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Withering Cash:
Is Sweden ahead of the curve or just special?*

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Abstract

There is much in our increasingly digitized economies to suggest that the use of cash should fall. However, in almost all countries, it is constant or rising with a few notable exceptions. Sweden, in particular, displays a divergent development. In this paper, we explore the drivers behind this development. We use a data set consisting of 129 developed and developing countries and an extensive set of possible explanatory variables to estimate panel regressions for cash demand. In line with earlier studies, we find that economic development, demography, and the interest rate are important factors. A new finding is that our estimations point to a negative relationship between cash and corruption, and between cash and trust in government and financial institutions. However, this is not enough to fully explain the divergent development in Sweden. We therefore also discuss some recent events and policy measures in Sweden that seem to have accelerated the decline in cash during the last decade.

Keywords: Cash Demand, Currency in Circulation, Money

JEL Classification: E41, E42, E51

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1 Introduction

There is much in our increasingly digitized economies to suggest that the use of cash should be falling. The number of online purchases is increasing; digital payments at physical points of sale are widespread; payment applications for smartphones and other mobile devices are advancing fast, and so forth. All of this makes digital payments more convenient, cheaper, and it opens for non-cash payments in situations where cash used to be the only option.

However, as can be seen in Figure 1 cash in circulation keeps on increasing. In many countries, for instance, the United States, the increase has been more than 100 percent since 2007. The growth in cash has even surpassed the growth of the economy in most countries (see Figure 2). From Figures 1 and 2, we see that Sweden stands out as a notable exception, since cash in circulation has fallen by more than 40 percent, and cash as a share of GDP has fallen by even more and now stands at less than 1.5 percent. Neighboring Norway has experienced a similar, but less pronounced development.

The picture of a general increase in cash—with Sweden and Norway as exceptions—stands the same if we were to extend the period to cover the last two decades.[1] However, during the last few years, the data for countries like Australia, Canada, and the United Kingdom suggests that the increase in cash is potentially coming to an end and that these countries might potentially be following Sweden into a situation where cash will start to decline.[2] Although our data only dates back to 2001, the currency-to-GDP ratio has been increasing since the mid-1980/early 1990s in many countries. See, e.g., Ashworth and Goodhart (2020) who present data for some of the major economies, and who also note the Swedish decline to be an outlier.

What explains the divergent development? Are Sweden and Norway just ahead of the other countries, or is there something special about these countries? Can other countries expect a similar development in the near future? What drives the demand for cash more generally? In this paper, we address these questions. These questions have become even more relevant during the COVID-19 pandemic when fear of contagion seems to have led to a reduction in cash as a means for transfer in some countries.

Understanding what drives the development of cash is important for several reasons. One is that cash payments are more costly for society than digital payments (see, e.g., Schmiedel

[1] See Figures A1 and A2 in the Appendix for data going back to 2001.
[2] See Figure A3 in the Appendix.

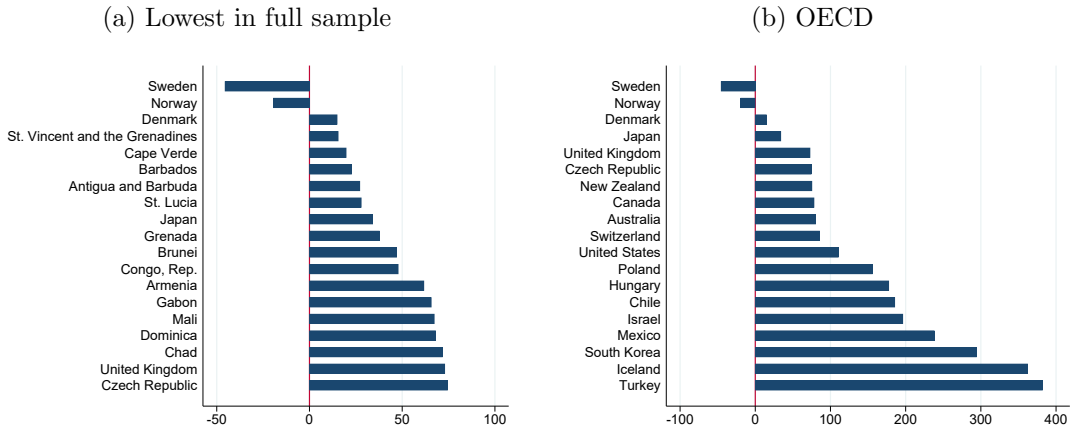

Figure 1: Percentage change in currency-in-circulation between 2007 to 2018

Notes: The graphs show the percentage change in currency-in-circulation between 2007 and 2018. In graph (a) we show the development for the 19 countries with the lowest increase in our whole sample while graph (b) shows the development for all the OECD countries in our sample. Both graphs rank the countries after the lowest increase.

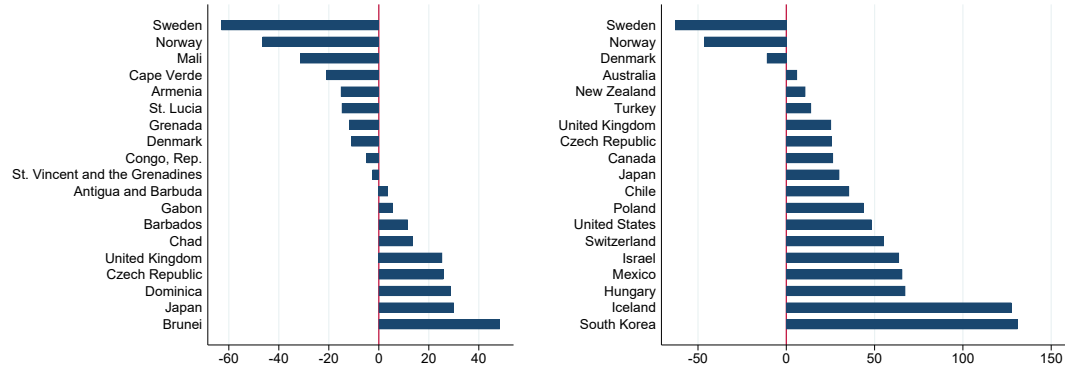

Figure 2: Percentage change in the cash-to-GDP ratio between 2007 to 2018

Notes: The graphs show the percentage change in currency-in-circulation/GDP between 2007 and 2018. In graph (a) we show the development for the 19 countries with the lowest increase in our whole sample while graph (b) show the development for all the OECD countries in our sample. Both graphs rank the countries after the lowest increase.

et al., 2012).[3] Another reason is that cash might ease criminal activity (see, e.g., Wright et al., 2017). Some countries may, therefore, want to understand how they can reduce the use of cash. Conversely, cash may be fundamental to our monetary systems since convertibility into cash ensures uniformity of commercial bank money and may make commercial bank money appear less risky (see, e.g., Armelius et al., 2020). Furthermore, cash may enhance economic resilience, make it possible for all to pay, and secure the financial independence of central banks trough seigniorage revenues (see, e.g., Sveriges Riksbank, 2017). Finally, Brunnermeier et al. (2019)

[3] For an alternative view, see Carbo-Valverde and Rodriguez-Fernandez (2019).

argue that cash protects against "digital dollarization."[4] Some countries may, therefore, want to stop a potential marginalization of cash. Whatever the reason, if we want to influence the development of the amount of cash in circulation, we need to understand what drives it.

Theoretical models of cash demand tend to focus on the cost of acquiring and holding cash. They predict a negative relationship between cash and interest rates. They also predict a negative relationship between cash and the availability of ATMs and bank branches as more ATMs and bank branches presumably reduce the need to hold cash inventories. However, these models do not explain the rise in digital payments as an alternative to cash payments. A (related) problem in econometric studies is simultaneity bias since some explanatory variables, like the number of ATMs, are determined in tandem with the demand for cash. We, therefore, extend the set of explanatory variables to include new (arguably) exogenous variables such as measures of regulatory quality, digital preparedness, corruption, trust, and human rights. The new explanatory variables improve on the econometric models and increase the model fit by up to 50 percent as measured by adjusted R-squared.

Our data set is extensive, consisting of 129 countries and covering the years 2001 to 2018. We aim to see if econometric models can identify factors that explain the development of cash in general, as well as the Swedish divergence. We start by estimating panel regressions for cash demand for our set of 129 countries. These estimations suggest that economic development is a key explanatory variable—richer countries have, in general, less cash in circulation relative to GDP. In line with the previous literature, we also find that increases in the opportunity cost of cash (the interest rate) reduce cash demand, while a higher average age in the population increases cash demand. When we limit the sample to OECD countries, higher corruption is associated with higher demand for cash. Furthermore, a bivariate analysis, using variables where there is limited data, suggests that trust in government and trust in financial institutions have a negative correlation with cash demand.

Our main specification performs well in explaining the development in most OECD countries. However, the econometric model cannot explain the development in Sweden, where we find that the model fit is more than twice as bad as for any other country. We, therefore, discuss potential explanations as to why Sweden is "unexplained" by the model. We specifically discuss policy measures to reduce tax evasion, an aggressive notes and coin changeover, the introduction of

[4] "digital dollarization," is a situation in which the national currency is supplanted by a digital platform's currency rather than another developed country's currency (Brunnermeier et al., 2019).

a mobile payments application, as well as a few other resent events in Sweden. While our estimations do not indicate that all countries will soon see a reduction in cash, the Swedish experience suggests that countries that simultaneously implement a combination of reforms that make cash less attractive and electronic payments more attractive may see a significant reduction in the use of cash.

This paper contributes to the literature in the following ways. First, our study covers a large number of countries, providing results for both developed and developing countries. Second, we provide evidence regarding variables—often excluded in cash demand studies—such as corruption, trust, and technology adaptation. Third, we provide a thorough discussion of events and institutional settings that can help us understand the divergent development in Sweden relative to other countries. This is highly policy-relevant since the development in Sweden is in the spotlight when central banks and governments contemplate about the future of physical cash, and money more generally.

The paper proceeds as follows. The next section provides an overview of the relevant literature. Section 3 describes the data while Section 4 explains the empirical strategy. Section 5 presents the main estimation results and Section 6 discusses the predictions of the model in light of the actual developments. Section 7 discusses potential reasons why the model cannot explain the development in Sweden and Section 8 concludes.

2 Related literature

Theories of cash demand often start from the Baumol (1952)–Tobin (1956) inventory model and predict that cash demand will be increasing in income or spending, decreasing in the opportunity cost of holding cash, and increasing in the cost of acquiring cash. Keynes (1937) three motives for holding cash give similar predictions and also suggest that people will hold more significant cash balances when there is increased uncertainty.

The empirical literature on money demand, taking theory as a starting point, is vast. Most relevant for us are the more recent papers where researchers estimate cash demand relations.[5] A robust finding in the literature is that cash in circulation increases with GDP and falls with the interest rate, in line with what theory predicts.[6]

[5] See, e.g., Amromin and Chakravorti (2009); Arango-Arango and Suárez-Ariza (2019); Ashworth and Goodhart (2020); Bech et al. (2018); Cusbert and Rohling (2013); Huynh et al. (2014); Jobst and Stix (2017); Shirai and Sugandi (2019)

[6] Bech et al. (2018) who use the ratio between cash and GDP as the dependent variable find a significant negative

The evidence is mixed for the cost of acquiring cash. Cusbert and Rohling (2013) find a negative effect of both the number of ATMs and the number of commercial bank branches. Amromin and Chakravorti (2009) find a negative but not always significant effect of ATMs and a positive and not always significant effect of bank branches. More specifically, Amromin and Chakravorti (2009) find that bank branches only have a significant (and positive) effect on bank-distributed denominations—those typically not distributed by ATMs—while the negative ATM effect only is observed for typically ATM distributed denominations (medium-sized bank-notes). In contrast, Arango-Arango and Suárez-Ariza (2019) find that more ATMs increases the demand for total cash and large denominations, but reduces the demand for small denominations.

There is little empirical evidence to support that increased uncertainty would increase cash balances. Cusbert and Rohling (2013) find significant effects of a dummy variable for the great financial crisis. However, Amromin and Chakravorti (2009) and Ashworth and Goodhart (2020) find no effect associated with the "Y2K crisis," and a great financial crisis dummy (Ashworth and Goodhart, 2020). Bech et al. (2018) and Shirai and Sugandi (2019) who explicitly test for "uncertainty variables" find them insignificant.[7]

Huynh et al. (2014) suggest that increased penetration of electronic payment alternatives reduces the demand for cash. Papers that include an EFTPOS variable find that this proxy for electronic payment alternatives has a significant negative effect on cash demand, although with some caveats. Arango-Arango and Suárez-Ariza (2019) find that the effect is insignificant for small denominations, while in Amromin and Chakravorti (2009), the effects are insignificant for medium and large denominations.

