EUROPEAN CENTRAL BANK

EUROSYSTEM

Occasional Paper Series

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Catch me (if you can): assessing the risk of SARS-CoV-2 transmission via euro cash

No 259 / July 2021

Contents

Abstract

In the light of fears that the SARS-CoV-2 virus might be transmitted via cash – fears that were stoked by statements in the media and from public authorities – this paper aims to address the following issues: (1) to provide a descriptive account of the change in the circulation of euro banknotes and the use of cash in transactions during the pandemic; and (2) to assess the survivability of the virus on cash and the potential transmission risks.

The pandemic has caused a significant increase in demand for cash as a store of value but a decrease in the use of cash in transactions. Although citizens reported using cash less in transactions partly out of fear of infection, research confirms that the risk of the virus being transmitted by banknotes and coins is very low. This supports the findings from the scientific community concluding that SARS-CoV-2 mainly spreads via respiratory fluids and airborne transmission, and that surfaces play a very minor role.

Keywords: COVID-19 pandemic, SARS-CoV-2 virus, survivability, transferability, safety, banknotes, coins, cash demand, cash use

JEL codes: I10, I12, E41, E58

1 Introduction

Today, the euro is the official currency of 19 EU countries and over 340 million Europeans. It is the second most important currency in the world (European Central Bank, 2021) and the European Central Bank (ECB), together with the national central banks of the Eurosystem, are entrusted with safeguarding it.

Safeguarding in this instance means ensuring that adequate volumes of banknotes are available at all times, especially in times of crisis. This paper provides a descriptive account of the change in the euro banknote circulation and on the transactional use of cash during the pandemic. It explores the perception of citizens regarding the use of cash in the pandemic, particularly whether citizens reported that the change in their payment behaviour was due to fears of contracting the coronavirus disease 2019 (COVID-19) from contact with banknotes and coins.

Safeguarding also implies the obligation and commitment to continuously ensure that euro banknotes are safe for the public to use. This is implemented by means of stringent rules, control systems and regular checks. At the start of the COVID-19 pandemic, fears emerged – which were supported by different media and public statements – regarding the safety of cash and the role of banknotes as a contributor to the spread of the virus. Although earlier research on different viruses (avian flu and swine flu) had already concluded that using cash does not pose a significant risk, the ECB commissioned more specific research not only on the survivability of SARS-CoV-2 but even more importantly, on the potential transmission of the virus through contact with banknotes and coins – involving novel transferability testing.

With this unique research element, we are covering an area that has not been the main focus of any previous research on the SARS-CoV-2 virus, thus contributing to the academic debate. The current paper provides the results of the research conducted throughout 2020-21, together with the details of the tests performed.

This paper is structured as follows. To provide a context of the change in euro cash demand during the pandemic, Section 2 presents a description of the ECB data on cash circulation and a presentation of survey evidence regarding citizens' fears of transmission via euro cash. Section 3 presents the main results of the research programmes conducted by the ECB on the risk of transmission of the SARS-CoV-2 virus via euro cash. It also gives an overview of the systems in place to ensure that euro banknotes remain safe to use (Box 2). Finally, Section 4 presents the main conclusions.

2 How demand for euro cash has changed during the pandemic

To understand how the COVID-19 pandemic has affected the demand for cash in general, and its use for transactions in particular, it is necessary to describe recent developments in euro banknote circulation and analyse survey data on payment behaviour. This section looks at movements in euro banknote issuance and changes in consumers' payment behaviour during the pandemic. It discusses how the crisis has caused net banknote issuance to become and remain exceptionally high, indicating how strong the demand is for euro banknotes as a store of value. At the same time, however, the pandemic has reduced the demand for their use in transactions. The reasons for this decrease are also analysed, in particular whether the fear of risk of contracting COVID-19 from banknotes had a negative effect on cash payments.

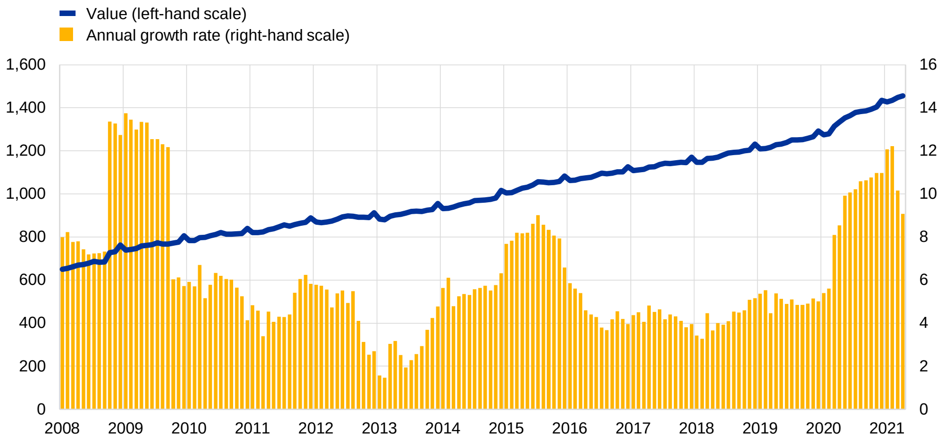
2.1 Developments in cash circulation during the pandemic

Although circulation of euro banknotes has expanded strongly since the currency was first introduced, the growth rate during crises – most notably the Lehman Brothers crisis – has been extraordinarily high. Such an exceptional increase was also observed during the COVID-19 pandemic, albeit with its own special features. Chart 1 shows the annual growth rising by 12% in February 2021 compared with the last month before the pandemic spread throughout Europe (February 2020), taking the total value of euro banknotes in circulation to €1,435 billion. This contrasts with the roughly 5% average annual growth observed in equivalent periods in the five years prior to the pandemic. Although the annual growth rate slowed in March (10%) and April (9%) – taking the total to €1,455 billion – the annual increase over the first months of the pandemic is still remarkable.

Chart 1

Euro banknote circulation from 2008

(left-hand scale: EUR billions, not seasonally- or calendar-adjusted; right-hand scale: percentages)

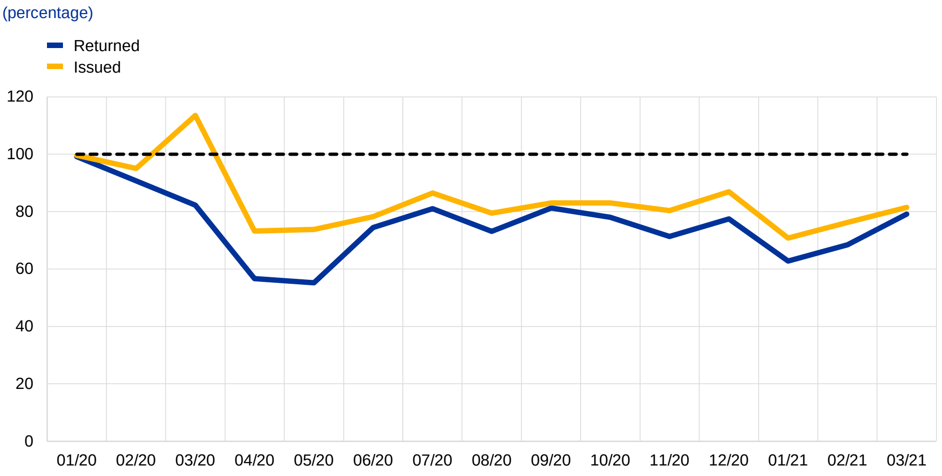


Source: ECB.
Notes: Euro banknote circulation is the sum of all banknotes issued on a net basis (issued minus returned) by Eurosystem central banks since the introduction of the euro. The latest observation is for April 2021.

The gap between banknote circulation growth in normal times and during a crisis has also been observed for other currencies (Bank of England, 2020; Bank of Canada, 2020; Rösl and Seitz, 2021). In most crises, the increase in circulation is mainly driven by higher banknote withdrawals and hence higher gross issuance. During the pandemic, however, the situation seemed to be rather different. Chart 2 shows that despite an increase in March 2020 at the start of the pandemic, the value of banknotes issued (outflows from central banks) during 2020 fluctuated at around 70% and 90% of the average level of the previous five years. However, the value of banknotes returned (inflows to central banks) decreased even further (around 60% and 80% of normal levels). This stronger decline in the value of returned banknotes results in higher overall circulation, as euro banknote circulation is the sum of banknotes issued on a net basis (i.e. issued banknotes minus returned banknotes).

Chart 2

Banknote flows in 2020-21 set against flows in the previous five (non-crisis) years



Source: ECB.
Note: Banknote flows (issued and returned) are compared with the average of those of the previous five (non-crisis) years (2015-2020).

Accordingly, the rather counterintuitive combination of weakened banknote flows and strong increase in overall cash demand indicates the uniqueness of this crisis. To understand these developments, it is important to acknowledge that demand for cash has three differentiated components (Zamora-Pérez, 2021): (1) transactional demand in the euro area, (2) store-of-value demand in the euro area, and (3) foreign demand. Hence, reduced cash operational activity in central banks – mostly associated with a decrease in the first component, i.e. diminished use of cash for daily transactions – is compatible with an overall increase in demand for cash if store of value in the euro area or foreign demand experienced a notable increase.

Although the extent to which the different demand components have changed during the pandemic is unknown – as estimates for 2020 are not available – it is likely that the increase in circulation was mainly driven by store-of-value demand in the euro area. Both banknote flows (see Chart 2) and survey evidence (see next section) indicate that the demand for euro cash for day-to-day transactions has decreased. It is worth considering whether the higher overall demand for cash came from outside the euro area, given that this component is far from negligible (Lalouette et al., 2021). ECB data show that net shipments of euro banknotes to countries outside the euro area have decreased. Although these shipments only represent part of the foreign demand – i.e. the registered channels through which euro banknotes can flow outside of the euro area – it is safe to assume that informal channels such as tourism and remittances did not play an important role (due to the sharp decline in tourist spending and commercial flights, for example). Hence, most of the increase in store-of-value demand is likely to have come from inside the euro area, offsetting the drop in transactional demand.[1]

1 The relative significance of the various causes of this increase for the euro area is still not clear and further research is needed. For the case of Italy, see Baldo et al. (2021).

