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Highlights

- Digital contact tracing is a promising digital public health intervention to manage epidemics.
- We review the literature and develop recommendations for policy-makers and for further research on how to achieve its widespread adoption.
Fostering participation in digital contact tracing

Dominik Rehse*  
ZEW Mannheim

Felix Tremöhlen  
University of Mannheim

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Abstract

Digital contact tracing is a promising digital public health intervention to manage epidemics. However, in order to reach its full potential, the technology has to be widely adopted and used. During the SARS-CoV-2 pandemic, this has not necessarily been the case. We review the literature with a focus on how participation in digital contact tracing could be fostered and provide policy recommendations on how to increase its adoption and usage as well as recommendations for further research.

Keywords: Public health, Public good, Public health intervention, Digital contact tracing

JEL classification: H41, I12, I18

* Corresponding author: dominik.rehse@zew.de
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1. Introduction

The beginning of the 2020s has been shaped by a worldwide public health crisis: the SARS-CoV-2 pandemic. As of mid of April, 2021, about 140.04 million infections with the new coronavirus and about 3 million deaths of people tested positive for the virus have been reported worldwide (Johns Hopkins University, 2021), by far exceeding 8,096 reported infections and 774 deaths attributed to the SARS-CoV-1 pandemic of 2002 and 2003 (WHO, 2003). In the absence of effective pharmaceutical interventions and of sufficient testing and tracing capacities, many governments repeatedly resorted to restricting individuals’ freedom of movement in order to contain the spread of the virus. However, school and business closures, social distancing, travel restrictions, mandatory quarantine and other drastic measures triggered significant adverse social and economic effects (Deb et al., 2020; Mulligan, 2020). As a consequence, earlier proposals to make better use of digital measures to manage the pandemic became more widely discussed (Budd et al., 2020; Ting et al., 2020). In an influential epidemiological modelling study published at the end of March 2020, Ferretti et al. (2020) suggested that sufficiently capable and widely used digital contact tracing technology could dramatically reduce the need for more restrictive containment measures. This proposal gained wide traction in the public debate and among policy-makers, which Figure 1 illustrates with the development of the relative number of internet searches for related terms over time.

As digital contact tracing apps were being launched over spring and summer 2020, three general adoption patterns emerged, as Figure 2 illustrates. First, adoption curves relatively quickly levelled off in most countries. Second, the adoption curves for some countries show more complex dynamics, which appear to be country-specific effects. For instance, Singapore’s government announced in October 2020 that its initially voluntary contact tracing app would become mandatory for everyday activities, which provided a subsequent boost in adoption. Another example is the Dutch contact tracing app, which initially started as a pilot study with relatively few users and was only officially launched only in October 2020. Third, the ultimate levels of adoption, except

![Google Trends indices for global searches in English language related to digital contact tracing apps](image-url)
for Singapore, are relatively low, ranging from 10 to 30 percent of installations per inhabitant in April 2021. Such levels lagged behind expectations and behind of what was necessary to reach the full potential of the technology.

In this paper, we review the literature relevant to answering the question of how the participation in digital contact tracing could be fostered and develop recommendations for policy-makers and further research. We use the term ‘participation’ as an umbrella term for both ‘adoption’, i.e. the first acceptance of the new intervention, and ‘usage’, i.e. the use after adoption.

We proceed as follows: first, we introduce digital contact tracing as a technology and digital public health intervention. Second, we review the literature on the determinants of an individual’s and a society’s collective decision to adopt and use digital contact tracing. Third, we review the literature with a focus on how to shape such decisions in favor of participating in digital contact tracing and develop related policy recommendations. Fourth, we provide recommendations for further

Figure 2: Adoption of digital contact tracing apps across countries

1 Singapore’s TraceTogether app was launched on March 20, 2020, Italy's Immuni app on June 1, 2020, Germany's Corona-Warn-App on June 16, 2020 and Switzerland's SwissCovid app was launched on June 25, 2020. Canada's COVID Alert app was first launched on July 31, 2020 and was gradually introduced to several Canadian provinces. The Spanish Radar Covid app was first introduced in a test phase at the end of June 2020 and was gradually introduced to the different Spanish regions from mid-August 2020 onwards. The Dutch CoronaMelder app's test period in selected regions started in August 2020 and the app was made available nationwide starting from October 10, 2020. The cumulated number of downloads until a respective date was divided by the total number of inhabitants in the respective country as of 2020 (Bundesamt für Statistik, 2020; Central Agency for Statistics Netherlands, 2021; Department of Statistics Singapore, 2020; National Institute of Statistics Italy, 2020; National Institute of Statistics Spain, 2020; Statistics Canada, 2021; Statistisches Bundesamt, 2020). For Canada, the inhabitants of Alberta, British Colombia, Nunavut and Yukon were excluded from the respective total number of inhabitants since the app could not be fully used in these provinces and territories by March 2021. For Switzerland, the number of app downloads is frequently published by the Swiss Bundesamt für Statistik (2021). Download numbers of the Dutch app are frequently published by the Dutch Ministry of Health, Welfare and Sport (2021) and numbers for the Spanish app are frequently published by the Government of Spain (2021). For Germany, the cumulated number of downloads is irregularly published by the German Robert Koch-Institut (2021). For Singapore, the cumulated number of downloads is irregularly updated on the app's website (Government of Singapore, 2021), which we reconstructed with the Internet Archive’s Wayback Machine. Using the Wayback Machine, we also reconstructed numbers for Italy (Presidency of the Council of Ministers, 2021) and Canada (Government of Canada, 2021) from the respective government authority's websites. The number of downloads does not correspond to the number of active users, since users could have uninstalled the app again or could have turned off Bluetooth.
research. Lastly, we conclude and provide an outlook on the relevance of this line of research for managing other individual and public health issues.

2. Digital contact tracing as a digital public health intervention

Digital contact tracing is a public health intervention. Beaglehole et al. (2004) define public health as concerted efforts to maintain desirable health outcomes of the general population or make positive and sustainable changes to undesirable ones. The term describes both an interdisciplinary research field and a policy goal. Public health interventions are means to achieve this goal and have to be differentiated from clinical interventions, which attempt to improve health at the individual level (Rychetnik et al., 2002). Digital public health interventions (DPHIs) are promising to address some of the limitations of more traditional public health interventions (TPHIs). Digital contact tracing is a prime example.

2.1. Benefits of digital contact tracing

The key non-pharmaceutical intervention in managing epidemics is to isolate the infected person as well as tracing, testing and – if necessary – isolating their contacts. The SARS-CoV-2 pandemic has shown that such test-trace-isolate strategies are limited by the capacity of public health authorities to reconstruct chains of infection. Furthermore, the strategy of tracing contacts is constrained, as an infected person may struggle to remember which individuals they have recently come into contact with, as well as the anonymity of casual contacts in public spaces. These problems might be exacerbated by characteristics of the pathogens and the illnesses they cause. With regards to SARS-CoV-2 and COVID-19, the illness caused by the virus, a significant share of the transmissions appears to occur before the person transmitting the virus has developed symptoms and the median time period between the infection of a person and the onward transmission to another person is only about five days (Cheng et al., 2020; Ferretti et al., 2020). These characteristics increase the length of the potential chains of infection and can lead to a “curse of dimensionality” for contact tracing. When contact tracing either becomes infeasible or too inaccurate, stricter measures to contain an epidemic may become necessary. During the SARS-CoV-2 pandemic, these have included the closure of businesses, schools and cultural institutions as well as mobility restrictions. Such measures bear significant economic and social costs. For example, Mulligan (2020) estimates that each workday at which non-essential businesses and activities are shut down in the U.S. due to lockdown measures, the country’s economic welfare is reduced by approximately 28.2 billion U.S.-Dollars.