Other factors sometimes included as explanatory variables are the size of the informal sector and the share of small merchants in the economy. Papers that include proxies for the informal sector tend to find positive albeit not always significant effects (e.g., Arango-Arango and Suárez-Ariza, 2019; Jobst and Stix, 2017). Amromin and Chakravorti (2009) find that the share of small merchants in the economy (as proxied by the share of the self-employed) is associated with higher cash demand. Ashworth and Goodhart (2020) find that in the UK cash demand increases with the ratio of self-employed to employed.

Finally, papers that include some measure of the average age of the population usually find

elasticity of -1.6 between cash-to-GDP and *log* GDP per capita.

[7] Bech et al. (2018) use an index from Ozturk and Sheng (2018) while Shirai and Sugandi (2019) use the VIX index (stock markets volatility index). Shirai and Sugandi (2019) also find that dummies for the "Y2K crisis" and for the financial crisis are insignificant.

that it has a positive effect on cash demand (e.g., Bech et al., 2018; Shirai and Sugandi, 2019). This would indicate that older people have a stronger affinity for cash as compared to younger people—potentially due to the fact that older people are less willing to adopt new technology. We summarize all these potential explanatory factors used in the empirical literature, and measures of these factors, in Table 1.[8]

Table 1: Explanatory factors in the current literature

Explanatory Factor	**Measures Used**	**Estimated Coefficient**
Scaling factor	GDP, GDP per capita	+
Alternative cost	Interest rates	−
Cost of withdrawing cash	Number of ATMs, Number of bank branches	+/−
Uncertainty	'Uncertainty Index', Crisis dummy	+/no effect
Ease of electronic payments	Number of EFTPOS terminals	−/no effect
Informal sector	Share shadow economy	+/no effect
Small business	Ratio of self employed	+
Age structure	Life expectancy, Old-age-dependency ratio	+

Notes: The signs refer to the factor and not the variable. As the elasticities in different studies are not directly comparable, we only refer to the signs. The listed variables represent a selected sample of commonly used variables, and should not be seen as a complete record of all variables used in the literature.

3 Data

We build a data set that consists of 129 countries, out of which 19 are OECD members. We exclude countries for which we could not find key data and countries in the European Monetary Union. All the countries in our sample are listed in Table A1 in the Appendix. The variable of interest is currency-in-circulation (CiC), or more specifically, the ratio between CiC and GDP. This ratio is convenient since it allows us to compare countries without worrying about exchange rates. Furthermore, the (*log*) ratio is likely to be stationary and has a simple theoretical interpretation as the inverse of money velocity.

In addition to CiC and GDP, we collect a large number of potential explanatory variables, aiming to find the best possible coverage of our large amount of countries. As explanatory variables, we use both standard variables from the existing literature and some new ones. We summarized the main variables used in the existing literature in Table 1. Among the variables in Table 1, we have collected data on GDP per capita, interest rates, ATMs, bank branches, the share of self-employed, and the old-age dependency ratio.

[8] Other related studies, but somewhat less relevant for our study, include empirical papers using microdata, and theoretical papers that study consumer behavior and cash usage. See, e.g., Attanasio et al. (2002), Alvarez and Lippi (2009), Bagnall et al. (2016) and Wakamori and Welte (2017).

Some of the new variables that we consider are motivated by the fact that cash provides anonymity and leaves no electronic traces, features that can be desirable for illegal activities (see, e.g., Wright et al., 2017). We, therefore, include measures of corruption and organized crime. We may also notice that higher crime rates may, on the one hand, raise the cost of distributing cash, and thereby the cost of getting hold of cash, and thus increase cash holdings. On the other hand, it might induce people to hold less cash for security concerns. The anonymity provided by cash might also be desirable in oppressive regimes, and we include a variable measuring human rights, and variables measuring trust (confidence) in the government and politicians. Trust in government and politicians (and crime rates) might also matter for cash demand since it influences the investment climate in general and, therefore, also investments in ATMs and infrastructure for electronic payments.

People who do not trust banks to protect their integrity might prefer cash to commercial bank deposits. Another reason why people might prefer cash to commercial bank deposits could be that they do not trust commercial banks to be sufficiently safe. This hypothesis is supported by monetary theory, which suggests that people will prefer cash or other forms of central bank money over private money if institutions that facilitate trust in commercial bank money are weak (see, e.g., Armelius et al., 2020). We, therefore, include a variable measuring trust in the financial sector and a variable measuring the regulatory quality in each country.

We also include variables reflecting restricting or facilitating factors. Examples are access to bank services—such as having a bank account and credit/debit card ownership—and variables measuring the number of mobile phone subscriptions and individuals using the internet. The latter two could also be seen as proxies for general attitudes towards technology adaptation in addition to capturing the technological possibilities and ease of electronic payments. Measuring digitization and technology adaptation is not straight forward, and the data that does exist is often not observable for many countries or for an extended time period. However, we collect a measure called Digital Adoption Index (DAI) and its sub-index for the business sector. The DAI covers a large number of countries but is only observed during the years 2014 and 2016.

All collected variables and their descriptive statistics are presented in Table 2. Given the large heterogeneity among the countries in our sample, we also consider a subsample limited to the OECD countries in our data set. Table 3 presents the descriptive statistics for this subsample. In Table 2, we see that the average CiC/GDP is 7 percent in the whole sample but ranges from 1.13 percent to 32.5 percent. In the OECD sample, Table 3, we see that the

average CiC/GDP is 5.57, and hence, slightly lower compared to the full sample.

With 129 countries and 18 years (2001–2018), we have a potential maximum of 2,322 observations for each variable. However, for most variables, we do not have observations for all countries and all years, which can be seen in the first column of Table 2. We treat all missing observations as "missing at random."[9] One concern regarding missing data is the coding of missing observations. For some of the variables, for instance, 'Mobile cellular subscriptions' and 'Individuals using the internet,' the minimum value is 0.00 in Table 2. In most cases, this reflects rounding, although there do also exist some exact zero observations in the data. The concern is that this might reflect missing data instead of a true zero. However, there are extremely few exact zero observations, and we have chosen to treat them as actual data in our estimations since missing values otherwise are coded differently.[10]

The data described above is collected from various sources, including the IMF, OECD, the World Bank, and the World Economic Forum. Sources, documentation and further descriptive statistics can be found in Section A.1 and Tables A2 and A3 in the Appendix.

4 Empirical strategy

We estimate the following fixed effects linear cash demand model,

$$C_{i,t} = \alpha_i + \delta_t + \boldsymbol{\beta}\mathbf{X}_{i,t} + \varepsilon_{i,t}, \tag{1}$$

where i is a country indicator, t a year indicator, $\mathbf{X}_{i,t}$ a set of explanatory variables and $\boldsymbol{\beta}$ the vector of the corresponding coefficients, and $\varepsilon_{i,t}$ is a random error term with mean zero. In our main specification of this model we use the natural logarithm of the cash-to-GDP ratio (*log* CiC/GDP) as the dependent variable $C_{i,t}$. As mentioned before, this ratio is convenient since it allows us to compare countries without worrying about exchange rates. Although our main model will be a fixed effects model we will also estimate the model without the country fixed effects, α_i, and the year fixed effects, δ_t. In all estimations we consider standard errors clustered at the country level to account for likely error correlation within each country (see, e.g., Abadie et al., 2017; Angrist and Pischke, 2008; Cameron and Miller, 2015).

[9] We do perform some interpolation and extrapolation in order to extend our data by filling in some of the missing observations. See Section A.1 in the Appendix for a more detailed data description.

[10] Including or excluding these observations does not impact the results as the problem only applies to nine observations in total.

Table 2: Descriptive statistics

	Obs.	Mean	Std Dev	Min	Max
Panel A:					
CiC/GDP	2,322	7.00	4.16	1.13	32.50
Interest Rate	2,206	6.18	5.49	-0.78	83.87
GDP per capita	2,322	10.44	16.72	0.11	102.91
Self Employed	2,232	45.15	27.15	0.41	94.83
Age Dependency ratio	2,286	10.93	7.03	0.80	46.17
Mobile cellular subscriptions	2,301	73.79	49.30	0.00	345.32
Individuals using the Internet	2,227	29.86	28.30	0.00	100.00
Human Rights	2,286	0.40	1.46	-3.24	4.94
Regulatory Quality	2,320	48.75	25.50	0.00	100.00
Control of Corruption	2,320	47.25	27.94	0.00	100.00
Panel B:					
Automated Teller Machines	1,734	41.15	45.24	0.00	324.61
Commercial bank branches	1,847	15.83	14.19	0.14	92.17
Confidence in Financial Sector (yes)	1,072	58.03	16.40	4.49	96.03
Confidence in Government (yes)	1,020	49.98	19.29	7.00	99.00
Corruption in Government (no)	1,042	21.00	17.99	1.00	95.00
Public Trust in Politicians	1,043	3.05	1.19	1.29	6.48
Organized Crime, 1-7 (best)	1,043	4.87	1.02	2.00	6.90
Account Coverage	283	51.16	28.80	1.52	100.00
Debit Card Ownership	283	34.20	28.57	0.49	98.63
Credit Card Ownership	283	16.18	20.02	0.00	82.58
Digital Adoption Index	252	0.49	0.18	0.14	0.87
DAI Business Sub-index	254	0.55	0.18	0.14	0.97

Notes: Descriptive statistics for the variables used in the empirical estimation. See Section A.1 in the Appendix for more details about measurements and sources and Table 3 for descriptive statistics limited to the OECD sample. See the Appendix Tables A2, for between and within variation statistics, and A3 for country and year details on the number of observations.

In the absence of sharp identification, the panel data structure is essential since it allows us to utilize two sources of variation: variation across countries within each year; and variation within countries across years. The year fixed effects capture any common time trend and are important since they absorb global trends and global shocks—such as the financial crisis. Our estimations excluding country fixed effects should be interpreted as cross country estimates that allow us to compare cash demand factors between countries, while our specification that includes country fixed effects allows for within-country interpretations. The country fixed effects will pick up any time-invariant effects from factors missing from our estimation. Thus the country and year fixed effects help us control for some differences across economies and years that cannot be explained by our data, and hence, reduce possible biases that arise because of omitted variables.

When deciding on the final set of variables to include in $\mathbf{X}_{i,t}$ we face several trade-offs. If we were to include all our collected variables, we would reduce the risk of omitted variable

Table 3: Descriptive statistics: OECD sample

	Obs.	Mean	Std Dev	Min	Max
Panel A:					
CiC/GDP	342	5.57	3.91	1.13	20.99
Interest Rate	342	4.20	5.79	-0.78	66.85
GDP per capita	342	35.28	22.18	3.12	102.91
Self Employed	342	17.71	9.04	6.25	46.88
Age Dependency ratio	342	20.95	6.50	8.58	46.17
Mobile cellular subscriptions	342	99.90	26.33	21.69	149.39
Individuals using the Internet	342	68.29	23.16	5.19	99.01
Human Rights	342	1.61	1.65	-1.87	4.94
Regulatory Quality	342	86.45	11.32	52.40	100.00
Control of Corruption	342	83.51	17.45	16.35	100.00
Panel B:					
Automated Teller Machines	273	95.30	61.03	25.44	288.63
Commercial bank branches	274	26.93	13.10	5.51	90.90
Confidence in Financial Sector (yes)	222	53.29	15.75	7.76	84.18
Confidence in Government (yes)	222	43.95	15.01	7.00	85.00
Corruption in Government (no)	222	35.73	23.25	2.00	84.00
Public Trust in Politicians	209	3.82	1.33	1.54	6.21
Organized Crime, 1-7 (best)	209	5.55	0.88	2.55	6.82
Account Coverage	52	85.83	18.75	27.43	100.00
Debit Card Ownership	52	70.42	25.94	7.46	98.63
Credit Card Ownership	52	48.15	21.40	9.53	82.58
Digital Adoption Index	38	0.73	0.08	0.54	0.86
DAI Business Sub-index	38	0.80	0.09	0.59	0.97

Notes: Descriptive statistics for the variables used in the empirical estimation for our OECD sample. See Section A.1 in the Appendix for more details about measurements and sources and Table 2 for the full sample statistics. See the Appendix Tables A2, for between and within variation statistics, and A3 for country and year details on the number of observations.

bias, but at the same time, we would drastically reduce the number of observations since many variables are observed only for some scattered years. By adding many variables, we also face multicollinearity concerns, since many of our variables are likely to be highly linearly related to each other. Furthermore, there might also be two-way causalities, for instance, between ATM networks and cash demand, and between crime and cash demand. Higher crime rates might induce high cash demand to secure anonymity, while less cash might reduce crime, as shown in Wright et al. (2017).