Box 1

Developments in euro coin circulation during the COVID-19 pandemic

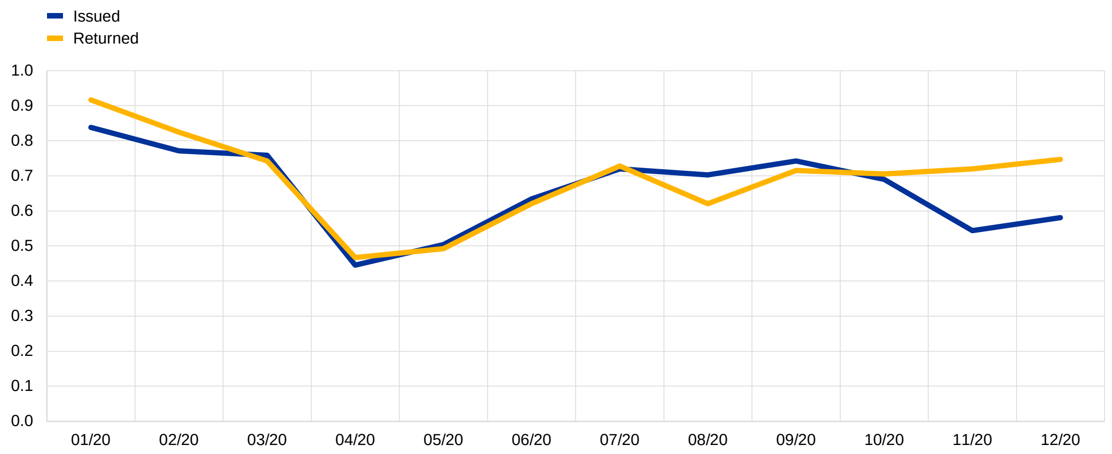
Euro coins represent a smaller portion of the cash in circulation, accounting for around 2% of the total in terms of value. Over the last ten years, the value of euro coins in circulation has grown by an annual average of around 3.5%, reaching €30 billion at the end of 2020. In February 2021 coin circulation rose by only 1.6% year on year, a far slower growth rate than for banknotes.

No crisis prior to the pandemic had had a significant impact on the circulation of coins, and the growth rate suggests that the pandemic has continued this trend. In a similar way to banknotes, however, there has been a significant decrease in the value of coins issued and returned since the start of the pandemic (Chart A). The most significant decline was recorded in April, when returns were 47% of the average of a non-crisis year. These difference in flows can likely be attributed to limited shopping and travel opportunities.

Chart A

Coin flows in 2020 set against flows in the previous five (non-crisis) years

(percentages)



Source: ECB.
Notes: Coins flows (issued to and returned by the public) are compared with the average of those of the five previous (non-crisis) years (2015 to 2019).

The main difference from banknotes is that the value of coins returned did not decrease significantly more than that of coins issued, meaning that the growth in circulation was not as large as that of banknotes. This might be mainly because, although both banknotes and coins are used for transactions (hence the weakened central bank flows), coins are rarely used to store value (which explains the modest growth in circulation).[2]

[2] A similar effect has also been observed for the different banknote denomination aggregates. For small denominations (€5, €10 and €20), also mostly used for transactions, the relative growth in circulation was more modest than that of the higher denominations, which are also used for store-of-value purposes. This is a further indication that the store-of-value demand has increased during the pandemic.

2.2 Change in the demand for cash as a means of payment during the pandemic

2.2.1 Survey evidence for reduced use of euro cash for transactions

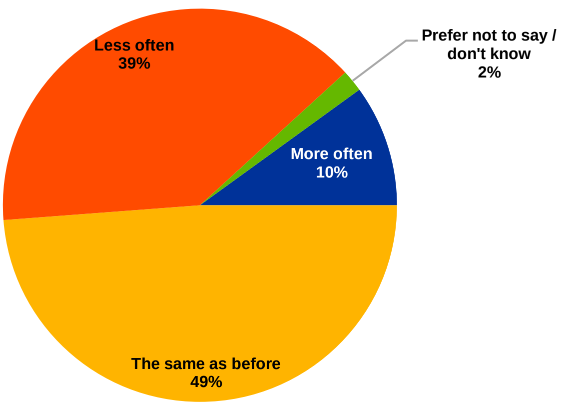
As shown above, ECB data preliminarily suggest that the increase in banknote circulation is mainly due to greater store-of-value demand in the euro area. Despite the decrease recorded in central bank banknote flows (see Chart 2), it is it difficult to assess with certainty the change in transactional demand for cash without resorting to consumer surveys. Since cash payments at the point of sale (POS) and between individuals (person-to-person or P2P) are not registered by any institution, the ECB conducts surveys of the payment behaviour of euro area citizens to assess the extent of this change (Esselink and Hernández, 2017; European Central Bank, 2020).

In order to shed light on the extent of the change of transactional demand for cash during the pandemic, the ECB carried out a small-scope euro area survey on the impact of the pandemic on cash trends. The IMPACT survey (European Central Bank, 2020) was conducted in July 2020, meaning that it provides early information on how euro area consumers perceive changes in their payment behaviour. According to the survey, the use of cash for transactions has decreased during the pandemic. As shown in Chart 3, around half of the respondents reported employing cash as frequently as in the pre-pandemic period. However, around 40% reported using cash somewhat less or much less often.[3]

Chart 3

Compared with the situation before the pandemic, are you using cash more or less often?

(percentage of respondents)



Source: European Central Bank (2020).

[3] This decrease is in line with the results of a study using a payment diary conducted by the Deutsche Bundesbank for Germany only (Deutsche Bundesbank, 2020).

The decline in the use of cash for transactions is paralleled by more frequent card payments than before the pandemic. Although this shift was observed in card payments involving PIN or signature (30% respondents reported using this method more often), it was even more marked in another question when asked about contactless payments (40% more often). This points towards an acceleration of the cash-to-card substitution trend which was already evident before 2020 in the euro area.[4]

The group of respondents using cash less often were also asked about their expected behaviour after the pandemic. 87% answered that they would likely pay in cash less when the situation went back to normal. However, it cannot be concluded with certainty that this early perception will translate into actual consumer behaviour once the pandemic is over (Zamora-Pérez, 2021). Further evidence will be needed to assess whether and to what extent the pandemic has a long-lasting effect on payment behaviour among euro area consumers.

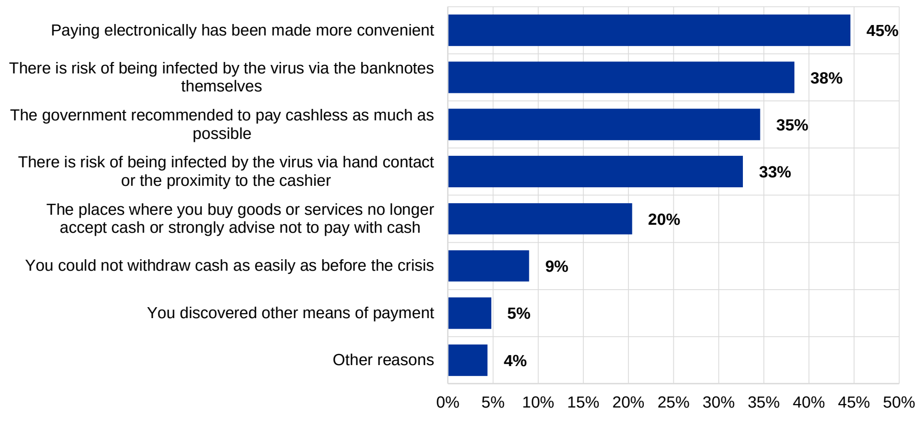
2.2.2 Reasons for the reduced use of cash for transactions

Respondents to the IMPACT survey were asked for the reasons why they were paying in cash less.[5] As shown in Chart 4, the increased convenience of electronic payments was the main reason cited by respondents; 45% of respondents answered that this was the case. This could be due to the measures that were taken by card payment service providers to increase contactless payment limits or initiatives launched by merchants to encourage consumers to use contactless card payments.

Chart 4

Reasons cited by consumers for using cash less often since the start of the pandemic

(percentage of respondents using cash less)



Source: European Central Bank (2020).

[4] Even though the magnitude of this decrease cannot be precisely determined since the IMPACT survey is not directly comparable with previous ECB surveys on payment behaviour (European Central Bank, 2020).

[5] It was possible to provide multiple answers to this question.

Fear of contracting SARS-CoV-2 is another major reason for using cash less. 38% of respondents mentioned a fear of being directly infected from banknotes as a motivation, while 33% pointed to a fear of being infected through hand contact or being close to the cashier. The share of respondents who point to fear of infection as a reason for paying less often in cash varies depending on the demographic group considered. For example, among citizens who reported paying in cash less often, those with higher education levels tended to be more concerned about becoming infected from banknotes (42%) than those with secondary (36%) or primary (33%) education. Similarly, respondents living in urban areas report greater concern (40%) than those living in rural areas (35%).

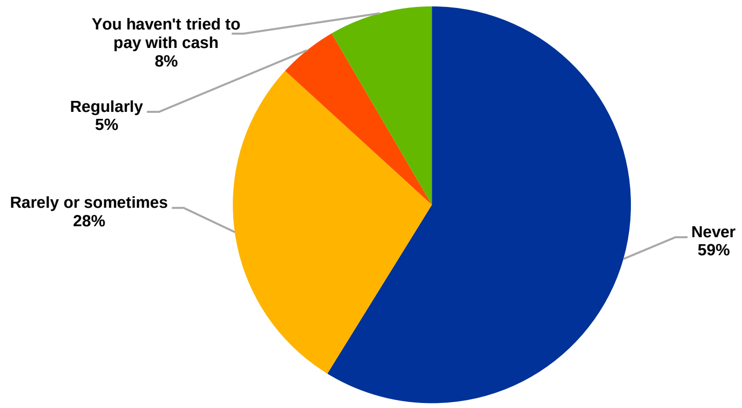
The choice of using cash less was not driven in all cases by consumer preferences or abilities. Other reasons for the decrease in cash usage stemmed from government recommendations to avoid cash payments (35% of respondents paying in cash less often) and merchants' limitations or advice against paying in cash (21%). According to the survey, around 20% of respondents who have been using cash less claim that the places where they usually buy goods or services no longer accept cash or strongly advise not to pay with it. In addition, in a question covering all respondents (both using and not using cash), 5% report that when going to a shop, cash payment was not possible or refused on a regular basis, while 28% faced this sometimes (Chart 5).

