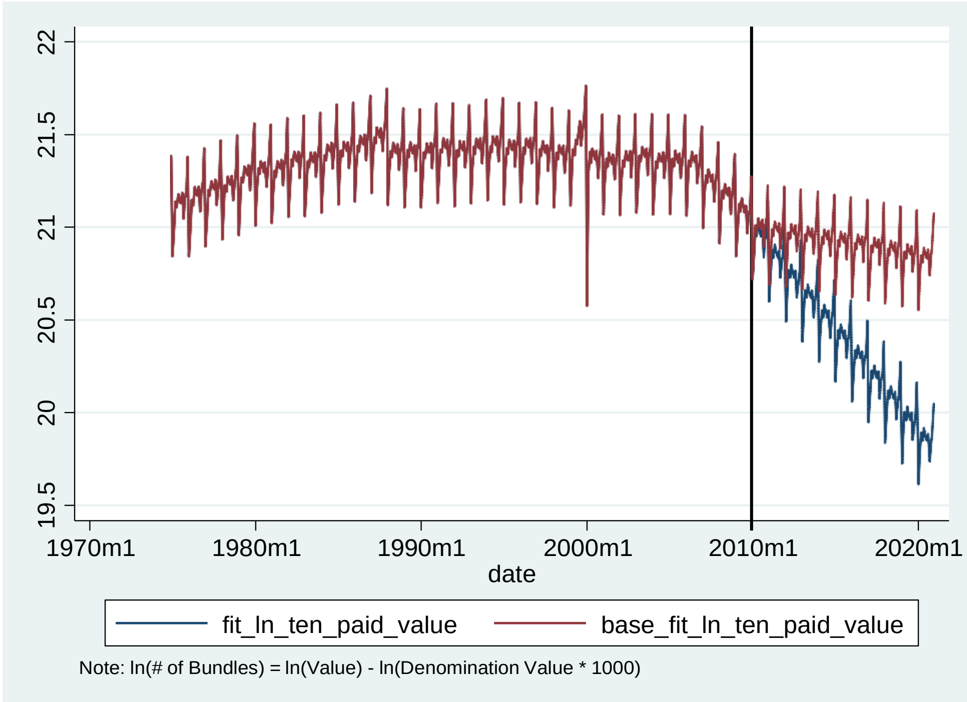
Panel C. Payments Value by Denomination (in logs) – 1s



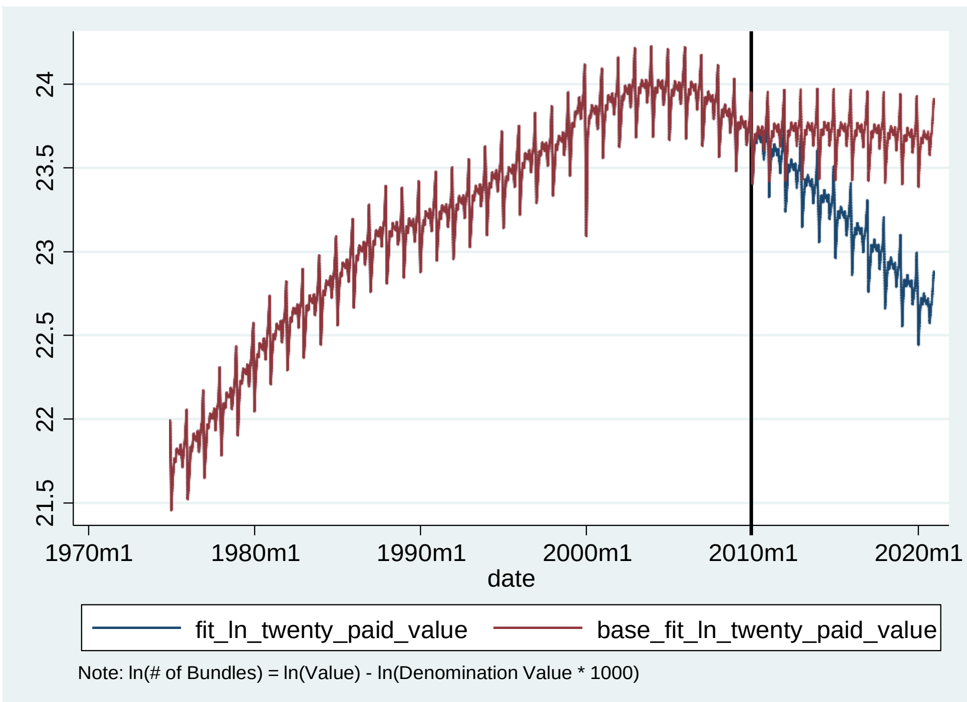
Panel D. Payments Value by Denomination (in logs) – 5s



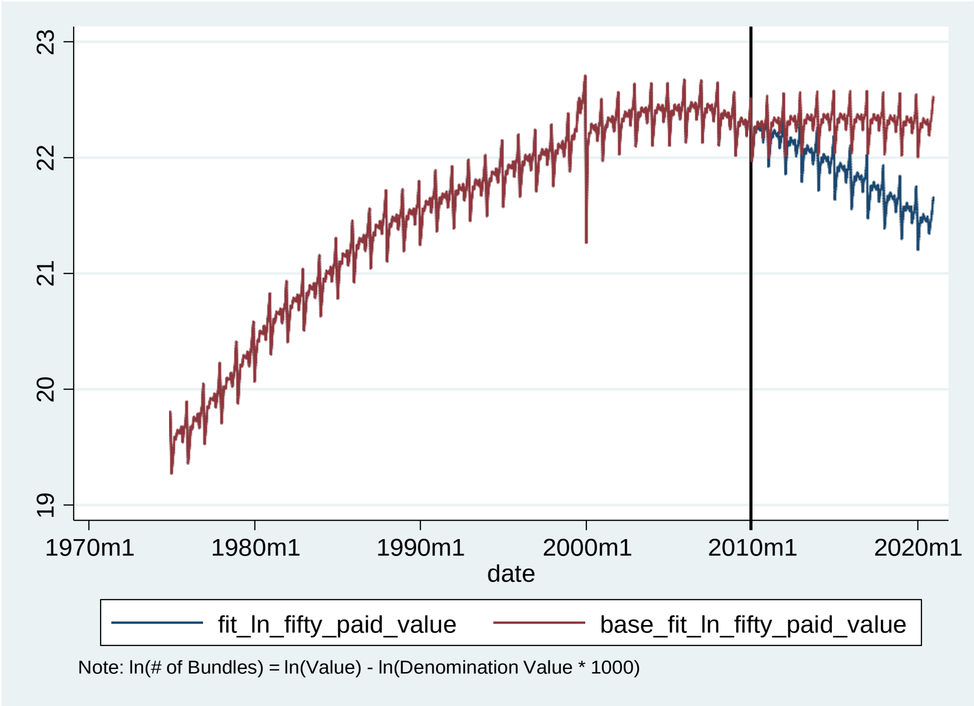
Panel E. Payments Value by Denomination (in logs) – 10s



Panel F. Payments Value by Denomination (in logs) – 20s



Panel G. Payments Value by Denomination (in logs) – 50s



Panel H. Payments Value by Denomination (in logs) – 100s

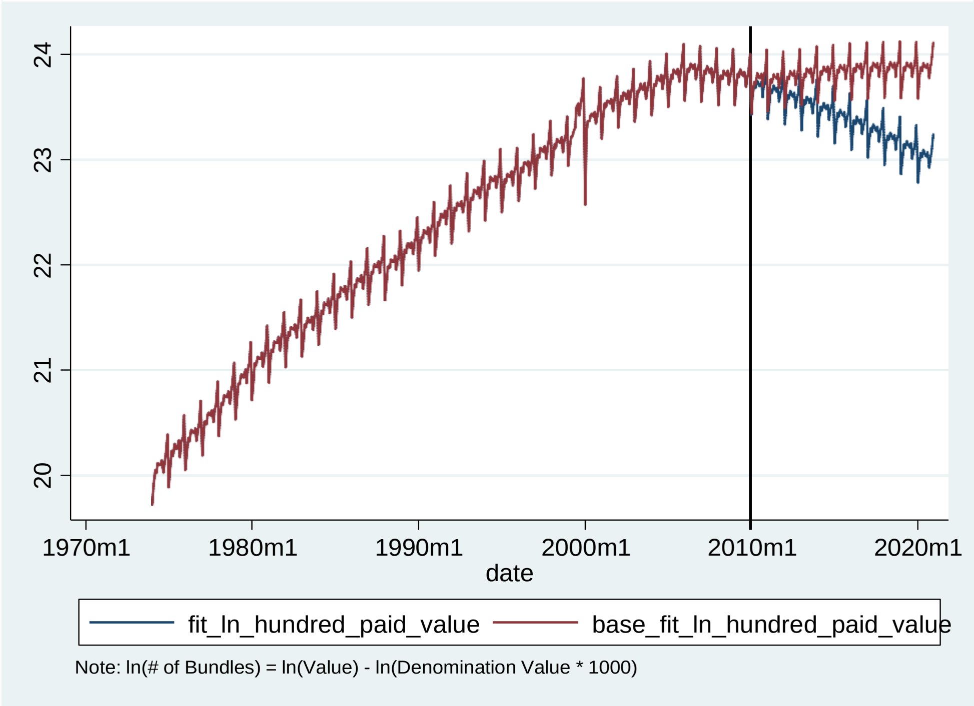
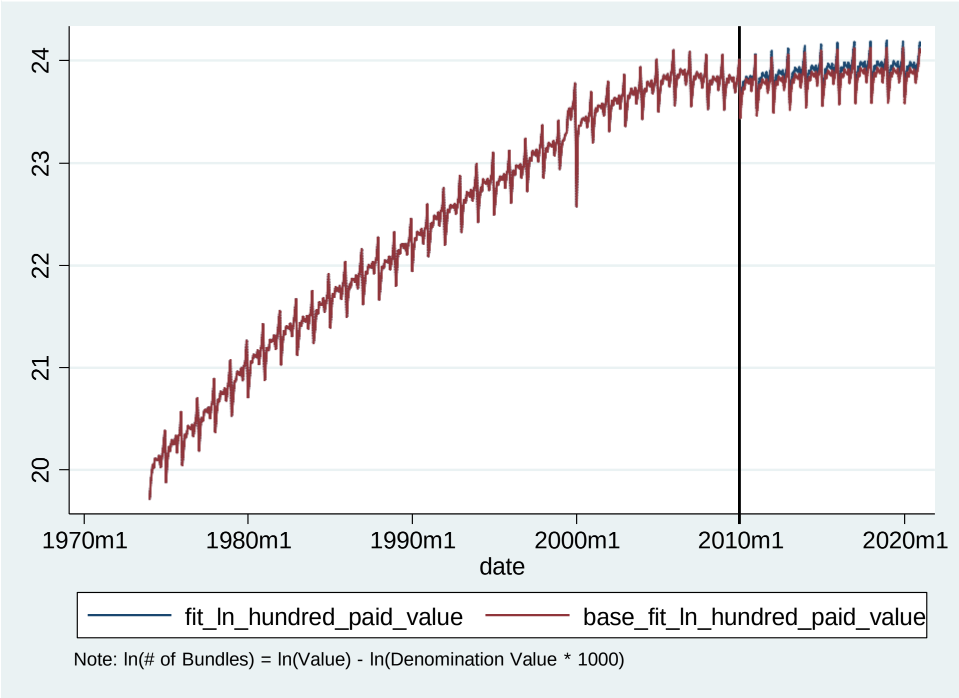


