The Surprising Recovery of Currency Usage*

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Currency usage began a long trend decline in the decades after World War II. This was expected to continue, and even accelerate, owing to payment technology innovations. Surprisingly, however, such usage as a percentage of GDP stopped falling and has increased quite sharply in recent years in most countries, with Sweden the major outlier. We examine to what extent this may have been due to increasing interest elasticity, nearing the zero lower bound, and also to rising tax evasion, as indirect taxes rise. We also show how currency holdings increased temporarily as the financial crisis struck in 2008.

JEL Codes: E40, E49, E63, H26, N10, N20.

1. Introduction

Currency usage, as a percentage of gross domestic product (GDP), peaked in most developed countries toward the end of World War II, and then began a long trend decline. Data for the United States, the United Kingdom, the euro zone, and Japan are shown in figure 1. This decline has been ascribed mainly to innovations and improvements in payments technologies, e.g., a widening use of bank accounts and checks, followed by the availability of plastic (debit and credit) cards, and now electronic transactions (Internet/mobile phones). Insofar as anyone thought much about currency usage, it was generally viewed as an outdated relic, whose survival was in some large part a kindliness to the aged, unfamiliar with a

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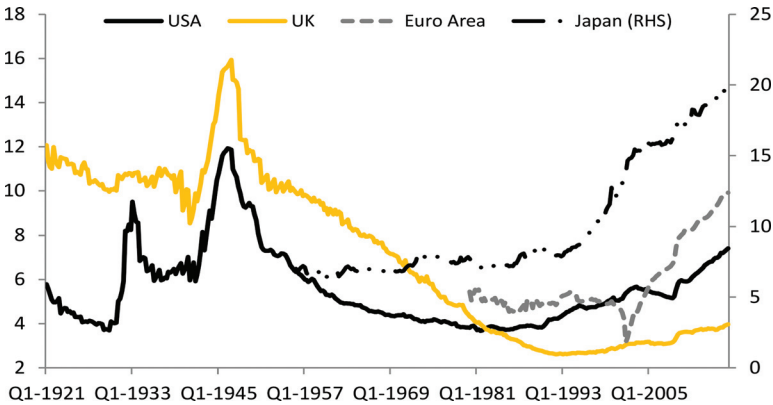
Figure 1. Currency-to-GDP Ratios (%)



Sources: Ashworth and Goodhart, Friedman and Schwartz (1963), U.S. Bureau of Economic Analysis, U.S. Federal Reserve Board, Bank of England: Three centuries of macroeconomic data—version 2.2, July 2015 (U.K. GDP data annual prior to 1955), U.K. Office for National Statistics, European Central Bank, OEF, Bank of Japan, Cabinet Office of Japan.
Note: For Japan we use gross domestic expenditure until the end of 1979 and gross domestic product subsequently.

world of swipe cards and PayPal; see Friedman (1999), King (1999), and more recently Wolman (2012). As the current generation of aged departed, so we would move toward a payment system where currency—notes and coins, but primarily notes[1]—would have disappeared. The opening page of Amromin and Chakravorti (2009) has the following quotes; also see Krueger (2016).[2]

> "Except for the smallest of transactions, money will no longer be a physical thing." (*Forbes* 1967 as cited in Flannery 1996)
>
> "The use of cash and currency will drop drastically." (Flannery and Jaffee 1973)
>
> "Cash is dirty, inefficient — and obsolete." (Gleick 1996)

[1]Bank notes typically account for around 95–97 percent of total notes and coins in circulation in developed countries.

[2]But for a more considered, and contrary, point of view largely based on empirical studies, see Bagnall et al. (2014), Beer, Gnan, and Birchler (2016), Boeschoten (1992), Drehmann, Goodhart, and Krueger (2002), and Fischer, Kohler, and Seitz (2004).

"The end of the cash era." (*The Economist* 2007, cover page)

Insofar as we did think along these lines—i.e., that cash holdings would continue to decline, relative to GDP—we were wrong. In section 2 of this paper we show that, in many developed economies, currency usage (as a percentage of GDP) stopped falling in the mid-1980s/early 1990s, and in a number of countries then began to rise.

Almost all of the alternative transaction technologies are bank mediated, i.e., check payments, debit/credit cards, etc. Banks can, and do, fail, whereas the liability of the government remains valid (often legal tender), e.g., for tax payment, as long as that form of government survives.[3] So, when a generalized concern for the creditworthiness of banks as a group develops, a shift from bank deposits into cash ensues, as in the United States in the Great Depression, 1929–33.

In a telling, but temporary, example of this, there was a spike in currency holdings in most, but not all, of the countries included in our analysis in 2008:Q4. This emergent panic was, however, soon halted by the aggressive, and often unconventional, monetary policies of central banks; see Bernanke (2015) and Geithner (2014). As we show in section 3, calm in this sense was soon restored, and the shift out of bank deposits into currency, i.e., a rise in the currency-to-deposit (C/D) ratio, was neither as long-lasting nor nearly as extreme as in the United States during the Great Depression in 1929–33. In a companion short paper, we shall compare developments in C/D ratios in 2008–09 with those that occurred in 1929–33, focusing primarily on the United States and the United Kingdom.

Although the effect of the 2008–09 bank crisis had mostly disappeared from our time series by 2009:Q4, this did not check the continuing upward trend in currency usage. Indeed, in several countries—e.g., the United States, Australia, South Korea, and Switzerland—this upward trend has become stronger.[4] This has

[3]Some governments also fail, owing to lost wars or revolutions, and then their paper notes become worthless, e.g., the Confederacy in the United States.

[4]An outlying example of a developed country where currency usage has continued to decline, even quite markedly, in recent years is Sweden. This is despite the fact that the central bank has introduced negative interest rates there. Sweden

practical policy relevance. The zero lower bound (ZLB) to (riskless) interest rates is caused by the ability of agents holding financial assets to switch them into zero-yielding currency notes. The recent sharp rise in currency usage, especially in high-denomination notes, is likely to be a symptom of this. We examine the developing relationship between interest rates and currency usage in section 4. Our particular focus is to examine whether the interest elasticity of demand for cash has increased as interest rates have fallen to the zero lower bound and beyond, into negative territory, i.e., whether such elasticity is potentially nonlinear.

Besides its zero-yield feature, another key characteristic of currency is that it is an anonymous, bearer, instrument. This makes it the payment mechanism of choice for those who do not want their transactions to be recorded, more widely known, and capable of being used in evidence against them. Since the black economy (illegal transactions) and the grey economy (transactions which would be legal if recorded and taxed, but are transacted anonymously by cash to evade taxation, plus some low-reputation activities) are not recorded by design, it is difficult to estimate how much of outstanding currency is held to facilitate such nefarious dealings. However, we do our best to explore this in section 5. The most vocal critic of this usage of currency, especially in the form of high-denomination notes, has been Rogoff (1998, 2015, 2016), but also see Sands (2016). Cryptocurrencies such as Bitcoin are also becoming a medium of choice for the black economy (see Wolf 2019) and could increasingly be favored over cash in activities such as blackmail, kidnapping, sanction busting, drug smuggling, etc., given that it avoids the need for physical pickup. Even though the speculative boom in Bitcoin is now past, its value has not gone down to zero, but has been quite stable over the last few months at around $3,800. One suspects this is because there is a regular clientele continuing to use it for black economy purposes.

Since the characteristics of currency cause this instrument to become the lower barrier to nominal interest rates, at a time of sluggish growth and low inflation (i.e., ZLB), and to be the transaction

provides an interesting case study, which again we shall review in a companion paper.

medium of choice both for criminality and tax evasion, it is not surprising that a cottage industry has grown up in this literature about how to abolish currency, or to change its characteristics in such a way as to mitigate these side effects. Much of this work was brought together in a 2015 conference titled "Removing the Zero Lower Bound on Interest Rates" at the Imperial College Business School where speakers included Kenneth Rogoff, Willem Buiter, Marvin Goodfriend, David Humphrey, and Miles Kimball. Also see Agarwall and Kimball (2015) and Buiter and Panigirtzoglou (2003). Our response to this was published in the Sveriges Riksbank's *Economic Review*; see Goodhart, Bartsch, and Ashworth (2016).

Our contribution here to this literature is fourfold. First, we extend the description, and analysis, of aggregate currency usage in a cross-country study by several years. Second, we are, we believe, one of the first to document the spike in currency demand in several countries caused by the financial panic in the final quarter of 2008 (post-Lehman).[5] Third, now that the zero lower bound has been reached, and in some countries transcended into negative interest rates, we revert to the question of the interest elasticity of demand for currency. Fourth, we explore further the relationship between the demand for currency and tax evasion.

