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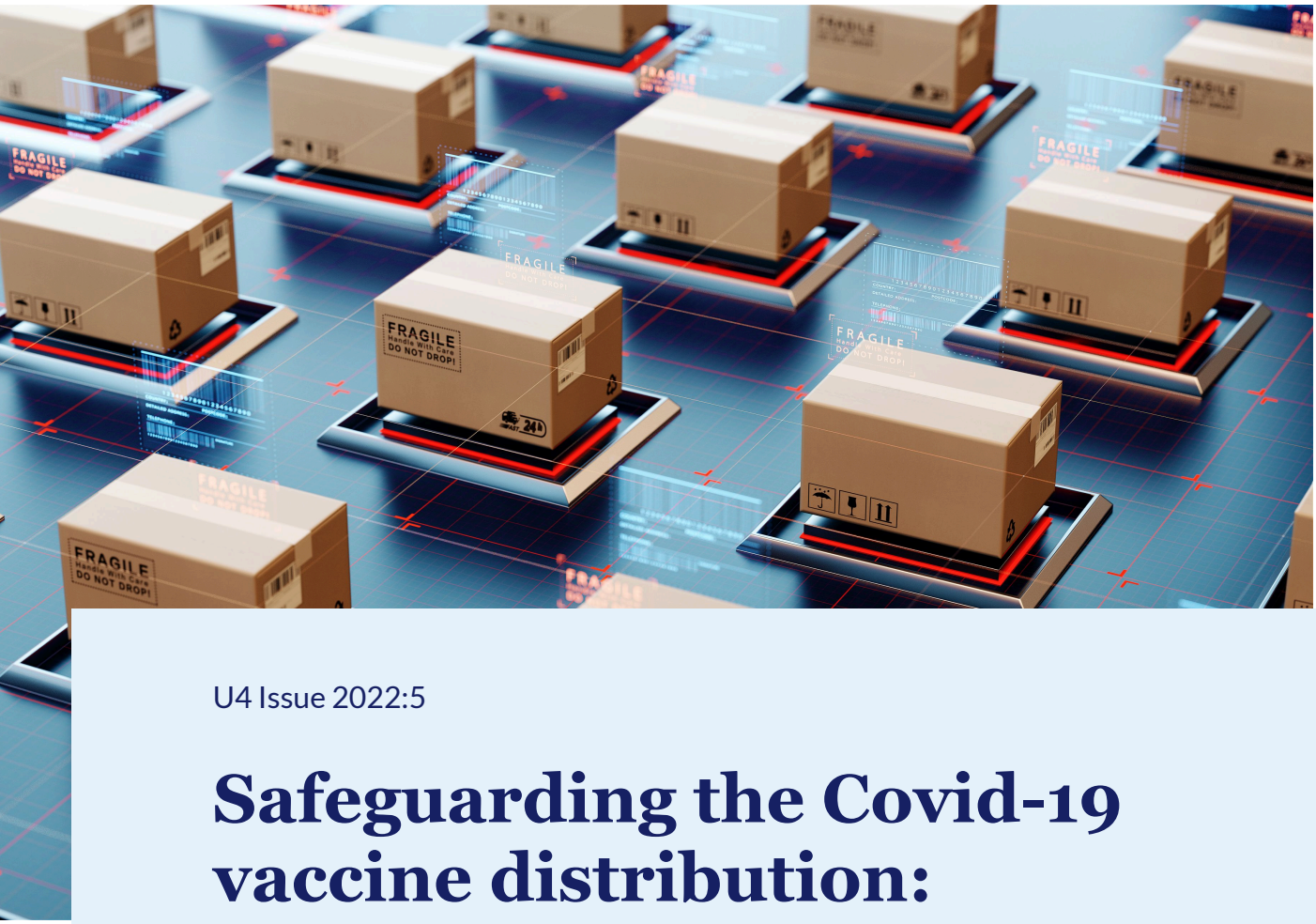

U4 Issue 2022:5

Safeguarding the Covid-19 vaccine distribution: Evaluating the role of blockchain

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Cover photo
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Keywords
Covid-19 - blockchain - accountability - supply chains - digital technology - transparency - vaccine

Publication type
U4 Issue

Blockchain is promoted as a trust-building technology to protect information in insecure environments, including safeguarding the distribution of Covid-19 vaccines and other medical products from corruption. However, real-world application is still limited. International organisations should examine blockchain's effectiveness against the many challenges identified by research and pilots. Context matters, and blockchain's effectiveness depends on factors such as technical capacity, trust, and a political commitment to reduce corruption.