Nearly 10% of respondents reported that the reduced use of cash was driven by it being harder to withdraw cash than before the pandemic. Different causes might explain this increased difficulty, such as a limited freedom of movement or (self-imposed) avoidance of withdrawing cash.[6]

Chart 5

How often has it happened that a cash payment was not possible or refused?

(percentage of total respondents)



Source: European Central Bank (2020).

Even though a large proportion of people indicate using cash less than before the pandemic, more than half of the euro area citizens surveyed (52%) still consider the option to pay in cash to be very important or important. The fear of becoming

[6] This, together with the above reasons, might also explain part of the weakened banknote flows in and out of the central bank described in the previous section.

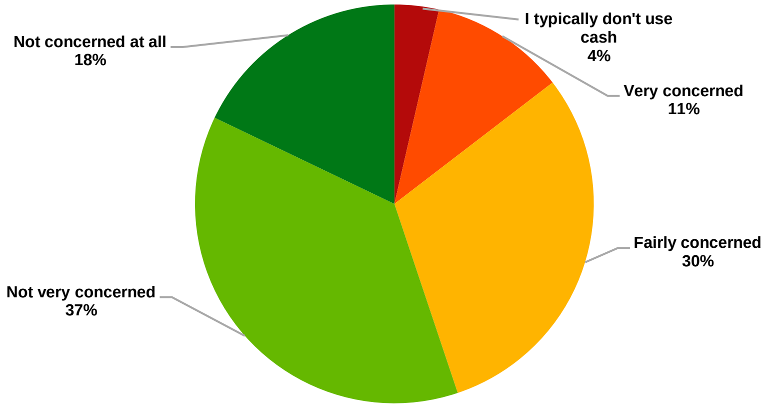
infected does not seem to influence the view on how important it is to have the possibility to pay in cash.

When looking at the overall population (including people both using and not using cash), the IMPACT survey suggests that 30% of citizens were fairly concerned about the risk of contracting SARS-CoV-2 from banknotes and 11% were very concerned (Chart 6). The following sections will demonstrate why these concerns, some of which were actively stimulated by public and private institutions, can be considered largely unfounded. Both the general academic literature and tests commissioned by the ECB demonstrate that using euro banknotes as a means of payment does not present a significant risk of infection.

Chart 6

Concerns about contracting SARS-CoV-2 from cash

(percentage of total respondents)



Source: European Central Bank (2020).

3 Dispelling concerns about contracting the virus from cash transactions – a look at the laboratory evidence

To understand whether the fear of contracting the virus from euro cash is justified, it is necessary to objectively assess the potential contribution of banknotes and coins to the transmission of the SARS-CoV-2 virus. To this end, this section presents the results of the research conducted by the ECB with independent laboratories and universities in 2020-21.[7]

The research programme included testing the survivability of SARS-CoV-2 and surrogate viruses on banknote and coin surfaces (time until no virus was detectable), as frequently performed in scientific studies on the transmission of viruses. We also devised a new method to investigate transferability from banknote and coin surfaces to human fingers (number of virus particles transferred from surface to finger). The combination of both aspects (survivability and transferability) is key to determining the risk of SARS-CoV-2 transmission via euro cash. While viruses might be deposited and survive on any solid surface for several hours or days, they may only be transferred in volumes too small to cause an infection. Additionally, the experiment conditions and their similarity to real-life scenarios (e.g. temperature, humidity and initial virus quantity) are important for objectively assessing the risk of virus transmission. Finally, a summary of relevant scientific publications is provided to support the discussion and conclusions.

A significant part of this ECB research work was conducted in cooperation with the Ruhr University Bochum in Germany. A first publication on the novel transferability method applied to SARS-CoV-2 (Todt et al., 2021) was released in April 2021 as a preprint including some of the results that are also presented in this paper.

3.1 Background information

When the COVID-19 pandemic started, little was known about the main modes of transmission of the novel coronavirus SARS-CoV-2. In general, viruses are mainly transmitted by infected people through the transfer of infected secretions such as saliva and respiratory secretions or droplets. This happens either directly, by close contact between people, or indirectly, via contaminated surfaces (known as “fomites”) or the air (aerosol transmission). At that stage, there was no reported evidence of indirect transmission of the SARS-CoV-2 virus via banknotes or coins, but only anecdotal evidence regarding similar or other inanimate objects in general.

[7] Cooperation was established with the Ruhr University Bochum plus two laboratories – Dr. Brill + Partner GmbH in Hamburg and BluTest Laboratories Ltd in Glasgow – which were commissioned to conduct some of the studies.

Research was therefore initiated to objectively assess whether the risk of transmission via banknotes is negligible or not.

Despite this lack of evidence supporting possible transmission via cash, and possibly guided by the precautionary principle (i.e. to avoid harm until further scientific evidence is available), some countries and international organisations took immediate measures with a view to limiting the spread of the virus by discouraging the use of cash in transactions. Some institutions even went as far as quarantining cash for substantial periods of time (e.g. seven to ten days (Schroeder and Irrera, 2020) and disinfecting or even destroying some paper currency (Keyes, 2020)). These initial preventive measures (Westdeutsche Zeitung, 2020) may have resulted from some previously published studies of influenza virus stability on banknotes and other materials (Thomas et al., 2008). Although this paper did not find any viruses on paper money withdrawn from circulation, it did show that in laboratory conditions, infectious (influenza) virus could survive on banknotes for up to three days when they were inoculated at high concentrations. The same inoculum showed an increase in survival time (up to 17 days) in the presence of respiratory mucus. This study considered that "although viruses have not been found on money, the potential for their transmission via money is possible". Nevertheless, it did not assess the quantity of viruses which could effectively be transferred by touching the contaminated surfaces and whether this quantity would be enough to cause an infection. Furthermore, laboratory simulations have demonstrated that the efficiency of viral transmission varies according to "viral strain, the nature of the host cells and surfaces, and atmospheric conditions" (Angelakis et al., 2014).

Since euro banknotes were launched in 2002, the ECB[8] has been committed to ensuring that they remain safe to produce and use by imposing stringent health and safety standards as part of its production management and monitoring system (see Box 2). This includes assessing any emerging health and safety concerns, including those expressed by the public such as the presence of specific chemicals or viruses on banknotes. When dangerous viruses emerged in the past (avian flu in 2006 and swine flu in 2009), the ECB organised tests with laboratories to assess the risk of cash contributing to the spread of these viruses. A summary of these investigations is presented in Annex 4; their conclusions are that the use of cash is not a significant risk and cannot contribute substantially to the spread of these types of virus.

In line with its commitment and in response to the publicised concerns, the ECB organised several test programmes at the start of the COVID-19 pandemic to assess whether euro banknotes and coins might potentially contribute to the transmission of the SARS-CoV-2 virus.

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[8] The ECB's many responsibilities include the coordination of the production, distribution, issuance and destruction of euro banknotes in cooperation with the euro area national central banks.

Box 2

Safety beyond virus testing: managing the production and safety of euro banknotes[9]

To ensure the integrity of euro banknotes as a means of payment, the ECB applies stringent environmental, health and safety, security and quality standards for their production and distribution. Accordingly, comprehensive management systems have continuously evolved across a wide-ranging suite of strict rules, control systems and regular checks. Only manufacturers that have been accredited by the ECB can be involved in banknote production.

In particular, the health and safety standards ensure that banknotes are fully functional and safe to handle, generating no health and safety risks to workers during the production process or the general public and professional cash handlers when using them.

Accreditation of manufacturers

The supply chain for euro banknote production involves some 50 manufacturers, including ink, security thread and foil suppliers, paper producers and printing works. The various production sites located in different countries contribute to the production of approximately six billion banknotes every year. In order to ensure that these banknotes are produced according to the standards defined by the ECB, all these manufacturers must be accredited by the ECB under the rules and procedures set out in an ECB Decision.[10] This approach ensures a robust, consistent and transparent accreditation process.

Ensuring the safety of banknote producers and users

Several health and safety related regimes have been put in place as one the main pillars to ensure the safety of all euro banknote producers and users. These requirements and processes comply with the EU regulations on product safety in general and are going even further in some instances.

As an example, as there are no EU health and safety regulations defined for banknotes as a specific product, the ECB requirements were compiled by combining several of the most stringent regulations governing such critical products as toys[11] and cosmetics[12]. Based on these regulations, the ECB has identified a list of substances whose presence should be avoided or at least limited to levels which are normally stricter than those defined in other related regulations.

As a first level of control, all manufacturers involved in the production of euro banknotes must supply the relevant safety data sheets (SDSs) for all their products in compliance with the REACH[13] regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals). The SDSs detail

9 This box on production control focuses exclusively on euro banknotes and does not address the management of coin production and distribution. This is due to the fact that the ECB is responsible solely for the management of banknote production and issuance. Euro coins are a national competence, usually managed by the finance ministries and coordinated by the European Commission.

10 Decision (EU) 2020/637 of the European Central Bank of 27 April 2020 on accreditation procedures for manufacturers of euro secure items and euro items (ECB/2020/24) (recast).

11 Directive 2009/48/EC of the European Parliament and of the Council of 18 June 2009 on the safety of toys.

12 Council Directive of 27 July 1976 on the approximation of the laws of the Member States relating to cosmetic products (76/768/EEC) and Regulation (EC) No 1223/2009 of the European Parliament and of the Council of 30 November 2009 on cosmetic products (recast).