2. The Recovery of Currency Usage

After falling steadily in the decades after World War II, currency usage began to stabilize as a share of GDP in a number of major countries—e.g., the United States and the United Kingdom in the mid-1980s/early 1990s—and then began to rise gradually during the 1990s (see figure 1 and table 1).

This stabilization and gradual rise came despite ongoing rapid developments in payment technologies, which should have reduced the use of notes and coins further. For example, the number of consumer transactions carried out by debit/credit cards soared during this period (see table 2). The number of card transactions has continued to rise sharply in the post-financial-crisis period, with data showing that card payments per capita increased from 62.5 and

[5] Cusbert and Rohling (2013) did this exercise for Australia, and Bartzsch and Seitz (2015) did so for Germany.

Table 1. Changes in Currency-to-GDP Ratios (%)

	United States	United Kingdom	Euro Zone	Japan	Australia	Canada	Sweden	Switzerland	Korea
1970:Q1–1980:Q1	−13	−38	—	13	2	−15	—	2	0
1980:Q1–1990:Q1	0	−36	−10	13	−3	−10	−18	−33	−29
1990:Q1–1999:Q4	33	4	2	46	18	20	2	−4	−19
1999:Q4–2007:Q4	2	7	30	26	−8	−6	−21	−6	−4
2007:Q4–2016:Q1	43	28	52	25	21	23	−54	93	110

Sources: Ashworth and Goodhart, Federal Reserve Board, U.S. Bureau of Economic Analysis, Bank of England, Office for National Statistics, European Central Bank, OEF, Bank of Japan, Cabinet Office of Japan, Reserve Bank of Australia, Australian Bureau of Statistics, Bank of Canada, Statistics Canada, Statistiska Centralbyran, Sveriges Riksbank, State Secretariat for Economic Affairs, Swiss National Bank, Bank of Korea.
Note: For Switzerland, we used bank notes in circulation data for the periods 1970:Q1–1980:Q1 and 1980:Q1–1990:Q1.

Table 2. Per Capita Use of New Payment Instruments

	Debit Cards		Credit Cards	
	1987	**1999**	**1987**	**1999**
United States	0.42	27.5	29.55	68.94
United Kingdom	0.00	35.3	9.19	25.10
France	9.69	48.6	0.05	N/A
Germany	0.01	5.2	0.62	4.00
Italy	0.00	4.3	0.22	3.80
Japan	0.01	N/A	2.88	6.51
Canada	0.01	54.3	27.16	37.50
Sweden	3.21	22.2	1.79	6.40

Source: Drehmann, Goodhart, and Krueger (2002).

140.3 in the euro zone and the United Kingdom in 2010, to 80.1 and 201.4, respectively, in 2014; see European Central Bank (2015). In the United States, card payments (credit plus debit) per capita increased from 191 in 2009 to 233 on the latest available data for 2012; see Board of Governors of the Federal Reserve System (2013).

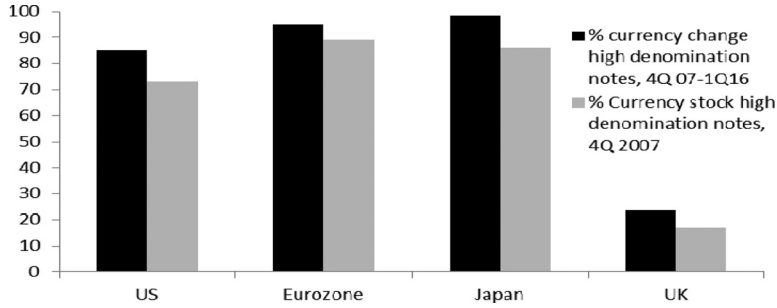
In most developed countries, currency usage declined or rose modestly in the pre-crisis decade, although the euro zone was the major outlier, perhaps due to the fact that the euro's introduction much increased its international attraction as a store of value.[6] Currency usage in Japan also continued to rise quite briskly, a continuation of the trend (albeit at a slower pace) since the slowdown in the economy after the bursting of its real estate bubble in the early 1990s. Key drivers likely were the lower interest rate (which has been close to zero since late 1995), falling prices, and concerns about the stability of banks. There was a particularly sharp jump in its currency-to-GDP ratio in the early part of that decade amid the ongoing banking crisis, although the currency-to-GDP ratio broadly flatlined in the immediate years before the Great Financial Crisis (GFC).

[6]There were particularly large gains in currency in circulation in Finland, France, and Germany, although it is not clear why this was the case, as a euro printed in one country is treated identically to one printed in another.

Subsequently, currency usage has been more generally rising, indeed quite sharply and consistently in most countries since the onset of the GFC. Our broader data set consists of 36 countries (OECD plus the BRIC countries), representing over three-quarters of global GDP when measured at purchasing power parity, and runs to 2016:Q1. We plan to revisit this analysis in a couple of years' time when we have an additional five years of data to utilize. Strikingly, 40 percent of countries still had declining currency-to-GDP ratios in the pre-crisis period between 1999:Q4 and 2007:Q4. The largest fall was recorded by Norway at −37 percent, followed by Spain, China, and Sweden at −36 percent, −26 percent, and −21 percent, respectively. Nevertheless, the median increase in the currency-to-GDP ratio of all countries during this period was 8.9 percent, with lower and upper quartiles of −5.9 percent and 31.1 percent, respectively. In the post-crisis period between 2007:Q4 and 2016:Q1, just five countries (14 percent of our sample) had a declining currency-to-GDP ratio. These were Sweden, Norway, China, South Africa, and Brazil, with all but the last previously having declining currency-to-GDP ratios in the pre-crisis period. Sweden registered the largest fall at −54 percent, followed by Norway and China at −12 percent and −11 percent, respectively. The other major Scandinavian country, Denmark, was also initially on course to have a declining currency-to-GDP ratio in the post-crisis period, until currency holdings began to accelerate since the introduction of negative rates in late 2014. The median increase in the post-crisis period was 38 percent, with the lower and upper quartiles at 19.2 percent and 60.9 percent, respectively. The OECD countries recorded a median increase of 50 percent, with the lower and upper quartiles at 25.1 percent and 64.9 percent, respectively. The largest increases in the post-crisis period were Greece, South Korea, Iceland, and Switzerland at 164 percent, 110 percent, 121 percent, and 93 percent, respectively.

As a result of the sharp rise since the financial crisis, the average amount of currency holdings per working-age individual has risen to $8,806 (Japan), $5,500 (United States), $4,106 (euro zone), and $1,907 (United Kingdom) at current market exchange rates. This represents real terms increases of 66 percent, 57 percent, 112 percent, and 56 percent since the beginning of the century. Note, large overseas holdings of the U.S. dollar (see Judson 2012) and the euro exaggerate the amount of currency held domestically per

Figure 2. High-Denomination Notes Have Been the Key Drivers of the Increase in Currency Holdings



Sources: Ashworth and Goodhart, U.S. Department of Treasury's Bureau of the Fiscal Service, U.S. Federal Reserve Board, European Central Bank, Bank of Japan, Bank of England.
Note: United States = $100; euro zone = €500, €200, €100, €50 notes; Japan = ¥10,000; United Kingdom = £50.

working-age individual in these regions. Nevertheless, even adjusting for that, the amounts per head still appear extremely large.

The rise in currency usage, and particularly sharp gains since the GFC, has been driven by a sharp increase in high-denomination notes (see figure 2). Of the 78 percent, 58 percent, 17 percent, and 55 percent increase in currency in circulation in the United States, the euro zone, Japan, and the United Kingdom since the beginning of the GFC, 85 percent (73 percent of stock in 2007:Q4) ($100 bill), 95 percent (89 percent of stock in 2007:Q4) (€50, €100, €200, and €500 notes), 98.5 percent (86 percent of stock in 2007:Q4) (¥10,000 note), and 23.7 percent (16.9 percent of stock in 2007:Q4) (£50 note) of the increase has come from the highest-denomination notes. However, the value of the very highest euro denomination note (€500) in circulation has declined by almost 8 percent since December 2015. This appears to be related to the increased spate of media stories linking it to use in crime and financing terrorism; see Brunsden and Spiegel (2016), Europol (2015), Kay (2015), and Sands (2016). In May 2016, the European Central Bank announced that it would end issuance and production of the note by the end of 2018.