A technological way to increase the capacity, speed and scope of contact tracing is digital contact tracing. The fundamental idea is that a mobile application records data on meetings or encounters of users of the application. If an app user tests positive for a pathogen after such an event, the data collected by the app can be used to reconstruct at-risk contacts and thereby parts of potential chains of infection. Ideally, the app includes the functionality to inform these contacts at high speed, to arrange clinical tests for the pathogen and to organize quarantine.

2.2. Approaches to digital contact tracing

Digital contact tracing technologies differ in a number of dimensions. One design dimension is whether the technology attempts to record locations or proximity to other technology users. Location could be recorded through GPS sensors included in most modern smartphones or through location triangulation with
the help of mobile phone masts. Proximity could be measured through the strength of Bluetooth signals or ultrasound signals, which most modern smartphones are capable of sending and receiving. All these technologies could also be used together.

Another design dimension is how the records of locations or encounters are stored and how they are used to inform technology users about their status. The two most frequently discussed models are a ‘centralized’ and a ‘decentralized’ approach. Contrary to what the terms might suggest, a central server run by a central party exists in both models. The app of a user records the location or proximity relative other app users. The app users identify each other with an identifier. In case of an infection, data is transferred to the central server. Under the centralized approach, this data only contains the hash key of the infected app user. Other users’ apps have access to the centralized server and can compare their respective collected list of keys with the keys of infected app users stored on the server. If their list of keys includes the key of an infected app user, the app can inform its user about the at-risk contact. Under the centralized approach, the data transferred to the server upon an infection contains the hash keys of the user as well as all recorded at-risk contacts. The central authority can then transparently redraw potential paths of infections and inform at-risk app users. In both cases it is necessary to develop a logic according to which at-risk contacts are defined, such as how long a user needs to have exposure to other users and at what distance. Other design dimensions are, for example, how an infected app user is identified in the first place and how this information is fed into the app. Further dimensions include, whether reporting such information to the app is mandatory or voluntary, how users can or have to react to at-risk contacts, how public health authority contact is established and how follow-up testing procedures are integrated.

During the SARS-CoV-2 pandemic, several countries have implemented digital contact tracing. The ‘TraceTogether’ app introduced in Singapore in March 2020 was an early centralized approach to app-based digital contact tracing via Bluetooth (Mello & Wang, 2020). In the following months, a number of public and private initiatives in several countries started to develop solutions for digital contact tracing. To mitigate privacy concerns, many approaches, such as ‘PACT’ and ‘DP-3T’, are built on privacy preserving protocols. These protocols use a Bluetooth-based decentralized design with Apple and Google providing specialized interfaces in their respective smartphone operating systems in order to give more elaborate access to Bluetooth sensors. Germany, Switzerland, Italy, Canada, Japan, Malaysia and several other countries built their contact tracing apps based on these interfaces. The majority of these apps uses randomly generated, frequently changing hash keys to anonymously identify their users and require user consent for reporting the personal identifiers to a central server after being tested positive for the virus (Sharon, 2020). Based on the same protocol, several country-specific apps have since become interoperable in order to improve their utility in border regions and while traveling (European Commission, 2021).

3. Determinants of the decision to participate in digital contact tracing

The decision to participate in digital contact tracing is shaped by the perceived costs and benefits. A rational individual’s decision is driven by weighing the private costs of participation, such as monetary costs, effort, switching costs or risk of privacy invasion against the private benefits, such as improvements in own health outcomes or the desirable feeling of doing one’s part to combat the spread of the disease. An individual will maximize their own utility and decide in favor of the intervention if the benefits outweigh the costs. However, a person’s cost-benefit analysis does not necessarily reflect the true costs and benefits, since individuals
often lack perfect information and might base their judgements on misperceptions (Nyhan, 2020). Furthermore, rationality can be bounded and cognitive and behavioral biases can affect decision-making (Siegal et al., 2009; Thaler, 2018). The decision to participate in a public health intervention strategy will also usually be made within a social network, which might alter an individual's perceived and actual costs or benefits from participation (Banerjee, 1992; Daughety & Reinganum, 2010; Rohlf, 1974; Young, 2009). In the following subsections, we review the literature relevant to the decision to participate in digital contact tracing in more detail.

3.1. Common issues in public good provision

The decision to participate in digital contact tracing is influenced by the public good character of the technology. Buchholz & Sandler (forthcoming) argue that eradicating infectious diseases can be seen as a global public good. More generally, ‘good’ public health can be understood as having the characteristics of a public good. First, it is non-excludable, meaning that everyone within a community enjoys the benefits of good public health (Siegal et al., 2009). For instance, the benefits of herd immunity through vaccinations or lower levels of pollution in potable water due to environmental regulation are usually available to all members of a community and cannot be restricted to a certain group. Second, public health is often characterized by non-rivalry in consumption. An increase in the number of people benefiting from a pre-existing good does not lead to additional production costs of that good and does not reduce other individuals’ utility from consumption (Feachem & Medlin, 2002). For instance, the costs of achieving herd immunity do not increase when an additional individual benefits from it. This public good nature implies that an individual's efforts to contribute to public health, such as getting vaccinated or refraining from smoking in the presence of others, unfold positive externalities while non-participation can lead to negative externalities (Elliott & Golub, 2019).

3.1.1. Cooperation

Digital contact tracing faces the same ‘free-riding’ problems as other public good provision measures. If a critical mass of individuals in a society participates in digital contact tracing, non-participants also enjoy the benefits from better containment of an epidemic without incurring the costs of participation. Even though cooperation would be mutually beneficial, it might not occur or might not be sustained due to individual incentives to maximize private utility by not contributing without considering public benefits (Fairfield & Engel, 2015; Frischmann et al., 2019). However, people have often been found to contribute more to the public good than one would expect based on the assumptions of neoclassical economic theory (Andreoni, 1995; Fischbacher & Gächter, 2010). A common explanation for this finding is that individuals do not only care about their direct benefits from consuming the public good but that intrinsic motivations, such as concerns about one’s self-image and others’ wellbeing, as well as concerns about one’s reputation also enter an individual’s utility function (Anderson et al., 1998; Andreoni, 1990; Bénabou & Tirole, 2011; Croson, 2007; Fehr & Gächter, 2000a).

Indeed, intrinsic motives and reputational concerns have been found to play a role in experiments and real-world settings. Wells et al. (2020) suggest that prosocial preferences like altruism played a role in parents’ decision to have their children participate in a polio vaccination campaign that primarily involved public and not private benefits. In the context of the SARS-CoV-2 pandemic, survey data collected by Campos-Mercade et al. (2020) in Sweden show that prosocial preferences are positively associated with contributing to the public good of disease
control during the SARS-CoV-2 pandemic by adhering to public health recommendations like social distancing. Catering to such intrinsic motives is important to encourage participation in digital contact tracing.

3.1.2. Trust

The decision to adopt and use digital contact tracing technology also depends on an individual’s trust in other individuals, institutions, science, and technology. Trust can generally be defined as a person’s willingness to put their own – material or immaterial – resources under the control of another party, with the expectation that this act will be beneficial for the trusting person but without any legal guarantee that this expectation will be met by the entrusted party (Fehr, 2009). The prevailing level of trust within the target population could affect the participation in digital contact tracing in several ways. First, a high level of trust in others might increase the willingness to cooperate in public good provision since it leads to the expectation of reciprocal behavior by others and thereby increases the expected benefits from participation (Gächter et al., 2004). Second, trust towards scientists, the media, the government and public health authorities can affect whether people perceive digital contact tracing technology as necessary and efficient (Cummings, 2014). It influences the formation of expectations about the private and public benefits of the intervention and can thereby increase an individual’s self-interest and altruistic motivation to participate. Trust in the parties involved in implementing digital contact tracing could also decrease the perceived costs of participation when it reduces concerns about aspects such as privacy invasion (Vaithianathan et al., 2020). Third, trust in the technology used for digital contact tracing can reduce the perceived costs of adoption (Eiser et al., 2002).