Main points

- Covid-19 vaccine supply chains are exposed to corruption, theft, and falsification of vaccines and vaccination certificates. This can fuel public distrust and limit coverage.
- 'Blockchain' is a distributed ledger technology which is often promoted as having the potential to reduce corruption risks and deficiencies in supply chain management.
- Blockchain's theoretical potential runs far ahead of its real-world use. Although only a few pilots are underway, there is momentum and interest in using blockchain to help address leakages, build trust, and secure an equitable distribution of vaccines.
- The reality is that the necessary conditions for blockchain to be effective are likely to be in places where corruption risks in supply chains are already low. The integrity of medical supply chains depends on factors such as political stability, collaboration among relevant interest groups, responsive legal frameworks, and technological capacity. These are also the conditions in which blockchain is most likely to be an effective tool.
- In fragile states, using blockchain can be challenging and more empirical research is required.
- International organisations, including aid donors, may consider the use of blockchain for supply chain management after evaluating the costs versus the benefits – as well as understanding how different designs will affect its performance in disparate settings.
- Funders and health organisations should invest in learning and training to understand how blockchain could contribute to reducing corruption in the health sector. It is also important to recognise the likely time scale, costs of projects, the need for integration with existing systems, and critical steps required for pilots, evaluation, and roll-out.

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Acknowledgements

We would like to thank Inge Amundsen and Peter J. Evans (CMI–U4) for valuable inputs and comments to the issue paper. We are also grateful for advice and external review by Timothy Mackey (UCSD). The fruitful collaboration with enpact and their identification of interview subjects from academia and practitioners within the field of medical supply chains and blockchain implementations was truly appreciated.

Since the World Health Organization (WHO) declared Covid-19 as a Public Health Emergency of International Concern in 2020, most national health systems have struggled to cope.

By April 2021, a WHO 'pulse survey' had found that 90% of countries reported one or more disruptions to essential health services. The pandemic has absorbed critical funding, sometimes at the expense of other health services. Governments' lockdown measures, households' inability to pay health bills due to falling incomes, and people's fear of getting infected – all these affected demand for and access to essential health care. Many countries have also experienced profound shortages of infection prevention supplies and testing capacity. By February 2022, Covid-19 had claimed the lives of 5.6 million people worldwide (and some estimates are far higher – such as the Economist's 20.7 million).

The pandemic has also weakened health systems' capacities and fostered opportunities for corruption. In many countries, responses to Covid-19 have prioritised the need for expediency over transparency and accountability. This has led to increasing procurement corruption, embezzlement, mismanagement of emergency funds, and favouritism, nepotism, and bribes at the point of health service delivery.

> *The delivery of vaccines from factory to people's arms presents one of the most wide-ranging risks of leakage and corruption imaginable.*

Corruption also threatens the production and distribution of Covid-19 vaccines, and contributes to the unequal distribution of vaccines globally. If the pandemic can only be conquered by vaccinating the entire world, we are in the midst of the most complex and diverse supply chain challenge ever faced. In turn, the delivery of vaccines from factory to people's arms presents one of the most wide-ranging risks of leakage and corruption imaginable. One tool proposed for reducing these risks is blockchain.

Why consider blockchain in Covid-19 vaccines distribution?

The Covid-19 vaccine roll-out has been 'the fastest in global history,' yet distribution has also been deeply unequal. According to the Center for Global Development, the world's poorest nations faced a much slower roll-out in 2021 than in previous vaccination campaigns. As of April 2022, 64.6% of the world population had received at least one Covid-19 vaccine dose. In low-income countries, first dose coverage was only 14.7%.

Many factors have contributed to this situation, including richer countries' hoarding of vaccines, faltering national vaccination campaigns, supply chain challenges, vaccine hesitancy, misinformation (ie the infodemic), and corruption.

Corruption has had relatively limited attention as a threat to the equitable distribution of vaccines. We conducted a thorough media analysis and identified several forms of corruption related to Covid-19. The two prominent forms were: the growing black markets for falsified Covid-19 vaccines; and the theft of Covid-19 vaccine doses. In both cases, corruption is facilitated by poor supply chain management. When there is no effective monitoring through all key points of a long supply chain (ie supply of critical components, manufacturing, transportation, distribution, and delivery), there are plenty of opportunities for misconduct.