Figure 9. Alternative Simulation of Cash Demand 2010-2020:
"Strong Foreign Growth"
Panel A. Payments Value by Denomination (in logs) – 100s



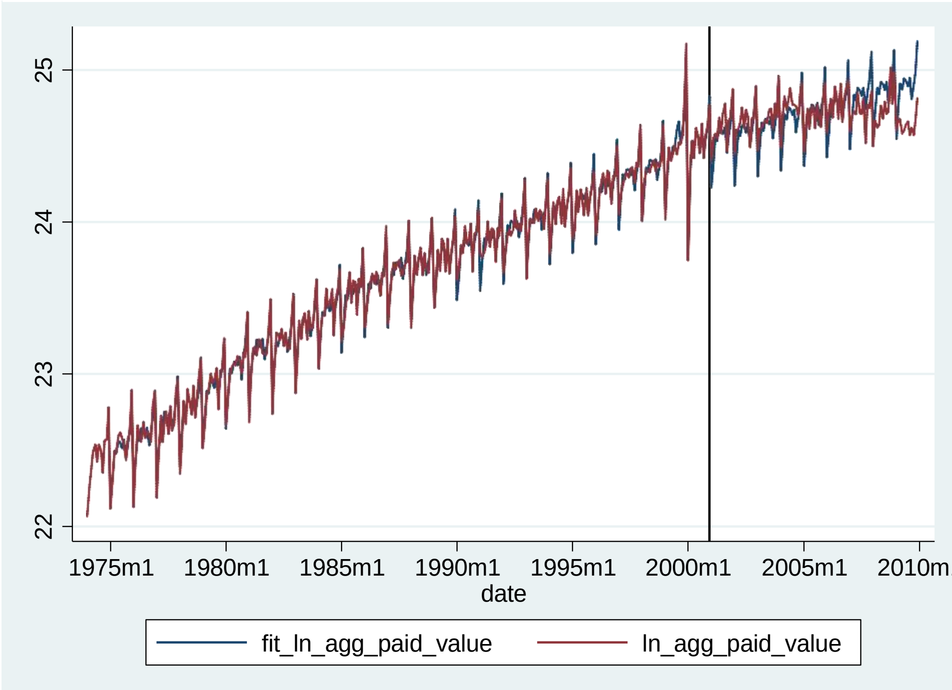
Appendix Table 1. Denomination by Denomination Model Regression Results

	$1's	$5's	$10's	$20's	$50's	$100's
Demographic						
Gini	-0.252	0.139	0.894	-1.000	-4.192***	7.468***
Average Age	-2.023***	-2.030***	-0.761	-2.938***	-3.287***	-0.398
Technology						
ATMs	0.154***	-0.018	0.051	0.352***	0.126*	0.297***
PCF of non-cash payments	-0.135**	-0.138***	-0.130**	-0.369***	-0.210***	0.007
i88	-0.817***	-0.15	-0.520**	-2.218***	-1.028***	-1.378***
Regulatory/Policy						
Sweeps 1995	-0.021	-0.024	0.008	-0.056**	-0.047	0.150***
Sweeps 1999	0.011	-0.018	-0.011	-0.048	-0.015	-0.011
Fed 2007	-0.006***	-0.004***	-0.004***	-0.012***	-0.006***	0.002
Macroeconomic: National						
Real GDP growth	0.236	0.256	-0.115	0.074	-0.226	0.253
Fed Fund	-0.003	-0.002	0.002	0.001	-0.005*	-0.002
Real PCE growth	-0.101	0.023	0.545	-0.014	0.158	-0.835
PCE inflation growth	0.038	0.358	0.730*	-0.564	0.27	2.908***
Macroeconomic: International						
Exch. Rate Growth	-0.007	-0.052	0.044	0.08	0.132	0.265*
Growth in Per Capita RGDP						
East Asia & Pacific	-0.263	0.43	-0.16	0.482	0.05	0.407
Europe & Central Asia	1.361***	0.499	0.229	0.558	0.876	0.843
Latin America & Caribbean	0.068	0.219	0.279	-0.262	-0.012	0.382
Middle East & North Africa	0.207	0.101	0.303	0.597***	0.166	0.591
South Asia	-0.396	-0.347	0.122	-0.403*	-0.442	-0.242
Sub-Saharan Africa	-0.982**	-0.522	-0.870**	-0.924**	-0.547	-1.631**
Y2k 1999	0.011	0.057*	0.101***	0.097***	0.256***	0.259***
Y2k 2000	-0.056	-0.319***	-0.507***	-0.409***	-0.557***	-0.458***
Time	0.001	-0.001	0.004***	0.009***	0.017***	0.022***
Time^2	0.000004	0.000006**	-0.000003	-0.000002	-0.000011***	-0.000017***
R^2	0.910	0.980	0.996	0.765	0.921	0.948

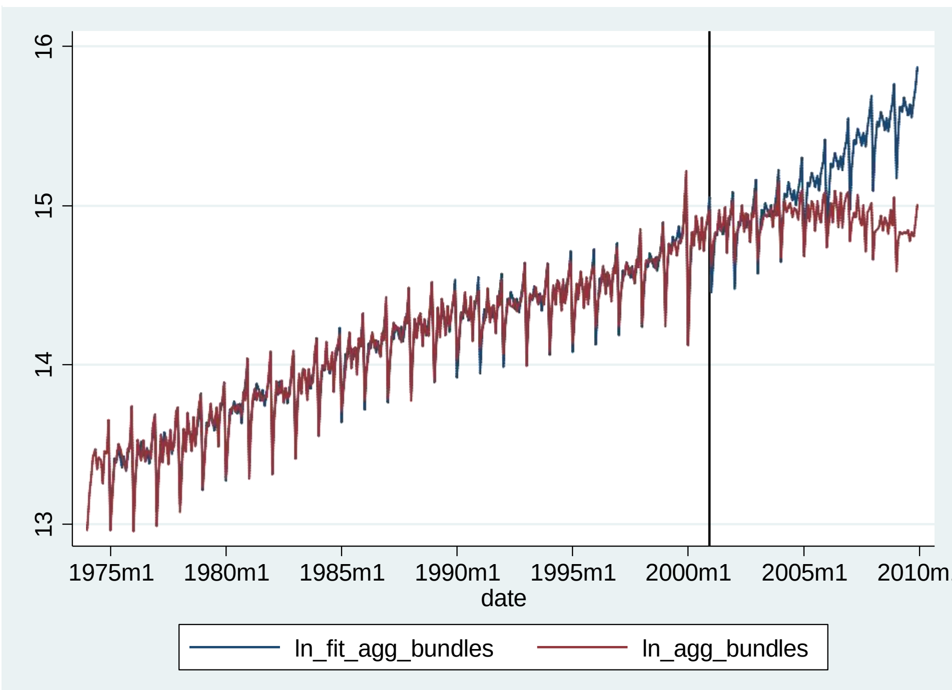
Note: Regressions include monthly dummy variables to capture the seasonal trends in payments. Due to space constraints their coefficients are not included above.