Given the different trade-offs and concerns, we have chosen to focus on variables where we have a large amount of data and seek to estimate a reduced form model, which will capture the net effects of the main drivers in explaining general trends in cash demand. In Table 2, the variables in panel A are the variables included in $\mathbf{X}_{i,t}$ in our main specification (net of CiC/GDP that serves as our dependent variable). By excluding the variables in panel B in our

main specification, we obtain a set of variables where we obtain a fully balanced panel for the OECD sample. Furthermore, with this setup we also avoid reducing the number of observations to any great extent in the full sample, and we limit the concerns regarding simultaneity and two-way causality. However, we are still interested in assessing the relationship and importance of the variables in panel B. We, therefore, estimate bivariate relationships using the following specification

$$C_{i,t} = \alpha + \gamma z_{i,t} + \varepsilon_{i,t}, \tag{2}$$

where $z_{i,t}$ is each of our additional explanatory variables one at a time. We first estimate this relationship without country and year fixed effects so that we can interpret the coefficients as pure cross-country relationships. We then add, to equation (2), our main set of variables $\mathbf{X}_{i,t}$ from equation (1), as well as country and year fixed effects, and estimate

$$C_{i,t} = \alpha_i + \delta_t + \gamma z_{i,t} + \boldsymbol{\beta}\mathbf{X}_{i,t} + \varepsilon_{i,t}, \tag{3}$$

where again, $z_{i,t}$ is each of our explanatory variables (those not included in $\mathbf{X}_{i,t}$) one at a time.

5 Empirical results

We estimate equation (1) using both the full sample of all countries and the subsample of OECD countries. The estimated coefficients are presented in Table 4. Columns (1)–(3) refer to the full sample while columns (4)–(6) limit the sample to the OECD countries. Columns (1) and (4) suppress both the country and year fixed effects while columns (2) and (5) include the year fixed effects but suppress the country fixed effects. The full specification of equation (1) is presented in columns (3) and (6).

In line with earlier studies, we find a negative and statistically significant effect of the interest rate on cash demand. Between countries, a one percentage point higher interest rate is associated with 3.4 to 4.3 percent lower cash-to-GDP ratio. When adding country fixed effects, the coefficients are attenuated to around -0.01 but are still significant, such that a one percentage point higher interest rate is associated with around one percent lower cash-to-GDP ratio. In line with, e.g., Bech et al. (2018), we find that richer countries have a lower cash-to-GDP ratio. The coefficient on *log* GDP per capita is negative and significant for the whole sample but insignificant (and attenuated) for the OECD subsample. In the full sample, a one

Table 4: Cash demand estimation results

	Full Sample			**OECD**		
	(1)	(2)	(3)	(4)	(5)	(6)
Interest Rate	-0.034***	-0.035***	-0.007**	-0.042***	-0.043***	-0.013***
	(0.006)	(0.006)	(0.003)	(0.008)	(0.009)	(0.004)
log GDP per capita	-0.280***	-0.291***	-0.162**	-0.067	-0.111	-0.041
	(0.067)	(0.069)	(0.077)	(0.252)	(0.281)	(0.107)
Age Dependency ratio	0.035***	0.035***	0.004	0.071***	0.075***	0.009
	(0.008)	(0.008)	(0.010)	(0.017)	(0.018)	(0.017)
Self Employed	-0.003	-0.002	-0.004	0.004	0.005	-0.039**
	(0.003)	(0.003)	(0.006)	(0.016)	(0.018)	(0.016)
Mobile cellular subscriptions	0.003***	0.004***	0.000	0.001	0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.003)	(0.004)	(0.002)
Individuals using the Internet	0.001	0.002	-0.000	-0.007	-0.005	0.008
	(0.002)	(0.003)	(0.002)	(0.006)	(0.006)	(0.005)
Human Rights	-0.046	-0.045	0.035	-0.099*	-0.107*	0.086
	(0.032)	(0.033)	(0.029)	(0.051)	(0.056)	(0.057)
Regulatory Quality	-0.003	-0.004	-0.003	0.000	0.000	-0.007
	(0.003)	(0.003)	(0.002)	(0.011)	(0.011)	(0.007)
Control of Corruption	-0.003	-0.003	0.000	-0.016*	-0.016*	-0.008*
	(0.003)	(0.003)	(0.002)	(0.008)	(0.008)	(0.004)
Observations	2,004	2,004	2,004	342	342	342
R^2	0.350	0.354	0.910	0.623	0.636	0.940
R^2 Adjusted	0.347	0.346	0.903	0.613	0.606	0.931
Year Fixed Effects		✓	✓		✓	✓
Country Fixed Effects			✓			✓

Notes: The dependent variable is the natural logarithm of the Cash-to-GDP ratio and the estimated equation is (1). In columns (1), (2), (4) and (5) the country fixed effects have been suppressed and replaced by a common constant. Columns (1) and (4) also suppress the year fixed effects. Standard errors robust to clustering at country level are in parentheses. *,**,*** represent the 10%, 5%, 1% significance levels.

percent increase in GDP per capita is associated with a 0.3 percent lower cash-to-GDP ratio between countries and 0.17 percent lower in the within-country estimates.

As expected, and in line with earlier findings, we find that age matters. The coefficient is positive in all specifications and highly significant in models without country fixed effects. Countries with a one percentage point higher age dependency ratio are associated with a 3.5 percent higher cash-to-GDP ratio in the full sample and 7.5 percent higher in the OECD sample. When adding the country fixed effects, the age variable becomes smaller and insignificant. This could be because much of our variation is between countries, while the variation within countries is limited (see Table A2 in the Appendix).

For the other variables, the results are mixed. In all estimations, internet usage and regulatory quality turn out to be insignificant. Variables such as self-employed and mobile subscriptions are generally insignificant and quite often have the opposite sign from what was expected. In the full sample, the human rights variable is insignificant, while in the OECD sample, we observe a significant negative relationship when we exclude the country fixed effects. In the

OECD sample, our estimates also suggest that better control of corruption reduces the amount of cash. Control of corruption does have a negative coefficient also in the full sample but is insignificant and attenuated. A one-unit increase in control of corruption is associated with 0.8 to 1.6 percent lower cash-to-GDP ratio in the OECD estimation. Hence, a one standard deviation increase of 17.45 in control of corruption would imply a decrease in the cash-to-GDP ratio of 16 to 30 percent.

The results so far have omitted the variables listed in panel B of Table 2. We are still interested in assessing their relationship and importance for cash demand. As described in Section 4 we estimate the bivariate regression specified in equation (2). These results are presented in the left panel of Figure 3. We also estimate the relationship controlling for the variables in $\mathbf{X}_{i,t}$ together with the year and country fixed effects. The results from estimating equation (3) are presented in the right panel of Figure 3.

In the left panel of Figure 3, we see that many of the variables have, as expected, clear negative correlations with the cash-to-GDP ratio. Higher trust and confidence in politicians and the government is associated with lower cash demand. Lower rates of organized crime and perceived corruption in the government are also associated with less cash, as is higher bank account coverage and higher debit/credit card ownership ratios. The digital adoption indices are also negatively correlated with cash, although the OECD sample estimates are extremely imprecise.

When we add the variables to our main model one by one, including all controls, most of the tested variables are attenuated and turn insignificant (right-hand panel in Figure 3). This is not very surprising given the scarcity of data and possible multicollinearity for some of the variables. However, in line with the results in our main specification in Table 4, corruption seems to play an important role. Our survey measure of perceived corruption in government stays significant in the full sample.

Regarding ATMs and commercial bank branches, we do not find any clear relationships from Figure 3. In the full sample, we see a negative correlation in the bivariate estimation for ATMs, which turns to zero when adding controls. In the OECD sample, ATMs are zero in the bivariate regression, but positively significant (at the 10% level) with controls. On the other hand, commercial bank branches have a precise zero estimate in all specifications except in the OECD sample with controls, where the coefficient turns negative.

To elaborate a bit further on ATMs and commercial bank branches, we present, in Table

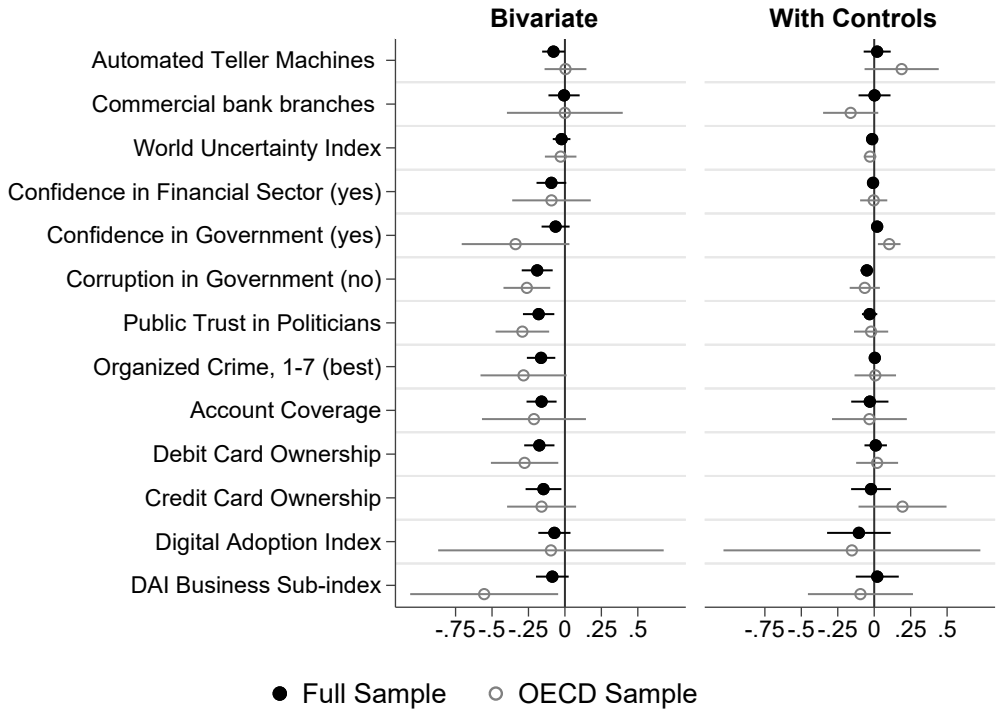

Figure 3: Additional explanatory variables

Notes: In the left panel, 'Bivariate,' we estimate, for each variable, equation (2) where $z_{i,t}$ is each variables one at the time. In the right panel, 'With Controls,' we add to each estimation the variables in $\mathbf{X}_{i,t}$ that was used in our main specification, as well as country and year fixed effects, such that the right panel estimates equation (3). 95% confidence intervals based on standard errors clustered at country level.

A4 in the Appendix, regressions where we include both ATMs and commercial bank branches together with our main set of variables. From the table, we see that in the OECD sample, we find a positive relationship between cash and ATMs, while in the full sample, there is no relationship at all. For commercial bank branches, the results are also mixed. Estimations where we are omitting the country fixed effects point towards a positive relationship, while estimations including the fixed effects point to a negative relationship in the OECD sample and a zero relationship in the full sample. Our main coefficients are robust to adding the ATMs and bank branches, although some coefficients change significance. In the OECD sample, individuals using the internet turns significant while human rights lose significance. When adding ATMs and commercial bank branches, we now see a significant negative effect of control of corruption also in the full sample.

As noted earlier, there is some scarce evidence in the previous literature that the financial crisis had a positive impact on the amount of currency in circulation. This seems to be visually supported for some selected countries in our data, where there seems to be a more pronounced

increase during 2007–2018 compared to 2001–2007 (see Figures A3 and A4 in the Appendix). However, looking at the estimated year effects, we do not find any evidence that the years associated with the financial crisis would be significantly different from the other years in our sample (see Table A5 in the Appendix). One caveat with this approach is that the year effects assume that all countries had a homogeneous exposure to the crisis. In order to obtain an estimate of uncertainty due to the effects of, e.g., the financial crisis, it is preferable to include variables that capture each country's heterogeneous exposure. We, therefore, turn to the World Uncertainty Index by Ahir et al. (2019). The work by Ahir et al. (2019) provides country-specific time series of uncertainty for a large set of countries. However, as can be seen in Figure 3, we do not find any significant relationship between the World Uncertainty Index and the cash-to-GDP ratio.

5.1 Robustness

As robustness of our model selection, we also estimate models where the explanatory variables are limited to the variables commonly used in the existing literature. In Table 5 we estimate a model using only the interest rate, *log* GDP per capita, the Age dependency ratio and Self-employment. From Table 5 we see that the estimates are robust and similar to the estimates obtained in Table 4. However, one notable difference is that the estimated coefficients for *log* GDP per capita, is significantly negative also in the OECD sample. Comparing the adjusted R-squared values in Table 4 with the values in Table 5 we see that adding variables capturing additional factors indeed improves the model fit as the adjusted R-squared values see an increase by up to 50 percent.[11]

We also perform an exercise using *Lasso* model selection (Hastie et al., 2015; Tibshirani, 1996). We allow the lasso-selection to choose from our main set of variables in $\mathbf{X}_{i,t}$ (i.e., panel A of Table 2), but force the selection of year and country fixed effects.[12] The results, presented in Table 6, show that the final model selection differs between the two samples compared to our main specification. In the full sample, the variables capturing internet usage and corruption are excluded, and in the OECD sample, the *log* GDP per capita and the human rights variables are excluded. The estimation results, of the remaining coefficients, are very well in line with the

[11] The increase in adjusted R-squared can mainly be seen in the estimations omitting the country fixed effects. This suggests that the added factors mainly explain level differences between the countries.