There is still a long way to go to achieve global coverage of Covid-19 vaccines. In theory, technologies such as blockchain could help make vaccine supply chains more transparent and effective. Several start-ups and technology companies, and even some bilateral and multilateral development organisations, have proposed blockchain as a potential tool to improve the integrity of supply chains for medical products, including Covid-19 vaccines.

Research methodology

Our research used a mixed methods approach consisting of a literature review – including secondary sources of quantitative research where relevant – and a primary data collection from conducting semi-structured interviews with experts.

The literature review included reports from major organisations which discuss blockchain technology in relation to health and or development programmes. We have also referred to academic papers and white papers from technology companies arguing how blockchain can be relevant for health care, vaccine distribution, or Covid-19 mitigation. The databases searched included Google Scholar and the websites of international organisations such as UNDP, the World Bank, and OECD. We also investigated if available online blockchains are in production or still in their pilot stage.

The time frame for our search query was 2017 onwards, and our search criteria were: Covid-19 supply chains + corruption; falsified vaccines + Covid-19 supply chains; theft + Covid-19 vaccines; medical supply chain management + blockchain; blockchain + Covid-19 vaccine distribution; anti-corruption + blockchain; health sector + anti-corruption + blockchain; development projects + anti-corruption + blockchain; blockchain + logistics + supply chains.

Although we focused on Covid-19 vaccine distribution, given how new and limited application of this technology is – and how recently the distribution of Covid-19 vaccines started – we also included adjacent fields such as examples of blockchain uses in other health- or supply chain-related approaches. These could provide lessons for Covid-19 supply chains, and also informed our conclusions and recommendations.

Our semi-structured interviews helped us to access in-depth information and expertise about blockchain, and its use in the public sector – especially in health. To identify the experts for interview, we first drew on our own networks. enpact, a non-profit entrepreneurship accelerator based in Berlin, contributed their connections to technology start-ups working on blockchain technology in health. We reached out to contacts in multilaterals, as well as experts working at the nexus between corruption and technology. We also used a 'snowball' method, asking individuals to refer us to other potential experts.

We identified 77 potential candidates from all world regions. Seventeen of the contacted individuals – mainly working in Latin America, USA, and Europe – agreed to participate. Unfortunately, we were not able to secure agreement from experts in other regions. From July to September 2021, we conducted interviews through video conferences with those 17 experts from pharmaceutical companies, academia, start-ups, governments, and international organisations. The interviews focused on implementation of blockchain technologies for vaccine delivery in low- and middle-income country contexts. The identity of the interviewees and the organisations they work for were anonymised.

Table 1. Interviewees' sectoral backgrounds

Interview type / Sub-total
Academia: 4
Practitioners/International development organisations: 6
Practitioners/Government: 2
Technical experts: 4
Pharmaceutical companies: 1
Total: 17

Following the interviews, the data collected were manually coded and classified into two main topics: advantages and challenges. Each topic was then categorised: four subcategories for advantages: trust, anti-corruption, transparency, and accountability; and two for challenges: technical and governance issues. We conclude with recommendations on how to use blockchain technologies for medical supply chains. Most of them are based on the responses from expert interviews.

Corruption risks across Covid-19 vaccine supply chains

A 'supply chain' describes the process of moving a product from raw materials, through to its manufacture, and then distribution to the end user. Any supply chain has a range of risks of loss and damage, and also opportunities for misconduct or diversion. Supply chain management, and ensuring security, is a sophisticated and specialist operation.

Vaccine supply chains have additional complexities because of the common need for refrigeration during transportation and storage – without this, vaccines may be rendered ineffective or useless. Cold-chain transportation is a particular challenge in hot climates and where electricity supply is unstable. Sensors and Internet of Things (IoT) devices which can report temperature and location have been suggested as a means to ensure that vaccine consignments are not damaged during transportation.

Corruption adds to these complexities and threatens the production and distribution of Covid-19 vaccines. If regulation is weak, manufacturing facilities

could produce vaccines of substandard quality; falsified vaccines could infiltrate the supply chain; vaccines could be stolen or diverted from factories or stores and sold on illegal black markets; politicians could influence the award of manufacturing contracts so they are given to companies they are connected to at the expense of better suppliers; and suppliers could exploit shortages to inflate prices, and collude with others to maximise profits.

Vaccines could also be stolen during transportation, from central and local storage facilities, hospitals, and health centres. In addition, a growing market for falsified vaccines and vaccination certificates, vaccine 'queue-jumping', bribes, favouritism, and nepotism are all reported as corruption problems at the point of delivery, in countries such as in Peru, Argentina, Mexico, Poland, and Spain, among others.