Empirical evidence on the role of trust in public good contributions suggests that it might be of importance for fostering participation in digital contact tracing. In the context of the SARS-CoV-2 pandemic, Bargain & Aminjonov (2020) use surveys on political trust across European regions and data on regional mobility patterns during the outbreak of the pandemic in Europe. They find that higher levels of trust in political authorities are associated with higher compliance to public health measures such as lockdowns and social distancing orders. They observe that increasing the stringency of pandemic control measures is more efficient in regions with high political trust. Brodeur et al. (2020) find similar results for the US. In a related study, Borgonovi & Andrieu (2020) find that individuals in US counties with a high degree of social capital, such as trust in others, reduce their mobility more in response to the rise of a pandemic even before official government measures mandate social distancing. Not only having trust in others, but also being trusted by others may be decisive factors with regard to participation in digital contact tracing and similar interventions. Moreover, trust has been suggested to be self-reinforcing (Fehr, 2009) and to signal social norms (Sliwka, 2007). An entrusted individual might therefore under certain circumstances be more motivated to participate in digital contact tracing than an individual who may feel that they are being forced or monitored in doing so. Overall, the decision to participate in digital contact tracing is likely to vary with these different aspects of trust in societies.

3.1.3. Misperceptions

Misperceptions have the potential to significantly affect the assessment of the costs and benefits of digital contact tracing and thereby to influence participation decisions. Nyhan (2020) defines misperceptions as beliefs in claims which are objectively false or unsupported by evidence. Evidence from experiments (Fischbacher & Gächter, 2010) suggests that beliefs can affect the decision to
contribute to public goods. Misperceptions could similarly influence public support for digital contact tracing.

Indeed, recent empirical evidence from lab experiments and observational studies suggests that misperceptions influence the reception of traditional public health interventions to contain the SARS-CoV-2 pandemic. For instance, Akesson et al. (2020) observe in lab experiments that beliefs about the infectiousness of the virus can be miscalibrated and can influence the willingness to adhere to social distancing measures. Similarly, Allcott et al. (2020) and Simonov et al. (2020) find in observational studies that compliance with public health policy measures shows partisan differences and that news reports contradicting recommendations by public health authorities reduce social distancing compliance. The importance of communication, expectation and belief formation is also stressed by Brisce et al. (2020), who study the effect of public health policy announcements on social distancing compliance. These studies confirm evidence on the importance of beliefs in public health interventions more generally. For instance, beliefs which associate vaccines against measles, mumps and rubella with the occurrence of autism – despite not being based on systematic evidence and contested by several scientific studies – have had a significant negative impact on vaccination rates, resulting in measles outbreaks in several countries (Swire-Thompson & Lazer, 2020).

The social dynamics leading to misperceptions and to their wider spread are an open area of research. The most relevant active line of research focuses on the spread of false information, which might lead to misperceptions. Recent research has particularly focused on online social networks like Twitter (Goel et al., 2016; Grinberg et al., 2019; Vosoughi et al., 2018) or Facebook (Chiou & Tucker, 2018). Theoretical models on information diffusion show that the dynamics of the spread of information strongly depend on the topology of the network (Kreindler & Young, 2014). It is therefore difficult to generalize from one online social network to another. However, the current set of empirical evidence suggests that understanding and making use of the dynamics of information diffusion is a central building block to avoid misperceptions about public health interventions such as digital contact tracing.

3.1.4. Information avoidance

The decision to participate in digital contact tracing could be detrimentally affected by peoples' tendency to actively avoid receiving and processing certain information. Evidence collected in the context of health suggests that even where information is available for free or at a relatively low cost, individuals may still choose to remain ignorant out of strategic considerations or because they directly derive utility from holding certain beliefs (Golman et al., 2017; Ho et al., 2021). For instance, Oster et al. (2013) document in the context of a study over a course of ten years that out of 1,001 individuals with a 50 percent chance or higher of inheriting Huntington’s disease, only about five percent took a perfectly predictive test before developing symptoms. Similarly, Ganguly & Tasoff (2017) show that 5.2 percent of college students in their sample are willing to forgo 10 US-Dollars in order to not get tested for the herpes virus HSV-1. In fact, even three times as many avoid getting tested for the HSV-2 strain which is more consequentially perceived, despite the financial incentives in place. This decision can be seen as a refusal to contribute to the public good of infectious disease control. Ho et al. (2021) observe that preferences for avoiding information are a stable trait within people but not easily predictable by demographic characteristics.

In the context of digital contact tracing, this could mean that individuals might actively avoid the potential costs that are attached to information provided by contact tracing apps. This could be the case, for instance, when an individual is notified via a contact tracing app that they are at risk of having contracted a
disease. This might lead to the decision to not participate in digital contact tracing in the first place.

3.2. Issues specific to public health interventions

3.2.1. Conditionality on the personal and public health situation

An individual’s willingness to participate in public health interventions such as digital contact tracing depends on its perception about their relevance. Those perceptions are in turn – at least partially – shaped by the current state of public health and the individual health and risk status. Observing the number of very severe outcomes (e.g., the number of deaths from a disease) and assessing one’s individual vulnerability (e.g., based on age or current health status) shapes perceptions about health threat severity. Even when interventions have little private benefits, observing the severity of the threat and others’ vulnerability might still alter altruistic individuals' benefits from intervention participation.

Confirming this view, several studies find that local case numbers and the proportion of more vulnerable people are positively correlated with the compliance with public health measures like social distancing during the SARS-CoV-2 pandemic (Brzezinski et al., 2020; Engle et al., 2020). Causality is difficult to assess in these cases, but it seems plausible that a deteriorating public health situation and a high level of individual vulnerability increase the expected benefits from public health interventions and the support for them. However, there is evidence that also opposes this view. For example, Akesson et al. (2020) observe a fatalism effect in an experiment conducted among more than 3,600 people. This effect refers to the observation that beliefs about higher infectiousness of SARS-CoV-2 are associated with decreasing willingness to comply with measures to contain the spread of the virus. Individuals seem to perceive interventions as ineffective due to the high perceived general risk. Whatever the net effect, the perceived personal and public health situation could significantly influence the decision to adopt and use digital contact tracing as well.

3.2.2. Integration into the wider health system

The integration of digital contact tracing into the wider health system response to epidemics is likely to shape its adoption and usage. Public health interventions are often implemented as vertical ‘stand-alone’ interventions that only tackle one specific public health problem and are not viewed within the broader context of the health system. While this might be necessary in some cases, a more horizontal embedding of an intervention into the structures of health system governance, resource planning, communication, clinical care, research and regulation, among others, could be more efficient (Atun et al., 2010; Budd et al., 2020; Gong et al., 2020; Mehl & Labrique, 2014). Furthermore, the integration of different interventions can also decrease the costs of participation by increasing convenience and facilitating access. In the context of digital interventions, one public health app might serve multiple purposes, such as public health communication, support of health-related behavioral changes, keeping track of vaccinations and reporting symptoms of infectious diseases. Digital contact tracing could be directly integrated into a single app, making it widely available and accessible from the start. While the integration of different interventions might significantly reduce the individual and public costs and increase their benefits, it might also raise new issues, for instance, if a badly-received intervention has negative effects on the adoption of other interventions.
3.2.3. Credence good issues

Many public health interventions have characteristics of credence goods, for which only the intervention provider can judge on its utility for the intervention participant (Dulleck & Kerschbamer, 2006). This is also the case for digital contact tracing. Users cannot directly observe whether they really receive warnings on the basis of a reasonable risk of infection or whether their data is potentially used for purposes besides public health (Vaithianathan et al., 2020). In terms of an individual’s cost-benefit calculation, such information asymmetries can lead to increased perceived private risks and costs and decreased perceived private and public benefits, thereby reducing participation rates. Whether worries about exploitation are justified evidently depends on the implementation of the particular digital contact tracing technology. For instance, potential participants might still be concerned about data collection for government surveillance (Vaithianathan et al., 2020). False information could play a role in reinforcing such worries (Bavel et al., 2020). The credence good character of digital contact tracing might especially raise the perceived costs of those with a low socioeconomic status as they have been found to be on average exploited more often in credence good situations and they therefore may be particularly/suspicious (Gottschalk et al., 2020). Whether such credence good issues affect participation rates in digital contact tracing depends on whether the related information asymmetries can be reduced, for instance, by trust in authorities and by building governance systems to increase transparency and accountability for the technology.