13 Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC.

all raw materials used in these products, and list and quantify chemical substances which are known. The SDS documents are systematically analysed by independent reviewers commissioned by the ECB to check compliance with existing and pending EU regulations.

A second level of control is to have the euro banknotes regularly and systematically analysed in eligible laboratories recognised by the ECB. These analyses are performed to validate the levels of hazardous substances, either during normal production or whenever a new product is being developed for future use. Only banknotes passing the tests qualify for issuance and use.

Furthermore, the ECB has commissioned an independent specialist company to provide technical and independent advice on all matters of health and safety related to the existence and use of known hazardous substances. If the classification of chemicals used in euro banknotes changes, the ECB together with its accredited manufacturers ensures it replaces or limits the presence of these chemicals within acceptable levels.

Additionally, the ECB conducts ad hoc investigations into any unforeseen events concerning the safe use of banknotes and coins, as it did in 2006 for avian flu and 2009 for swine flu (see Annex 4).

3.2 How long does the SARS-CoV-2 virus survive on euro cash? Virus survivability tests on banknotes and euro coins

To answer this question, we set up a testing programme for which the test protocols and results are described below and in the annexes. We compare these results with results available from scientific literature on SARS-CoV-2 and other surrogate viruses related to stability (survivability) on cash and other inanimate surfaces. Finally, we conclude that as for many other similar viruses, SARS-CoV-2 survives on banknotes and coins for 30 minutes to a maximum of several days (significantly shorter than on door handles, for instance), but only in limited quantities.

3.2.1 Test protocols and results

The surface stability of SARS-CoV-2 and some surrogate viruses was evaluated on a series of euro banknotes, coins and other representative surfaces (e.g. stainless steel for door handles). The banknotes included in the testing programme were the €10 denomination.[14] The €10 banknote is mainly used for transactions and is distinctive for being coated with a varnish to protect its surface and prolong its lifetime in circulation. As for coins, 5 cent, 10 cent and 1 euro coins were tested to

[14] The first testing programmes with the surrogate viruses also included uncoated €50 banknotes. However, as the survivability results for the €10 and €50 banknotes did not show any significant differences, only testing on €10 banknotes was conducted thereafter (being more representative of the banknotes used for physical transactions).

cover the different euro coin alloys. A stainless steel carrier was used as a reference material.[15]

Droplets of a liquid containing a controlled amount of virus, prepared according to a very specific standard process under controlled conditions, were placed on the surface of the samples and left untouched for predefined periods (e.g. 15 minutes, one hour, two days).

Afterwards, they were treated using another specific and standard virus recovery process to quantify the amount of virus still surviving at a viable level on the surfaces. The quantity of virus remaining is expressed on a logarithmic scale as 50% tissue culture infectious dose per millilitre solvent (TCID50/mL titre) of the collection medium.[16] The test method and materials used are described in detail in Annex 1.

The tests were performed with an initial virus titre (VIC) of around 10^6 TCID50/mL, which is a typical viral load used by laboratories to study the stability of viruses on surfaces. Nevertheless, some publications indicate that such viral load should be considered as very high (Goldman, 2020) and not fully representative of real-life conditions, meaning that it could lead to an overestimation of the quantity of virus which would effectively exist on surfaces. To address this concern, some tests were also conducted using a lower viral load of around 10^4 TCID50/mL, which is considered to be more representative of real-life conditions (Goldman, 2020). Therefore, the results below for the survivability must be interpreted with caution.

Chart 7 compares SARS-CoV-2 survivability (in hours) on the €10 banknote, the three different coin types and a stainless steel carrier as a reference. Panel (a) shows the decay of the quantity of viable virus on the different surfaces. The dashed horizontal lines indicate the limit of detection, which was determined to be 15.8 TCID50/mL in this case. In panel (b), the regression plots indicate the predicted decay of virus titre over time, also on a logarithmic scale.

15 PVC was also used in the study as an additional reference material in Section 3.3; however, PVC was not included as a reference material in Section 3.2.

16 TCID50 signifies the concentration at which 50% of host cells in a culture are infected after being inoculated with a diluted solution of viral fluid.

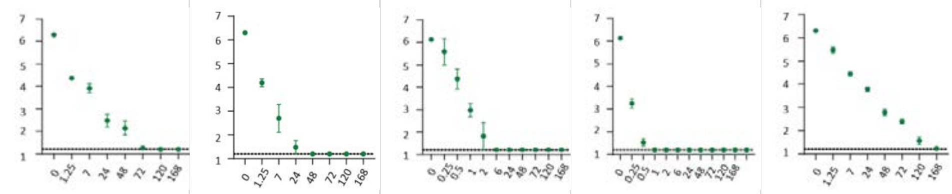
Chart 7

Survivability of SARS-CoV-2 on €10 banknote, 1 euro, 10 cent and 5 cent coins and a stainless steel disc, expressed in simple logarithmic scales, plus the predicted decay times, with starting load of approx. 10^6 TCID50/mL

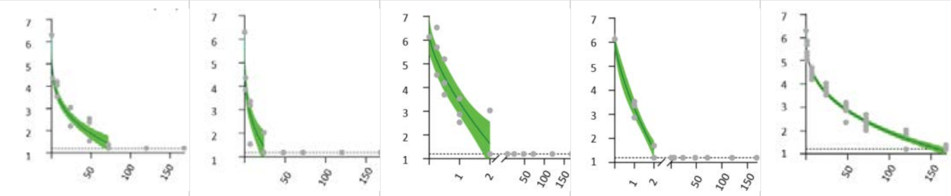
(x-axis: desiccation time (hours), y-axis: log_{10} TCID50/mL)

Banknotes	Coins			Control
10 euro	1 euro	10 cent	5 cent	Steel disc

Panel (a)



Panel (b)



Source: Ruhr University Bochum.

As indicated by the non-linear decay of the charts 7 in panel (a), the virus showed an exponential decay on all surfaces studied. The virus was more stable and therefore survived longer on stainless steel than on the €10 banknote and all the coin types. For stainless steel, the results show that some viable virus could persist on its surface for up to seven days after inoculation. On the €10 banknote, viable virus was detected just above the detection limit for up to 72 hours after application. On the 5 cent coin, no viable virus was measured after only 30 minutes while on the 10 cent coin, no viable virus was measured after six hours. On the 1 euro coin, no viable virus was measured after 24 hours.

SARS-CoV-2 virus survives on banknotes and coins for a shorter period of time than stainless steel. The fast decay on the 5 cent coin can be attributed to the coin's copper plating. The antiviral activity of copper has often been reported in literature (Vincent et al., 2018). Also, for the 10 cent and 1 euro coins, the presence of copper in the coin alloy plays a certain antiviral role, albeit a less significant one.

For the €10 banknote, the amount of virus decreases in the range of 10 to 100 times faster than stainless steel in the first few hours. After 24 hours, the virus titre TCID50/mL has even decreased ten thousand times, close to the detection limit. This could be attributed to the porous character of the banknote material, into which the virus may penetrate from where it cannot be measured and therefore cannot be transmitted. It should be remembered that the risk of contamination mainly comes from the virus remaining on the surface of a banknotes, if at all.

These general observations on the survivability of viruses are also validated by some earlier tests conducted by the ECB using several surrogate coronaviruses in early 2020, before having access to the actual SARS-CoV-2 virus. The surrogates were the bovine coronavirus (BCoV) and murine hepatitis virus (MHV)/murine coronavirus (MHV), which belong to the same family as the SARS-CoV-2 virus (betacoronavirus genus). The tests with SARS-CoV-2 and the surrogates were performed at different laboratories with some small differences in the testing protocols (e.g. sample preparations, preparations of viral suspensions) and environmental conditions (temperature and humidity differing to some extent at individual sites and in different periods of the year). While some differences in results were observed, we conclude that the testing of surrogate viruses has proved to be effective in simulating the activity of the actual SARS-CoV-2 virus on cash. Annex 3 provides more detailed results from the tests of SARS-CoV-2 and surrogates' stability on cash.

3.2.2 Discussion of the ECB results and other scientific studies on the stability of SARS-CoV-2 and other relevant viruses on inanimate surfaces

It would be expected that, given the similarities and the porosity of the surfaces, the stability of SARS-CoV-2 on paper currency would be similar to that shown in studies on other paper-based materials; however, the effect of inks on the virus remains unknown (Harbourt et al., 2020). SARS-CoV-2 has been reported to remain stable on cardboard for 24 hours (Van Doremalen et al., 2020). Other previously published sources claim that SARS-CoV survives on paper for four to five days (Duan et al., 2003). Another source describes the activity of SARS-CoV on paper ranging from up to 24 hours and three hours to less than five minutes, depending on the original viral load applied to the paper (ranging from 10^6 and 10^5 to 10^4 TCID50/mL respectively) (Lai et al., 2005). To date, there have not been many studies directly assessing the stability of SARS-CoV-2 on banknotes. Articles published so far describe SARS-CoV-2 as remaining infectious on a banknote for two days (Chin et al., 2020). The longest survival period of SARS-CoV-2 described by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for paper and polymer banknotes was up to 28 days (Riddell et al., 2020).

The results obtained from our study show viable SARS-CoV-2 being detectable on €10 banknotes for up to 72 hours. This is in line with the bottom range of the results reported for banknotes and other paper-based materials published in the literature. We cannot expect the results to correlate fully, as they depend greatly on experiment conditions: humidity, temperature, mode of virus application to the surface, dosing and finally interpretation of the results play an important role and are not always clear from the published studies. The CSIRO study (Riddell et al., 2020) reporting the longest survival time (up to 28 days) emphasises that the samples were kept in highly regulated laboratory conditions, i.e. in a dark environment, avoiding exposure to UV light and in strictly regulated humidity conditions. Those conditions have been described as "virus friendly", allowing for long virus survival. In addition to the differences in experiment conditions, the origin of the samples, Hong Kong dollar

(Chin, 2020) banknotes or demonetised Australian banknotes (Riddell et al., 2020) might not be directly comparable with the euro banknotes we tested.