The global scale of Covid-19 vaccine roll-out is unprecedented and requires the creation and operation of probably the largest supply chain ever. There are significant challenges in vaccine distribution – from physical damage to theft. In theory, transparent data management could help ensure that vaccines are not stolen, of substandard quality, or falsified. It could also secure fair distribution and guarantee safe access.

In 2020, an article in the Lancet warned that 'without preparation for the quality assurance of diagnostic tests, drugs, and vaccines, the world risks a parallel pandemic of substandard and falsified products.' Two years later and with nine WHO approved vaccines being rolled out, the world has witnessed a proliferation of falsified vaccines and a surge in black market sales. In January 2021, the sale of falsified Covid vaccines on the dark web was reported to have grown by 400%. U4's monitoring throughout 2021 found reports of falsified vaccines across the world, including Iran, Uganda, India, Myanmar, Germany, Venezuela, USA, Mexico, Poland, the Philippines, South Africa, and Nigeria.

Falsified medical products constitute a clear form of corruption, as these are poor-quality products which are deliberately misrepresented and sold for private gain. When legitimate and licensed manufacturers and suppliers within regulated supply chains are producing and distributing falsified Covid vaccines, we consider it to be primary corruption.

Vaccine thefts have been reported from a range of countries, often enabled by lack of transparency and accountability in national supply chains. In Kenya, investigative journalists reported that a network of cartels, including corrupt

officials at the Ministry of Health, were selling donated Covid-19 vaccines for as much as 20,000 Kenyan shillings (approximately US$ 177). In Uganda, Kampala's Capital City Authority was asked to account for 21,000 doses that went missing in June 2021. Police also started investigating the theft of 600 AstraZeneca doses that had been found in two private clinics in Kampala.

Among potential responses to reduce these risks to vaccine roll-out, governments and international organisations have considered whether digital tools can be deployed effectively and rapidly. The European Parliament listed blockchain as one of the technologies to potentially use to fight Covid-19. Academics from the University of Cambridge and the University of Pisa, the University of Cluj-Napoca, and SMBA University, have discussed the potential of blockchain technologies to enhance transparency in the Covid-19 vaccines' supply chains.

What is blockchain?

Blockchain is a type of distributed ledger technology (DLT) in which data are encrypted and bundled together in 'blocks', and 'chained' together in a manner that prevents records from being changed.

The database, or ledger, is shared on a network of computers (or nodes). Each block contains a timestamp for the exact entry of the data, a cryptographic hash (a unique identifier) of the previous block, and the transaction data. This means that all the blocks of entries in the database are 'chained' to the previous entry, and it is impossible to unilaterally change data in one block, as all subsequent blocks would also have to change. The distributed computers in the network calculate a cryptographic hash for new blocks. Depending on the type of blockchain, most participants must agree if a new record is to be deemed as valid and then written to the blockchain.

The encryption of the entries – linked together, shared in a network, and secured by consensus of all parties – makes the records in a blockchain database impossible to alter (or 'immutable'), once the entry is agreed upon. There are different methods to arrive at this agreement, referred to as 'consensus protocols'. Some of these, such as the 'proof of work' protocol (PoW), require very large computational power (and processing consumes large amounts of energy). The calculations required to approve a new block of records take time, leading to low and slow transaction rates.

Other protocols used in private or consortium blockchains, where only permitted participants have access, use consensus protocols with lower computational demand, and so have higher, and faster, transaction rates.

Programmers can also enter executable code into a block's content, which is carried out when given conditions are met. The resulting so-called 'smart contracts' will execute actions automatically, based on these codes. These actions are transparent and irreversible, without being under the control of any entity or third party. For instance, a coded transaction could trigger the transfer of ownership of an asset after all conditions determined by the code are fulfilled. Inputs from external sensors – such as cameras, temperature sensors, location trackers (GPS trackers), or other IoT devices – can also trigger transactions by sending information to the smart contract. Such third-party services are called blockchain oracles.

In supply chain management, such blockchain oracles could help verify the condition of medical products, or their safe arrival, and so trigger payment. When sensors are attached to objects and report via the internet to a database, it is referred to as the Internet of Things (IoT).

There are four main types of blockchain technologies.