Appendix Figure 1. Estimation of Denomination by Denomination Model for 1974-2000 and 10-Year Ahead Out-of-Sample Forecasts

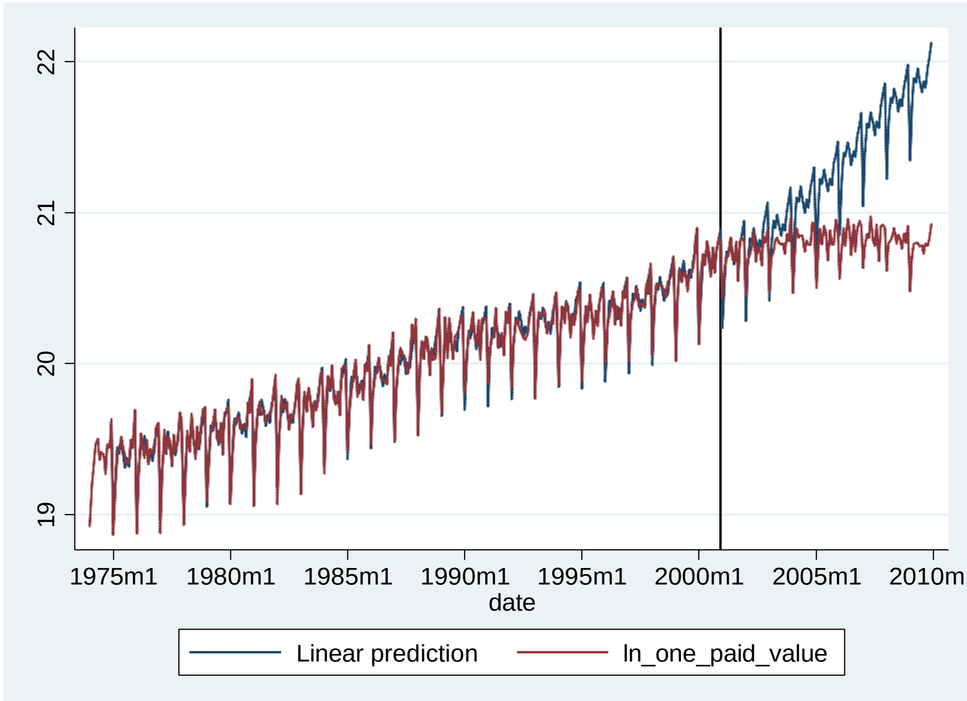
Panel A. Payments Value by Denomination (in logs) – 1s



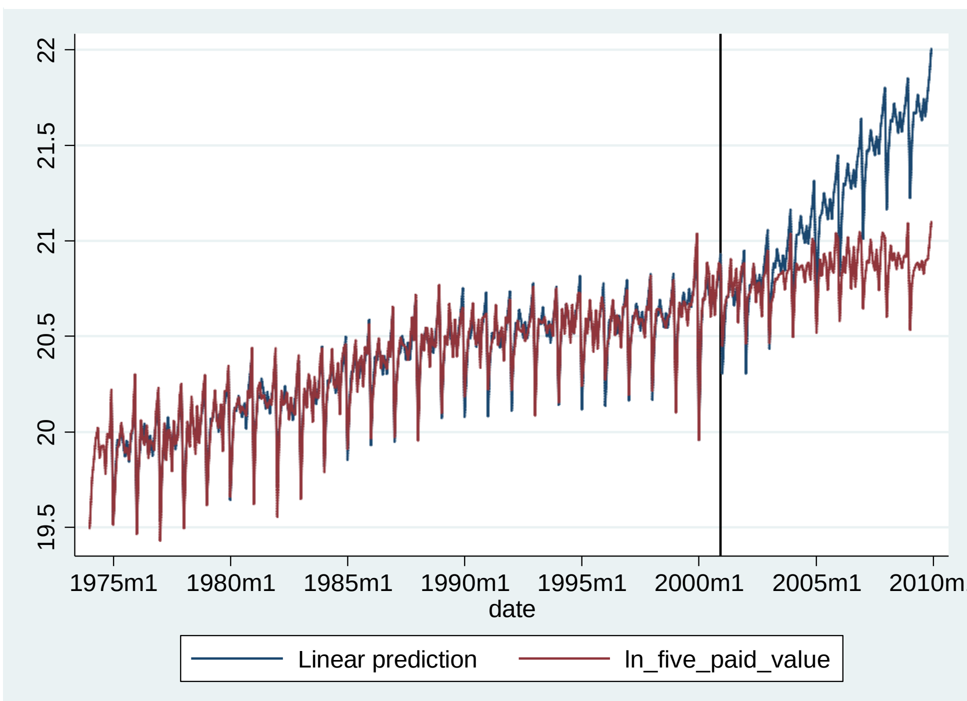
Panel B. Aggregate Number of Bundles (in logs)



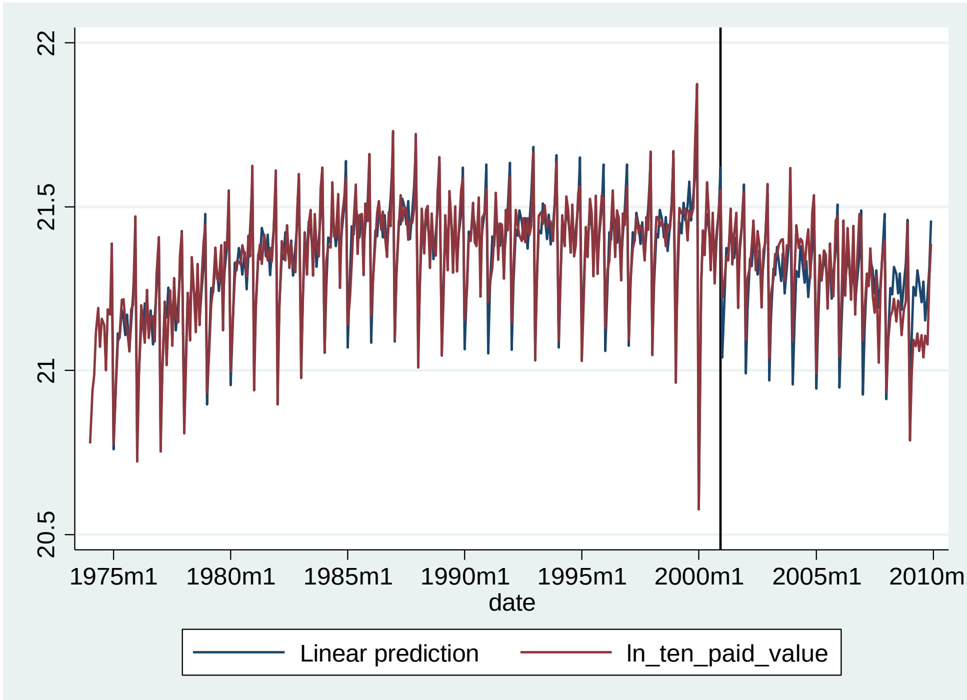
Panel C. Payments Value by Denomination (in logs) – 1s



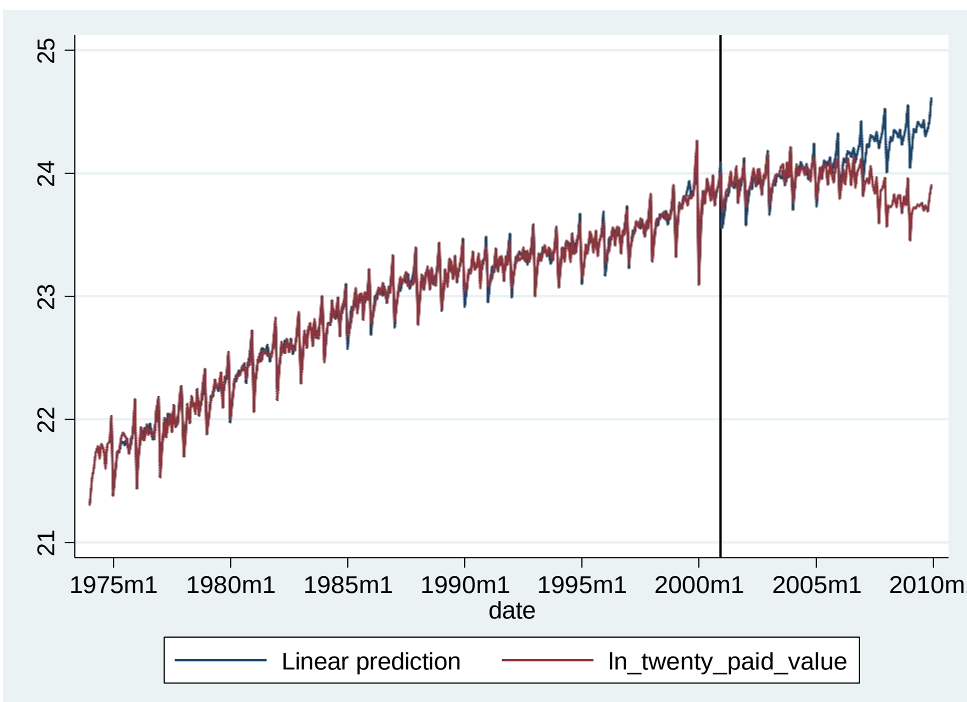
Panel D. Payments Value by Denomination (in logs) – 5s