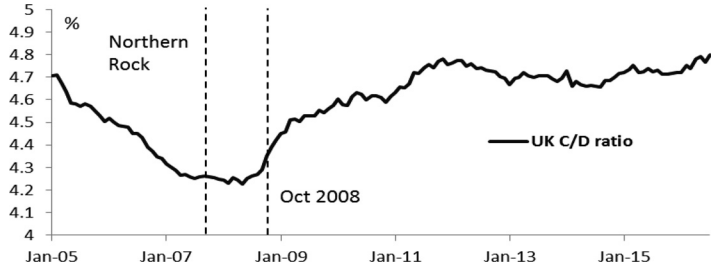
3. Measuring Public Panic in the Great Financial Crisis

Monetary authorities around the world did learn from the bitter experience of the United States in 1931–33 that it should be their responsibility and duty to halt banking panics and to prevent the collapse of the banking system. As then Federal Reserve Governor Ben Bernanke remarked at a conference speech in honor of Milton Friedman (Bernanke 2002): "Let me end my talk by abusing slightly my status as an official representative of the Federal Reserve. I would like to say to Milton and Anna: Regarding the Great Depression. You're right, we did it. We're very sorry. But thanks to you, we won't do it again." Indeed, central banks supported the financial system in several ways during the Great Financial Crisis. In particular, they injected massive extra liquidity into the banking system and reduced interest rates toward the zero lower bound, followed by more quantitative easing (see Ashworth 2013, Bank for International Settlements 2016, and International Monetary Fund 2013); they widened and eased access to their lender-of-last-resort facilities and, where short-term markets became dysfunctional, they became market makers of last resort; and, in conjunction with the fiscal authorities, they prevented, after the collapse of Lehman Brothers, any further failures of large, systemically important banks.

This strong response, which is by now well documented, meant that the initial panic was relatively short-lived. In order to capture its onset, duration, and intensity, one ideally needs monthly data. Our metric here is changes in the C/D ratio. We use data for the levels and the monthly and three-month-on-three-month changes in these ratios for a selection of developed countries (see figures 3–8). The main countries/regions we focus on are the United States, the United Kingdom, and the euro zone; data for Canada, Australia, New Zealand, Sweden, and Japan are available separately from the authors.

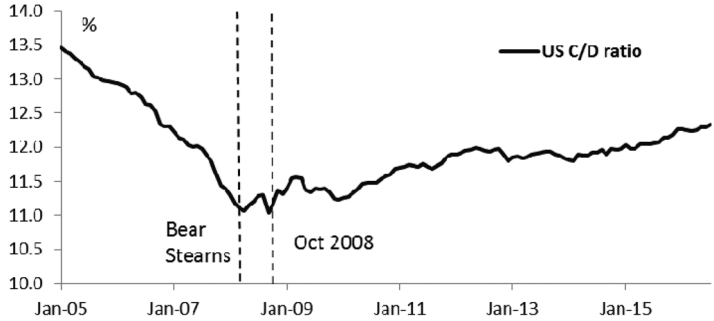
For the United Kingdom, the monthly percentage change in the C/D ratio in October 2008 (seasonally adjusted) is relatively large, at 1.5 percent, but, as can be seen from figure 6, this is not that much greater than some other large monthly changes in what is a quite volatile series. There were, however, a number of other months around that date when there were other sizable increases in the C/D ratio, so the three-month-on-three-month percentage change does

Figure 3. U.K. Currency-to-Deposit Ratio



Sources: Ashworth and Goodhart, Bank of England.

Figure 4. U.S. Currency-to-Deposit Ratio

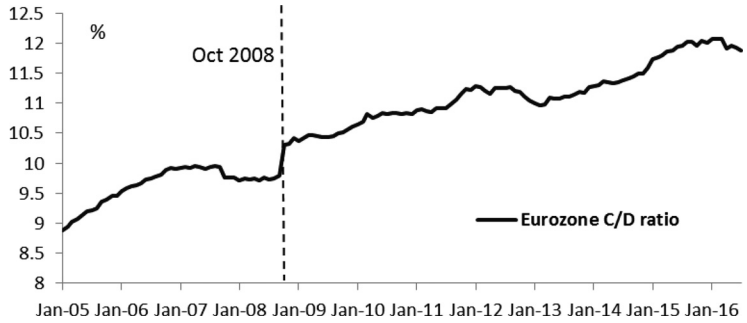


Sources: Ashworth and Goodhart, U.S. Federal Reserve Board.

rise to a clear peak of 2.7 percent in December 2008. In the United Kingdom there had been an earlier concern with the safety of bank deposits on the occasion of the run on Northern Rock bank in September 2007; as highlighted in figures 3 and 6, however, the response of the C/D ratio to the financial disturbances in September/October 2008 is far greater than in September/October 2007. Indeed, there was little change in the C/D ratio in response to the Northern Rock incident, perhaps because it was seen as a small, regional bank, having only around 2 percent of aggregate retail deposits, whose problems were largely idiosyncratic, and with few systemic implications.

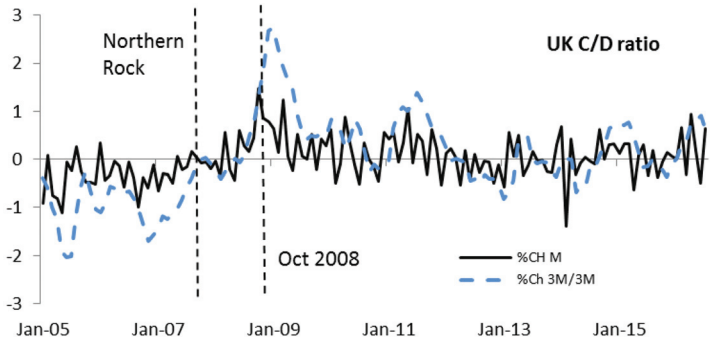
There is an exactly similar break in the downward trend in the C/D ratio in the United States (figure 4), although the reversal is

Figure 5. Euro-Zone Currency-to-Deposit Ratio



Sources: Ashworth and Goodhart, European Central Bank.

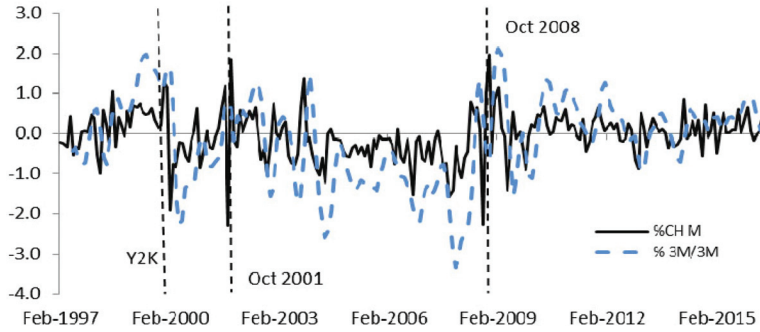
Figure 6. Changes in U.K. Currency-to-Deposit Ratio



Sources: Ashworth and Goodhart, Bank of England.

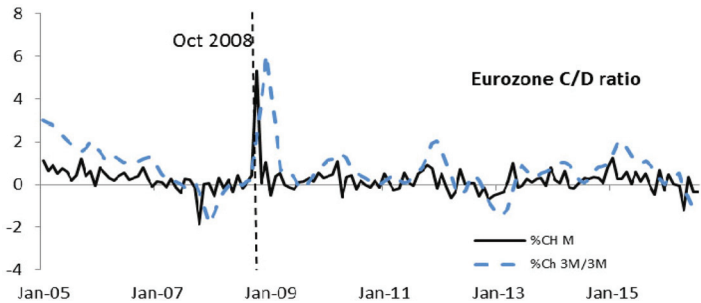
not as sharp as in the United Kingdom. There is some indication of an earlier increase in the C/D ratio in the aftermath of the rescue of Bear Stearns in March 2008, but this appears to have been decisively reduced in September, perhaps in relief after the rescue of the two government-sponsored enterprises, Fannie Mae and Freddie Mac. Then there is a whole series of months, until about March 2009, with large percentage changes in the C/D ratio, so that the three-month-on-three-month change rises to a local peak of 2.1 percent in February 2009 (figure 7). We extended the chart showing the percentage monthly and three-month-on-three-month changes in the United States back to 1997, to illustrate the jumps in December 1999

Figure 7. Changes in U.S. Currency-to-Deposit Ratio



Sources: Ashworth and Goodhart, U.S. Federal Reserve Board.