3.3. Issues specific to the digital realm

Digital contact tracing technologies face a number of issues specific to their digital nature. Since digital contact tracing uses existing technologies, such as mobile devices, the availability, capability and affordability of these technologies is critical to their adoption and usage. The decision to participate is also influenced by an individual’s and the wider society’s expectations towards technologies, such as security and privacy standards. In the following, we review the literature on such issues relevant to the case of digital contact tracing.

3.3.1. Privacy concerns

Digital contact tracing records interactions among people and, depending on the technological implementation, locations of interactions. This might raise concerns about the use of such data for purposes not agreed upon by the users of digital contact tracing (Altman et al., 2020). Such concerns typically include the fear of discrimination by governments, social contacts, employers or health insurers (Acquisti et al., 2016). Allen (2000) defines privacy as the inaccessibility of certain aspects related to an individual. She organizes privacy concerns into four dimensions: informational privacy, physical privacy, decisional privacy and proprietary privacy (Allen, 1997, pp. 33-34). The first three of these dimensions have particular relevance for the decision to participate in digital contact tracing. Informational privacy – the inaccessibility of personal data – has been front and center in much of the public debate on digital contact tracing. However, this is not the only relevant dimension of privacy. An individual’s physical privacy – the inaccessibility of the person or their personal space – could be invaded if location data from digital contact tracing apps is disclosed to third parties. For instance, not every user would be happy to share data on where they spend their time. An
individual’s decisional privacy – the freedom of personal choice – could be at risk if peers exert pressure to use the app or policy measures require app use.\textsuperscript{2}

In the context of the decision to participate in digital contact tracing, the risks of such invasions of privacy have to be weighed against the benefits. This includes both personal benefits such as being informed about an increased risk of transmission as a result of being in close contact with an infected person and contributions to the collective effort to contain an epidemic as a public good. If privacy is understood as a public good in itself, as argued by Fairfield & Engel (2015), an individual’s decision to participate in digital contact tracing corresponds to trading off two public goods. Abowd & Schmutte (2019) provide an economic model for this choice, according to which the optimal level of privacy protection is chosen where the marginal social benefits equal the marginal social costs of privacy protection in terms of lower data accuracy and representativeness. Approaches to digital contact tracing need to address this tradeoff in order to maximize participation in such interventions.

One difficulty in finding the ‘right’ level of privacy when implementing digital contact tracing is the measurement of preferences on privacy itself since stated and revealed preferences are oftentimes strongly at odds. Generally speaking, stated preferences for privacy and the protection of personal data are strong (Acquisti et al., 2016). However, Athey et al. (2017) find in an experiment among students that even a small incentive like a pizza significantly increases the probability that students would share their friends’ contact data. Due to this ‘privacy paradox’, it is unclear whether stated preferences collected by Altmann et al. (2020), which list privacy concerns as the main reason for not taking part in digital contact tracing, can be taken at face value. Acquisti et al. (2015) suggest that the paradox might be explained by the uncertainty, context dependence, and the potential for malleability involved in decisions over privacy protection. First, privacy decisions often have to be made in a context of significant uncertainty, for instance, regarding which data is actually collected and for which purpose, as well as an individual’s real value of privacy. Second, privacy behavior seems to be highly context-dependent. Preferences stated about general attitudes and the concrete behavior in a certain situation do not need to be closely associated (Acquisti et al., 2016). Third, privacy behavior is found to often be easily malleable, for instance, by changing decision frames or changing the ordering and default of options. False information might play an especially important role in this context (Acquisti et al., 2015). If these reasons for the privacy paradox also apply to digital contact tracing, finding an appropriate level of privacy amounts less to a passive and observational activity but more to an active information campaign trying to reduce uncertainty about the technology, rolling it out at the right time and place and finding ways to correct false information. This poses a significant challenge.

However, assuming rational cost-benefit analysis by individuals deciding to participate in digital contact tracing might be short-sighted in the first place since decisions in the realm of privacy might not be purely rational. For instance, Marreiros et al. (2017) provide experimental evidence that even information about positive changes to a company’s privacy policy reduces an individual’s willingness to disclose personal data. This can be interpreted as salient privacy policy reminding individuals of their privacy preferences. This finding is at odds with Athey et al. (2017), who document that even irrelevant positive information about data protection increases the willingness to share data.

The privacy aspects in the decision to participate are not only influenced by the design of the digital contact tracing system and the communication around it but

\textsuperscript{2} More choice is not necessarily socially optimal. Reducing privacy might in fact be a policy tool to foster participation in public good provision. Daughtey & Reinganum (2010) and Ali & Bénabou (2020) argue that decreased privacy and increased observability of individual actions involves social costs but also increases individual contributions to the public good due to reputational concerns.
also by the institutions that implement it. Low trust in such institutions (e.g. due to concerns over governmental surveillance) might pose a barrier to adoption, while trust in institutions can be a way to overcome privacy concerns (Vaithianathan et al., 2020).

3.3.2. Digital divide

The decision to participate in digital contact tracing is not only a matter of will but also a matter of possibility. Many low- and middle-income countries still have significantly lower per capita rates of ownership and usage of digital technologies and also lack the necessary infrastructure compared to wealthy countries (Arakpogun et al., 2020). Furthermore, even within developed countries, groups with lower socioeconomic status and of an older age have been found to have on average less access to digital technologies and lower digital literacy (Aiello et al., 2020; Blom et al., 2020). For instance, in 2017, 13 percent of the population of the European Union had never used the internet. In Romania, Greece and Bulgaria this share was even higher than 25 percent (European Commission, 2018). In the United Kingdom, less than half of the citizens older than 65 own a smartphone (Osman et al., 2020). A lack of access to the technologies required for digital contact tracing could therefore hinder adoption and usage.

Low participation rates in digital contact tracing of certain groups due to such a ‘digital divide’ impose costs both on these groups and the general public (Budd et al., 2020; Kontos et al., 2014). For the disadvantaged group this might be particularly consequential since they might be the individuals particularly in need of public health interventions, such as by belonging to an older age group (Blom et al., 2020). Furthermore, negative externalities to the general public result from the digital divide when public health interventions require high rates of adoption throughout the whole population to work efficiently. This is particularly the case with digital contact tracing.

3.3.3. Technology design and compatibility

The design and architecture of digital contact tracing apps can have a significant impact on the individual perceived costs of adoption and usage. For instance, the more time a user needs to invest to become acquainted with the app, the higher the opportunity costs as this time is not used for other purposes. Opportunity costs also arise if an app poses limits to the use of other applications on the same device. This might be the case, for instance, if a contact tracing app increases battery usage or demands significant storage capacity (Ghose & Han, 2014; Redmiles, 2020). Furthermore, the design of a technology can influence the transparency and privacy perceptions (Trang et al., 2020). However, the objective costs might only be weakly correlated with the subjective perceived costs, as suggested by Read (2019). Additionally, there might be significant heterogeneity in how different demographic groups perceive the costs of using a technology like digital contact tracing and this could also potentially be a consequence of the digital divide (Loi, 2020).

Not only perceptions but also technological capabilities can determine the decision to participate in digital contact tracing. For example, if digital contact tracing can piggyback on an already widely available technology, it is much easier to realize network effects and marginal private and public benefits from participation. In the case of digital contact tracing it would be particularly valuable if the related apps would run on as many existing smartphones as possible and would be compatible across different operating systems.
3.4. Issues specific to innovation diffusion

The rollout dynamics of digital contact tracing and other DPHIs can be understood as innovation diffusion processes. Such processes are discussed in the literature of different fields. The literature is vast and we only briefly review a selection of these strands of literature before getting back on its relevance for digital contact tracing.