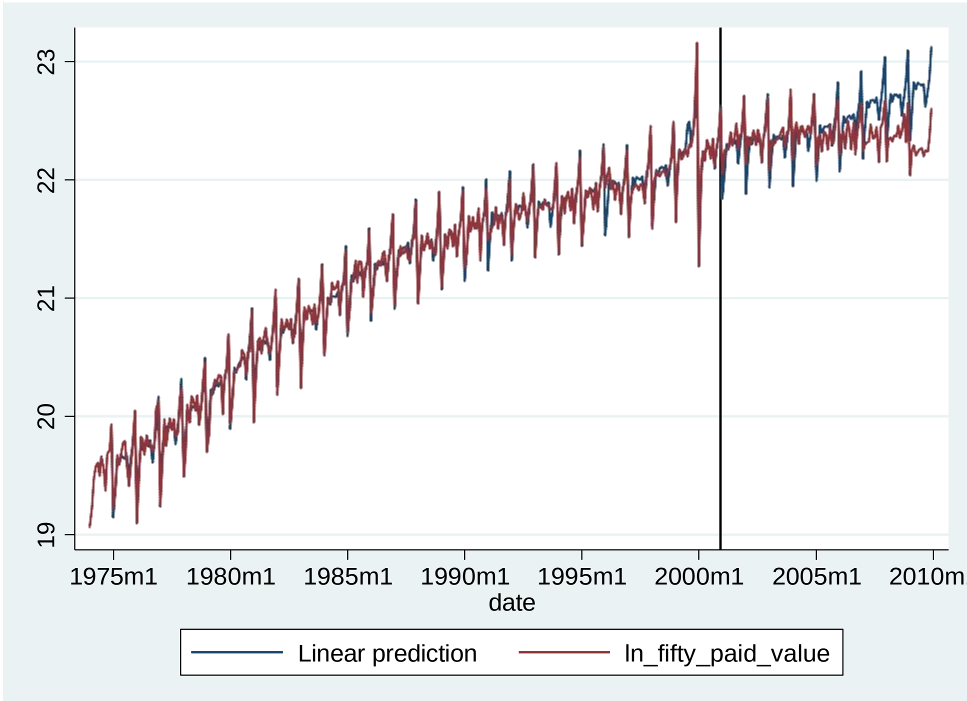
Panel E. Payments Value by Denomination (in logs) – 10s



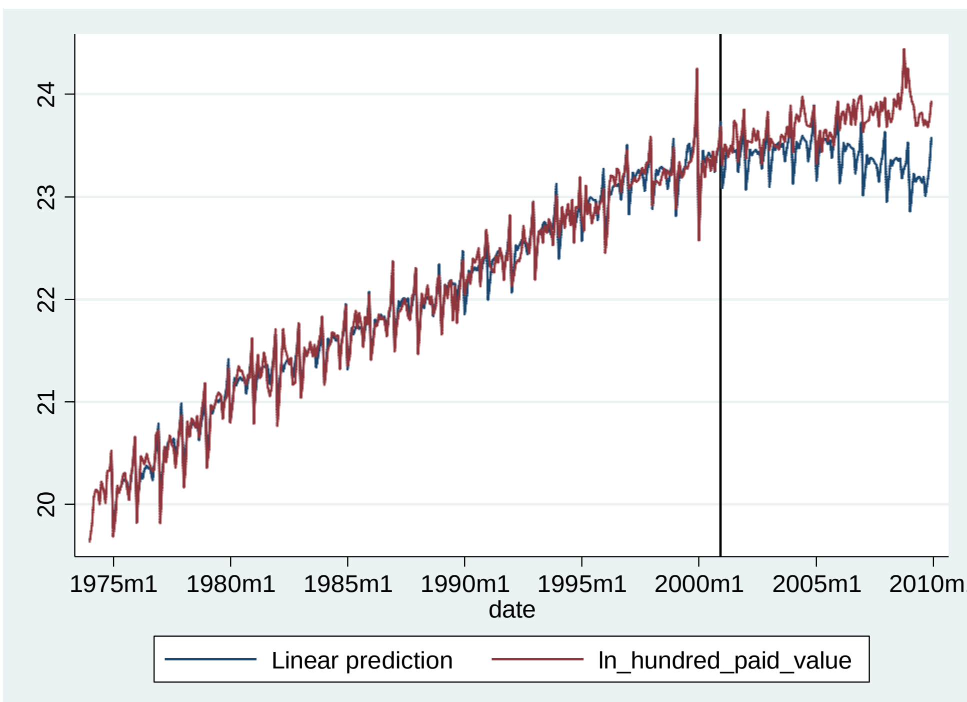
Panel F. Payments Value by Denomination (in logs) – 20s