1. **Public blockchains** are open and transparent for anyone who registers. They are primarily known for holding cryptocurrencies or operating smart contracts such as Bitcoin or Ethereum. 'Permissionless', or public, blockchains have longer verification times for new entries because most of the network must arrive at a consensus for each correct entry. Public blockchains explicitly do not limit who can participate.
2. **Private blockchains** are controlled by a single organisation which governs access to the blockchain. A private blockchain may be more vulnerable to fraud or misconduct by the owner because all the power to add records sits with that single entity.
3. **Consortium blockchains** are managed by a consortium of organisations. The right to read content can be private or public, and certain nodes in the blockchain can have the right to enter information.
4. **Hybrid blockchains** can be governed by a single entity, but the ability to read and write to the blockchain may be given to a network of organisations. Public access can also be granted to all, or parts of, the data.

Could blockchain mitigate corruption in medical supply chains?

There has been much discussion and interest in applying blockchain technology in a variety of supply chains, to safeguard them and reduce the risks within – including the supply of medical goods. However, our research finds that most examples that have been identified are still 'proof of concepts' and 'pilots', and many are still to be completed.

The following examples show how blockchain has been considered as an anti-corruption tool for medical products; for supply chain management in general; and, finally, in Covid-19 vaccine supply chains.

Blockchain can help ensure compliance, but there are few 'live' applications

US government-commissioned pilots

In 2019 the US Food and Drug Administration (FDA) commissioned pilot projects to ensure compliance with the Drug and Supply Chain Security Act (DSCSA). These pilots, to be implemented in 2023, include the main objective of preventing stolen, falsified, or harmful pharmaceuticals from entering the supply chain.

The MediLedger Project[1] proposed a supply chain model based on blockchain technology. The pilot phase is now completed and the blockchain company Chronicled is currently the custodian of the project. The 2021 progress report explains how they explored using blockchain technology to 'create an electronic interoperable system between the many databases involved in the medical supply chain.' They demonstrate that using a particular consensus protocol (zero-knowledge proof) and a private blockchain network can help overcome data privacy challenges, deliver significant transaction speed at acceptable costs, and make transactions more transparent.

1. Initiated in 2017, the MediLedger Project is a collaboration between 25 partners in the pharmaceutical and related industries, such as manufacturers, distributors, logistics, and transportation companies. The MediLedger Network is powered by blockchain and its purpose is to run solutions for data alignment, validation, and transaction settlement between trading partners.

However, the report also notes the challenges in making different 'track and trace' systems collaborate. There are no standards that currently exist which would enable different systems to 'talk to each other,' and the report concludes that 'without appropriate standards, it is not likely that disparate systems can be made successfully interoperable.'

European research

The European consortium behind PharmaLedger has a similar agenda to the MediLedger Project – to investigate if blockchain technologies could support security and trust in health industries. EU regulations and the European Federation of Pharmaceutical Industries and Associations (EFPIA) has made it compulsory for manufacturers to add serial numbers to prescription drugs. PharmaLedger builds on this identification system and on the EU's Falsified Medicines Directive. One aim is to demonstrate how blockchain can be deployed to ensure trust and compliance throughout the supply chain, to eliminate falsified drugs.

This project is still in its research phase. During an internal panel discussion in June 2021 on blockchain and falsified drugs, questions arose around the need to protect both drug packages, and the drugs themselves, from being replicated or falsified. One of the suggested interventions was to use a blockchain ledger and the participation of consumers with smartphones to verify the authenticity of drugs.

Private initiatives using blockchain to protect the quality of health products

An early application in Asia

Zuellig Pharma, Accenture and Microsoft have launched eZVax, a blockchain developed for the management and monitoring of vaccine distribution and for tracing the provenance of drugs. A family of mobile phone apps are connected to the system and the eZTracker enables users to verify the authenticity of pharmaceuticals, while eZConsult manages individuals consulting their doctor.

According to the project website, eZConsult has been in use in Hong Kong, Thailand, and the Philippines. In locations where the system is in use, citizens can also access information about vaccine availability and download vaccine

certificates. The system was launched in March 2021; however, our research did not identify reports providing evidence of its outreach or effectiveness.

Approaches using monitoring sensors

Similar to Zuellig Pharma's approach, the Ambrosus anti-counterfeiting solution aims to use blockchain together with IoT as a supply chain tool in food and pharmaceuticals. The Swiss-based company has suggested a concept where sensors automatically feed information along the supply chain and the data is then safely stored on the blockchain. The company won a series of awards in 2018 but there have been significant delays in delivering outcomes, with the company noting in a 2020 blog post that 'contrary to popular belief, the adoption of cryptocurrencies and blockchain technology moves slower than initially expected.'