Figure 8. Changes in Euro-Zone Currency-to-Deposit Ratio

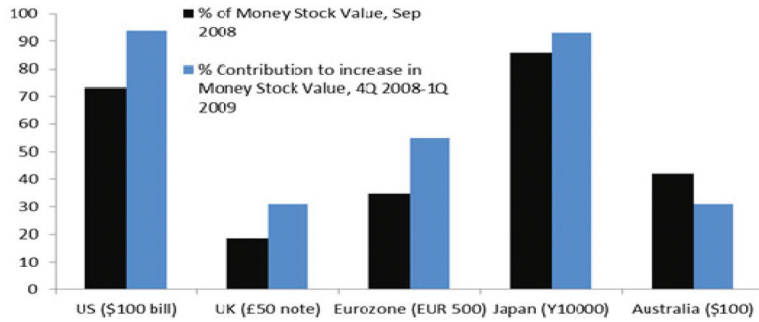


Sources: Ashworth and Goodhart, European Central Bank.

and January 2000, amid the Y2K scare, and its immediate reversal in February 2000. There is also a sharp increase in October 2001, perhaps in response to the September 11 terrorist attacks.

Unlike the United Kingdom and the United States, the C/D ratio in the euro zone had been trending upward, prior to the GFC, most likely due to the euro's greater use as a store of value internationally beyond the boundaries of the European Union (EU). This upward trend had slackened, however, by late 2006/07 (figure 5). Then in October 2008, there was a marked, sharp increase in the C/D ratio,

Figure 9. Contribution of High-Denomination Notes to Change in Money Stock Value in Various Countries, 2008:Q4–2009:Q1



Sources: Ashworth and Goodhart, U.S. Department of Treasury's Bureau of the Fiscal Service, Bank of England, European Central Bank, Bank of Japan, Reserve Bank of Australia.

of no less than 5.3 percent (figure 8). This was, however, a one-time occurrence, with no subsequent reversal but no continuation.

Whereas the short-lived shift out of deposits into currency was clearly apparent in the United Kingdom, the United States, and the euro zone, it was less so in other developed countries.

Meanwhile, this shift into currency was primarily driven by a sharp, but temporary, increase in the holdings of the highest-denomination notes (see table 3 and figure 9), providing some support to the view that it was driven by an incipient panic rather than an interest rate effect. In the United States and the United Kingdom, the holdings of $100 and £50 notes increased by 3.5 percent in both countries in October 2008, which represented 14- and 6-standard-deviation increases, respectively, relative to the average of comparable months in previous years. In 2008:Q4 and 2009:Q1, the holdings of $100 and £50 notes increased by approximately four to five standard deviations of the typical rise in those quarters over recent history. There was very little evidence of a consistent pickup in note holdings at lower denominations in either country in response to the crisis, although in October 2008 there were quite strong increases in the demand for $50 and £20 and £10

Table 3. Change in High-Denomination Notes in Circulation during the Financial Crisis

		Oct. 2008 %M	SDs from Average	2008:Q4 %Q	SDs from Average	2009:Q1 %Q	SDs from Average
United States	$100	3.5%	14.2	7.0%	5.1	2.8%	4.4
United Kingdom	£50	3.5%	5.6	7.6%	3.5	3.2%	5.2
Euro Zone	€500	10.1%	9.7	12.1%	1.7	2.4%	−0.2
	€200	7.2%	74.8	7.1%	2.5	0.5%	2.5
	€100	5.7%	22.7	11.3%	2.7	−0.9%	1.4
Japan	¥10,000	1.6%	3.5	7.7%	−0.5	−5.4%	−0.2
Australia	AUD $100	3.5%	5.8	7.2%	13.8	1.8%	3.9
New Zealand	NZD $100			17.0%	7.0	−2.6%	2.8

Sources: Ashworth and Goodhart, U.S. Department of Treasury's Bureau of the Fiscal Service, Bank of England, European Central Bank, Bank of Japan, Reserve Bank of Australia, Reserve Bank of New Zealand.
Notes: Data are non-seasonally adjusted. For the calculating of the standard deviations from averages, we used the last five corresponding readings, e.g., for 2008:Q4 we used 2007:Q4, 2006:Q4, 2005:Q4, 2004:Q4, and 2003:Q4. For the United Kingdom, we only had four years of data prior to 2008.

notes.[7] For the period of elevated financial market stress, 2008:Q4–2009:Q1, $100 and £50 notes accounted for 94 percent and 31 percent of the increase in the money stock, despite representing a far lower proportion of overall money holdings. In the euro zone, in addition to quite a significant pickup in €500 notes in circulation, there was also a significant increase in both €200 and €100 notes in circulation over 2008:Q4 and 2009:Q1 (see table 3). Holdings of €500, €200, and €100 notes represented 80 percent of the increase in money stock between 2008:Q4 and 2009:Q1, despite representing around 57 percent of the stock in money holdings. There was not much evidence of a consistent pickup in demand for lower-denomination notes over the six-month period, although there was a sharp pickup in demand for €20 and €50 notes in October 2008.

4. Relationship between Interest Rates and Currency Usage

Since the work of Baumol (1952) and Tobin (1956), virtually all studies of the demand for currency have incorporated a measure of the scale of transactions, e.g., consumption or GDP, a short-term interest rate, and, usually, some statistic to represent trend innovation in transaction technology, e.g., usage of automated teller machines (ATMs) and plastic (credit and debit) cards. The econometric techniques have become more sophisticated, from simple regression analysis (e.g., Becker 1975, Dotsey 1988), to cointegration analysis (Drehman, Goodhart, and Krueger 2002; Fischer, Kohler, and Seitz 2004), to vector error-correction models (Bartzsch and Seitz 2015; Bartzsch, Seitz, and Setzer 2015). For an application of VECM techniques to a less-developed economy, see Nachane et al. (2013).

But the general findings have remained rather stable, with a transaction demand for currency nearer unity, rather than the value

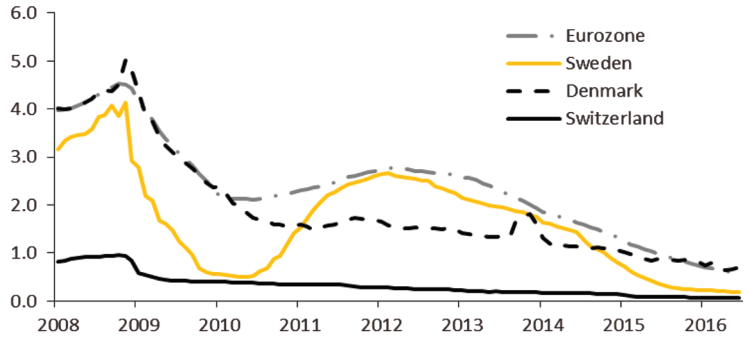
[7] In their analysis of consumer cash usage, Bagnall et al. (2014) did not observe any unusual developments in the usage of low-denomination notes in the seven countries in their study in 2008–09.

of 0.5 suggested by Baumol and Tobin, and an interest elasticity that is negative and usually significant, but rather lower than had been expected. There is a common chorus remarking on its relatively low level, e.g., Alvarez and Lippi (2007, p. 34); Bartzsch and Seitz (2015, p. 37); Becker (1975, p. 69); and Briglevics and Schuh (2014, pp. 22–23). An issue of more discussion and debate is whether the market and demand for high-denomination notes, for hoarding at home or abroad, differs significantly from that for low-denomination notes, purely for transactions and, if so (and it is generally agreed that they do differ), whether the interest elasticity is much greater in the case of high-denomination notes. Drehmann, Goodhart, and Krueger (2002, p. 197) are among those who agree that "there are two separate markets (needs) for currency, although the precise dividing lines between them are fuzzy," but, in their econometric work, do not find differing interest elasticities; see table 5, p. 209. In contrast, Amromin and Chakravorti (2009, table 5, panel B, p. 329) and Fischer, Kohler, and Seitz (2004, section 4.2.2) do find that, whereas large bank note holdings have a significant negative interest elasticity, small note holdings do not. The general consensus now is that the interest elasticity of demand for high-denomination notes is absolutely greater (negative) and more significant than for low-denomination notes.

We do not aim to revisit this latter question of the distinction between the interest rate elasticity on high- and low-denomination note holdings here. Instead, our focus is whether the interest elasticity might increase as interest rates decline toward the ZLB or, in some instances, even below.

There is no strong reason to assume a linear relationship between the level of interest rates available on bank deposits, and on other liquid assets, and the demand for currency. Briglevics and Schuh (2014, pp. 25–26 and figure 5) suggest that the interest elasticity of currency demand might rise at low levels of interest rates. Indeed, commercial banks, up until now, have been reluctant to impose negative interest rates on retail bank deposits (particularly for households) (see figure 10), partly for fear of a mass exodus out of deposits into cash, but as the nominal return on deposits and other liquid assets approaches (and perhaps moves below) zero, it is perfectly possible that the absolute value of the interest elasticity of currency demand might rise, perhaps very sharply so.