[12] We consider three different selection criteria: Cross-Validation, BIC, and Adaptive. All provide the same selection result.

Table 5: Baseline model

	Full Sample			**OECD**		
	(1)	(2)	(3)	(4)	(5)	(6)
Interest Rate	-0.035***	-0.033***	-0.007**	-0.040***	-0.039**	-0.010***
	(0.005)	(0.006)	(0.003)	(0.011)	(0.014)	(0.002)
log GDP per capita	-0.278***	-0.317***	-0.171**	-0.508***	-0.565***	-0.055
	(0.056)	(0.062)	(0.078)	(0.155)	(0.186)	(0.181)
Age Dependency ratio	0.029***	0.030***	0.004	0.058**	0.059**	-0.005
	(0.007)	(0.007)	(0.010)	(0.022)	(0.025)	(0.018)
Self Employed	-0.002	-0.004	-0.004	0.008	0.005	-0.038**
	(0.003)	(0.003)	(0.006)	(0.017)	(0.021)	(0.017)
Observations	2,116	2,116	2,116	342	342	342
R^2	0.259	0.287	0.907	0.422	0.444	0.926
R^2 Adjusted	0.258	0.279	0.900	0.415	0.408	0.917
Year Fixed Effects		✓	✓		✓	✓
Country Fixed Effects			✓			✓

Notes: The dependent variable is the natural logarithm of the Cash-to-GDP ratio. In columns (1) and (2) the country fixed effects have been suppressed and replaced by a common constant. In column (1) we suppress the year fixed effects. Standard errors robust to clustering at country level are in parentheses. *,**,*** represent the 10%, 5%, 1% significance levels.

results from our main model presented in Table 4. Using the OECD sample, we have a balanced panel, and hence, the model selection does not impact the number of observations—preserving the estimation sample. However, in the full sample, the panel is not balanced due to missing observations. Hence, the model selection could, potentially, both increase and decrease the number of observations altering the estimation sample. From Table 6, we see that the number of observations increases when omitting the internet and corruption variables.

While the robustness tests so far have focused on the selection of explanatory variables we further assess the robustness of our results in Table 4, by estimating the model on a subset of OECD countries where we remove the following reserve currency countries: United States, Switzerland, the United Kingdom, and Japan—countries whose currency is also used abroad to a large extent. We also estimate the model using *log* CiC (and not the cash-to-GDP ratio) as the dependent variable to ensure that our results are not solely driven by changes in GDP. In that estimation we add *log* GDP to the set of variables in $\mathbf{X}_{i,t}$.[13] The results from these two exercises are shown respectively in Tables A6 and A7 in the Appendix. Our main takeaways from Table 4 are robust to these permutations to the sample selection and the dependent variable.

[13] In this estimation, the country fixed effects are crucial since they allow us to measure CiC in national currencies without having to translate all into a common currency.

Table 6: Lasso model selection

	Full Sample	**OECD**
	(1)	(2)
Interest Rate	-0.007**	-0.014***
	(0.003)	(0.004)
log GDP per capita	-0.170**	
	(0.083)	
Age Dependency ratio	0.005	0.016
	(0.010)	(0.016)
Self Employed	-0.004	-0.033*
	(0.006)	(0.018)
Mobile cellular subscriptions	0.000	0.001
	(0.001)	(0.002)
Individuals using the Internet		0.008
		(0.005)
Human Rights	0.038	
	(0.029)	
Regulatory Quality	-0.002	-0.007
	(0.002)	(0.007)
Control of Corruption		-0.007**
		(0.003)
Observations	2,064	342
R^2	0.907	0.939
R^2 Adjusted	0.901	0.931
Year Fixed Effects	✓	✓
Country Fixed Effects	✓	✓

Notes: The dependent variable is the natural logarithm of the Cash-to-GDP ratio and the estimated equation is (1), where $\mathbf{X}_{i,t}$ have been selected via *Lasso*. Standard errors robust to clustering at country level are in parentheses. *,**,*** represent the 10%, 5%, 1% significance levels.

6 Can the model explain the divergent development?

In this section, we analyze if our empirical model can predict ("explain") the actual outcomes. We limit the analysis to the OECD sample, and we use the estimation presented in column (6) of Table 4 as our preferred specification.[14]

Based on the estimation in column (6) of Table 4 we calculate the Residual Sum of Squares (RSS) for each country. We report the RSS value for each country in Figure 4, where we have ordered the countries from best to worst model fit. The figure shows that the model has a good fit for countries like the Czech Republic, Canada, the United Kingdom, Japan, and Australia. The countries that stand out as being not predictable by the model are Iceland and Sweden. The low predictability for Iceland is likely to be due to the great financial crisis that hit Iceland particularly hard and where the cash-to-GDP ratio after the crisis increased substantially. We notice that the development in Sweden has been exceptionally hard to predict—as the RSS

[14] We limit this analysis to the OECD countries since we in that sample have a fully balanced panel using our main specification and we believe that the OECD sample is more homogeneous than the countries in the full sample.

value is more than twice as large as for any other country—indicating that Sweden is, indeed, special.[15] An interesting observation is that Norway, which also stands out in the comparisons made in the introduction, is relatively well explained by the model.

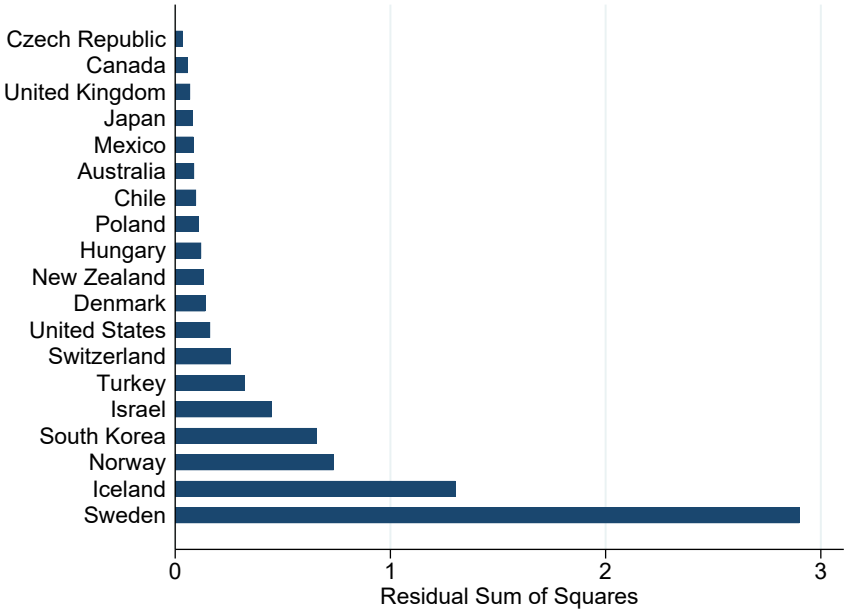

Figure 4: Residual Sum of Squares

Notes: The graph shows, for all OECD countries, the Residual Sum of Squares (RSS) based on the estimation in column (6) of Table 4. The countries have been sorted from lowest to highest RSS.

In order to get a picture of the model's fit and explanatory power over time, we plot the fitted values (as dashed lines) and the actual values (as solid lines) for each country in Figure 5. The figure shows that the model has a good fit for most countries. It predicts an increase in cash in several countries. The increase in actual *log* CiC/GDP in Iceland after the great financial crisis, resulting in the high RSS value, is evident from the figure. We can also notice that South Korea, Switzerland, and the United States are countries where the financial crisis might have had a substantial impact on the trend in actual *log* CiC/GDP.

Looking at Sweden, we see that the model fails to capture the sharp decline as the model predicts an unchanged level. The model also fails to fully predict the decrease in Norway, although we notice that Norway is the only country where the model predicts a decline. To assess the robustness and uncertainty of our model predictions, we show, in Figure A5 in the Appendix, the model prediction for Sweden and Norway using the full sample and the OECD sample excluding the reserve currencies. We also include, for Sweden, a model range in Figure

[15] It is worth noting that also in the full sample, not limited to the OECD countries, we find that the RSS value for Sweden is the largest.

A6 showing model predictions based on the estimations in: Table 4 (columns 3 and 6), Table A6 (column 3), and all the estimations in Figure 3. The picture stays the same regardless of model and sample choice.

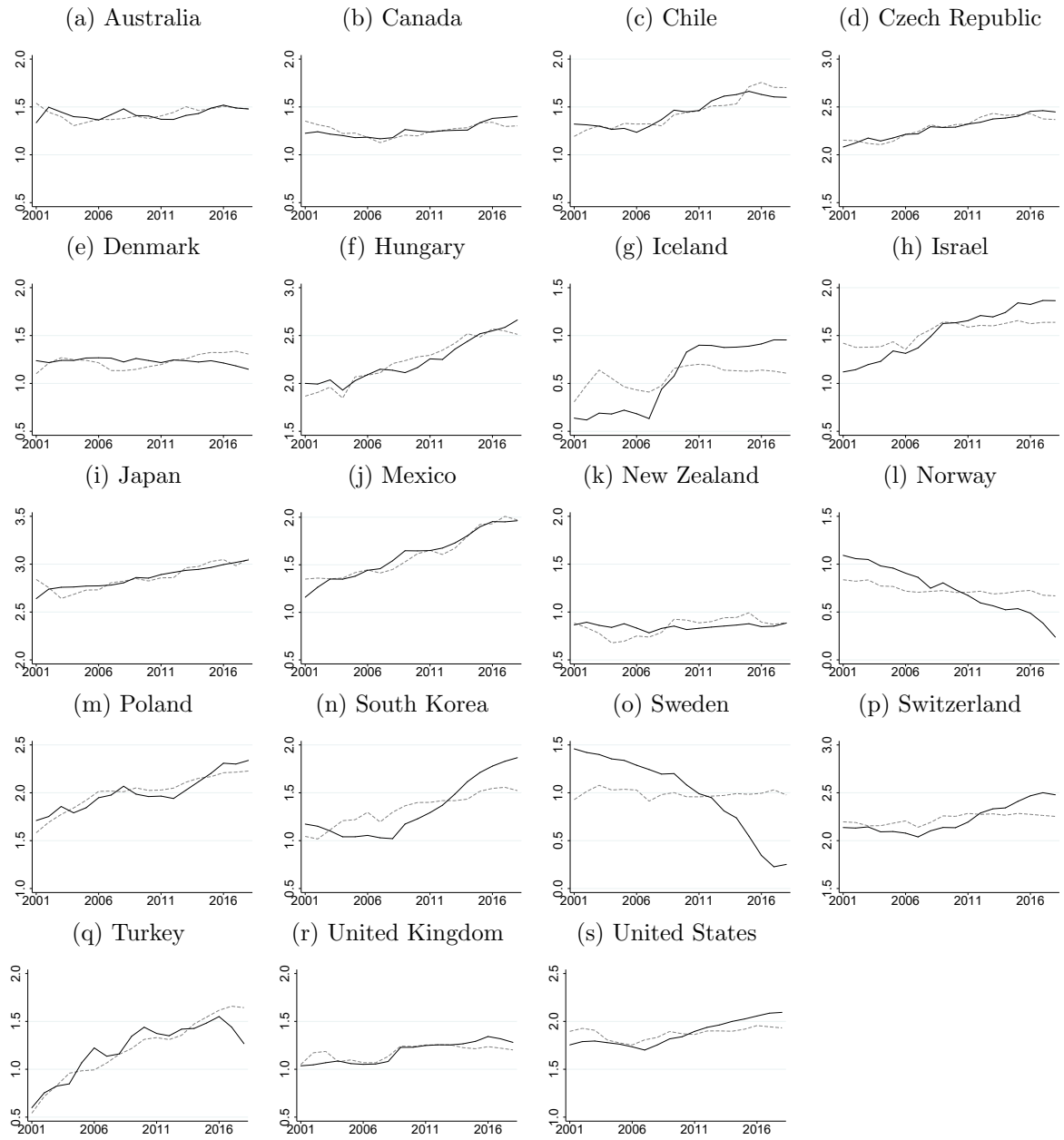

Figure 5: *log* CiC-to-GDP, actual value and model prediction

Notes: The figure shows, for all OECD countries, the model prediction (fitted values) based on the estimation in column (6) in Table 4 as dashed gray lines, and the actual outcome as solid black lines. The graphs show the *log* CiC-to-GDP ratio.

7 Discussion: Why is Sweden special?

Having explored what we can learn from cross-country data, we now discuss some Swedish policy measures and developments that may help explain why the model cannot explain the divergent developments in Sweden. More specifically, we suggest that Swedish measures to reduce tax evasion, an aggressive notes and coins changeover, and the introduction of a new mobile payment application could be important for the development in CiC in Sweden. While these types of events and changes are not unique to Sweden, the fact that they were all implemented within a short period of time could have amplified their effects. The timing of these events is illustrated in Figure 6. We also discuss, in Section 7.4, a few other aspects that could help explain why Sweden is special.