Panel G. Payments Value by Denomination (in logs) – 50s

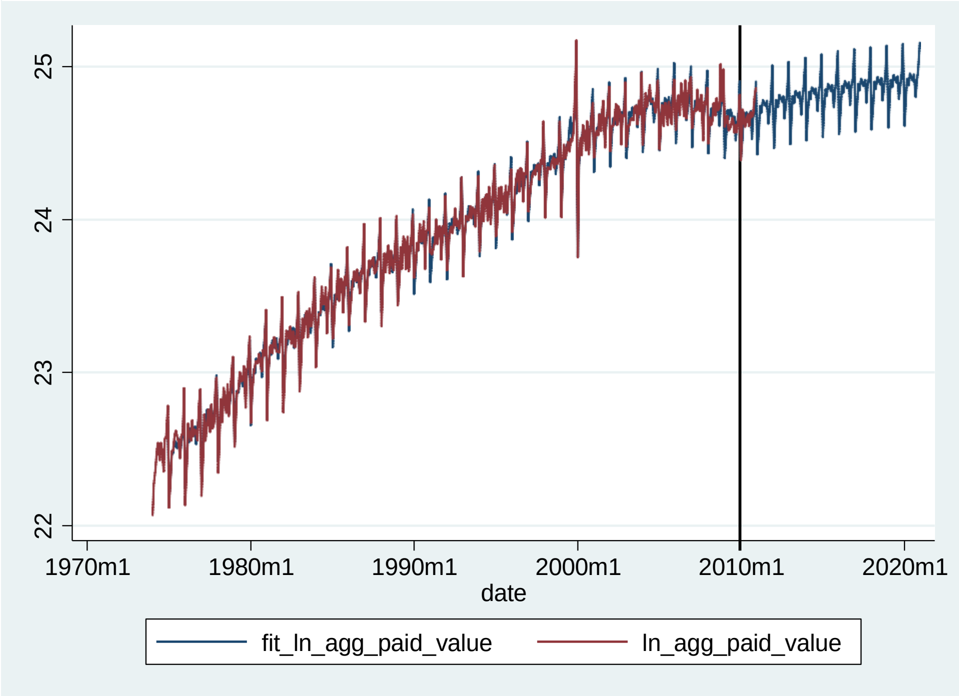


Panel H. Payments Value by Denomination (in logs) – 100s

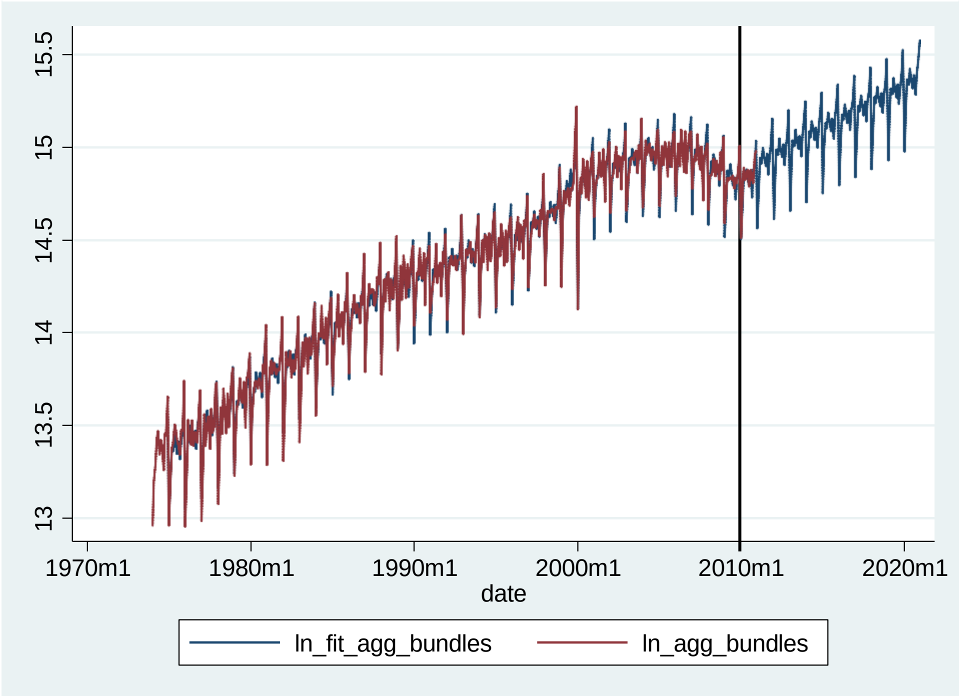


Appendix Figure 2. Denomination by Denomination Model, Projections for 2010-2020

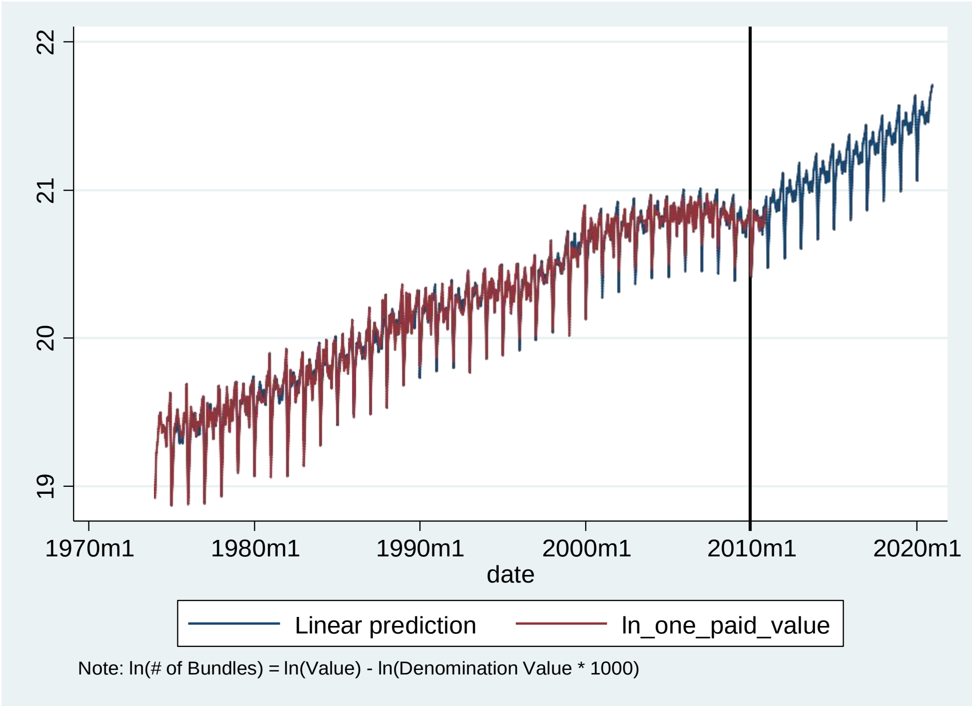
Panel A. Aggregate Value of Cash Payments (in logs)



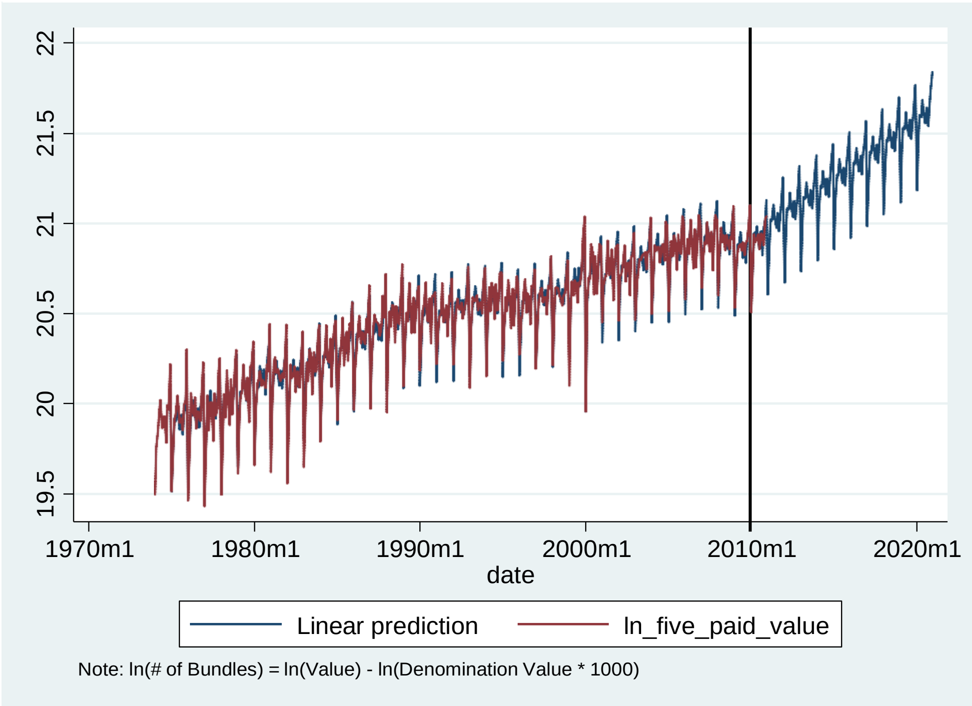
Panel B. Aggregate Number of Bundles (in logs)



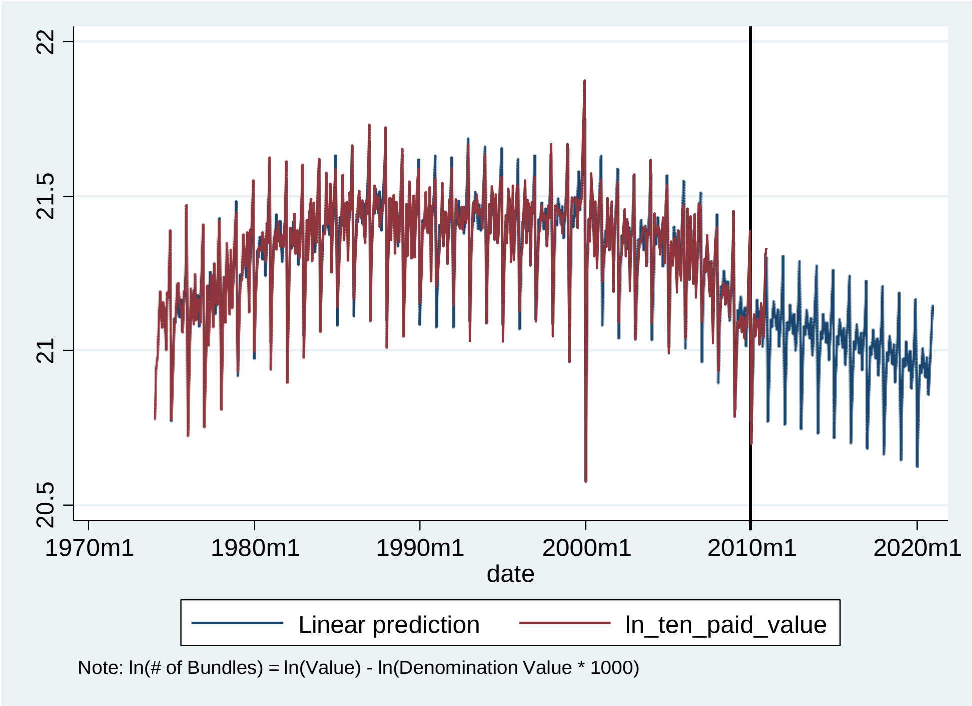
Panel C. Payments Value by Denomination (in logs) – 1s



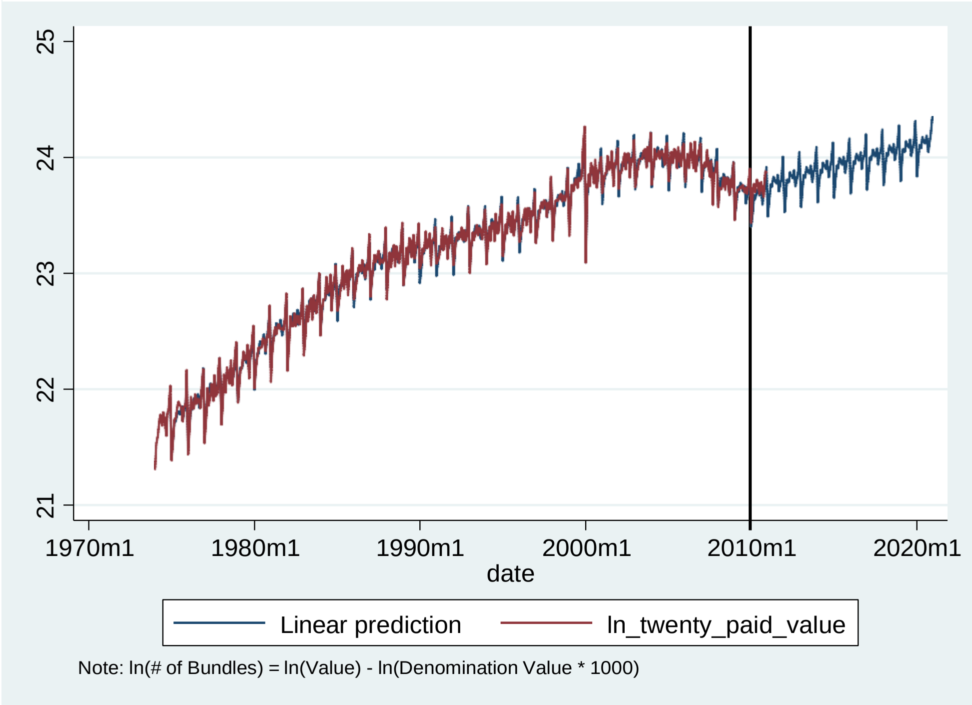
Panel D. Payments Value by Denomination (in logs) – 5s