Figure 10. Interest Rates on Household Deposits at Commercial Banks, %*



Sources: Ashworth and Goodhart, European Central Bank, Swiss National Bank.
*Deposits with agreed maturity less than two years outstanding. Interest rates on savings deposits for Switzerland.

The relationships between changes in cash holdings and changes in interest rates vary from country to country; charts on this relationship for Australia, Denmark, the euro zone, Sweden, Switzerland, and the United Kingdom are separately available from the authors. We exclude Japan from our analysis since the official target rate has been near the ZLB throughout the period under review; the United States is also excluded since over half of its currency is held abroad (see, for example, Judson 2012). In Denmark, Switzerland, and to a lesser extent the euro area, there appears to be a reasonably strong inverse relationship between changes in official interest rates and current and subsequent changes in the percentage growth of currency outstanding. Admittedly, at times there have been large moves in currency in circulation not caused by changes in interest rates, and it is likely to have been the panic caused by the financial crisis that drove the sharp jump in currency demand in 2008 and 2009 rather than the collapse in interest rates per se. Similarly, the intensification of the euro crisis over 2011 and 2012:H1 is likely to have been a factor driving currency holdings higher in some countries. Nevertheless, as banking-related worries have subsided, as the euro-zone economy has recovered over the past couple of years, cash holdings have still risen quite sharply in all three regions as interest

rates have moved into negative territory.[8] In Sweden, no such relationship can be observed. While the initial move there into negative interest rates appears to have caused a temporary hiatus in the pace of decline of currency holdings, the sharp structural downtrend appears to have subsequently resumed.

In order to attempt to quantify these bilateral relationships more precisely, we used regression analysis. We initially considered regressing the monthly change in currency in circulation against its lagged value and lagged changes in official short-term central bank policy rates. But in an attempt to identify the sensitivity of currency demand by the general public to changes in interest rates somewhat more accurately, we used actual interest rates on household deposit accounts at commercial banks. Indeed, using official interest rates, many of which have gone negative, could underestimate the impact (potentially nonlinear) on the currency demand of the general public from negative interest rates. This is because in almost all cases commercial banks have yet to move interest rates into negative territory on household deposit accounts.[9] In our equation (see below) we used the contemporaneous value of the interest rate on household deposits rather than the lagged value. This is because changes in interest rates on household deposits typically lag changes in official interest rates by around one month, and there might be some level of anticipation of forthcoming changes.

We attempted to test for nonlinearity (changes in the sensitivity of currency demand to changes in interest rates) in three main ways. First, in our full-sample regressions we included a squared measure of the distance between the contemporaneous interest rate and the lowest level reached. A positive and significant coefficient would indicate the presence of nonlinearity. Second, we also ran the regressions over three subperiods: (i) pre-crisis[10] (beginning of 2003

[8]In Australia and the United Kingdom, where interest rates are still positive, currency in circulation has been growing quickly, particularly in the former. Australian interest rates have been coming down quite sharply in recent years, from almost 5 percent in 2011 to just 1.5 percent at present.

[9]In some countries commercial banks have imposed negative deposit rates on nonfinancial corporations, and in Switzerland negative rates have been applied on household accounts focused on individuals with higher net worth.

[10]Caution must be exhibited with our pre-crisis estimates for the euro zone and Sweden due to limited sample sizes. For the euro zone, we began the sample in

to 2008:M6); (ii) post-crisis (2009:M7 to 2016:M1); and (iii) since *official* interest rates hit the zero lower bound in the respective countries (this is yet to occur in Australia and the United Kingdom). We used the zero bound instead of the point that interest rates went negative because in some countries official interest rates have not been in negative territory long enough to generate a significant enough sample size. We wanted such a subsample because we suspected a priori that the media attention around a move in rates to zero/negative would likely focus the attention of the general public on the low and declining rates (even though actual interest rates on household deposits have yet to hit zero or turn negative) and could potentially fuel nonlinear changes in currency demand. Third, we also ran various rolling regressions in the post-crisis period. The general form of the equation was

$$\%\ \mathrm{d}\ \mathrm{curr}_{\mathrm{t}} = a + b\ \mathrm{d}\ \mathrm{curr}_{\mathrm{t-i}} + c\ \mathrm{d}\ \mathrm{int}_{\mathrm{t}} + \gamma(\mathrm{int}_{\mathrm{t}} - \mathrm{int/low})^2 + \varepsilon_{\mathrm{t}}. \tag{1}$$

In table 4, we show the coefficient on the change in interest rates and its p-value and for the full sample we also show the coefficient on the squared term, its p-value, and the adjusted R2. We included a dummy variable, where appropriate, for the GFC and extremely sparingly when there were other large seemingly inexplicable changes. Our regressions were run in levels rather than logs. This is because we would not have been able to include the squared term to test for nonlinearity, as the term is zero when interest rates are at the minimum (natural log of zero is undefined). The coefficients on interest rates in Australia, the euro zone, Switzerland, and the United Kingdom have the correct sign over the full sample, with Australia significant at the 1 percent level, Switzerland and the United Kingdom significant at the 5 percent level, and the euro zone insignificant. The coefficients on Denmark and Sweden have the incorrect signs and are not statistically significant. The squared terms are statistically insignificant or have the wrong signs.

2006:H2 because before that, currency usage had been trending strongly higher due to the euro's increased use as a storage of value after the introduction of notes and coins in 2002. In Sweden, the data on deposit rates only started in September 2005.

Table 4. Relationship between Changes in Interest Rates on Household Deposits and Currency Demand

	Full Sample		Squared Term		Adjusted	Pre-crisis		Post-crisis		Since Zero Rates	
	Coeff.	P-Value	Coeff.	P-Value	R^2	Coeff.	P-Value	Coeff.	P-Value	Coeff.	P-Value
Australia	−0.051	0.00	0.000	0.88	0.38	−0.027	0.43	−0.058	0.00	—	—
Denmark	0.018	0.23	−0.001	0.01	0.38	0.040	0.14	−0.018	0.42	−0.017	0.59
Euro Zone	−0.002	0.84	0.000	0.41	0.71	0.089	0.04	−0.028	0.13	−0.170	0.02
Sweden	0.005	0.46	0.000	0.85	0.12	0.011	0.41	−0.003	0.76	−0.047	0.37
Switzerland	−0.018	0.04	−0.003	0.17	0.49	0.005	0.72	−0.031	0.03	−0.037	0.00
United Kingdom	−0.009	0.04	0.000	0.97	0.20	−0.009	0.38	0.010	0.28	—	—

Sources: Ashworth and Goodhart, Reserve Bank of Australia, European Central Bank, Swiss National Bank, Bank of England, Statistika Centralbyran, Sveriges Riksbank, Danmarks Nationalbank.
Notes: Interest rates are on the following: deposits with agreed maturity less than two years for Denmark, Sweden, and the euro zone; savings deposits for Switzerland (we used savings deposits because of the lack of historical data on sight deposits prior to 2008); sight deposits for the United Kingdom; retail deposit and investment rates; savings accounts; bank's bonus savings accounts for Australia. Our full-sample period was from early 2003 until January 2016. For the euro zone, we began the sample in 2006:H2 once the surge in euro-area currency holdings after the introduction of euro notes and coins had begun to settle down somewhat. Swedish data only begin in September 2005. The pre-crisis period was the period to the end of 2008:H1, while the post-crisis period was from 2009:H2 onward. "Since Zero Rates" reflects the point at which official central bank interest rates reached zero. The relevant rate for the euro zone was the deposit rate.

Comparing the pre-crisis and post-crisis periods, only Australia and the United Kingdom have the correct sign in the pre-crisis period, and both are statistically insignificant. In the post-crisis period, the coefficient on interest rates in all countries has the correct sign, except for the United Kingdom.[11] But only the coefficients on Australia and Switzerland are statistically significant. In the period since official interest rates hit zero in Denmark, the euro zone, Sweden, and Switzerland (they have yet to do so in Australia and the United Kingdom), the coefficients all have the correct signs, and the absolute magnitude of the coefficients has increased in three of the four countries (significantly so in the euro zone). The relationship also appears to have turned statistically significant in the euro zone.