The literature reports that the virus decays faster on copper, with no viable SARS-CoV-2 or SARS-CoV being measured after four hours and eight hours respectively (Van Doremalen et al., 2020). Our studies show fast virus inactivity on the 5 cent coin, with no viable virus being measured after 30 minutes. These results can be considered comparable, again given the differences in experiment conditions.

Our stability test results show that the virus applied in high viral load can survive on banknote surfaces for several days and on coin surfaces from several hours up to several days, which is not a surprise. Taken in isolation, this may generate some concerns that the virus could still be transmitted by banknotes and coins. We have to bear in mind that all of these stability studies were performed in laboratory conditions and with a very large initial virus titre (around 10^6 infectious units per mL). These conditions do not fully replicate a real-life situation. Such viral loads are considered very high (Goldman, 2020) and could lead to an overestimation of the quantity of virus which would effectively survive on cash and hence to an exaggeration of the risk of banknotes and coins transmitting COVID-19.

Finally, we refer to the previous studies performed by the ECB on cases of dangerous viruses (avian flu in 2006 and swine flu in 2009), which are summarised in Annex 4. It was found that, as with normal seasonal influenza and as on any other surface (e.g. door handles, newspapers or keyboards), respiratory droplets from a person infected with the swine flu virus deposited on a banknote could survive for a short period. However, there was also there no evidence of any virus having been spread via banknotes. The conclusion was that the use of cash was not a significant risk and could not contribute substantially to the spread of viruses.

It is important to stress that even if the virus can survive on inanimate surfaces for a certain period of time, it would still need to be transferred first onto human skin (fingers) and second from the hand to reach the mucosal routes.[17] With the research on SARS-CoV-2, we wanted to go further than drawing conclusions based only on the survivability of viruses on cash. We aimed to assess whether enough remaining virus could be transferred from banknote and coin surfaces to human fingers (transferability) and contaminate a person. This question is analysed below.

3.3 Can COVID-19 be transmitted to humans from euro cash? Transferability analysis

Regarding the question of whether SARS-CoV-2 can survive on cash, we conclude that it can survive for several days but in more limited quantities than on other surfaces, and that the use of cash is not a significant risk compared with other surfaces. The follow-up question is how much of this remaining virus can be

[17] According to Ross McKinney, chief scientific officer of the American Association of Medical Colleges, the infection cannot happen through the skin but entering the body via mucus membranes, e.g. from the fingers to the nose or eyes. See Begley (2020).

transferred from a contaminated banknote or coin to a human being via fingers, and could this quantity be enough to be infectious. The available data on such transfer mechanism are very limited at the moment. As a result of this gap, the tests implementing a new protocol to study touch-transfer efficiency between fomites and skin were organised to answer this question. We then compare our results with results available from the scientific literature on the SARS-CoV-2 transmission routes. Finally, we provide a conclusion on SARS-CoV-2 transmission from euro cash.

3.3.1 Test protocols and results

Transferability testing was performed on a series of representative banknotes and coins, mainly using €10 banknotes and 10 cent coins. Stainless steel and plastic (PVC[18]) carriers were used as references and for comparison with everyday objects (e.g. door handles or keyboards). SARS-CoV-2 and bovine coronavirus (BCoV) testing was performed in two different laboratories according to two slightly different test protocols, but both using the stability test protocol as a basis (Annex 1).

As pointed out for the survivability testing, an initial virus titre of around 10^6 TCID50/mL can be considered very high and not fully representative of real-life conditions. Therefore, the virus titres were applied to the sample surfaces in two viral loads: a high viral load of approximately 10^6 TCID50/mL and a lower viral load of approximately 10^4 TCID50/mL to better mimic the real-life conditions.

The transferability testing was conducted using human fingers in the case of BCoV and artificial skin imitating the finger (in the case of SARS-CoV-2 for safety reasons) by either touching or rubbing the contaminated surfaces. The transfer tests were performed in two conditions: first, with “wet” inoculum, i.e. immediately after the virus inoculum (droplets) was applied to the tested surfaces; and second, with “dry” inoculum, i.e. after the visible drying of the inoculum on the tested surfaces (normally after around 30 minutes on the banknote and up to one hour on hard surfaces). Further details of the test methods and materials used for this novel transferability methodology are described in Annex 2.

As regards the methods used, we can conclude that transferability testing of SARS-COV-2 and BCoV using artificial skin and human fingers provided comparable results. Nevertheless, some differences can be observed, which are probably due to different laboratory conditions and more obviously to the differences in the testing protocols (human versus artificial fingers).

The transferability test results for SARS-CoV-2 and BCoV are provided in Charts 8 and 9 respectively. They show the transferability of the viruses from the 10 cent coins, €10 banknotes, PVC and stainless steel carriers. For each substrate tested, the starting viral load applied to the surfaces (input) is shown in the first bar together with the transferability results for the two transfer modes – rubbing (second bar) and touching (third bar) the surface. The figures show the transferability in “wet” status,

18 Polyvinyl chloride.

i.e. immediately after the virus was applied onto the tested surfaces, and “dry” status, i.e. approximately after 30 minutes on the banknote, up to one hour after the virus was applied to the hard surfaces. The values above the respective transfer columns indicate the reduction factor (RF), which is the difference between the input (virus on the surface) and the transferred amount of the virus to artificial/human finger (expressed in $\log_{10}$ TCID50/mL). The dashed lines indicate the limit of detection.[19]

Chart 8

SARS-CoV-2 transferability test results from €10 banknote, 10 cent coin, PVC and stainless steel carrier, expressed in simple logarithmic scales, for initial viral loads of approx. 10^6 and 10^4 TCID50/mL

(x-axis: first bar: “input”; second bar: “rubbing the surface”; third bar: “touching the surface”, y-axis: $\log_{10}$ TCID50/mL)

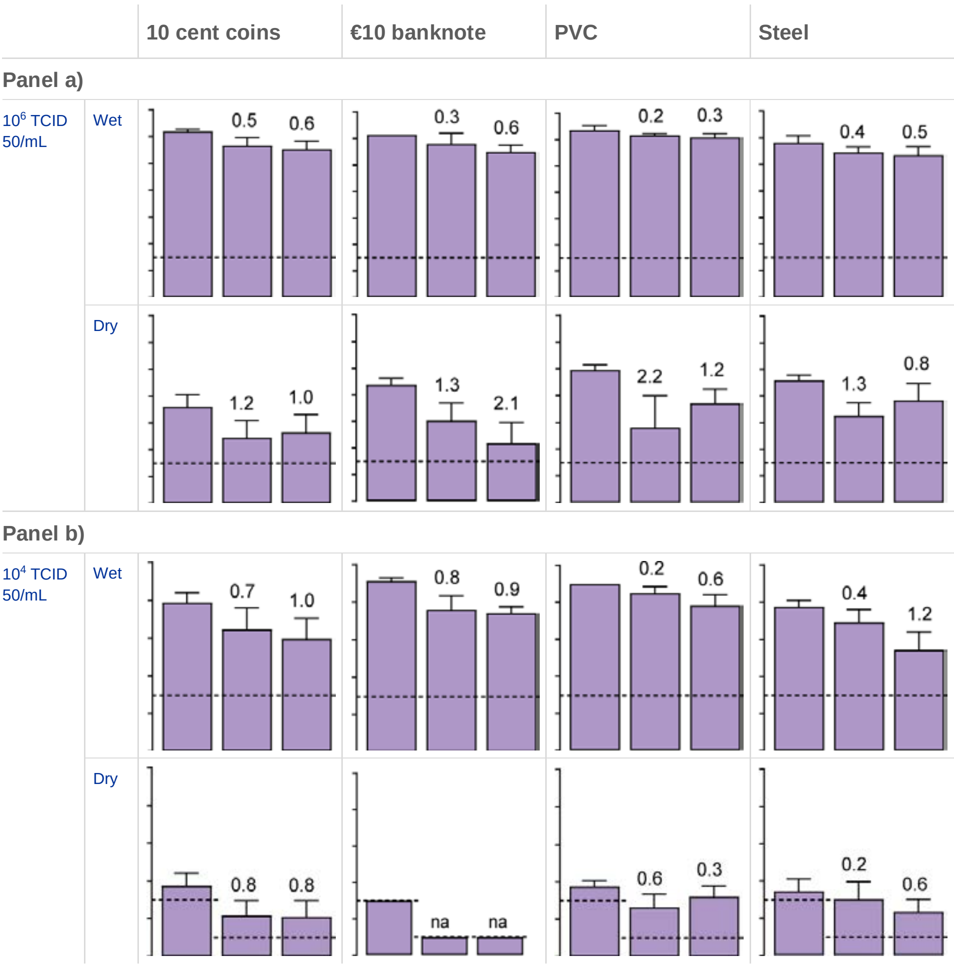
Source: Ruhr University Bochum.
Note: The values above the respective transfer columns indicate the reduction factor (RF), which is the difference between the input (virus on the surface) and the amount of the virus transferred to the artificial/human finger (expressed in $\log_{10}$ TCID50/mL).

19 For BCoV, the detection limits were 31.6 and 3.16 TCID50/mL, depending on the assay and indicated by differences in dashed lines.

Chart 9

BCoV transferability test results from €10 banknote, 10 cent coin, PVC and stainless steel carrier, expressed in simple logarithmic scales, for initial viral loads of approx. 10^6 and 10^4 TCID50/mL

(x-axis: first bar: "input"; second bar: "rubbing the surface"; third bar: "touching the surface", y-axis: log_{10} TCID50/mL)



Source: Ruhr University Bochum.
Note: The values above the respective transfer columns indicate the reduction factor (RF), which is the difference between the input (virus on the surface) and the amount of the virus transferred to the artificial/human finger (expressed in log_{10} TCID50/mL).