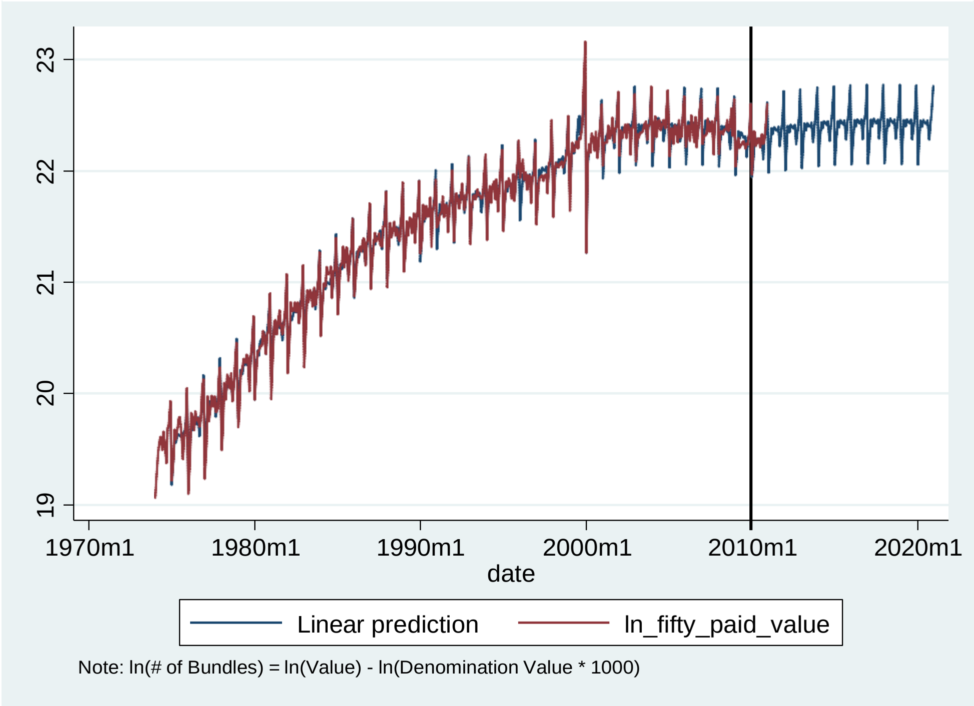
Panel E. Payments Value by Denomination (in logs) – 10s



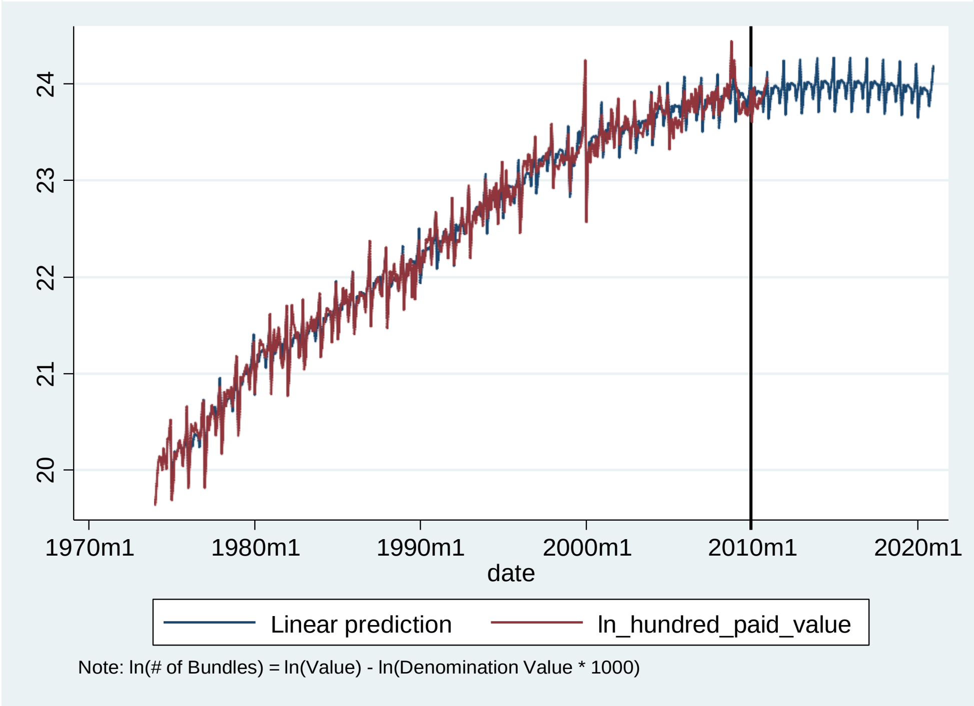
Panel F. Payments Value by Denomination (in logs) – 20s



Panel G. Payments Value by Denomination (in logs) – 50s



Panel H. Payments Value by Denomination (in logs) – 100s



Box 1. Impacts of Changes in Depository Institutions' Cash Management Practices

by Alexander Wolman
(Federal Reserve Bank of Richmond, Economic Research)

In solving their cash inventory management problem, households use the services of depository institutions. In turn, this generates an inventory management problem for DIs: they must hold cash in order to provide for withdrawals by their depositors, but they would like to hold as little cash as possible because – for the most part – cash held by DIs does not bear interest.

How DIs solve this inventory problem can have important implications for the nature of the demand for FedCash services. For given behavior of households, DIs could manage their inventories tightly and engage in frequent, small transactions with the Fed, or DIs could take a passive approach and engage in infrequent but large transactions with the Fed.

One factor that has affected DIs' inventory problems in recent years is the Fed's Recirculation Policy. Cross-shipping fees have made it costlier for DIs to engage in frequent transactions with the Fed, and the Custodial Inventory program has allowed DIs to earn interest on vault cash under certain conditions. Both aspects of the policy push DIs toward holding relatively high vault cash and transacting infrequently with the Fed. In addition, the cross-shipping fees have provided an impetus to the provision of cash processing services by third parties. That is, to the extent that third parties can provide a cost-effective substitute for cross-shipping, DIs will choose to deal with those third parties instead of the Fed. Only DIs may have accounts with the Fed, so the third-party providers must themselves use a DI as their source of cash or they must be affiliated with a DI. Nonetheless, it seems plausible that intermediation of cash services by third parties would be associated with a decrease in the demand for FedCash services.

Figure 1 plots vault cash as a percentage of currency outstanding, from 1980 to 2010. We plot the ratio of vault cash to currency rather than the level of vault cash in an attempt to focus on changes in DIs' inventory behavior. If inventory behavior were constant, the level of vault cash would nonetheless fluctuate with households' demand for currency, whereas the ratio of vault cash to currency would be unaffected.[28] There is a noticeable seasonal component in this series. Vault cash moves with households' transactions demand for cash, which is highly seasonal. On the other hand, a large fraction of currency is aseasonal since it is held overseas as a store of value. Thus, seasonality in vault cash still appears in the ratio of vault cash to currency. At lower frequencies, the figure shows a decline in the ratio of vault cash to currency until 2003, followed by a slight upward movement over the next four years, and then a pronounced decline since 2007.

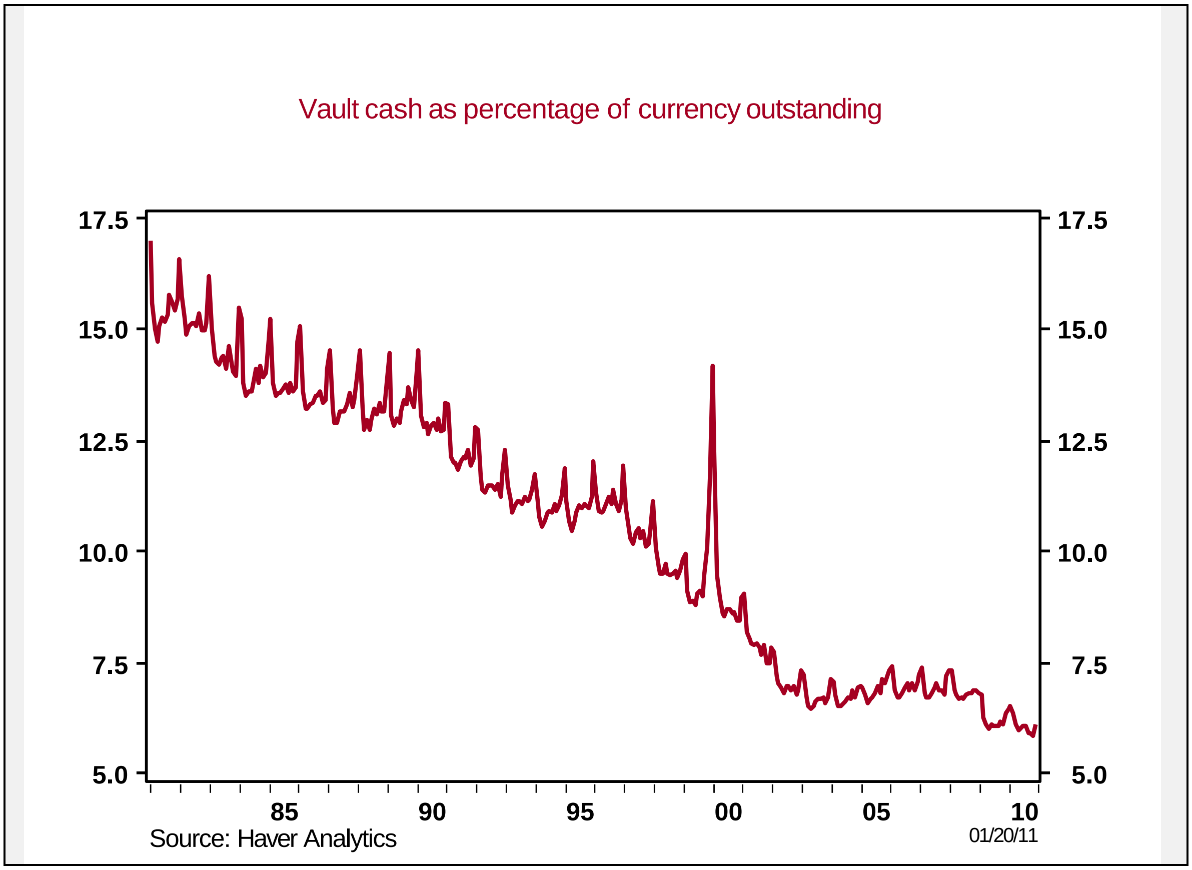
Recent trends in vault cash have almost certainly been influenced by the recirculation policy. Although the policy was not implemented until 2007, the Fed began soliciting comments in 2003. As early as 2004 then, DIs could have changed their behavior in anticipation of the recirculation policy. In particular, DIs may have reduced their cross-shipping by generally holding larger vault cash over this period. As DIs adapted their own practices to the new policy, and as third party providers expanded their activities, DIs were able to operate with (relatively) lower levels of vault cash since 2007.[29]