Running various rolling regressions for the post-crisis period, we found that the Swiss deposit rate on savings had the correct sign from June 2013 onward but only became statistically significant in February 2015, at which point the negative coefficient on deposit rates increased by a multiple of almost 10. There was quite a large increase in the adjusted R2 too at this point. The Swiss National Bank had cut its official rate from 0 percent in November 2014 to −0.25 percent in December and −0.75 percent in January 2015, but savings rates had only experienced rather modest declines of 0.02 percent and 0.03 percent in January and February 2015 and still remained at 0.1 percent (not significantly lower than the 0.15 percent at which they ended 2014). However, interest rates on time deposit accounts with at least CHF 100,000 fell sharply into negative territory in January 2015 (rates on three-month deposits fell from 0.02 percent in December 2014 to −0.11 percent in January 2015 and −0.13 percent in February 2015),[12] suggesting that it may have been the decisions of individuals holding these accounts that was responsible for the big jump in the elasticity of currency demand.

In the euro zone, while the coefficient on interest rates has had the correct sign in the whole post-crisis period since July 2009, the

[11] One issue affecting the U.K. result may be the fact that there have been very few changes in *official* interest rates in the post-crisis period.

[12] There were similar declines for 1-month, 6-month, and 12-month time deposits.

coefficient has typically not been statistically significant when beginning with a 24-month window and extending forward the end date by one month. However, the coefficient has had the correct sign (with a very significant increase in magnitude) and has been statistically significant (primarily at the 5 percent level of significance) for the whole time since official interest rates became zero in July 2012, with the adjusted R2 in this period ranging from 23 percent to 51 percent. Indeed, the coefficient on interest rates became consistently statistically significant in December 2011 (when looking over the whole period to 2016:M1), which coincided with back-to-back reductions of 25 basis points in official interest rates, from 0.75 percent in October 2011 to just 0.25 percent in December 2011.

In Australia, the relationship between deposit rates and currency changes appears to have strengthened since late 2012 as the rate-cutting cycle has progressed further, with the average coefficient on interest rates of −0.0965, almost double the sample period as a whole (with the coefficients statistically significant). In Sweden, the coefficient on interest rates has taken on the correct sign in the post-crisis period, and the coefficient has increased significantly as interest rates have declined further and moved into negative territory. However, the coefficient has not been statistically significant.

Overall, the data tend to show a fairly clear negative relationship in most of the countries under our analysis between changes in interest rates and currency in circulation, although Sweden appears to be a key outlier. The negative relationship appears to have become more prominent in the post-crisis period, particularly as interest rates have moved yet lower and reached the zero bound. Indeed, the magnitude of the elasticities has typically risen since countries reached the zero lower bound (and approached it in Australia's case), markedly so in some instances. As yet, interest rates on household deposits have not typically moved into negative territory, so it is a little difficult to gauge whether there would be a large nonlinear change if that were to occur across the board at commercial banks. The big jump in the interest elasticity in Switzerland in February 2015, as interest rates on accounts aimed at higher-net-worth individuals moved sharply into negative territory, provides some tentative evidence that it could happen.

5. Grey Economy/Black Economy

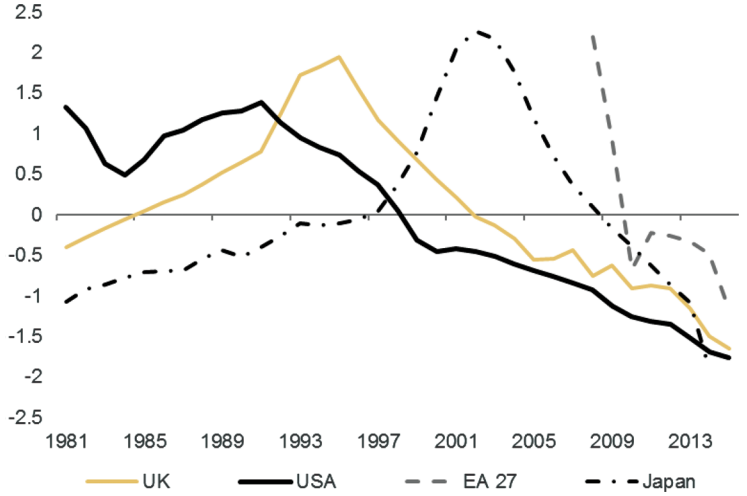
An important determinant of the upward trend in currency usage in recent decades in most advanced economies is, therefore, the continuing decline in nominal interest rates. But neither our estimates of the relevant interest elasticities in section 4 nor those of others who have studied this subject would suggest that it can explain all, or even most, of that increase, particularly at a time when the continued shift to more advanced payments techniques, e.g., over the Internet/mobile phones, has continued and should be pushing down further on currency in circulation and the currency-to-GDP ratio. Moreover, the short-term panic blip in the C/D ratio at the end of 2008 (see section 3) soon subsided.[13]

So, there must be something else as well. The most likely answer is a continuing rise in the use of anonymous currency to hide transactions from prying eyes, e.g., of police and tax collectors. This is given further credence by the fact that most of the rise in currency usage is represented by high-denomination notes (see section 2), rather than the lower-denomination notes which are more generally used in regular transactions and are made available in ATMs.

Rogoff (2016) provides very interesting anecdotal evidence in support of his view of a fast-growing shadow economy (both the black and grey economies) over recent years, but doesn't provide much empirical or quantitative evidence. The black economy is defined as consisting of illegal activities, e.g., organized crime, drug trafficking, while the grey economy is defined as otherwise legal activities that are deliberately not recorded in order to avoid or evade taxation. Official national crime data actually reveal large falls in crime in the United States, the euro area, the United Kingdom, and Japan over recent decades (see figure 11). This would appear to suggest that the black economy may have been contracting over recent years or, certainly at a minimum, it may not have been growing sharply with a consequent rise in cash usage. Admittedly, there is significant uncertainty, and traditional surveys of crime may struggle

[13]Admittedly, the panic-driven surge into cash was extremely large in several smaller economies at the epicenter of the financial crisis—e.g., Greece, Iceland, Ireland, and Spain—with gains in currency in circulation of between one-fifth and one-third between September 2008 and March 2009 alone.

Figure 11. International Crime Statistics (normalized in Z-scores)



Sources: Ashworth and Goodhart, U.S. Federal Bureau of Investigation, Uniform Crime Reports, prepared by the U.S. National Archive of Criminal Justice Data, Crime Survey for England and Wales, U.K. Office for National Statistics (ONS), Eurostat, National Police Agency of Japan.
Note: For comparability purposes we have normalized the data for the four countries by subtracting from each reading its mean and dividing by the standard deviation.

to keep up with the rapid growth in new areas, e.g., cyber crime, which has been rising.[14] Further research is needed in this area. In general, it is our belief, without wanting to take a particularly strong stand on the directionality of the black economy, that the main driver of growth in the shadow economy over recent years has been the grey economy, amid depressed demand for labor from traditional firms in the aftermath of the Great Financial Crisis, rising tax rates as governments tried to repair their damaged finances, and the continued rise in less traditional forms of working, e.g., self-employment, zero-hours contracts, part-time work, etc.

The currency demand approach (see in particular Schneider and Buehn 2013, especially section 3.2.4) has historically been one of

[14]It is possible that fears that bank accounts, or access to them, could be hacked might increase demand for currency.

the main methods for estimating the size of the "shadow economy" (grey plus black economy). The basic idea is that, since tax evasion is illegal, almost all grey (and black) economy transactions will be made in cash (Bitcoin and other cryptocurrencies are now also being used, particularly in the black economy), although not all transactions in the shadow economy are paid in cash (Isachsen and Strom 1985 used the survey method to find out that in Norway, in 1980, roughly 80 percent of all transactions in the hidden sector were paid in cash).

For obvious reasons, cash is almost always anonymous, whereas most other payment mechanisms leave a record. What one then can do is to estimate how much of the change in currency in circulation or the currency-to-GDP ratio is due to incomes/consumption, interest rates, technological trends, and such other variables as theory or direct observation suggest (a standard currency demand regression). One can then either take the residuals from such an equation as an estimate of the shifting shape of the hidden economy or, better, add additional variables that should be correlated with the grey economy, such as tax rates—especially value-added tax (VAT) and various excise taxes—and the ratio of the self-employed and unemployed to the total workforce. For a critique of such an approach, and a literature survey, see Kirchgässner (2016), though we do not share his enthusiasm for the survey method, which we consider to be unwarranted.[15] Also see the earlier paper by Caridi and Passerini (2001).