Trying to unify innovation adoption models from different fields, Young (2009) categorizes the dynamics of innovation adoption processes into three approaches: In contagion models, innovations spread like epidemics, with agents adopting innovations upon contact with prior adopters. In social influence models, agents adopt an innovation once sufficiently many other agents have already adopted it. And in social learning models, agents adopt innovations once they have collected sufficient evidence that an innovation is worth adopting, with the evidence being collected among earlier adopters. Young (2009) shows theoretically that these different models lead to different adoption curves, which can but need not to be S-shaped as commonly observed (Griliches, 1957).

Within the information systems and marketing literature, two prominent models provide frameworks to study the determinants of innovation adoption behavior. In the diffusion of innovations (DOI) model, five perceived characteristics of an innovation determine an individual's willingness to adopt (Rogers, 1983): first, the improvement over the status quo by adopting the innovation (relative advantage). Second, the difficulty to use the innovation (complexity). Third, the fit to existing values, needs or systems (compatibility). Fourth, the visibility of the improvements by adopting the innovation (observability). Lastly, the opportunities to experiment with the innovation before finally adopting it (trialability).³ In the technology acceptance model (TAM), Davis et al. (1989) argue that the beliefs about two characteristics of an innovation ultimately determine its adoption: First, the perceived ease of use and, second, the perceived usefulness. The beliefs about these characteristics determine – partly indirectly by affecting their attitude towards using the technology – a potential user's intention to adopt and use an innovation. These intentions are in turn assumed to be positively correlated with actual adoption and usage. Empirical studies have found support for the TAM and the role of both perceived characteristics in determining adoption and usage. Davis et al. (1989) find that perceived usefulness plays a more important role in this regard than perceived ease of use. Several extensions of the TAM have been developed which, for instance, adding additional constructs to the framework which affect perceived usefulness and ease of use or directly affect use intentions (Venkatesh & Davis, 2000; Venkatesh et al., 2003).

Within the economics literature, the dynamics of innovation diffusion are discussed in work on network externalities. The adoption decision of others does not only signal information relevant for learning from others but also directly affects the benefits from adoption via network externalities (Arieli et al., 2020). If, due to network effects, an individual's benefits from a technology increase through the number of other users, an individual that observes an increasing number of adopters is also more likely to adopt an innovation based on their own cost-benefit calculus (Rohlfs, 1974). Another form of network externality can arise from the fact that an individual wishes to conform to the behavior or expectations of its social environment, i.e., social norms (Young, 2015). An individual might therefore have strong incentives to adopt an innovation if their social environment adopts it and it becomes standard to use it (Beidas et al., 2020). This leads to potentially complex dynamics. In the initial phase when there are only few adopters, the lack of strong network effects or social norms favoring the innovation can significantly decelerate

³ Moore & Benbasat (1991) add two further aspects: the voluntariness of use and the effect that usage of the innovation has on one's social image.
the speed of adoption or might even stop it. At an advanced stage, network externalities lead to a self-reinforcing effect that speeds up the adoption of an innovation, which has already gained a foothold within a social network. Empirical evidence suggests that addressing and intentionally shaping innovation diffusion processes is important to ensure widespread adoption (Beaman et al., 2018; Conley & Udry, 2010). The economics literature also considers the speed at which innovations spread through a social network. The speed depends on a variety of factors such as network topology, the injection points of the innovation, the relative benefits of the innovation compared to the status quo, and the noise in individual’s behavior (Banerjee et al., 2020; Kreindler & Young, 2014; Young, 2011).

With respect to digital contact tracing, the various strands of the literature on innovation diffusion emphasize that the decision to adopt and use the technology depends on both individual perceptions, such as perceived ease of use and usefulness, and the adoption behavior of others. The dynamics of adoption become complex relatively quickly, but are potentially shapeable.

4. Recommendations for fostering participation in digital contact tracing

The relatively low adoption rates of digital contact tracing apps during the SARS-CoV-2 pandemic illustrate that widespread participation can be difficult to achieve. Since the technology and implementation processes are still evolving at the time of writing this paper and strategies for digital contact tracing vary widely around the globe, it is difficult to get a detailed picture of which measures have been taken so far to increase participation and how they have thus far fared. In this section, we therefore develop general recommendations on how participation in digital contact tracing could be fostered based on the academic literature. We assume that participation is entirely voluntary and that participants have to be convinced of adopting and using contact tracing apps. Furthermore, we focus on recommendations that are likely to have a short-term impact. Cultural aspects, norms and society-wide attitudes evolve very slowly and are difficult to change in response to a public health crisis. For instance, trust in public health authorities and general attitudes towards compliance appear to be relatively stable over time (Schmelz, 2021). While it might be worthwhile to aim at changing such unbeneficial attitudes in the long run, we rather focus on the aim of increasing participation in digital contact tracing in the short-term. To make the relatively large number of recommendations more palatable, we provide a summary at the end of each subchapter. Most of the determinants of the participation decision introduced in the previous chapter resurface multiple times.

4.1. Information provision

Information provision is an essential measures to foster participation in digital contact tracing. However, providing more information is not always better. The effects of information provision on participation are likely to be more nuanced. In the following, we develop recommendations for effective communication based on the relevant literature.

Communicators For the successful provision of information on digital contact tracing, both the messages and the messengers themselves are important. Due to the credence good characteristics of digital contact tracing and other DPHIs, it is important that those who communicate the benefits of participation are perceived as trustworthy (Bavel et al., 2020). Initial evidence on the efficacy of communication measures during the SARS-CoV-2 pandemic and past vaccination campaigns shows that choosing trustworthy communicators can be helpful to increase...
participation in public health interventions. For example, Allcott et al. (2020) show that diverging messages by political leaders in the U.S. across the political spectrum appears to have shaped beliefs and participation in public health measures. Similarly, Banerjee et al. (2020) find in a randomized controlled trial involving 28 million Indians that sending a mobile text message containing a message by a prominent and trusted scientist – Nobel laureate Abhijit Banerjee – is associated with increased compliance to public health measures during the SARS-CoV-2 pandemic. This matches the observation from the U.S. that trust in scientists and health professionals seems to be significantly higher than trust in the media and the government (Swire-Thompson & Lazer, 2020).

Communication channels The previous example also highlights that digital technologies are an important medium to spread information about digital contact tracing and other DPHIs. Many people seek health-related information online (Bento et al., 2020). Websites, mobile applications, messengers and social media can therefore be important channels to provide information on digital contact tracing as well. Digital media also make it possible to tailor information provision to different groups. For instance, the effect of information provision might depend on risk preferences, trust towards the communicator or expectations formed prior to receiving the message, which might vary between different parts of society (Briscese et al., 2020; Fan et al., 2020). Digital technologies can provide a solution to this by sending individuals tailored messages based on their observable characteristics (Bennett & Glasgow, 2009). However, in order to bridge the digital divide, more traditional communication channels such as billboard, radio and TV advertisement should also be used to encourage participation in digital contact tracing. Information provision should also not be seen as a one-way street from providers to participants. Providers should encourage feedback from potential participants, which provides a form of social licensing and potentially builds up trust in the project (Vaithianathan et al., 2020). The choice of communication channels should reflect this.