For both viral loads, the higher level (approximately 10^6 TCID50/mL) and the more realistic level (approximately 10^4 TCID50/mL), we see a significant transfer from all the surfaces studied in the wet status. The wet status represents a situation where a person adds the virus to the banknotes via liquid or viscous material which is directly touched by another person. In real life, this situation would be rare as it is not be expected that someone would touch a banknote or coin with still wet materials on its surface. Therefore, the transferability testing in the dry status and based on an initial viral load of 10^4 TCID50/mL is more realistic and should be considered when drawing conclusions about the risk of the SARS-CoV-2 virus being transmitted by touching surfaces.

In the dry status, the transferred viral load is significantly reduced (numerically expressed by the logarithmic reduction factor RF above the columns in the charts).

Even in the case of the high viral load (10^6 TCID50/mL), the transfer (e.g. of SARS-CoV-2 from the €10 banknote using an artificial finger "rub") reduces the viral load by several hundreds of TCID50/mL. For the 10 cent coin, we observe a reduction by a thousand TCID50/mL after the transfer, providing results just above the detection limit. Lower reduction factors are observed on the other non-porous surfaces (PVC and stainless steel).

For the more realistic lower viral load of SARS-CoV-2, the virus remaining on the surface of the €10 banknote and 10 cent coin after drying is below detection limit, and its transfer from the €10 banknote and 10 cent coin is below the detection limit. Only from the PVC could low amounts (21.9 TCID50/mL) of infectious virus be recovered. For the €10 banknote, similar results were obtained for the BCoV transfer testing; once dried and for the realistic viral load of 10^4 TCID50/mL, the amount of BCoV transferred from the €10 banknote was below the detection limit.

3.3.2 Discussion of the ECB results and other scientific studies on the stability of SARS-CoV-2 and other relevant viruses on inanimate surfaces

The transfer of SARS-CoV-2 from surfaces to skin has not so far been analysed systematically, which makes it difficult to directly compare our results with any previous publication. In addition, previously published studies largely focus on the transmission of pathogens rather than on the transmissibility of viruses. Furthermore, to determine the transmission of pathogens, some of these studies calculate transfer efficiencies[20] which cannot be used to reflect the reductions observed in virology (Rusin et al., 2002; Lopez et al., 2013). Up to now, the possibility of fingerprint transmission has been quantitatively examined only in the context of bacteria (Knobloch et al., 2017). However, this article focuses on antibacterial activity of surfaces in a healthcare-related environment, again making it difficult to compare with the results of our study.

Nevertheless, to generally compare the results of the studies dealing with the transmission of pathogens, we refer to some of the conclusions of these papers. Some studies assume that although different viruses are readily exchanged between skin and surfaces, the fraction of virus transferred is dependent on multiple factors, including virus species, surface material (porous or non-porous), differences in the hands of different subjects and whether the hands were washed or unwashed (Julian et al., 2010). According to this study, the transfer efficiency is generally much lower for porous materials (such as the paper substrate used for euro banknotes) than it is for non-porous materials. Apparently, the absorbance of the inoculum into porous substrates to a large extent prevents the transfer of pathogens to the hands. This is in line with the conclusion of another article discussing the transfer efficiency of bacteria and viruses from porous and non-porous fomites (Lopez et al., 2013). This study paper also included currency (cotton-based one dollar note). Here again, the

[20] Transfer efficiency is defined as the number of colony-forming units (CFU) or plaque-forming units (PFU) recovered from finger relative to the CFU or PFU recovered from the control fomite.

transfer rates for porous fomites, cotton, polyester and paper currency were lower than the transfer rates found for non-porous materials such as stainless steel.

Both these studies conducted the transferability tests once the surfaces were visibly dry. In this same condition, our studies conclude that the transferability of the virus from cash is almost non-existent and also lower than for the reference surfaces (PVC and stainless steel). This could be attributed to its porosity in the case of the €10 banknote and to the presence of copper in the coin alloy in the case of the 10 cent coin and to its surface characteristics (coin design).

A recent study determined the inter-human genetic bottleneck size for SARS-CoV-2[21] to average around 10^1-10^3 viral particles. The broad range of the values gained in that study indicates that lower numbers of transmitted particles may also lead to a successful infection (Popa et al., 2020). In agreement with these experimentally determined bottleneck sizes, a recent preprint also describing a dose-response modelling study estimated that $3x10^2$-$2x10^3$ SARS-CoV-2 viral particles were necessary to initiate an infection (Prentiss et al., 2020).

Considering this level of SARS-CoV-2 ($3x10^2$-$2x10^3$ viral particles) needed to cause an infection, we already see from our SARS-CoV-2 transferability test results that even for the higher initial viral load after drying, the virus transferred from cash onto the artificial skin is in the range of 10^2-10^3 particles. From the finger, it would additionally need to reach the mucosal routes, thus again being reduced by this subsequent transfer step.

Today, there is more widespread evidence regarding the modes of transmission of the SARS-CoV-2 virus. Most recent publications indicate that respiratory fluids and aerosol transfer between people are the most significant contributor to the spread of the virus (Box 3).

This further supports our results, demonstrating that the potential transfer of SARS-CoV-2 by indirect contact (fomite) via cash is very limited in everyday life conditions, and therefore that cash does not contribute to the spread of COVID-19.

Box 3
Respiratory fluids and airborne transmission are the most significant contributors to the spread of the virus

Respiratory viruses can be transmitted via four major modes of transmission: direct (physical) contact, indirect contact (fomite), (large) droplets and (fine) aerosols.

Genomic material can be found on all everyday surfaces for periods ranging from hours to days, depending on the ambient environment (including temperature and humidity). However, the simple existence of the viral genome on surfaces is not in itself a major concern and must be balanced with other more significant aspects such as transferability. This was emphasised by the World Health Organization when it reported that "despite consistent evidence as to SARS-CoV-2 contamination of

[21] The inter-human genetic bottleneck size for SARS-CoV-2 is the number of virions that start the infection and produce progeny in the viral population.

surfaces and the survival of the virus on certain surfaces, there are no specific reports which have directly demonstrated fomite transmission" (World Health Organization, 2020).

There is growing evidence that the primary route of transmission of SARS-CoV-2 is via virus-positive airway droplets, whereby the virus infection occurs through direct or indirect contact with the nasal, conjunctival or oral mucosa when aerosols are inhaled or deposited on these mucous membranes (Leung, 2021).

Host receptors are found primarily in the human airway epithelium, including the oropharynx and upper airways, where SARS-CoV-2 predominantly replicates (Salzberger et al., 2020). The conjunctiva and gastrointestinal tract are also prone to infection. Previous evidence suggests that the risk of transmission depends on several factors, including contact patterns (duration of contact, size of gathering, proximity, activity), environment (outdoors, indoors, ventilation) and host-specific susceptibility patterns (i.e. viral load in relation to the course of the disease, severity of the disease, age). Different epidemiological studies indicate that the infection also occurs seasonally.

Aerosol transmission likely plays an important role in "superspreading events", in which a small number of patients – or even a single infected person – transmits the virus to a large number of individuals in the same limited space (Cevik et al., 2021). Contaminated surfaces have been discussed as a possible source of transmission, as several studies showed very long viral detection rates in laboratory-based examinations. The US Centers for Disease Control and Prevention (CDC) has recently published a "Science brief" on the possible transmission of SARS-CoV-2 from surfaces. This summarises that while it is possible for people to be infected through contact with contaminated surfaces or objects (fomites), surface transmission is not the main route and the risk is generally considered to be low (CDC, 2021). Based on different quantitative microbial risk assessments, it was considered to be generally less than 1 in 10,000 (Harvey et al., 2021; Pitol and Julian, 2021). Under low viral bioburden conditions (< 1 genome copy per cm^2), it was described to be below 1:1,000,000 (Wilson et al., 2020).

4 General conclusions

Many things were unknown at the start of the pandemic. Decisions and actions were taken without knowing the full context, sometimes based on irrational fears, such as the fear of using cash. While much is still in the unknown, scientific research is helping us to understand the phenomena of the COVID-19 pandemic better.

This paper and the underlying research have contributed to closing the knowledge gap on the impact of SARS-CoV-2 on the demand and use of cash and the role of euro banknotes and coins as potential contributors to the spread of the virus.

Cash is seen as a safe haven in all crisis situations, including the COVID-19 pandemic. In times of insecurity, people tend to increase their precautionary holdings of cash to be prepared for whatever lies ahead. As shown, the increase in the overall demand for cash during the COVID-19 pandemic was extraordinary compared with pre-crisis years, mainly due to higher store-of-value demand from euro area citizens. However, cash payments were reduced partly due to fears of contagion via cash, which were probably magnified by media statements and recommendations by public authorities.

Not much was known about the transmission mechanisms of the SARS-CoV-2 virus at the start of the pandemic. The results of our stability tests show that when a high viral load is applied, the SARS-CoV-2 virus can survive on banknote and coin surfaces for up to several days, albeit at very low levels. The application of a high viral load does not fully replicate a real-life situation and may lead to an overestimation of the quantity of virus which would effectively survive on cash and the consequent exaggeration of the risk of SARS-CoV-2 transmission by banknotes and coins.

Even if the virus can survive on inanimate surfaces for a certain period of time, it needs to be transferred first onto human skin (fingers) and then from the hand to the mucosal routes. Therefore, studying the transfer of the virus from banknotes and coins onto human and artificial fingers was needed to fully assess any risk of SARS-CoV-2 transmission by banknotes and coins.

Our novel transferability testing results, which have not previously been reported in the available published literature, show that the SARS-CoV-2 virus is only transferred from cash to the human finger in very low quantities. The levels are below what would be needed to be infectious, making the risk of transfer very low. Both banknotes and coins perform very similarly in this regard, with steel and PVC transferring slightly more than the currency.