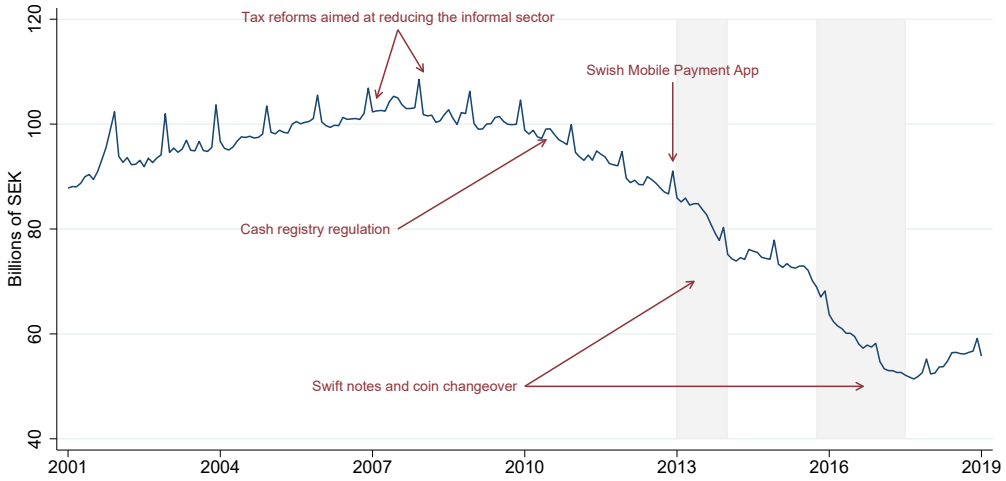

Figure 6: Events that help explain the decline in CiC in Sweden

Notes: The graph shows monthly currency-in-circulation (in billions of SEK) in Sweden.

7.1 Reduced tax evasion and a smaller informal sector

Starting in 2007 the Swedish authorities introduced measures aimed at transferring jobs from the informal to the formal sector and reducing tax evasion.

- In 2007 a substantial tax deduction for the purchase of household services such as cleaning was introduced. In 2008 a similar tax deduction for services related to house repairs and maintenance was introduced. The objective of the schemes was to reduce undeclared work by encouraging demand for declared work in domestic services through tax deduction and subsidies from the government. The measures appear to have reduced the size of the

informal sector (Swedish Tax Agency, 2012, p. 15–16).

- In 2010 it became mandatory for firms selling goods or services in return for cash to have a certified cash register and report the cash register to the Swedish Tax Agency. The provisions also involved an obligation to produce and offer the customer a receipt. In addition, the Tax Agency was allowed to conduct more supervision and inspection visits. The new law made it more difficult for businesses to withhold income by receiving payments in cash. The law hence aimed to make it harder to evade taxes and to reduce undeclared work. The Swedish Tax Agency (2012) provides clear indications that the cash register regulation has reduced tax evasion.

These measures are not directly captured by the explanatory variables of our model. Although variables such as regulatory quality and corruption might capture some of the effects, the reforms are likely to be too narrow to be proxied by the broader measures that we observe on a country level. Here we would also like to note that although the Swedish Tax Agency reports that the measures have reduced the informal sector and tax evasion, it is hard to separate out the measures' effect on cash demand empirically. A key reason is that we do not have sector-specific cash demand data. Moreover, as noted by Engert et al. (2019), numerous countries in the last 10 to 20 years have experienced a general trend of declining underground economies. We assess that it is unlikely that declining tax evasion and a smaller underground economy in Sweden *alone* can explain why the model cannot explain cash demand in Sweden.

7.2 An aggressive notes and coins changeover

During two intervals in the period from 2012 to 2017, the Riksbank pursued a notes and coins changeover. A particular feature of this changeover was that the window for exchanging old notes for new ones was short, only nine months. Furthermore, the Riksbank applies relatively strict redemption rules. Invalid notes can only be redeemed at the Riksbank's main office in Stockholm for a fee, and only if proper documentation of their origin is presented (in order to avoid money laundering). The changeover started in November 2012 when, as a preparatory measure before new notes would be introduced, older 50- and 1,000-krona notes without foil strip still in circulation were declared to be invalid from year-end 2013. At the same time, Sveriges Riksbank (2012) announced that the versions of the 50- and 1,000-krona with foil strips, that had been introduced in 2006, would be valid only until June 2017. This meant that anyone

holding the oldest version of, e.g., the 1,000-krona banknote, knew that they would have to do at least one more switch in the near future.

After the preparatory measures, the changeover was conducted in two steps. The first began in October 2015, when the Riksbank issued new 20-, 50-, 200- and 1,000-krona banknotes. In September and October 2015, the Riksbank sent out information brochures to the general public and also through other channels informed the public about the banknote and coin changeover. This information included the announcement that the old versions of the respective notes would become invalid after nine months.[16] The second step was initiated in October 2016, when the Riksbank issued new 100- and 500-krona banknotes, and new 1-, 2- and 5-krona coins. The procedure was once again that the old banknotes and coins were valid for only nine months after the new ones had started to be issued. However, this validity limit was announced already in September 2015.[17]

Having to exchange notes can be seen as an inconvenience for the cash holders. In addition, the inconvenience had already increased as large denominations notes were hardly used for purchases, and several shops did not accept big notes. Furthermore, by 2013 it had become harder to do a note switch at a bank office. The number of bank offices had declined, and many of the remaining ones had become *cashless*. In the period from 2011 to 2016, the number of bank offices offering cash services was more than halved. By 2016 only 40 percent of the bank offices offered cash services (The Riksbank Committee, 2018). It thus became increasingly cumbersome to replace old banknotes for new ones.

Looking at the timing of the changeover and the time series for total CiC and the largest banknote denominations, we can see clear drops during the two changeover periods. In Figure 7, we see that the preparatory period of 2013 coincides with a significant drop in the 1,000-krona banknote, while the main changeover period displays a large decline in the 500-krona banknote.[18] Engert et al. (2019), who compares the development of cash in Sweden and Canada, asses that the relatively aggressive notes- and coins changeover are likely to have reduced the demand for larger notes in Sweden relative to Canada.

[16] The Riksbank's communication measures regarding the notes and coins changeover are documented in Sveriges Riksbank (2018b).

[17] We summarize the validity and introduction of the banknotes in Figure A8 in the Appendix. See also Sveriges Riksbank (2018a) for a summary and evaluation of the banknote and coin changeover.

[18] During the changeover period, the 500-krona banknote makes up for around 70 percent of the total amount of currency-in-circulation.

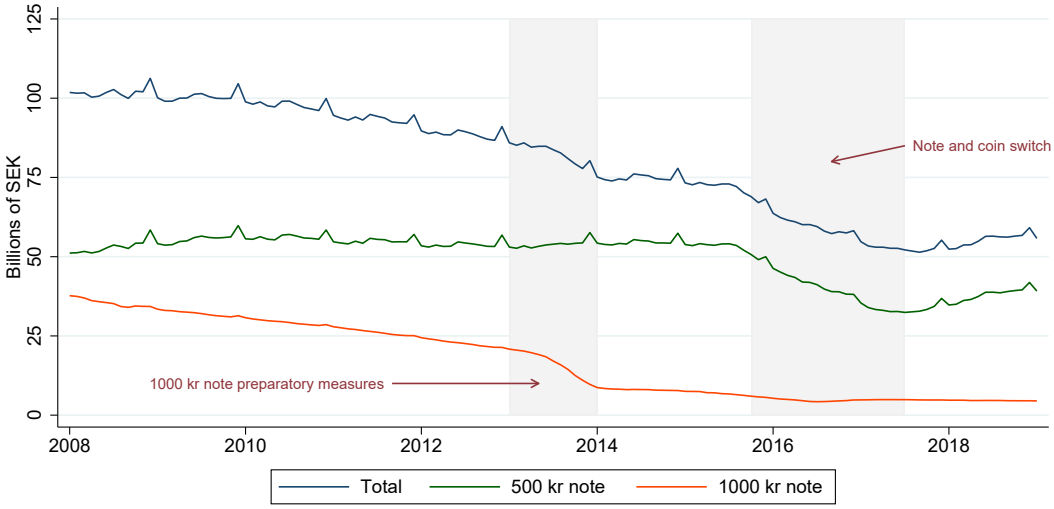

Figure 7: The Swedish notes and coins changeover

Notes: The graph shows monthly currency-in-circulation (in billions of SEK) for different denominations in Sweden. The 'Total' series corresponds to all banknote denominations available.

7.3 An attractive mobile payments application

In December 2012 a new payment application for smartphones called *Swish* was introduced in Sweden. The application offers digital real-time payments (person-to-person and person-to-business) between commercial bank accounts in different banks. Its user-friendliness, real-time properties, and broad reach opened for digital payments in essentially all areas where cash payments had previously been the only option. About 80 percent of the adult Swedish population now has the application. Since this corresponds to the latest available estimate of the share of smartphone ownership, Swish has essentially reached full market penetration in this age group.

The introduction and rise of Swish as an alternative to cash is not captured directly by any of the explanatory variables in our model. However, including variables like the number of Swish users as an explanatory variable would lead to spurious estimation results. Swish and CiC are likely to be just mirrors of each other since both are determined by the same exogenous variables, for instance, the age, regulatory quality, and technology adaptation.

Other countries have implemented similar services, but Swish differs from many of these by covering the whole banking sector and having, in principle, a universal reach. In many countries, the services appear to be more piecemeal and fragmented. The fact that the Swedish banks were able to come up with a common solution is in line with a long tradition in Sweden. Swedish banks are used to set up jointly owned infrastructure-related companies that provide

services for all banks that are compatible with competition among the banks. One example is *Bankomat AB*, which operates the vast majority of ATMs in Sweden, and is jointly owned by the major banks. Another example is that the banks also have a common digital identification system (called *BankID*) that is used by all banks for online banking services, by Swish, by public authorities, and so on. This is different from the workings of the banking sector in many other countries and is hard to measure and include in the empirical estimation.

7.4 Other aspects that could explain the fall in CiC

As noted above, the number of Swedish bank branches that offer cash services have declined. Engert et al. (2019) notice that Sweden has fewer bank branches that handle cash per inhabitant than Canada and suggest that access to cash trough banks can play a role. We have not included any variables for bank branches accepting cash in our empirical model. This is partly due to lack of data (it will be close to impossible to gather time-series for such variables for all of our countries) and partly due to econometric (simultaneity) reasons. Like ATMs, the number of bank branches offering cash services is likely to be determined in tandem with cash demand.

During the 1990s and early 2000s, the Riksbank reduced the number of cash distribution centers and withdrew implicit subsidies. By 2014, the bank only had one banknote distribution center. This differs from the situation in many other countries where the central bank has a much more prominent role in cash distribution. As most of the reduction in the Riksbank's cash distribution centers happened before the period we have in our sample, variables capturing central bank involvement in cash distribution may not help much in explaining the fall in cash in Sweden. However, it might help in explaining the differences between countries and could also be a factor that could help to explain the banks' reduction in offices offering cash services.

Finally, we would like to highlight one final factor suggested by Engert et al. (2019). They notice that the demand for small denomination notes has also fallen in Canada. Thus, the increase is in larger denomination notes. This is likely to be, at least partly, for store of value purposes. In Canada and many other countries, there seems to have been an uptick after the great financial crisis. In Sweden, there was no similar uptick. This could be because there is strong trust in the ability and willingness of the Swedish government to protect bank money in times of crisis. Sweden has experienced two systemic banking crises during the last three decades, and public authorities have proven willing and able to protect commercial bank deposits. The payment systems have been up and running without interruptions, and no

reductions have been applied to the value of commercial bank deposits during these crisis times. In other countries where there has not been a similar systemic banking crisis, there might be weaker trust in commercial bank money and, therefore, higher demand for cash for store of value purposes.

We may conclude our discussion of why the model cannot explain the divergent development in Sweden, and what is special in Sweden as follows. Several events and policy measures that have had mutually reinforcing effects on cash demand that are not captured in our model may explain the divergence. These include measures to reduce tax evasion and the informal sector, an aggressive notes and coins changeover, the introduction of Swish, and the withdrawal of central bank subsidies to cash distribution. These factors are, however, hard to capture in an econometric time series model covering multiple countries and, therefore, not included in our empirical model.

8 Conclusions

In this paper, we have analyzed developments in the amount of cash in circulation using a novel data set consisting of 129 developed and developing countries. Our main specification performs well in explaining cash developments for most OECD countries. We find that economic development, demography, and the level of the interest rate are key explanatory variables. The results also show that adding additional factors improves the model fit and that better control of corruption is negatively related to the level of cash. Our results also point to a negative correlation between cash and trust in government and financial institutions, as well as a negative correlation with bank coverage and debit/credit card ownership.