Earlier, the currency demand approach had been one of the most commonly used approaches, first used by Cagan (1958) and extended by Tanzi (1980, 1983), and later employed by one of us (Drehmann and Goodhart 2000, and Drehmann, Goodhart, and Krueger 2002). More recently, however, it has fallen out of favor. Perhaps the main reason for this has been the scale of the international use of the U.S. dollar, and more recently of the euro, both for transactions and for savings purposes. This makes it hard to disentangle in those

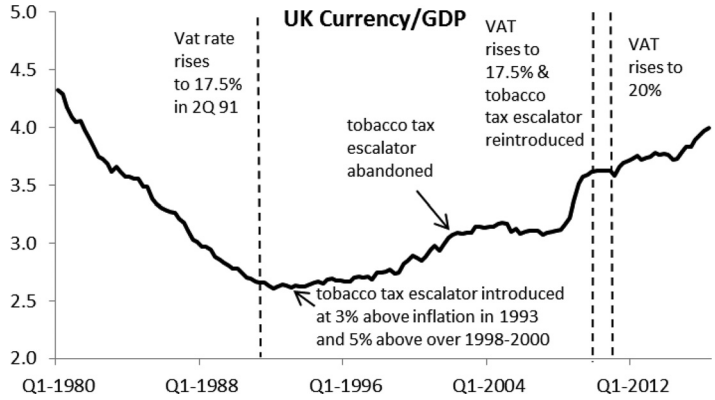
[15]In this the subjects of the survey "were first asked whether they have carried out activities in the black economy during the last 12 months. Those who affirmed that they have were asked how many hours per week they spent on these activities. They were also asked for their average wage per hour." Somehow, we are skeptical that this approach will get full and truthful answers.

instances domestic from international determinants of the demand for currency. See Fischer, Kohler, and Seitz (2004), however, for an ingenious method to try to distinguish between the demands for currency caused by (i) transactions needs, (ii) domestic hoarding, and (iii) foreign usages. For other similar methods, see Rogoff (2016).

The issues discussed above with estimating the drivers of currency usage are not, however, such a problem in the case of the United Kingdom, as sterling notes are not unduly held, or usable, abroad. Moreover, black (illegal) transactions are largely undertaken in high-denomination notes (such as €500 or CHF 1,000), and the highest U.K.-denomination note (£50) is of commendably low value. The £50 note was introduced on March 20, 1981 and is a very low-denomination note compared with those available in the euro and Swiss franc (at current exchange rates, a £50 note would buy about €58 and CHF 63). Meanwhile, there is little evidence to suggest that the size of the *black* economy in the United Kingdom has been increasing over recent years, with crime falling over recent decades (see figure 11). The number of recorded offenses in England and Wales has declined by around two-thirds since the peak in 1995 and has continued to decline since the financial crisis despite the deep and extended recession in the United Kingdom.

In contrast, we believe that the *grey* economy has been expanding quite rapidly over recent years in the United Kingdom. Why do we think that? Of course, we cannot be sure, because the grey economy's rationale is largely to evade tax, especially VAT, national insurance contributions (NICs), pay-as-you-earn (PAYE) and excise duties, and hence goes unreported. The easiest way to avoid records of taxable transactions is to mediate these via cash payments. In the last two or three decades, such tax rates have been rising sharply (see figure 12), with the rate of VAT increasing from 15 percent at the beginning of the 1990s to 20 percent at present and cigarette taxes increasing significantly above the rate of inflation during this time. The latter changes fueled a surge in cross-border smuggling of cigarettes from the European continent where comparable taxes were dramatically lower. According to the Tobacco Manufacturers' Association, by 1999 non-U.K. duty paid cigarettes represented around one-quarter of the market from just 3 percent at the beginning of

Figure 12. Indirect Taxes Have Risen Sharply in the United Kingdom over Recent Decades



Sources: Ashworth and Goodhart, Bank of England, ONS.

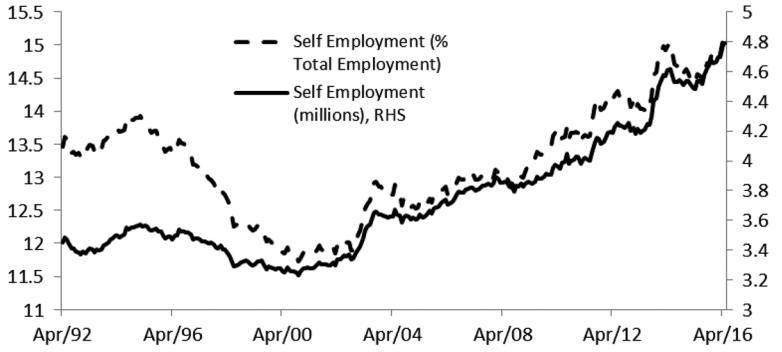
the decade.[16] Also, see *The Economist* (1999) for a brief summary of the surge in cross-channel smuggling of alcohol and tobacco into the United Kingdom.

Meanwhile, there is a general belief, which we share, that the self-employed find it easier to operate in the grey economy than those in employment. Some individuals may prefer to be in self-employment partly because of the subsequent ease of avoiding, or evading, tax on incomes and/or consumption.[17] Pissarides and Weber (1989) estimated that in the United Kingdom *actual* self-employment income is 1.55 times as much as *reported* self-employment income. Based on this they estimated that the grey economy was 5.5 percent of GDP (although they referred to the grey economy as the black economy). Cabral, Kotsogiannis, and Myles (2015) find that income reported by the self-employed in the United Kingdom must be multiplied by a factor of 1.24 to obtain their true income. Using data from random tax audits by Her Majesty's Revenues & Customs (HMRC), the independent Institute for Fiscal Studies (2017) found that

[16]See http://the-tma.org.uk/tma-publications-research/facts-figures/uk-cigarette-consumption. Admittedly, the increase would not solely reflect increased commercial smuggling; some of the rise was also likely due to increased cross-border shopping and duty-free sales.

[17]Amromin and Chakravorti (2009, pp. 324–5) share this view.

Figure 13. U.K. Self-Employment



Sources: Ashworth and Goodhart, ONS.

59 percent of those reporting self-employment income were noncompliant (noncompliance includes both mistakes and deliberate underreporting), with those in the construction, transport, and hospitality sectors having the highest levels of noncompliance.

U.K. self-employment has grown very strongly over the past decade (see figure 13), particularly so in the post-crisis period (around one-third of all jobs created in the post-crisis period have been in self-employment) amid weaker demand for employees from traditional firms. Self-employment gains have been significantly greater than in other developed countries; see Goodhart and Ashworth (2014). This would seem to be consistent with a fast-growing grey economy and, indeed, the government appears to have become increasingly concerned about the threat from rising tax evasion. HMRC has launched numerous campaigns encouraging workers in sectors known for tax evasion—e.g., self-employed, building trades, Internet traders, rental property landlords, etc.—to voluntarily disclose untaxed income in exchange for reduced penalties. This also included a "Second Incomes Campaign" targeting employees of firms who pay taxes through the traditional channel for their main job but do undeclared self-employed work on the side. Meanwhile, in the 2015 Autumn Statement the government launched a call for evidence to better understand the links between "cash, tax evasion and the hidden economy" (see HMRC 2015), and in the Budget of 2018 launched a call for evidence on "cash and digital payments

in the new economy."[18] Moreover, the Taylor Review of Modern Working Practices (Taylor 2017), commissioned by the Prime Minister, recommended that the "government should consider accrediting a range of platforms designed to support the move towards more cashless transactions with a view to increasing transparency of payments, supporting individuals to pay the right tax." This was related to those who hire casual self-employed workers—for example, gardeners, window cleaners, child minders, etc.

We attempted to find some metrics that could serve as proxies for a shift of expenditures out of the recorded economy into the grey economy. We think that we may possibly have found three such metrics. The first is the ratio of self-employment to total employment, the second is the rate of VAT, and the third is the estimated proportion of U.K. cigarette consumption that was not subject to U.K. duties.[19] We used a vector error-correction model, somewhat similar to Cusbert and Rohling (2013) for Australia and Miller (2017) for the United Kingdom.[20] Our variables for seeking to explain the recent rise in currency holdings in the United Kingdom are as follows

[18]In the latter, the government noted that £50 notes are believed to be rarely used for routine purchases and are instead held as a "store of value" and that there is also a general perception that they are used for money laundering, hidden economy activity, and tax evasion. Whilst acknowledging that the value of the £50 note is low compared with other countries' highest-denomination notes, the government noted that in an attempt to tackle the hidden economy and illegitimate use of cash, some countries have removed their highest-value notes from circulation. This encouraged media speculation that the government is considering getting rid of £50 notes; see Barrett and Cook (2018). The government also noted that several countries have introduced limits on cash transactions.