Finally, there is growing evidence that physical contact is not the main route of transmission, as the virus does not survive on the surface of inanimate objects any longer than many other similar viruses (SARS-CoV, influenza), neither can it be transferred efficiently to the human hand/finger. There is widespread evidence that the most significant contributor to the spread of the virus between people is the transmission of the SARS-CoV-2 virus via respiratory fluids and the air (aerosol transmission).

Based on our test results, recent scientific literature on SARS-CoV-2 transferability and also our previous findings on the avian flu and swine flu viruses, it can be concluded that the risk of transmission via banknotes and coins is very low, and that cash is safe to use.

The ECB remains fully committed to continually ensuring the integrity of euro banknotes by applying stringent health and safety controls. This includes conducting regular and ad hoc research, in the case of unforeseen events, to ensure that cash will always remain safe for the public to use.

Annexes

Annex 1: Test protocol for survivability of a virus on banknote and coin surfaces

Methods and materials

Preparation of test virus suspension

To prepare the SARS-CoV-2 test virus suspension, Vero E6 cells were seeded in a 25cm^2 flask at 2x10^6 cells in Dulbecco's modified Eagle's medium (DMEM), supplemented with 10% (v/v) fetal calf serum (FCS), 1% non-essential amino acids, 100IU/mL penicillin, 100µg/mL streptomycin and 2mM L-glutamine. The monolayer was inoculated with the SARS-CoV-2_Bochum strain. After three days and upon visible cytopathic effect, the supernatant was again harvested by centrifugation at 1,500rpm for five minutes at room temperature, aliquoted and stored at -80°C until further use.

To prepare the BCoV test virus suspension, U373 cells were cultivated in a 75cm^2 flask in Eagle's Minimum Essential Medium (EMEM), supplemented with L-glutamine, non-essential amino acids, sodium pyruvate and 10% FCS. Before virus infection, cells were washed twice with phosphate buffered saline (PBS), incubated for three hours with EMEM without FCS and washed once with EMEM supplemented with trypsin. For virus production, BCoV strain L9 was added to the prepared monolayer. After an incubation period of 24 to 48 hours, cells were lysed by a rapid freeze-thaw cycle. Cellular debris was removed by low speed centrifugation, and the supernatant was used directly as the test virus suspension.

Preparation of specimen

The €10 banknotes were cut into 2x2cm pieces. Prior to use, the 5 and 10 cent and 1 euro coins were dipped in a bath containing 70% (v/v) ethanol for five minutes. The €10 banknotes and PVC plates (only used in the transferability testing) were pre-cleaned with 70v% (v/v) propanol and cut into 2x2cm pieces. Banknotes were UV-irradiated before the tests. Stainless steel discs (2cm diameter) served as reference control. Prior to use, the discs were decontaminated with 5% (v/v) decon 90 for 60 minutes and 70% (v/v) propanol for 15 minutes. The discs were then rinsed with distilled water sterilised by autoclaving (steam sterilisation).

Preparation of virus inoculum

Nine volumes of test virus suspension were mixed with one volume of interfering substance solution (EN 5.2.2.8). The stability tests were performed with initial virus titre (VIC) mimicking a high viral load of approximately 10^6 TCID50/mL. For transferability testing, two initial viral loads were used: a higher load of approximately 10^6 TCID50/mL and a lower load of approximately 10^4 TCID50/mL.

Stability assays and controls

Tests were carried out based on European norms (EN 16777 and prEN 17430) at room temperature.

For stability testing, specimens were placed aseptically in a Petri dish and inoculated with 50µl of the virus inoculum (5x10µl drops, one in each corner and one in the middle of the specimen; see Figure A.2.1). After visible drying (desiccation) of the inoculum, the specimens were dried for another 15 minutes. Then the Petri dishes were closed with a glass lid and the specimens were incubated for the appropriate desiccation time (up to seven days). After the desiccation time, the specimens were transferred directly to 2mL cell culture medium (without FCS) in a 25mL container with about 1g of glass beads. The container was vortexed for 60 seconds to re-suspend the virus. Directly after elution, a series of ten-fold dilutions of the eluate in ice-cold maintenance medium were prepared and inoculated on cell culture (see EN 5.5.2).

The measurement time periods chosen were 15, 30 and 75 minutes, 1, 2, 6, 7 and 24 hours, and 2, 3, 5 and 7 days. Eluates were retained after appropriate desiccation times and residual infectivity was determined.

The initial virus titre (VIC) was determined by adding 50µl of the virus inoculum directly to 2mL cell culture medium without any desiccation time.

Furthermore, a cell control (only addition of the medium) was incorporated.

Determination of infectivity

Infectivity was determined by means of end-point dilution titration using the microtitre plate method. For this, samples were immediately diluted with ice-cold EMEM with trypsin at the end of the exposure time, and 100µL of each dilution were placed in eight wells of a sterile polystyrene flat-bottomed plate with a preformed U373 monolayer. Before the virus was added, cells were washed twice with EMEM and incubated for three hours with 100µL EMEM with trypsin. Incubation was at 37°C with constant RH in a CO2-atmosphere (5.0% CO2 content). Finally, cultures were observed for cytopathic effects for six days after inoculation. The infectious dose (TCID50) was calculated according to the method set out by Spearman (1908) and Kärber (1931).

Fitting of the virus titre decay

The Weibull distribution fit in GraphPad Prism version 9.0.2 for Windows (GraphPad Software, San Diego, California, USA) was implemented to model the decay in virus titre.

Calculation of the reduction factor

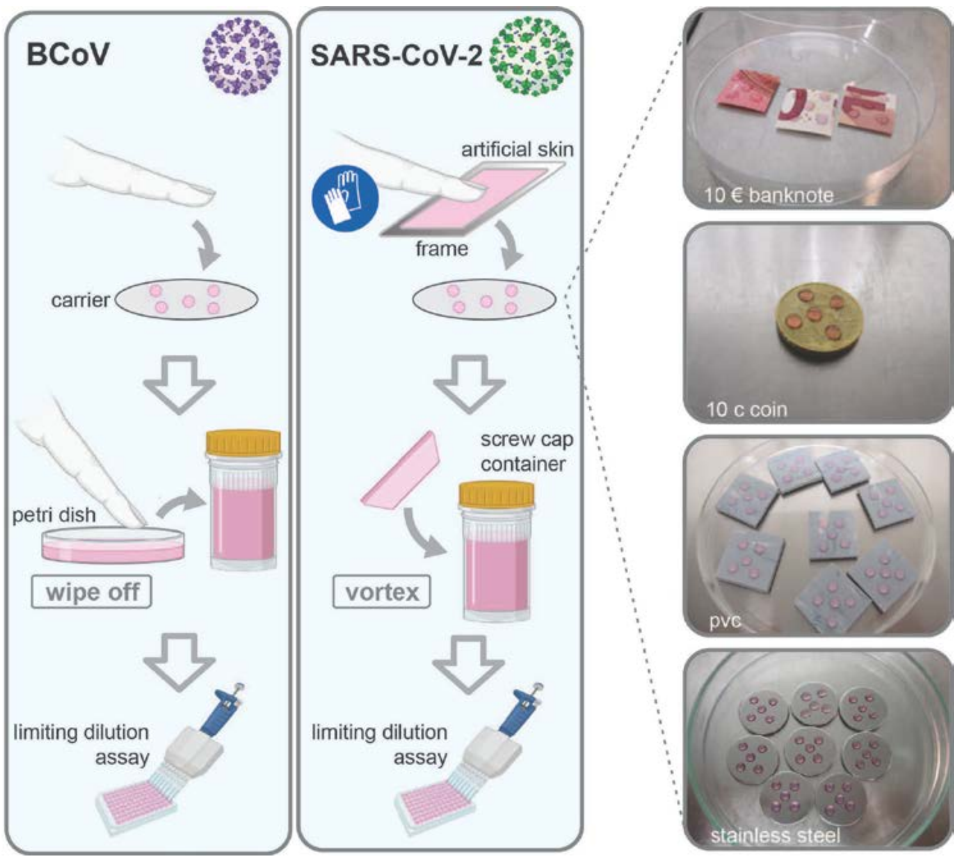
The loss in virus titre by desiccation was calculated by subtracting the titre obtained on the specimen samples after desiccation from the titre of the initial virus control.

Annex 2: Test protocol for transferability of a virus from banknote and coin surfaces to the human and artificial finger

For the BCoV touch-transfer test, three test persons simulated virus transfer by pressing a finger directly onto the dried inoculum on the 10 cent coins, €10 banknotes, PVC and stainless steel surfaces and then rubbed once, with pressure, over the respective carrier. Three other test persons simulated virus transfer by pressing a finger on the dried inoculum on the respective carrier for five seconds. Each test person performed the transfer test separately with the two different virus concentrations with eight fingers each. For each test person and virus concentration, two fingers were used for virus transfer without the inoculum drying. The transfer procedure was the same as for the dried inoculum (Figure A.2.1).

Figure A.2.1

BCoV and SARS-CoV-2 transferability testing procedure



Source: Ruhr University Bochum.

The amount of virus transferred to the fingers was determined by dipping and/or rubbing each finger in turn on the base of a Petri dish containing 2mL cell culture medium without FCS as a sample fluid for one minute. A separate dish was used for each finger test. The eluates were then transferred to a 25mL container. Directly after elution, a series of ten-fold dilutions of the eluate in ice-cold maintenance medium were prepared and inoculated on cell culture (see section 5.2.2 of

EN 16777). The initial virus titre (VIC) was determined by adding 50µl of the virus inoculum directly to a 2mL cell culture medium without any drying. Furthermore, a cell control (addition of medium only) was incorporated.

For the SARS-CoV-2 touch-transfer test, one person performed all assays due to Biosafety Level 3 (BSL-3) restrictions. An artificial skin substitute[22] placed in a plastic frame was used to mimic the texture and nature of human fingertips (Figure A.2.1). After printing or rubbing as described above, the complete artificial skin was released from the frame and transferred to a 25mL container with cell culture medium.