The development in Sweden consistently stands out. It is one of few countries that has had a decreasing amount of cash during the past couple of decades, not only as a share of GDP but also in nominal terms. We find that our model is not able to explain the divergent development in Sweden, while it performs relatively well for neighboring Norway, where cash has also declined. We discuss some events and policy measures that could have accelerated the decline in cash usage in Sweden. These include measures to fight tax evasion and an aggressive notes and coins changeover. The combination of these measures, which had a negative influence on the incentives to hold and accept cash, combined with the rise of an electronic peer-to-peer alternative to cash (Swish) have probably been decisive for developments in Sweden. However,

it is not possible to reach a firm conclusion of the effects of these measures and events, as more detailed data is lacking.

With this paper, we shed light on the divergent development in Sweden. Our empirical results and our discussion of some recent events in Sweden suggest that not only general economic conditions shape the demand for cash, but also, central bank policies such as note and coin changeovers, government policies targeting tax evasion and the informal sector, and the competition and general workings of the banking sector.

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A Appendix

A.1 Data description

Currency-in-Circulation (CiC) is collected from the IMF (IFS) database. We complement the IMF data with CiC data for the United Kingdom, China, India, Switzerland, and Singapore collected from national sources.[19] In our final selection of countries, we focus on those where we observe CiC throughout 2001–2018. For Djibouti, we extrapolate using a spline function to obtain a missing value in 2001. Note that all Euro countries are excluded. The CiC is expressed in local currency nominal terms.

Interest rates for our OECD countries is the short term interest rate from the OECD database. When the OECD data is unavailable, as it is for most countries in our full sample, we create a measure that we call *Mean of IMF Interest Rates*. The mean IMF interest rate is the mean of four different short interest rates from the IMF (IFS) Database. These four rates are Deposit rate, Money market rate, Government T-bill, and Central Bank policy rate. Note that for many countries, only a subset of the four rates is available, and for many countries, the rates are not observed during all the years. Taking the mean of the four rates covers 2,204 observations leaving us with 118 missing observations. In our OECD sample, the correlation between our OECD interest rate and our mean IMF measure is 0.97. See Figure A7 for illustrations of their closeness.

GDP and **GDP per capita** is collected from the World Bank database using the Azevedo (2011) Stata module. GDP is expressed in the local currency and current prices, while GDP per capita is expressed in 1,000 USD and current prices.

From the World Bank database we also collect: **Self-employed** (% of total employment, modeled ILO estimate), **Age dependency ratio (old)** measuring the fraction of old as % of the working-age population, **Individuals using the Internet** (% of population),[20] **Mobile cellular subscriptions** (per 100 people), **Automated Teller Machines** (per 100,000 adults), **Commercial bank branches** (per 100,000 adults).

From the Worldwide Governance Indicators (Kaufmann et al., 2011) database we access data on **Control of corruption** (Percentile Rank) and **Regulatory Quality** (Percentile Rank).[21] **Organized crime** (1–7 with seven being the best) and **Public trust in politicians** (1–7 with seven being the best) is collected from Global Competitiveness Index (World Economic Forum).

Confidence in Financial Sector (% responding yes), **Confidence in Government** (% responding yes) and **Corruption in Government** (% responding no) is collected from the Gallup World Poll. **Human Rights** score is collected from Fariss (2019) (via ourworldindata.org) and indicate the degree to which governments protect and respect human rights (the higher score the better).[22]

We collect the **Digital Adoption Index** from the World bank. The DAI is a worldwide index that measures countries' digital adoption across three dimensions of the economy: people,

[19] National sources are: Bank of England, People's Bank of China, Reserve Bank of India, National Bank of Switzerland, and Singapore Department of Statistics. We access the data via Macrobond.
[20] For Individuals using the Internet we interpolate (and extrapolate) to obtain 9 missing OECD observations.
[21] We extrapolate the data to obtain values for 2001.
[22] We extrapolate the data to obtain values for 2018.

government, and business, and is defined to be on a 0–1 scale. We also utilize the **DAI Business sub-index**. The data is only available for the years 2014 and 2016.

As a country-specific measure of uncertainty, we use the **World Uncertainty Index** by Ahir et al. (2019). We use the "T2" measure in the online data file and take the mean of the quarters to obtain a yearly number. As robustness, we have also considered the "T3" measurement. Both measures provide the same results.

Finally, we also add data on **Account coverage** (%, Age 15+), **Debit card ownership**(%, Age 15+) and **Credit card ownership**(%, Age 15+) from the World Banks Global Findex database. These variables are only available for the years 2011, 2014 and 2017 and cover only a subset of our countries.

See Tables 2, 3, A2 and A3 for descriptive statistics covering all the variables and Table A1 for a list of all the observed countries.

A.2 Figures

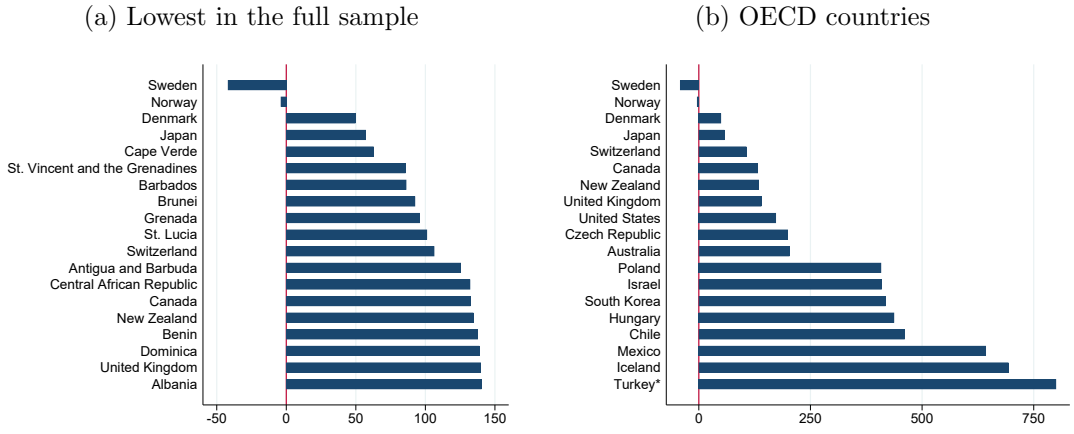


Figure A1: Percentage change in currency-in-circulation between 2001 to 2018

Notes: The graphs show the percentage change in currency-in-circulation between 2001 and 2018. In graph (a) we show the development for the 19 countries with the lowest increase in our sample while graph (b) show the development for all the OECD countries in our sample. Both graphs rank the countries after the lowest increase. *For illustrative purposes, the graph show an increase of 800 percent for Turkey—while the actual increase was 2,864 percent.

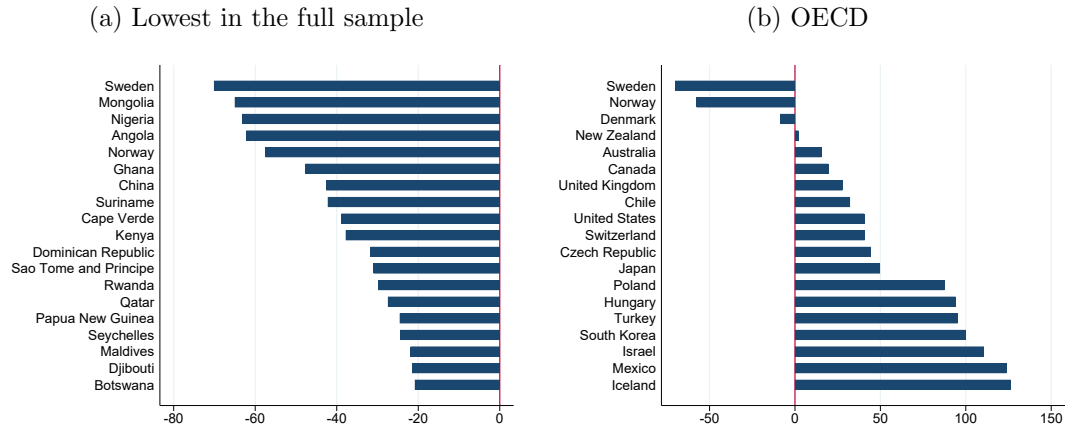


Figure A2: Percentage change in the cash-to-GDP ratio between 2001 to 2018

Notes: The graphs show the percentage change in currency-in-circulation/GDP between 2001 and 2018. In graph (a) we show the development for the 19 countries with the lowest increase in our sample while graph (b) show the development for all the OECD countries in our sample. Both graphs rank the countries after the lowest increase.

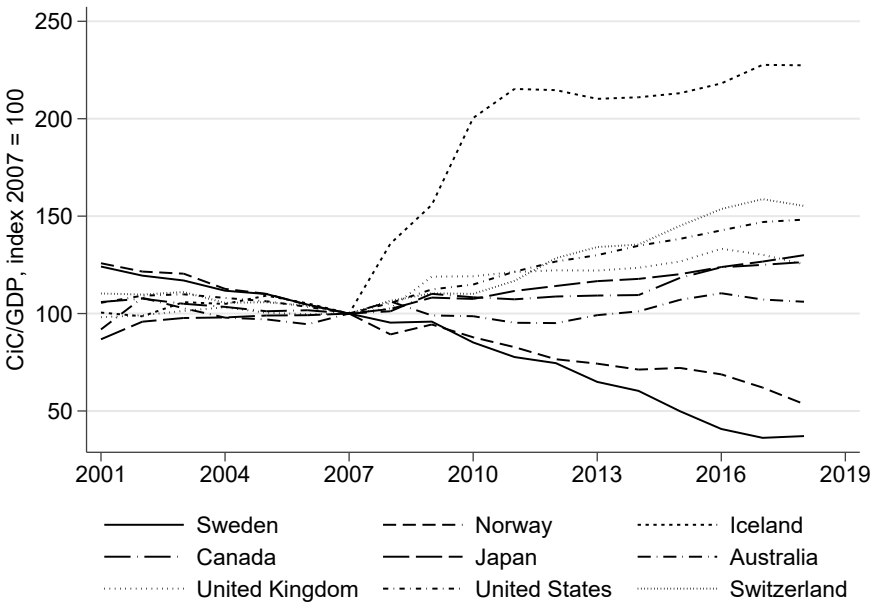
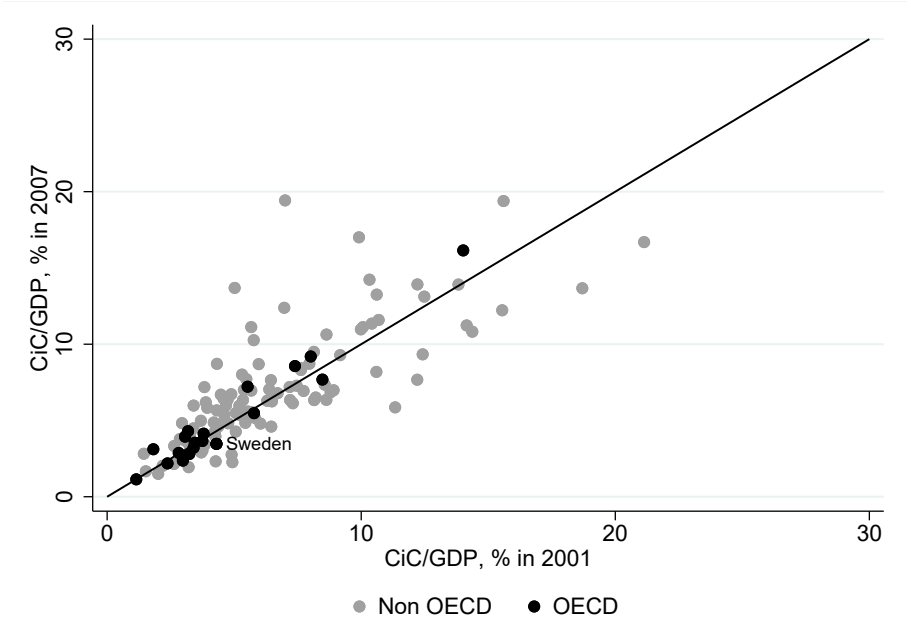


Figure A3: Cash-to-GDP development over time

Notes: The graph show, for selected countries, the development in currency-in-circulation/GDP over time. The series have been indexed to be at 100 during the year 2007.