Information content The information provided on digital contact tracing should be rigorously tested and designed to maximize its effect on participation. A few guiding principles are provided by literature. First, the information provided should be clear and transparent, ideally based on scientific evidence and should avoid conflicting messages (Weerd et al., 2011). If changes or errors occur, communication should be particularly clear and transparent. Second, the framing of the information matters. Public health communication often emphasizes the public benefits of an intervention. This can appeal to people’s prosocial motives and make social norms salient. However, as shown by Wells et al. (2020), this effect depends on the degree of altruistic preferences in the population. Therefore, the private benefits of participating in digital contact tracing should also be actively communicated, which might be a way to reach those who refuse participation out of information avoidance considerations (Oster et al., 2013). Third, it is important to find the right level of emphasizing the effects of a lack of participation in digital contact tracing. On the one hand, the consequences of not addressing an ongoing epidemic should become salient in order to trigger cost-benefit considerations. On the other hand, if threats are perceived as overwhelming, this might trigger a fatalism effect such that the willingness to participate decreases (Akesson et al., 2020). Fourth, the costs and benefits of different nature have to be made salient. While interventions might involve costs like personal effort or privacy risks, these costs need to be presented in relation to the associated benefits, such as potentially saving lives or avoiding more invasive interventions like lockdowns. One way to illustrate such trade-offs is to present evidence on potential counterfactual outcomes (Mello & Wang, 2020). Lastly, the information provided needs to make clear that digital contact tracing complements but does not substitute other measures, such as physical distancing or wearing of a face mask (Raskar et al.,
2020). Otherwise, adopters and users of digital contact tracing might develop a false sense of security, which could reduce the efficacy of digital contact tracing.

**Addressing misperceptions** An increasingly important category of information provision is meant to address misperceptions of public health interventions. This also applies to digital contact tracing. The literature suggests two measures to do so. First, information provision should be used to correct misperceptions. Experimental evidence collected by Akesson et al. (2020) and Lammers et al. (2020) during the SARS-CoV-2 pandemic suggests that providing true information has the potential to correct misperceptions. However, this might not always work, especially if false information has been spread intentionally. Nyhan & Reifler (2010) even argue that the correction of misperceptions by evidence-based information can lead to a backfire effect and strengthen beliefs in false claims. Second, Nyhan (2020) suggests that misperceptions could be prevented by reducing uncertainty about the trustworthiness of information sources. For instance, both verified and false information on digital contact tracing could be labeled by fact-checking services. However, consistently labeling information on different media requires strong cooperation between different parties, such as media companies, scientists, health professionals, technologists and fact-checking services.

**Timing of communication** Not only the message, the messenger and the medium of communication are important for successful information provision but also the timing of communication. For instance, Bento et al. (2020) show that large events associated with public health threats might only induce a short period of increased attention to information regarding the threat. This suggests that communication on digital contact tracing needs to be conducted quickly after a public health crisis arises. In this context, being quick in setting up a digital contact tracing system could matter greatly.

**Recommendations for information provision**
- Use trusted figures, such as known scientists and science journalists, as communicators.
- Choose different communication channels for different target audiences and provide feedback mechanisms.
- Tailor information content to different target audiences and rigorously test its effects on participation and other behavior relevant to fight the epidemic.
- Try to correct misperceptions through information provision and prevent their formation through labeling verified and false information.
- Provide information when attention and demand for information is greatest.

**4.2. Explicit incentives**

Both material and non-material incentives have the potential to increase participation in digital contact tracing. However, such incentives can backfire if applied naively. The related literature on encouraging contributions to public goods is vast. In the this section, we highlight only the most relevant aspects and deduct recommendations for fostering participation in digital contact tracing. We refer to Bowles & Polania-Reyes (2012) for a more elaborate treatment of this strand of literature. The incentive schemes suggested in the following should be seen as candidates for rigorous testing before being implemented more broadly. We discuss how such incentives could yield unintended consequences in passing.

**Monetary incentives** Material incentives could increase participation in digital contact tracing. Such incentives could consist of direct payments or of the provision of valuable goods and services. If an individual faces private costs but perceives little private benefits from adoption and usage of digital contact tracing, incentives could compensate for the private costs and thereby increase their
willingness to participate. Both positive and negative incentives have been shown to increase cooperation in public good provision under certain circumstances (Fehr & Gächter, 2000b; Kraft-Todd et al., 2015). However, material incentives can trigger a number of undesirable effects. First, material rewards might alter people’s reference point such that they expect to also be compensated for participation in the future (Kőszegi & Rabin, 2006). Second, material rewards might crowd out intrinsic motivation. For instance, incentives might signal a lack of trust by authorities (Gneezy et al., 2011) or a lack of private benefits (Bénabou & Tirole, 2003). They might also crowd out motivation from reputational concerns (Ariely et al., 2009; Bénabou & Tirole, 2006). To avoid such adverse effects, material rewards should ideally complement intrinsic motivation. To achieve this, referral bonuses or other forms of explicit incentives for app adoption should be accompanied by a clear message about their substantiation. The moral and prosocial component of participation should be explained, community feedback needs to be permanently collected and the observable effects continuously evaluated (Kranton, 2019). Survey evidence from the U.S. by Frimpong & Helleringer (2020) indicates that receiving a payment in exchange for downloading a contact tracing app significantly increases a user’s willingness for adoption. However, stated and revealed preferences might differ. One way of circumventing crowding-out effects might be to allow for voluntary sorting into either incentivized or completely intrinsically motivated app adoption (Meyer & Tripodi, 2018). Although the long-term effects might be unclear, the more immediate observed benefits might balance out longer-term costs of applying such schemes.

**Non-monetary material incentives** As an alternative to direct payments for adoption, other material incentives could also be used to foster participation in digital contact tracing. Depending on the public health system, free pathogen testing for those who received a notification by the app and direct or financial support for those who voluntarily self-isolate when receiving a notification could decrease the perceived costs of app usage and thereby increase adoption (Bonardi et al., 2020). Furthermore, the provision of smartphones with a pre-installed contact tracing app for free or at discounted prices to those who do not own a smartphone could help to ensure wide access and address challenges associated with the digital divide (Loi, 2020). While such schemes might appear costly at first sight, the benefits could very well outweigh the immense costs of other public health interventions. A more indirect but still material incentive would be to provide immediate advantages for participating in digital contact tracing. For instance, app users could obtain easier access to public spaces, such as retail stores or restaurants, which otherwise might require manual registration. This might also alleviate privacy concerns with paper-based registration procedures. App users could also get discounts on purchases, for avoiding peak shopping times or time periods reserved for vulnerable people. While such incentive schemes might put parts of society with limited access to modern smartphones at a disadvantage, subsidizing smartphones with pre-installed contact tracing apps might alleviate such concerns at least in part.

**Non-material incentives** Besides material incentives, non-material incentives for adoption could also be considered. Awards and social recognition could increase the perceived benefits of participating in digital contact tracing. Traditional awards — similar to those often presented in the context of blood donations — could be presented to people who have continuously participated in digital contact tracing for a certain amount of time or referred a certain number of contacts to the app. However, the scalability of such awards is limited since awards need to be kept in short supply to preserve their value as a sign of social distinction (Frey, 2007). They might therefore not be suitable to incentivize participation and adoption by many millions of people. Other forms of social recognition might be more efficient. First, the exclusive provision of items to app users that make their participation visible to others could serve this purpose, such as a t-shirt or a mug.
stating ‘I contribute to stopping the pandemic’. Second, sending a personalized text message to thank an app user for the continuous use of the app or providing users with a purely symbolic ‘gold status’ in the app as a form of referral bonus or reward for continued use could serve as a further incentive. Even though such signs of recognition are not visible to others, they still might enhance self-identification with the community and increase intrinsic motivation (Gallus, 2017). However, it has to be noted that trust in and respect towards the institutions – which are in most cases related to the government – presenting such forms of social recognition is needed for these measures to be valuable to individuals (Frey, 2007). When trust in public institutions is low, this form of explicit incentives might therefore fail to have a significant positive effect or might even lead to public ridicule and rejection.

**Recommendations for making use of explicit incentives**

- Consider to provide referral bonuses, free virus testing or other forms of explicit incentives for app adoption but simultaneously emphasize the moral and prosocial aspects of participation.
- Test to provide smartphones for free or at discounted prices with pre-installed contact tracing apps.
- Consider to exclusively provide benefits to users of contact tracing apps.
- Send messages of appreciation to users of contact tracing apps.