Looking ahead, continued technological improvements by DIs and third-party processors can be expected to allow DIs to more efficiently manage their inventories. The existence of cross-shipping fees naturally suggests that whatever form this improved inventory management takes, it will not result in a marked increase in demand for FedCash services. However, one should not rule out the possibility that the details of the cross-shipping fees become "exploited" by third-party providers. There may be transactions between several DIs and the Fed which would involve multiple cross-shipping fees for the DIs, but which could be reshuffled by a third party to avoid the cross shipping fees. Although that possibility is pure conjecture, it does highlight an important consideration in any discussion of the role of third-party cash processors: to the extent that the Custodial Inventory program remains limited, DIs will always have an

[28] Admittedly the correction is imperfect, because much of currency demand comes from overseas and is associated with the store of value rather than the transactions motive. It might be preferable to use transactions deposits in the denominator, but those are available only back to 2003. For that period their behavior is consistent with the interpretation offered here.

[29] Of course another factor in the low growth of vault cash in recent years may have been the generally low level of economic activity.

incentive to return currency to the Fed so as to earn interest, whether through the Fed Funds market or through IOR. Third party processors can only pay interest to "depositors" of cash to the extent that they are able to return cash to the Fed. The current situation of extremely low interest rates has reduced this incentive, but it will likely pick up in the coming years.



Box 2. Debit Cards and Cash Demand: A Cross-Country Analysis

by Eugene Amromin and Sujit Chakravorti
(Federal Reserve Bank of Chicago, Economic Research)

While payment card usage has increased dramatically, empirical studies have not documented a concurrent decline in the stock of outstanding currency. In this box, we summarize our recent article in which we find that transactional demand for cash indeed decreased with growth in merchant adoption of debit card infrastructure in 13 OECD countries between 1988 and 2003.[30] The key innovation in the paper is partitioning of currency holdings into categories that allows us to disentangle the store of wealth and payment functions of cash.

In particular, we define denominations commonly dispensed by ATMs in a given country as the "medium" category, which accounts for the bulk of transactional currency demand by volume. The "small" and "large" categories are defined by denominations on the either side of this threshold. The intuition behind this approach is simple: large denominations are better suited for store of value purposes, and thus should not be affected by changes in payments infrastructure. On the other hand, small denominations are required to make change for purchasers that obtained currency from ATMs. Since change is given only in the case of cash transactions, changes in the stock of small notes and coins likely provide the most accurate reflection of fluctuations in transactional demand for currency. At the same time, the demand for small denomination notes is unlikely to be affected by other demand factors such as the level of interest rates, illicit activity, and foreign demand.

In spite of its simplicity, this categorization of currency denominations allows us to also gain insight into a surprising number of areas. In particular, we gauge the potential of tax evasion as an explanatory factor of domestic currency holdings, the effect of industry organization on adoption of electronic payment infrastructure, and the net effect of ATM proliferation on currency demand.

[30] Amromin, Gene, and Sujit Chakravorti (2009), "Whither Loose Change? The Diminishing Demand for Small Denomination Currency," *Journal of Money, Credit and Banking*, 41 (2-3), 315-335. The 13 OECD countries that we study are: Austria, Belgium, Canada, Finland, France, Germany, Italy, Japan, the Netherlands, Sweden, Switzerland, the United Kingdom, and the United States.

Our empirical specification relates the total outstanding currency in each category normalized by the country's GDP to a set of factors that capture aspects of electronic payment infrastructure, cash distribution networks, proportion of small merchants, and the opportunity cost of money. We augment the standard Baumol-Tobin demand factors such as shoe-leather costs (ATMs per capita and bank branches per capita) and the opportunity cost (short-term interest rates) with other cash demand factors such as the number of debit card terminals per capita and the share of self-employed. The latter variable serves as a proxy for the prevalence of small merchants that may be less able to incur fixed costs of switching to electronic payments. The relatively small size of our data set necessitates a parsimonious specification. As argued in greater detail in the paper, it is crucial to allow for country-level fixed effects and clustering of error terms to obtain appropriate statistical inference. The results of our analysis are summarized in the table below.[31]

As hypothesized, debit card terminals have a very strong negative effect on demand for small denominations, but not for medium or large denominations. This underscores the idea that by eliminating the need to make change, electronic payment instruments have the most measurable effect on the subset of currency used for this purpose. In contrast, note that the aggregate demand specification (column 1) fails to detect any effect of debit card infrastructure.

Also, the ATM infrastructure is found to affect only the ATM-dispensed medium category. This effect is fairly precisely identified (p-value of 0.04) and is negative, indicating that, on net, ATM proliferation lowers the stock of medium denomination notes. The bank branch infrastructure has a significant (and positive) effect only on bank-distributed denominations – i.e. those that cannot typically be obtained from ATMs. The ratio of self-employed is influential only for small denomination demand, and is entirely absent for large denomination notes. This is consistent with the hypothesis of high fixed costs of installing electronic payments terminals for small merchants but not with the idea that high self-employment translates into greater currency demand through black market activity. Finally, we note that short-term interest rates – the cornerstone of money demand models – retains strong significance only in the aggregate and large-denomination demand specifications, and then only

[31] These results correspond to column (3) in Table 3 and Panel B of Table 5 in the published version of the paper.

after excluding countries with large currency holdings abroad (the United States, Germany, and Switzerland).

These results lend empirical support to the hypothesized link between debit card adoption and transactional demand for currency. In addition, the findings on bank branch infrastructure and interest rate effects provide ex post verification of our approach to disentangling the store-of-wealth and payment functions of money. Our empirical results suggest that electronic alternatives to cash will indeed reduce the demand for cash of certain denominations. However, the general demand for cash will continue to be strong in the future because of cash's anonymity and store of value features.

Table 1. Denomination-specific currency demand

	logarithm of			
	(1)	(2)	(3)	(4)
Dependent variable:	Aggregate/GDP	Large/GDP	Medium/GDP	Small/GDP
log(Debit terminals/pop)	-0.024	-0.028	0.029	-0.044**
	(0.012)	(0.025)	(0.026)	(0.014)
log(ATMs/pop)	-0.034	0.052	-0.267*	0.004
	(0.031)	(0.066)	(0.097)	(0.039)
log(Bank branches/pop)	0.352**	0.475*	0.260	0.301*
	(0.078)	(0.186)	(0.201)	(0.101)
log(Ratio of self-employed)	0.221	0.218	0.239	0.396*
	(0.220)	(0.249)	(0.440)	(0.147)
log(Short-term interest rate)	-0.092**	-0.131**	-0.035	-0.030
	(0.021)	(0.025)	(0.046)	(0.019)
Y2K dummy	0.038	0.054	0.000	-0.009
	(0.022)	(0.033)	(0.031)	(-0.018)
constant	-3.278	-3.806	-4.999	-6.068
N	128	128	128	128
Goodness-of-fit measure	within R^2	within R^2	within R^2	within R^2
	0.43	0.26	0.46	0.64

Note: All specifications are estimated with country fixed effects, with standard errors adjusted for within-country serial correlation by using cluster adjustments. ** and * denote statistical significance at the 1 and 5 percent levels. The sample is comprised of 10 OECD countries (pre-Euro, if applicable) that excludes Germany, Switzerland, and the U.S. as countries with large shares of currency abroad or out of circulation.

Box 3. The Effects of the Current Recirculation Policy on Cash Volumes by Douglas Conover and Lisa Whalen (Federal Reserve Bank of San Francisco, Cash Product Office)

In July 2006, the Federal Reserve began to implement the current Recirculation Policy. The policy was intended to reduce depository institutions' overuse of Federal Reserve Bank currency processing services, and to promote depository institutions' recirculation of fit $10 and $20 Federal Reserve notes.[1] The Recirculation Policy has two major components, both of which apply to $10s and $20s; these components are the Custodial Inventory (CI) program and the cross-shipping fee.

The CI program, which was implemented in July 2006, one year before the introduction of the cross-shipping fee, encourages DIs to re-circulate fit currency by allowing them to transfer limited amount of $10s and $20s to FRB books, even though the currency remains on the DI's premises. As shown in the following table, DIs with CIs in a given geographical zone reduced cross-shipping more than DIs not operating CIs in a zone.[2] Total cross-shipping by DIs with CIs fell 20.3 percentage points more than total cross-shipping by DIs without CIs from the year before the cross-shipping fee was implemented to the year after, although some of this effect probably reflects the fact that DIs with CIs are more likely than other DIs to face cross-shipping fees. Orders and deposits follow a similar pattern.