(a) 2001–2007



(b) 2007–2018

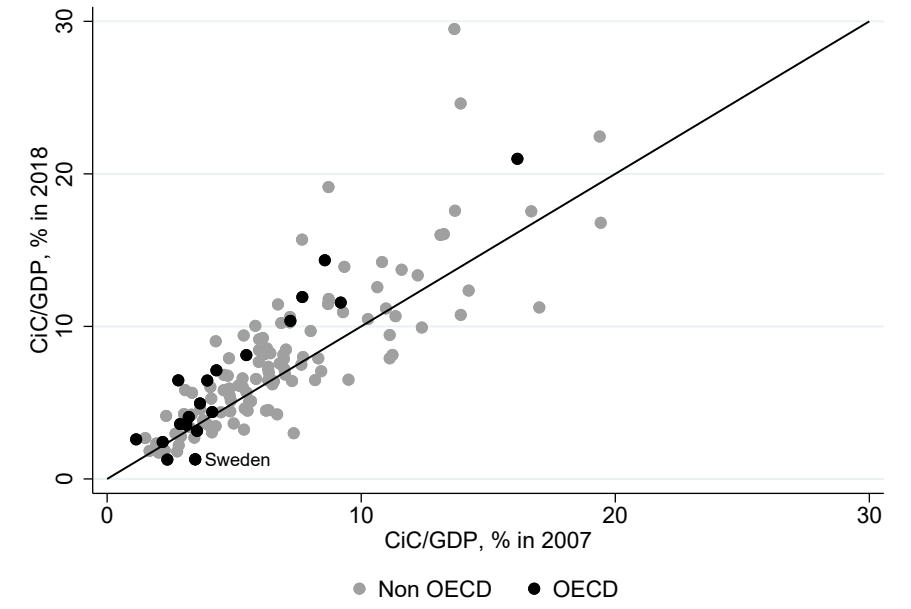
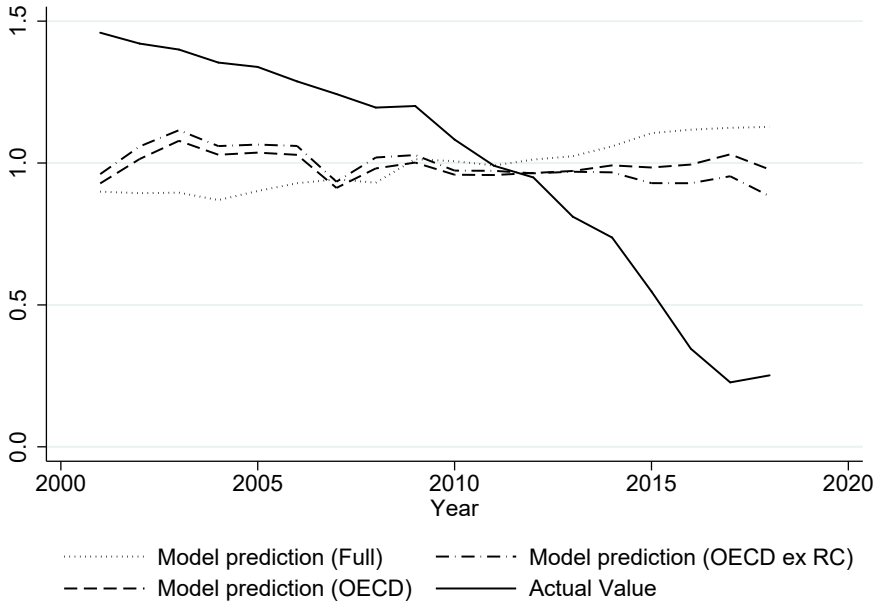


Figure A4: Cash-to-GDP development over time for all countries

Notes: The graph show, the development in the cash-to-GDP ratio over time for all countries. Each marker represent a country. The solid lines are 45 degree lines, such that each country above the line have experienced an increase while countries below the lines have experienced a decline in cash-to-GDP.

(a) Sweden



(b) Norway

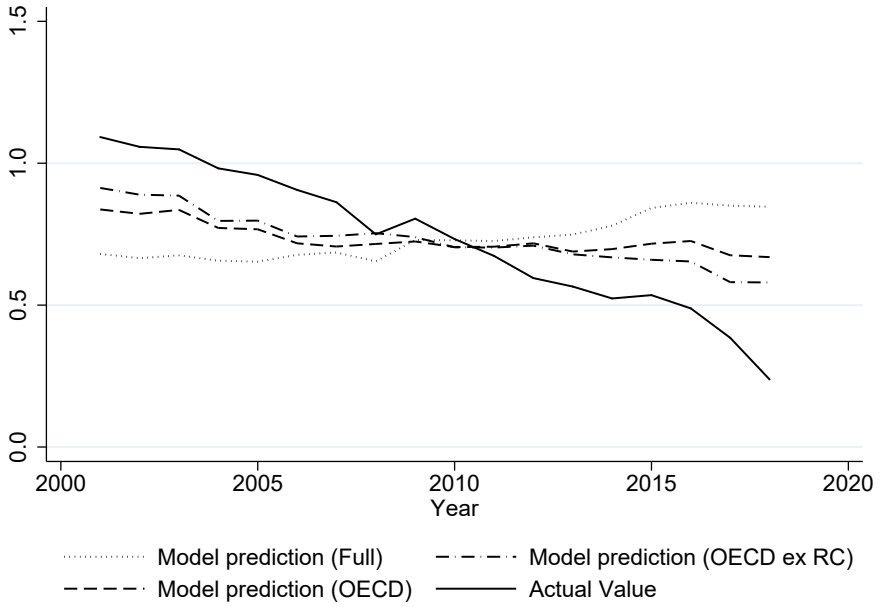


Figure A5: *log* CiC-to-GDP, actual value and different Model predictions

Notes: The graph show, the model prediction (fitted values) based on the estimation using the full sample, the OECD sample excluding the reserve currencies, and the OECD sample. The actual outcomes are represented by the solid lines.

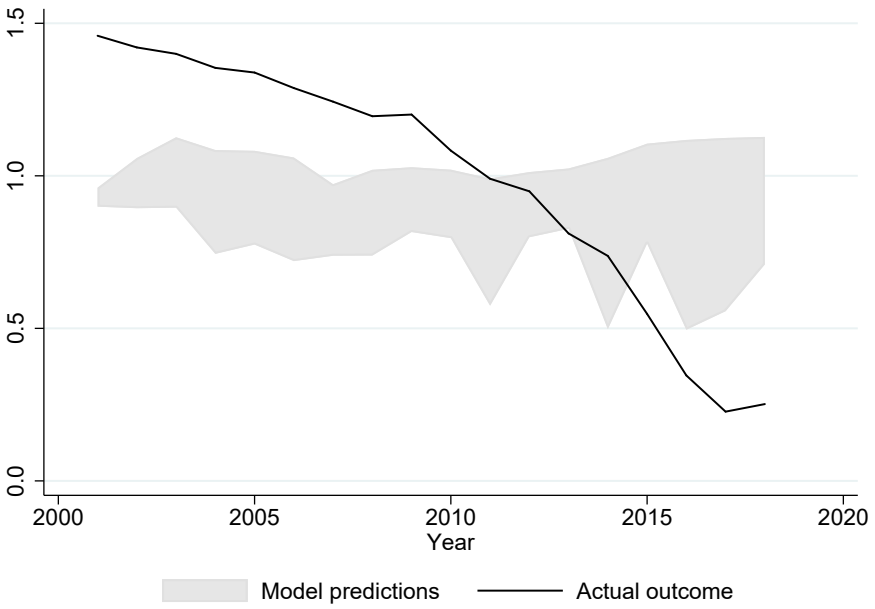


Figure A6: *log* CiC-to-GDP, actual value and model range for Sweden

Notes: The graph show, a range of model predictions (fitted values) based on the estimations in Table 4 (columns 3 and 6), Table A6 (column 3), and all the estimations in Figure 3. The choppy pattern for the model range is due to some models being estimated using only a limited number of years.

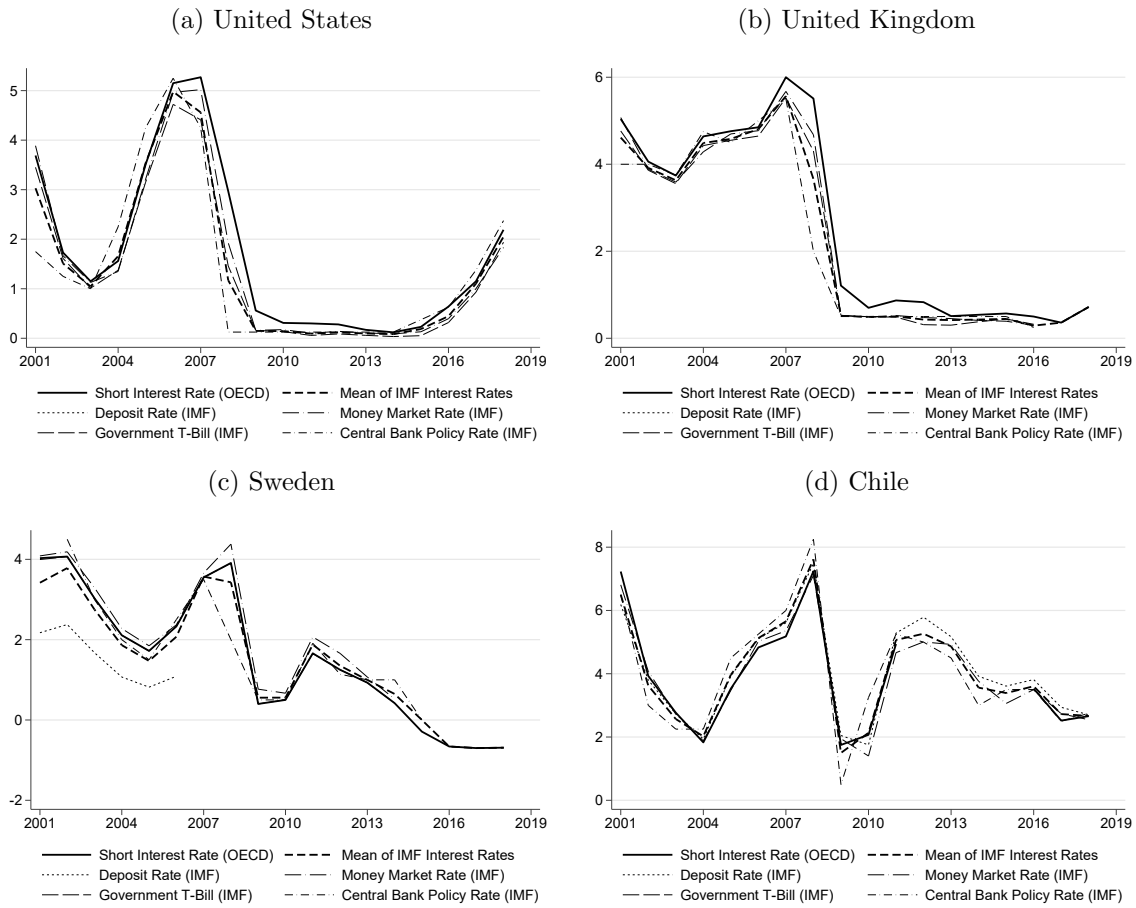


Figure A7: Interest rate examples

Notes: The graphs provide some examples of our interest rate data. For our OECD countries our main measure of the interest rate is the short term interest rate from the OECD database. When the OECD data is unavailable, as it is for most countries in our full sample, we create a measure that we call *Mean of IMF Interest Rates*. The mean IMF interest rate is the mean of four different interest rates from the IMF IFS Database. These are marked with (IMF) in the graphs. In our OECD sample the correlation between our OECD interest rate and our mean IMF measure is 0.97. See Section A.1 for more details.

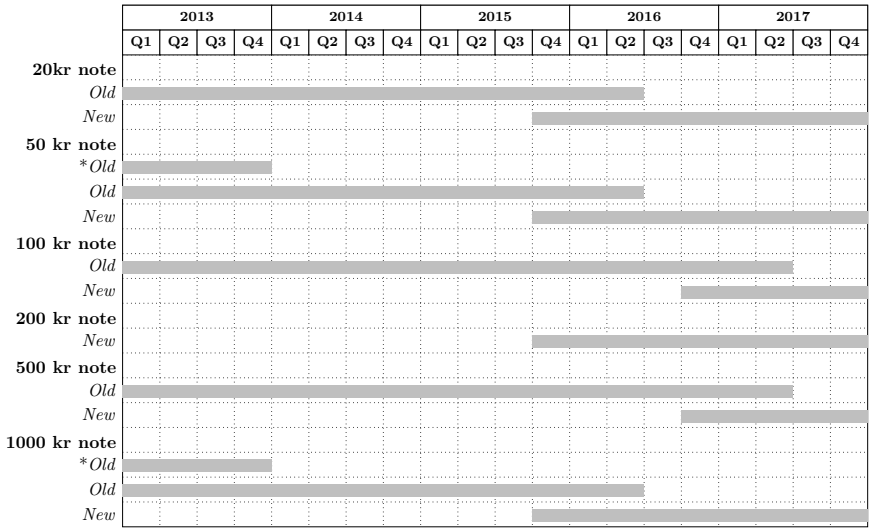


Figure A8: Timeline of the Swedish notes changeover

Notes: Gray areas represent respectively the period when each note is valid. Old notes marked with an * (star) mark old notes without foil strip.