### 4.3. Nudges

Nudges offer a variety of possibilities to foster participation in digital contact tracing. Nudges are “features of the choice architecture that influence the decisions people make without changing either objective payoffs or incentives” (Thaler, 2018, p. 1283). Since individuals do not incur any significant costs to avoid them, nudges should not affect the decisions of rational individuals who are fully aware of their preferences and simply weigh the costs and benefits of a decision. From a social planner’s perspective, they should, however, lead to better decisions made by individuals who are not fully rational and rely on intuitive thinking or heuristics in their decision-making processes. Changing defaults, promoting commitment strategies, increasing the ease and convenience of certain decisions, changing the framing of a decision or providing reminders are typical examples of nudges. They are appealing as policy instruments since they usually have low implementation costs and are perceived as less invasive than other measures (Bhargava & Loewenstein, 2015; Capraro et al., 2019). Similar to the literature on incentives to foster contributions to public goods, the literature on nudges is extensive. In the following, we first provide some selected examples of nudges in the context of health and public goods to illustrate common benefits and issues of nudges. We then outline nudges which might be worth testing to encourage participation in digital contact tracing.

A successful example of the application of nudges in the area of health is presented in Johnson & Goldstein (2003). They show for a sample of European countries that the rate of individuals consenting to organ donation ranges between 85 and almost 100 percent in countries where this is the default option, whereas the rate is lower than 30 percent in countries where an active opt-in is necessary. This seems to lead to significantly higher organ donation rates in countries with a default choice to opt in. Reminders and implementation intention prompts are another class of nudges which have shown to be successful in the context of health. Yokum et al. (2018) find that reminding people to get vaccinated against influenza had a significant positive impact on vaccination rates. Similarly, Milkman et al. (2011) find that implementation intention prompt, i.e., letters that non-bindingly asked people to write down the date and time when they plan to get a vaccination, had a significant positive effect on vaccination rates relative to mere informational reminders.
A harmful effect of nudges in the context of health is presented by Goette & Tripodi (2020). They provide blood donors with positive feedback on the use of their past donations in order to increase their intrinsic motivation. The authors find that this information has a negative effect on people’s future blood donations. This could be explained by moral licensing (Bénabou & Tirole, 2011). Another issue with nudges is that they might crowd out support for more invasive but also more effective measures. Hagmann et al. (2019) document that respondents are less likely to support a carbon tax if they are provided with the alternative of implementing a default nudge aimed at choosing renewable energy supply. However, they show that such crowding-out effects can be prevented by correcting people’s beliefs about the effectiveness of both policy tools before they make their decision.

To encourage participation in digital contact tracing, we consider default nudges and reminders as well as social nudges to be particularly worthy of testing for their efficacy. We emphasize that these nudges would need to be tested rigorously before being rolled out more broadly, in order to avoid crowding-out effects with respect to other public health interventions and other unintended consequences.

**Installation defaults and reminders** The installation of digital contact tracing apps could be made the default option in newly released smartphones. The default installation could be part of the regular updating process of the mobile operating system. However, users could remain free to stop the installation at any time or to uninstall it afterwards. Altmann et al. (2020) find in a cross-country survey that more than 60 percent of the respondents would agree with an opt-out design for digital contact tracing. However, this kind of nudge might also undermine people’s sense of autonomy and their trust in the providers of digital contact tracing. A less invasive option could be to send text messages reminding people of the public and private benefits of adoption and providing a link for installing the app. Modern messaging services such as WhatsApp, Signal or Telegram could be used to make such messages interactive by providing direct help with installations in the form of chat bots.

**Publishing installation rates** Public health authorities could frequently publish and visibly communicate data on the share of the population has adopted the contact tracing app in a certain neighborhood as a social nudge. This would, in the spirit of Chen et al. (2010), who show that digital social nudges can be effective in encouraging contributions to public goods. Similarly, the app might inform users how many other users they encountered in the past week to encourage sustained usage. Of course, such nudges would only work with increasing adoption rates. They are not a tool to boost adoption if this appears to be stagnating or even decreasing. It could be the case that they even reinforce trends of low adoption and therefore this policy tool should be used with care (Michalek & Schwarze, 2020). Individuals might also update their beliefs on the benefits of app usage when the negative consequences of not using the app are made more salient. If sufficient information on the effects of the app are collected, it might well be feasible to provide estimates for the counterfactual outcomes had digital contacts tracing apps not been adopted and to present them in an easily comprehensible format (Bonardi et al., 2020). In order to make such social nudges more effective, the use of modern messaging services which allow rich-form content should be taken into consideration.

**Recommendations for utilizing nudges**
- Consider to install digital contact tracing apps with a mobile operating system update by default and allows users to uninstall or deactivate them if needed.
- Enable mobile phone network operators to send reminders to their customers to install digital contact tracing apps.
• Publish installation rates prominently, if adoption rates are increasing.
• Provide estimates of counterfactual outcomes had the app not been used.

4.4. Regulation

A transparent and reliable regulatory framework for digital contact tracing can significantly foster participation. The literature on designing regulation for digital public health interventions is relatively small. However, it is clear that many aspects of the recommendations developed in the previous subchapters require a suitable legal base and adequate governance. As we discuss in the following, this can be particularly helpful to build trust, to alleviate privacy concerns, and to reduce the spread of false information.

Clarity and purposefulness Regulation of digital contact tracing should be explicit and crystal-clear. In most jurisdictions, some existing regulation might already apply and it might be tempting to solely rely on existing legal frameworks, even if they are not fully suitable. In other jurisdictions it might be necessary to develop entirely new regulatory means. In both cases, it is important that potential participants in digital contact tracing do not consider the interpretation of existing or the design of new rules as regulatory arbitrage or as having hidden or unintended consequences. Any regulation should be appropriate to achieve the goal of managing an epidemic with minimally invasive means (Ienca & Vayena, 2020). In line with Amit et al. (2020), we suggest that some of the following measures are considered to make explicit that the regulation of digital contact tracing serves the sole purpose of overcoming an epidemic. First, the time period in which digital contact tracing is used should be limited. Second, the operator of the digital contact tracing system should be a trusted and potentially civilian institution to mitigate concerns over government surveillance. Third, the data collected by the app should be minimized to what is needed for efficient contact tracing and access to that data should be restricted as much as possible. Fourth, mandating a privacy preserving approach to digital contact tracing by law could be helpful to foster participation. Fifth, a guarantee that participation remains voluntary encoded in law could be perceived as more reliable than lip service by politicians and public health authorities. Lastly, an oversight board should be established to ensure the compliance with the regulatory framework.

Curbing the spread of false information Another area where regulation might play an important role is the reduction of the spread of false information on digital contact tracing. Websites associated with systematic false information could be regulated or even banned. Reducing the reach of social media groups that frequently communicate false claims is another possible measure to increase participation in public health interventions such as vaccinations or digital contact tracing. However, such regulations raise substantial concerns over censorship and restrictions of the right to freedom of speech and the freedom of the press. The proportionality of such regulation has to be assessed (Nyhan, 2020).

Addressing regulatory side-effects All regulatory measures undertaken to foster participation in digital contact tracing should be monitored for unintended consequences. One area could be spillovers from and to other areas of regulation or other approaches to combat the epidemic. For instance, Lucas et al. (2020) argues that stricter legal enforcement of self-isolation measures for people infected with SARS-CoV-2 could be associated with a decreasing willingness to report an infection and to comply with contact tracing measures. Such unintended side-effects of regulation should be monitored and addressed if needed.

Recommendations for regulation
• Use, adjust and design regulation for digital contact tracing such that it is clear, transparent and serves the sole purpose of managing the particular epidemic.
• Consider the use of regulation to fight the spread of false information on digital contact tracing.
• Monitor the consequences of existing and new regulation for unintended side-effects beyond digital contact tracing.