July '06 – June '07 vs. July '07– July '08[3]	DIs Without CIs	DIs With CIs	All DIs
Cross-Shipping	-38.9%	-59.3%	-46.8%
Orders	-13.5%	-39.7%	-18.9%
Deposits	-16.7%	-24.5%	-19.1%

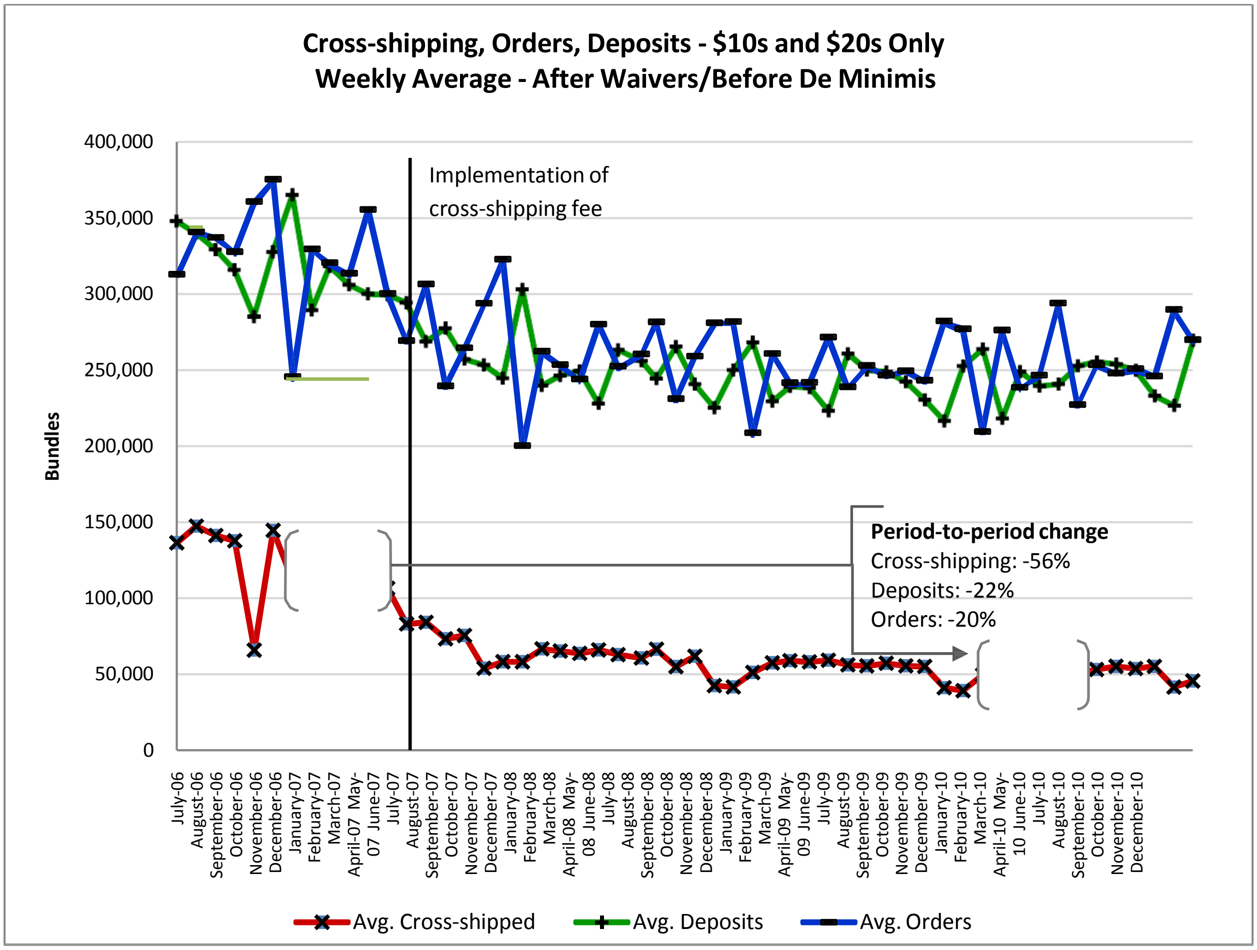
The cross-shipping fee, which provides banks with a market-based incentive to reduce cross-shipping, was introduced in July 2007. Cross-shipping fell sharply over the six months following the implementation of the cross-shipping fee of $5 per bundle. Cross-shipping has continued to decline, though more and more slowly, since that time period. The following graph illustrates these trends.[4]

[1] Federal Reserve System Federal Register Notice, Docket No. OP-1164

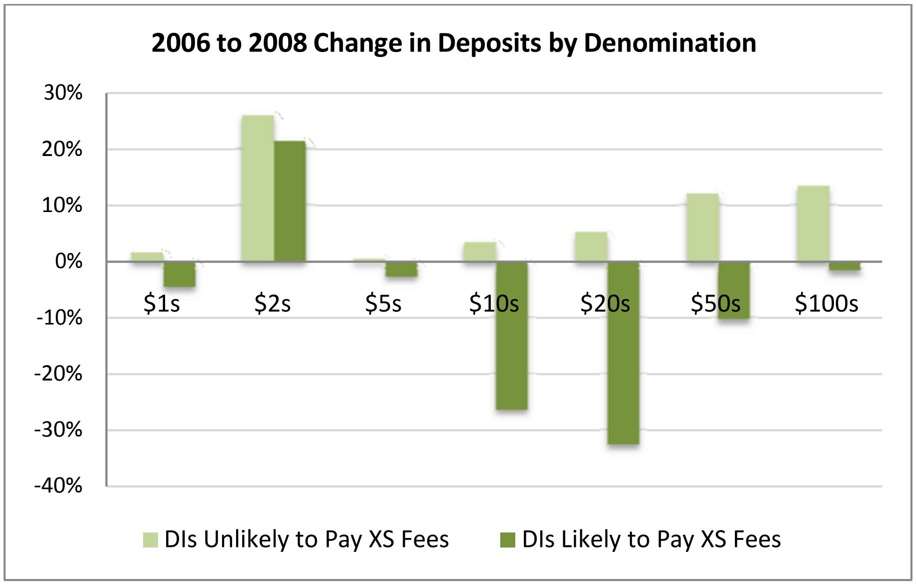
[2] The easiest way to explain which data is in the "CI" category is with an example. Wachovia has a CI in Atlanta, so its Atlanta cross-shipping, orders and deposits are in the "CI" category, but cross-shipping, orders and deposits from Wachovia in Boston, where it has no CI, are in the "non-CI" category.

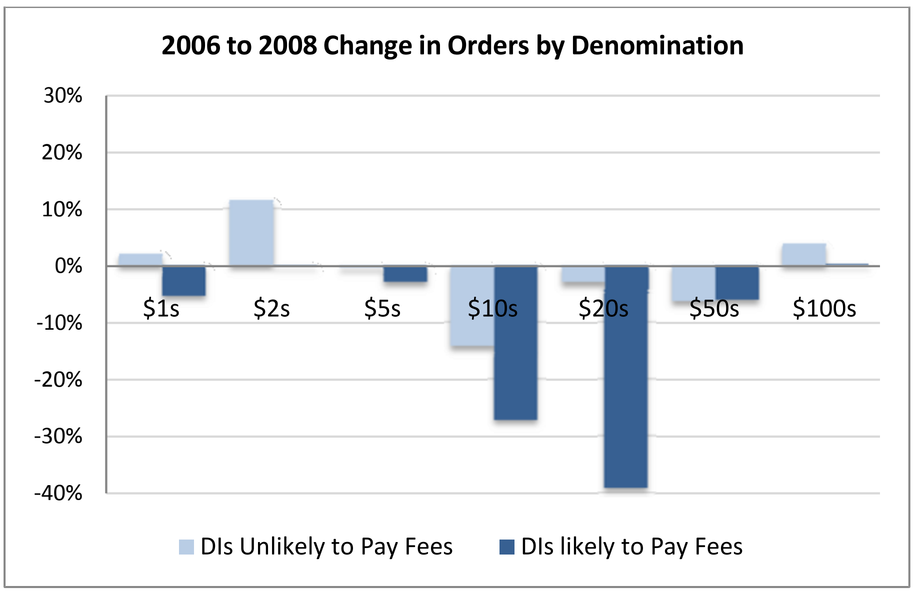
[3] Data are adjusted for the fact that the first half of the comparison has 12 months and the second has 13 months.

[4] Each year, DIs are granted Holiday New Currency waivers in November and December, thereby reducing the amount of cross-shipping that occurs in those months.



As expected, the majority of the reductions in deposits and orders came from DIs that were likely to pay cross-shipping fees. DIs likely to pay fees reduced their deposits and orders of $10s and $20s significantly more between 2006 and 2008 than those DIs unlikely to pay fees, as illustrated by the following two graphs. In addition, as shown in the first graph, those banks likely to pay fees also reduced their deposits of $1s, $5s, $50s and $100s, while those unlikely to pay fees increased their deposits of these denominations, which are not covered by the Recirculation Policy. This suggests that banks likely to pay cross-shipping fees altered their operations in a manner that affected their deposits in these other denominations, even though those denominations are not covered by the fee. In addition, although not shown below, both types of banks—those likely to pay cross-shipping fees and those unlikely to pay fees—decreased their deposits between 2008 and 2009, likely as a result of the recession, possibly suggesting that those likely to pay fees had completed the adjustments to their operations by the end of 2008.





In addition to the CI program and the cross-shipping fee, the Recirculation Policy required the Reserve Banks to implement a currency quality monitoring program. The results of the monitoring program to date indicate that currency quality remains stable, and continues to be fit-for-commerce.[5]

[5] More information about the currency quality monitoring program, and the results of the annual currency samples, is available from the CPO upon request.