A.3 Tables

Table A1: Country list

Non-OECD			**OECD**
Albania	Equatorial Guinea	Pakistan	Australia
Algeria	Eswatini	Papua New Guinea	Canada
Angola	Fiji	Paraguay	Chile
Antigua and Barbuda	Gabon	Philippines	Czech Republic
Armenia	Georgia	Qatar	Denmark
Azerbaijan	Ghana	Romania	Hungary
Bangladesh	Grenada	Russia	Iceland
Barbados	Guatemala	Rwanda	Israel
Belarus	Guinea Bissau	Samoa	Japan
Belize	Guyana	Sao Tome and Principe	Mexico
Benin	Haiti	Senegal	New Zealand
Bhutan	Honduras	Serbia	Norway
Bolivia	India	Seychelles	Poland
Bosnia and Herzegovina	Indonesia	Sierra Leone	South Korea
Botswana	Jamaica	Singapore	Sweden
Brazil	Kazakhstan	Solomon Islands	Switzerland
Brunei	Kenya	South Africa	Turkey
Bulgaria	Kuwait	Sri Lanka	United Kingdom
Burkina Faso	Kyrgyzstan	St. Kitts and Nevis	United States
Burundi	Lesotho	St. Lucia	
Cambodia	Macao	St. Vincent and the Grenadines	
Cameroon	Malaysia	Sudan	
Cape Verde	Maldives	Suriname	
Central African Republic	Mali	Tajikistan	
Chad	Mauritius	Tanzania	
China	Moldova	Thailand	
Colombia	Mongolia	Togo	
Comoros	Morocco	Tonga	
Congo, Dem. Rep.	Mozambique	Trinidad and Tobago	
Congo, Rep.	Myanmar	Tunisia	
Costa Rica	Namibia	Uganda	
Cote d'Ivoire	Nepal	Ukraine	
Croatia	Nicaragua	United Arab Emirates	
Djibouti	Niger	Uruguay	
Dominica	Nigeria	Vanuatu	
Dominican Republic	North Macedonia	Zambia	
Egypt	Oman		

Notes: List of all the 129 countries for which we have cash-in-circulation data during 2001–2018. Our OECD sample consist of 19 countries.

Table A2: Standard Deviation details

	Standard Deviation		
	Overall	Between	Within
Panel A:			
CiC/GDP	4.163	3.863	1.587
Interest Rate	5.494	3.985	3.812
GDP per capita	16.724	15.961	5.176
Self Employed	27.152	27.125	2.663
Age Dependency ratio	7.032	6.943	1.265
Mobile cellular subscriptions	49.304	31.920	37.696
Individuals using the Internet	28.300	23.306	15.864
Human Rights	1.463	1.418	0.379
Regulatory Quality	25.501	24.777	6.503
Control of Corruption	27.937	27.310	6.333
Panel B:			
Automated Teller Machines	45.237	42.958	15.094
Commercial bank branches	14.193	13.587	3.884
Confidence in Financial Sector (yes)	16.405	14.896	7.531
Confidence in Government (yes)	19.287	18.153	9.143
Corruption in Government (no)	17.994	17.117	5.363
Public Trust in Politicians	1.194	1.123	0.372
Organized Crime, 1-7 (best)	1.023	0.944	0.383
Account Coverage	28.804	27.430	8.781
Debit Card Ownership	28.568	27.250	8.055
Credit Card Ownership	20.016	19.541	3.119
Digital Adoption Index	0.179	0.178	0.022
DAI Business Sub-index	0.182	0.181	0.022

Notes: The *Overall* standard deviation is calculated based on the country-year data. The *Between* column show the variation across countries while the *Within* column show the variation within countries.

Table A3: Observation details

	Observations		
	Total	Countries	Years
Panel A:			
CiC/GDP	2322	129	18.00
Interest Rate	2206	125	17.65
GDP per capita	2322	129	18.00
Self Employed	2232	124	18.00
Age Dependency ratio	2286	127	18.00
Mobile cellular subscriptions	2301	129	17.84
Individuals using the Internet	2227	129	17.26
Human Rights	2286	127	18.00
Regulatory Quality	2320	129	17.98
Control of Corruption	2320	129	17.98
Panel B:			
Automated Teller Machines	1734	129	13.44
Commercial bank branches	1847	129	14.32
Confidence in Financial Sector (yes)	1072	106	10.11
Confidence in Government (yes)	1020	103	9.90
Corruption in Government (no)	1042	103	10.12
Public Trust in Politicians	1043	104	10.03
Organized Crime, 1-7 (best)	1043	104	10.03
Account Coverage	283	105	2.70
Debit Card Ownership	283	105	2.70
Credit Card Ownership	283	105	2.70
Digital Adoption Index	252	126	2.00
DAI Business Sub-index	254	127	2.00

Notes: The *Total* column refers to the total number of observations while the *Countries* column show the number of countries for which we observe at least one observation. The *Years* column show the average number of years a country is observed for each variable.

Table A4: ATMs and Bank Branches

	Full Sample			**OECD**		
	(1)	(2)	(3)	(4)	(5)	(6)
Interest Rate	-0.049***	-0.051***	-0.011***	-0.052***	-0.059***	-0.031***
	(0.009)	(0.009)	(0.004)	(0.016)	(0.019)	(0.005)
log GDP per capita	-0.312***	-0.342***	-0.198***	-0.205	-0.235	0.052
	(0.072)	(0.071)	(0.061)	(0.212)	(0.226)	(0.160)
Age Dependency ratio	0.032***	0.031***	-0.001	0.072***	0.070***	0.022
	(0.008)	(0.008)	(0.009)	(0.009)	(0.010)	(0.017)
Self Employed	-0.002	-0.001	-0.003	-0.000	-0.003	-0.027
	(0.003)	(0.003)	(0.005)	(0.014)	(0.014)	(0.023)
Mobile cellular subscriptions	0.003***	0.005***	0.000	0.004	0.003	0.003**
	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)	(0.001)
Individuals using the Internet	0.002	0.005	-0.002	-0.013**	-0.015**	0.011*
	(0.003)	(0.003)	(0.001)	(0.006)	(0.007)	(0.005)
Human Rights	-0.056	-0.052	0.040	-0.066	-0.061	0.057
	(0.035)	(0.036)	(0.026)	(0.040)	(0.040)	(0.059)
Regulatory Quality	-0.004	-0.005	-0.001	-0.002	-0.003	-0.008*
	(0.003)	(0.003)	(0.001)	(0.010)	(0.010)	(0.004)
Control of Corruption	-0.004	-0.004	-0.003**	-0.017**	-0.015*	-0.007*
	(0.003)	(0.003)	(0.001)	(0.007)	(0.007)	(0.004)
Automated Teller Machines	-0.000	-0.000	0.000	0.002*	0.002**	0.007***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Commercial bank branches	0.008**	0.007*	-0.001	0.014**	0.015**	-0.018***
	(0.004)	(0.004)	(0.003)	(0.006)	(0.006)	(0.006)
Observations	1,470	1,470	1,470	263	263	263
R^2	0.410	0.419	0.953	0.754	0.765	0.968
R^2 Adjusted	0.405	0.409	0.947	0.743	0.740	0.962
Year Fixed Effects		✓	✓		✓	✓
Country Fixed Effects			✓			✓

Notes: The dependent variable is the natural logarithm of the cash-to-GDP ratio and the estimated equation is (1), where we have added the variables Automated Teller Machines and Commercial Bank Branches. In columns (1), (2), (4) and (5) the country fixed effects have been suppressed and replaced by a common constant. Columns (1) and (4) also suppress the year fixed effects. Standard errors robust to clustering at country level are in parentheses. *,**,*** represent the 10%, 5%, 1% significance levels.

Table A5: Estimated year effects

	Full Sample	**OECD**
	(1)	(2)
Interest Rate	-0.035***	-0.043***
	(0.006)	(0.009)
log GDP per capita	-0.291***	-0.111
	(0.069)	(0.281)
Age Dependency ratio	0.035***	0.075***
	(0.008)	(0.018)
Self Employed	-0.002	0.005
	(0.003)	(0.018)
Mobile cellular subscriptions	0.004***	0.000
	(0.001)	(0.004)
Individuals using the Internet	0.002	-0.005
	(0.003)	(0.006)
Human Rights	-0.045	-0.107*
	(0.033)	(0.056)
Regulatory Quality	-0.004	0.000
	(0.003)	(0.011)
Control of Corruption	-0.003	-0.016*
	(0.003)	(0.008)
Year = 2002	-0.035	-0.020
	(0.032)	(0.054)
Year = 2003	-0.055	-0.025
	(0.037)	(0.078)
Year = 2004	-0.099**	-0.079
	(0.047)	(0.120)
Year = 2005	-0.093	-0.022
	(0.057)	(0.132)
Year = 2006	-0.078	0.033
	(0.067)	(0.154)
Year = 2007	-0.055	0.070
	(0.080)	(0.190)
Year = 2008	-0.060	0.144
	(0.092)	(0.203)
Year = 2009	-0.101	0.035
	(0.100)	(0.196)
Year = 2010	-0.143	0.012
	(0.114)	(0.216)
Year = 2011	-0.128	0.027
	(0.125)	(0.239)
Year = 2012	-0.155	0.019
	(0.133)	(0.244)
Year = 2013	-0.177	-0.021
	(0.141)	(0.253)
Year = 2014	-0.181	-0.061
	(0.146)	(0.271)
Year = 2015	-0.188	-0.089
	(0.150)	(0.265)
Year = 2016	-0.201	-0.110
	(0.153)	(0.282)
Year = 2017	-0.213	-0.170
	(0.159)	(0.295)
Year = 2018	-0.222	-0.185
	(0.152)	(0.307)
Observations	2,004	342
R^2	0.354	0.636
R^2 Adjusted	0.346	0.606

Notes: Estimated year effects in columns (2) and (5) of Table 4. Standard errors robust to clustering at country level are in parentheses. *,**,*** represent the 10%, 5%, 1% significance levels.

Table A6: Excluding the major reserve currencies

	OECD ex. Reserve Currencies		
	(1)	(2)	(3)
Interest Rate	-0.029***	-0.030***	-0.015***
	(0.005)	(0.005)	(0.004)
log GDP per capita	-0.521***	-0.584***	0.050
	(0.161)	(0.176)	(0.148)
Age Dependency ratio	0.028	0.034	0.038
	(0.026)	(0.027)	(0.049)
Self Employed	-0.015	-0.015	-0.046**
	(0.014)	(0.015)	(0.018)
Mobile cellular subscriptions	0.003	0.002	-0.001
	(0.002)	(0.003)	(0.002)
Individuals using the Internet	0.002	0.003	0.010
	(0.004)	(0.004)	(0.007)
Human Rights	-0.049	-0.058	0.005
	(0.038)	(0.037)	(0.095)
Regulatory Quality	0.013	0.012	-0.008
	(0.009)	(0.009)	(0.010)
Control of Corruption	-0.019**	-0.018**	-0.010*
	(0.007)	(0.007)	(0.005)
Observations	270	270	270
R^2	0.734	0.752	0.911
R^2 Adjusted	0.725	0.725	0.895
Year Fixed Effects		✓	✓
Country Fixed Effects			✓

Notes: The dependent variable is the natural logarithm of the cash-to-GDP ratio and the estimated equation is (1). In columns (1) and (2) the country fixed effects have been suppressed and replaced by a common constant. In column (1) we suppress the year fixed effects. The estimations are performed using the OECD sample excluding Switzerland, the United States, the United Kingdom and Japan. Standard errors robust to clustering at country level are in parentheses. *,**,*** represent the 10%, 5%, 1% significance levels.

Table A7: CiC specification

	Full	**OECD**	**OECD ex. RC**
	(1)	(2)	(3)
log GDP	0.776***	1.071**	1.413***
	(0.053)	(0.386)	(0.457)
Interest Rate	-0.008***	-0.013**	-0.012*
	(0.003)	(0.006)	(0.007)
log GDP per capita	0.019	-0.053	-0.043
	(0.078)	(0.150)	(0.191)
Age Dependency ratio	-0.013	0.013	0.070
	(0.011)	(0.026)	(0.045)
Self Employed	-0.004	-0.036*	-0.026
	(0.005)	(0.018)	(0.019)
Mobile cellular subscriptions	0.001	0.001	-0.000
	(0.001)	(0.002)	(0.002)
Individuals using the Internet	-0.000	0.008	0.009
	(0.001)	(0.005)	(0.006)
Human Rights	0.037	0.089	0.005
	(0.029)	(0.057)	(0.098)
Regulatory Quality	-0.003	-0.007	-0.005
	(0.002)	(0.006)	(0.007)
Control of Corruption	0.000	-0.008*	-0.011**
	(0.002)	(0.004)	(0.005)
Observations	2,004	342	270
R^2	0.997	0.997	0.995
R^2 Adjusted	0.997	0.996	0.995
Year Fixed Effects	✓	✓	✓
Country Fixed Effects	✓	✓	✓

Notes: The dependent variable is the natural logarithm of the currency-in-circulation (CiC). In column (3), estimations are performed using the OECD sample excluding Switzerland, the United States, the United Kingdom and Japan. Standard errors robust to clustering at country level are in parentheses. *,**,*** represent the 10%, 5%, 1% significance levels.

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