Annex 3: Comparison of the performance of SARS-CoV-2 and surrogate viruses in stability tests

When we started our study, access to the actual SARS-CoV-2 virus was very restricted and limited to specific laboratories. Hence, surrogate viruses were initially used worldwide to serve as a comparative virus model. They were selected on the basis of their morphological similarities to the SARS-CoV-2 virus. Namely bovine coronavirus (BCoV) and murine hepatitis virus (MHVV), both belonging to the betacoronavirus genus, were used.

Chart A.3.1 compares the survivability of SARS-CoV-2 and the surrogate viruses (BCoV and MHV) (in hours) on the €10 banknote. In Panel (a), the decay of the titre of the viable virus is expressed on a logarithmic scale y-axis, with categorical x-axes to depict raw titre, TCID50/mL[23]. The dashed lines indicate the limit of detection. Panel (b) shows the shape of a Weibull non-linear model fitted to the data points indicating the predicted decay of virus titre over time; note the titre is also plotted on a logarithmic scale with continuous y-axes.

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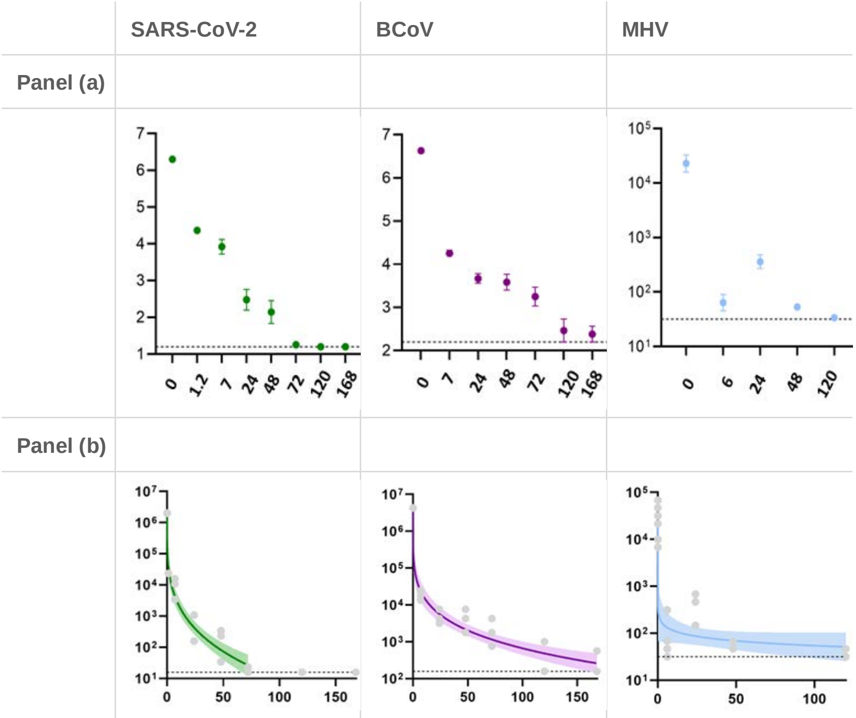
[22] VITRO-SKIN – IMS Florida Skincare Testing, Inc., FL, USA.

[23] TCID50 signifies the concentration at which 50% of host cells in a culture are infected after being inoculated with a diluted solution of viral fluid.

Chart A.3.1

Survivability of SARS-CoV-2 and surrogate viruses on €10 banknotes, expressed in simple logarithmic scales, plus the predicted decay times

(x-axis: desiccation time (hours), y-axis: log_{10} TCID50/mL)



Sources: Ruhr University Bochum and independent laboratories.

Panel (a) in Chart A.3.1 shows that viable virus was detected on the €10 banknote contaminated with SARS-CoV-2 for up to 72 hours, whereas viable virus was detected on the €10 banknote contaminated with the surrogate viruses MHV and BCoV for up to five days and over the entire experiment (up to seven days – although for the five- and seven-day time points, the virus titre was just above the limit of detection).

It should be noted that there are certain differences in the decay of the three viruses on the €10 banknote. However, it should be borne in mind that the testing with SARS-CoV-2 and the testing with the surrogates were performed at different laboratories with certain differences in the testing methods and also differences in the environmental conditions (temperature and humidity differing to some extent at individual sites and over time (e.g. summer period)). In support of this phenomenon, we also see some differences as well as some structural similarities when looking at a study published on the comparison of the SARS-CoV-2 and SARS-CoV stability on different surfaces (Van Doremalen et al., 2020). This study reports that SARS-CoV-2 survived on cardboard for a longer period of time (24 hours) than SARS-CoV, which survived for only eight hours under the same laboratory conditions. In general, the use of surrogates has proven to be a reasonably effective option for simulating the initial survivability of the actual SARS-CoV-2 virus on the surfaces of banknotes, coins and other media. The curves in Chart A.3.1 show different levels of virus in the medium term, around 72 hours, but perhaps the most important aspect is the initial decay in the first 24 hours, which is dramatic. The stability and persistence on €10 banknotes observed for BCoV resembles the initial decay for SARS-CoV-2. Given that BCoV can be handled at lower biosafety levels and therefore a BSL-3 lab is not required, this virus appears to be a suitable surrogate to study SARS-CoV-2 stability and transmission scenarios. However, whether these findings can be transferred to other fomites needs to be addressed by experimentation in the future.

Annex 4: Previous assessments of the risk of cash contributing to the spread of avian flu (2006) and swine flu (2009)

Banknotes in circulation are exposed to a wide variety of potentially harmful chemicals and substances, including everyday viruses and bacteria. Since euro notes and coins were first introduced, there have been two notable virus outbreaks that have caused widespread international concern: the H5N1 virus, or avian flu, in 2006, followed by the H1N1 virus, or swine flu, in 2009. The ECB responded to public concerns about general transmission by initiating a series of investigations to assess the interaction and any residual risk that there might be between the use of cash and the spread of the respective viruses. These two investigations are summarised below.

A.4.1 Analysis of avian flu (2006)

The first testing programme involved a series of tests designed to establish the duration of the biological viability[24] of similar micro-organisms on the surface of euro banknotes, with a special focus on the influenza virus. The approach adopted would allow the results generated to be used in many different scenarios in any future investigations rather than just focus on one particular strain of virus.

To this end, twenty well-known, representative organisms – divided between bacteria, bacterial endospores, mycobacteria, fungi and viruses[25] – were tested for their potential to retain microbial viability on the surface of euro banknotes. This gave an estimate for the potential of banknotes to carry different types of micro-organisms and provided a comparative analysis for the potential for euro banknotes to carry influenza virus. The human influenza A virus (H1N1) was used as surrogate for the closely related avian influenza A virus (H5N1).

The data showed the stability of the viral organisms, characterised by the estimated half-life, the estimated post-desiccation half-life and the duration of viability of each virus type. Most organisms tested lost considerably more than 50% of their viability within the first two hours of contact with the banknote surface, during initial

[24] The ability of a virus to maintain a level of infectivity.

[25] The viruses tested were: influenza A H1N1 ATCC VR-1469, feline coronavirus, rhinovirus 1A ATCC VR-1559, adenovirus 5 ATCC VR-5, rotavirus Wa ATCC-2088, feline calicivirus (norovirus surrogate), bovine virus, diarrhoea virus VR-1422 (Hepatitis C virus surrogate) and poliovirus type 1 ATCC VR-1562.

desiccation, where in general most viability is normally lost. The exceptions to this were the MRSA strains that retained marginally more than 50% of their viability after two hours. After desiccation, most organisms again had lost more than a further 50% of their viability within four hours.

Influenza A virus (H1N1) and feline coronavirus (acting as SARS coronavirus surrogate) lose viability to either undetectable or low levels 24 hours post-inoculation. On this basis, it was concluded that these viruses represented a lower risk for widespread transmission on banknotes. These data implied that there was a lower risk of the closely related H5N1 strain of influenza A ("avian flu") being carried.

This study showed that the influenza virus and SARS-CoV are the micro-organisms with the least stability on the surface of banknotes. This would therefore be expected to curtail their ability to potentially spread within the human population via banknote surfaces. These viruses are also respiratory viruses, where the most effective route of transmission would be through aerosol-mediated penetration into the lung.

Generally, the data and the literature available at that time indicated that the potential for banknotes to spread infectious disease organisms and then for disease to become established in humans after banknote contact is low.

ECDC statement

The European Centre for Disease Prevention and Control (ECDC) was contacted as part of this investigation and provided some useful clarifications of the risks involved. The ECDC did not see any significant possibility that banknotes might help spread the virus, and therefore no recommendations on any specific risk-reduction measures were made within the Eurosystem. The view of the ECDC remains very similar in the current SARS-CoV-2 outbreak.[26]

A.4.2 Analysis of swine flu (2009)

The H1N1 virus – commonly known as "swine flu" – emerged in 2009, and similar concerns again arose concerning its transmission via banknotes and coins. The analysis relied on the extensive testing previously conducted in 2006 on the possible interaction between euro banknotes and the avian flu virus.

The test results obtained were considered applicable. Consequently, the ECB concluded that the transmission of the swine flu virus via banknotes is of insignificant importance compared to other transmission means in the case of a pandemic.

[26] We consider it unlikely that potentially contaminated euro banknotes play a major role in the transmission dynamics of the COVID-19 outbreak, especially in view of the fact of the large-scale suppression measures that have been implemented by the majority of Member States. Recommendations for banks, cash handlers and retailers are that they should follow the regular prevention advice for the public: physical distancing from customers (1-2 metres); frequent hand-washing with soap and water and the use of alcohol disinfectants, particularly before eating, drinking or smoking; avoiding touching face, eyes and mouth; applying respiratory hygiene and cough etiquette.

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Acknowledgements
The authors would like to thank Sylvain Calluaud, Doris Schneeberger, Björn Fischer and an anonymous referee for their helpful comments. They would also like to thank the laboratories Dr BRILL + Partner GmbH and BlueTest Laboratories for their assistance in conducting the experiments.

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PDF ISBN 978-92-899-4564-6, ISSN 1725-6534, doi:10.2866/141321, QB-AQ-21-006-EN-N