[19]Much of this is bought abroad but intended for private resale in the United Kingdom. It is also possible that this variable is a proxy for a more widespread willingness to purposefully evade British indirect taxation.

[20]The VECM model in Miller (2017) was estimated over two periods: 1993:Q4–2008:Q2 and 1993:Q4–2015:Q4. The model included eight explanatory variables including consumption, bank rate, number of link ATMs per person, number of bank branches per person, self-employment, unemployment rate, exchange rate, and the number of regular payments made per person in cash. In the full-period model from 1993:Q4–2015:Q4 which included dummy variables for the financial crisis and the millennium, all variables in the model were statistically significant, except for the number of regular payments made in cash. Of the variables we shared in common, the coefficients on interest rates were almost identical, whilst the coefficients on consumption and self-employment were broadly similar. The adjusted R2 was slightly higher in Miller (2017), at 0.36.

(data are quarterly from 1992:Q4 to 2014:Q4 with forecasts made to the present date).

These are in log form:

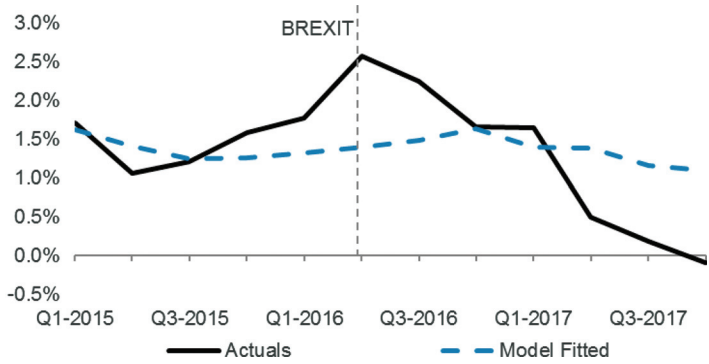
- household consumption;
- interest rate;
- self-employment as a proportion of total employment;
- VAT rate;
- the estimated proportion of U.K. cigarette consumption that has not paid U.K. duty;
- two dummies, one for Y2K and the other for the 2008–09 spike due to the financial crisis.

The resulting regression (see equation (2)), passes the Johansen test of cointegration, and all the variables have the correct signs and are statistically significant at the 5 percent level. The magnitude of the coefficient on consumption is close to unity as expected, and interest rates have a small negative sign. A 1 percent rise in the proportion of self-employed in total employment leads to a rise in currency in circulation of almost 0.7 percent; a 1 percent rise in the rate of VAT leads to a 0.4 percent rise in currency in circulation, whilst a 1 percent rise in the proportion of U.K. cigarette consumption that is non-U.K. duty paid is expected to lead to a rise of almost 0.1 percent in currency in circulation. The only dynamic variable that was statistically significant was the lagged change in currency in circulation, which we have included below.

The speed-of-adjustment coefficient has the correct negative sign and is statistically significant at the 1 percent level and suggests that more than 4 percent of the long-term disequilibrium from the steady-state level of currency in circulation is corrected every quarter. The adjusted R2 was 0.31, and the Durbin-Watson statistic of around 1.8 suggests little evidence of residual autocorrelation.

Admittedly, some caution should be exhibited. We experienced a certain amount of parameter instability in various regressions we ran, some variables we thought a priori would be significant were not, and our out-of-sample forecasts have not been particularly accurate to date (see figure 14). That said, the impact of the United Kingdom's EU referendum appears to have been an important factor driving currency movements in our out-of-sample period. The year-on-year

Figure 14. Actual versus Model-Fitted U.K. Quarterly Changes in Currency in Circulation



Sources: Ashworth and Goodhart, Bank of England, ONS, Tobacco Manufacturers' Association.
Note: For the regression we assumed that the proportion of U.K. cigarette consumption that was non-U.K. duty paid remained stable after 2014.

percentage change in currency in circulation accelerated ahead of the June 23, 2016 referendum and then surged further to peak at 9 percent year-on-year in September (which was greater than its peak in the Great Financial Crisis) amid fears about the possibility of a major financial and banking shock. However, the economic and financial impact of the vote quickly subsided and the year-on-year pace of currency increase slowed sharply and actually went negative in March 2018 for the first time in decades.

d(Currency in Circulation) (dependent)

Constant	0.012 (6.8)
Household consumption	1.121 (19.1)
Interest rate	−0.025 (−3.0)
Self-employment/employment	0.633 (2.7)
VAT rate	0.372 (4.4)
Cigarette consumption non-U.K. duty	0.057 (2.2)
d(Currency in Circulation(t−1))	0.210 (2.1)
Speed of adjustment	−0.042 (−2.9)
Adjusted R-squared = 0.31	
Standard error = 0.005	
DW statistic = 1.83	

(2)

The effect of the grey economy variables appears to be reasonably large in explaining the rise in currency in circulation over time. In the decade between 1992:Q4 (when the currency-to-GDP ratio appeared to reach a trough) and 2002:Q4, the increase in non-U.K. duty paid cigarette consumption appears to account for around a third of the increase in the currency in circulation, although there was very likely some lagged impact from the rise in the VAT rate to 17.5 percent in 1991:Q2. Since end-2007, when the currency in circulation began to accelerate sharply, the self-employment and VAT variables account for around one-fifth of the rise in the currency in circulation.

Conducting equivalent econometric exercises for other countries—e.g., U.S. dollar, euro, and Swiss franc—is complicated by the widespread use of their notes abroad, which precludes the use of the currency demand approach. Analysis of the euro area is further complicated by the large number of countries in the bloc and the vastly contrasting economic performances in the post-financial-crisis era. In the future, we aim to publish a paper examining the likely increase in the size of the grey economy in the United States. In addition, in a forthcoming paper we will conclude that an important driver behind the sharp fall in currency in circulation in Sweden over recent decades has been a *reduction* in the size of the grey economy.

6. Conclusions

Under the influence of technological improvements in payment technologies (paper checks, plastic debit/credit cards, and, later on, electronic digital payments), currency usage underwent a long, continuous trend decline in the decades following World War II. What is perhaps quite surprising is that this decline ended, and then reversed, in a number of developed countries, starting in the late 1980s/early 1990s; see sections 1 and 2. Moreover, since the aftermath of the GFC there has been a very significant rise in the currency-to-GDP ratio in most countries, with Sweden being the major outlier.

The currency-to-deposit ratio in the United States surged in 1929–33 as the public feared whether their banks were safe. There

was a similar upward blip in the C/D ratio in several major developed countries in 2008:Q4, after the failure of Lehman Brothers, but it was short-lived and reversed quickly; see section 3.

Instead, we document two main reasons for the recent rise in currency-to-GDP ratios. The first, discussed in section 4, is the sharp decline in nominal interest rates on alternative asset holdings, particularly on deposits. We reconfirm earlier findings of a significant (negative) interest elasticity of demand. Our examination of whether such elasticity increased (nonlinearly) as interest rates, e.g., on bank deposits, approached zero was somewhat inconclusive. There are some signs of this happening in the countries under our analysis, but it is too soon to be sure.

Nevertheless, the estimated effect of falling interest rates on currency demand has not been large enough to account for all of the considerable rise in the currency-to-GDP ratios in recent years. So in section 5 we turn to study whether this can be explained by its use as an anonymous means of payment in the shadow economy (black and grey economies). With crime rates falling sharply over recent decades in most major developed countries, however, we are somewhat doubtful the black economy has been growing particularly strongly, if at all.

We use a currency demand approach to test whether grey economy variables could help explain the rise in currency in circulation in the United Kingdom. This approach had been commonly applied in earlier studies but has fallen out of favor in some large part because the major currencies—the U.S. dollar and the euro—were so widely held abroad. But sterling is not subject to much foreign holding. Currencies where there are high-value denominations—e.g., the Swiss franc, euro, and dollar ($100 bill)—will also be used for black economy purposes (e.g., drugs, terror, people smuggling), but this is less likely with sterling, where the top denomination (£50) is commendably small; and the black economy has probably not grown much in the United Kingdom in recent years anyway. We establish that the currency in circulation reacts significantly to grey economy proxies, self-employment as a proportion of total employment, VAT rates, and cigarette consumption that evades tax. Hence, our work supports the view that the grey economy has likely been growing in the United Kingdom, particularly in the aftermath of the Great

Financial Crisis amid weaker labor demand from traditional firms, growth in less traditional forms of employment, and rising indirect taxes.

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