4.5. Technology design

Digital contact tracing apps should be designed such that the perceived costs of participation are as small as possible while the benefits are salient and easily comprehensible. Similar to the regulation of digital contact tracing, the literature explicitly addressing the design of digital contact tracing technology is relatively small. However, it has been growing recently in response to the SARS-CoV-2 pandemic. In the following, we outline how the appropriate design of digital contact tracing can help to reduce the costs and increase the benefits of participation, to bridge the digital divide and, to alleviate privacy concerns.

**Low technological requirements** Digital contact tracing apps should use limited memory and have low battery usage. Trang et al. (2020) conduct a survey study in which they present different hypothetical scenarios for a contact tracing app to their respondents. They report that a highly convenient app design where the app operates smoothly in the background with automatic updates and requiring low levels of battery power can significantly increase the willingness to use the app compared to a design with lower convenience. This is especially true for undecided participants who do not yet have an established opinion on digital contact tracing.

**Low skill requirements** Digital contact tracing apps should be easy to install and use, even for those with limited technical skills. In many countries, parts of the population do only have limited or no such skills, or lack the financial resources or willingness to adopt more advanced digital technologies. Digital contact tracing should therefore have low digital literacy requirements. Reducing such barriers to participation ensures equitable access to the intervention and contributes to achieving the highest possible adoption rate (Loi, 2020).

**Accuracy** The accuracy of digital contact tracing systems should be sufficiently high. Kaptchuk et al. (2020) find that the accuracy of a contact tracing app plays a significant role in the decision to participate. According to their findings, false negatives – i.e. an at-risk user is not notified by the app – affect user perceptions more than false positives – i.e. individuals are notified to be at risk even though they had no close encounter with an infected person. Communication about the possibility of false positives and negatives and how to deal with them needs to be transparent. Both the accuracy as well as the communication on potentially risky encounters have to be tested rigorously.

**Interoperability** Digital contact tracing systems should ideally be interoperable both geographically and among various demographics. This maximizes network effects and thereby also the individual and public benefits of the intervention. This has increasingly been the case throughout the SARS-CoV-2 pandemic (European Commission, 2021).

**Track record of trust in provider** High levels of trust in the developers and operators of contact tracing systems based on previous experience might also mitigate privacy concerns, which survey participants state to have (Kaptchuk et al., 2020; Trang et al., 2020). Simko et al. (2020) report relatively high levels of trust in Google and Apple and in their products such as Google Maps and Apple Maps. An integration of digital contact tracing in an app like Google Maps could therefore mitigate concerns, and also increase convenience (since potential users already have the app installed and know how to operate it) and facilitate opt-out approaches (contact tracing could simply be added to Google Maps with a regular update with the option to deactivate the add-on). Such an approach involves significant concerns when a public health intervention is tied closely to a commercial product.
However, if a similarly trusted non-commercial provider is not available, piggybacking on an existing commercial product might be the only viable option to reach wide-spread adoption.

**Complementary functionality** To increase the immediate benefits of installing and using a contact tracing app, developers might also consider adding additional features to the app. These could be, for instance, the provision of general recommendations regarding an individual’s behavior during the pandemic or frequently updated information on the regional development of the pandemic and on local hotspots that should be avoided. Li et al. (2020) report survey evidence that the hypothetical provision of information on local hotspots of SARS-CoV-2 infections adds to a user’s perceived benefits from app usage and may increase adoption rates.

**Data donations** Privacy preservation can be in conflict with other activities to foster participation. For instance, providing detailed information on the positive effects of digital contact tracing requires data collection based on location, which might be perceived as privacy-invasive. More generally, the ongoing evaluation of digital contact tracing as a means to break chains of infections requires a certain level of data collection, which might raise privacy concerns. One way to counter these concerns could be to provide a second version of a given contact tracing app, which collects additional data. This app could be advertised to a random sample of citizens, with acceptance being monitored and making potential selection effects in participation visible. Users would agree to donate more data than regular app users. This sample could then be used to evaluate the efficacy of an app.

**Recommendations for technology design**
- Optimize digital contact tracing technology for low technological and skill requirements, interoperability and high accuracy in terms of determining potential infections.
- Consider piggybacking on existing trusted providers of technology.
- Consider adding complementary functionalities to contact tracing apps.
- Offer random sample of citizens to donate more elaborate data for the purpose of improving contact tracing technology.

**5. Recommendations for further research**

All these proposed measures to foster participation would need to be properly evaluated. Ideally, the introduction of digital contact tracing apps is designed such that all data necessary to evaluate the efficacy of the respective design is collected. However, intentionally introducing experimental variation when rolling out an app requires levels of willingness to learn, scientific sophistication and technical literacy rarely observed in political circles and in public health authorities. During a public health crisis, these requirements might be fulfilled even less. Furthermore, ethical considerations also need to be taken into account when designing experiments. In the absence of such experimental variation, quasi-experimental and other observational analyses could sometimes provide an approach for evaluation. Surveys and experiments with potential and actual app users could also provide a means to evaluate certain aspects of the related cost-benefit calculations, potentially even in real-time. However, given the multi-dimensionality of the measures to foster participation and their interdependence, only cooperation with public health authorities and other parties involved in operating digital contact tracing systems and intentional testing will lead to reliable evaluations.

By and large, the problem of increasing participation in digital contact tracing and other DPHIs has similarities with problems occurring in development economics. Similar to development economics, hardly any particular measure to foster participation is likely to generate all necessary improvements on its own. It is
more likely that a carefully selected set of different measures induces greater adoption and usage. Implementation details, such as the format of information provided by an app, could matter greatly. The research approach described by Duflo (2017) as “the economist as a plumber” will be more suitable than that of an “economic architect”. The process of properly evaluating the different measures to foster participation in digital contact tracing is potentially long and tedious rather than a one-off effort with clear results. But similar to development economics, the scale of the problem which digital contact tracing has the potential to address should provide sufficient encouragement to pursue this line of research.

Research into how participation in digital contact tracing could be fostered would not only be helpful managing the SARS-CoV-2 pandemic but also other future epidemics. Since most developing countries have leapfrogged to smartphone devices, the additional technological requirements would be modest even for them. Digital interventions to increase public health could also be a useful tool to move from national public health initiatives to global public health initiatives. Viruses such as Ebola do not stop at country borders. If digital contact tracing technology were to be made freely available, interoperable and easy to adopt, it could provide the technological base for greater international cooperation among health authorities to tackle such pandemics.

6. Conclusion

Digital contact tracing is a promising technology to fight epidemics. However, adoption rates during the SARS-CoV-2 pandemic have been disappointing in most countries. In this paper, we review the literature relevant to the question of how adoption and usage of this technology could be increased. We develop a relatively large number of recommendations for policy-makers and encourage researchers to get involved in rigorously testing measures to improve participation.

While research on enhancing adoption and usage of digital contact tracing is in itself a worthwhile endeavor, it can also provide valuable insights for other digital health innovations. Such innovations donot only have the potential to play an important role in managing immediate crises, but also in tackling slower-moving – but nonetheless widespread – health issues, such as cardiovascular diseases, which is the number one cause of death globally. For instance, experiments by Perez et al. (2019) with Apple's smartwatch suggest that optical sensors on wearable devices can potentially predict atrial fibrillation. Another experiment by Chandrasekhar et al. (2018) assesses the potential to measure blood pressure via a sensor integrated in a smartphone as a further means to monitor cardiovascular conditions. However, to make such approaches broadly available, large-scale data sets are needed which rely on voluntary data contributions. Such voluntary data donations are also a prerequisite to develop personalized and precision medicine. Digital technologies enable the large-scale collection and analysis of individuals’ genotypic and phenotypic data if people are willing to share this information. Based on such analysis patients could receive tailor-made treatments for diseases, such as cancer, that take into account individual characteristics and can result in increased efficacy, efficiency and safety of the respective therapy (Kohane & Altman, 2005; Kohane, 2015). However, widespread adoption and usage will be critical to the success of most such digital health innovations. More contributions to the state of knowledge on how to accomplish this are needed.

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