Mongolian government pilot

FarmaTrust also aims to combat the falsification of drugs by applying blockchain and artificial intelligence (AI) technology. It signed a one-year pilot project in 2018 to work with the Mongolian government to secure pharmaceutical supply chains. The government implemented regulations against falsification, and rules as to how medicines should be labelled to enable identification of each batch or package.

A national verification system was also established by putting a tamper-proof seal (a QR code) on the medicine packages, so each point in the supply chain – from manufacturer to distributors – could scan the code referred to on the blockchain. A consumer could also verify the authenticity of the package by scanning the code with a smartphone app. The concept was selected for the OECD's 2019 Global Trends report, although it clarified that 'the programme is still in its early stages and the new software solution has just been rolled out. It is therefore too soon to show demonstrable results or impacts.' Additionally, two challenges surfaced during the feasibility study: first, it was difficult to 'ensure collaboration among all supply chain partners in Mongolia;' and second, to 'ensure compliance from drug manufacturers with the new Mongolian regulations.'

It has not been possible to establish whether FarmaTrust is still working in Mongolia. However, in 2021 the company secured UK research funding, together with a consortium of pharmaceutical industry partners, to develop a

proof of concept for a digital supply chain in the UK, based on the blockchain they had developed.

Further, blockchain is being investigated as a tool to safeguard pharmaceutical e-procurement. An e-procurement system with a blockchain securing layer could have a 'permission structure that makes certain data available to all participants.' This could enhance transparency and facilitate audits for compliance purposes.

Beyond health: Blockchain at scale in freight supply chain management and logistics

In 2018, IBM and Maersk initiated TradeLens – a supply chain platform using blockchain technology in the handling of global freight. The platform digitises paper-based freight handling and so increases efficiency. More importantly for tackling corruption risks, TradeLens breaks down typical information asymmetries between freight companies, traders, customs, and harbour authorities. This enables secure access to information for all parties connected to a shipment, and facilitates audits and monitoring of transactions – thus reducing the opportunities for fraud and corruption.

TradeLens has been scaled up quickly and now includes more than 300 organisations such as shippers, freight companies on land and sea, and customs authorities. The container logistics system handles data from over 600 ports and terminals around the world, tracking more than 55 million containers with agents on all continents.

In food supply chains, Carrefour and Nestlé are applying blockchain for tracking some of their products. The system ensures that falsified products do not enter the supply chain, and speeds up the identification of a producer in cases when contaminated food reaches the market.

Early promise: Blockchain efforts in Covid-19 vaccines

In 2018 (so well before the Covid-19 pandemic), StaTwig[2] developed VaccineLedger, an open-source blockchain tool. Endorsed by the UNICEF

2. StaTwig is a Singaporean and Indian start-up that provides digital solutions to make global supply chains 'resilient and sustainable.'

Innovation Fund, the aim was to 'track the journey of each vaccine from manufacturer to child.'

Each package carried a QR code, and as the code was scanned down the supply chain, it was possible to track any shipment and identify where vaccines were lost on the way. VaccineLedger stores data such as serial numbers, expiry dates, and other manufacturing information.

StaTwig now aims to use VaccineLedger for Covid-19 vaccines and has partnered with the Indian IT company Tech Mahindra to use blockchain to address challenges in the global supply chain. LACChain is a global alliance that is working to develop a blockchain ecosystem in the Latin American and Caribbean region, and StaTwig has partnered with them to integrate VaccineLedger into the LACChain platform.

However, although VaccineLedger has been around for a few years, our research could not identify any evaluations or research on its functionality and ability to prevent diversion or theft of vaccines, or tackle the proliferation of falsified vaccines.

Research published in 2021 by the Technical University of Cluj-Napoca suggests improving Covid-19 vaccine supply management using a blockchain combined with smart contracts. These smart contracts could be updated via sensors reporting over IoT protocols, combined with tracking codes on the packages. This could enable, for example, the automatic release of a payment when a cargo of vaccines is scanned at its destination with an approved record of storage conditions. Such technology aims to reduce the risks that storage conditions are not maintained and/or vaccines are stolen or re-directed on the route to their destination, thereby increasing trust in the distribution process.

It is also important to note that such applications could be vulnerable to cyber attacks. Cyber attacks on supply chains are on the rise as IoT third-party devices, such as cameras and sensors, can be compromised, and there has been an increase in such attacks from 2020 to 2021.

Despite widespread discussion of its potential, and a degree of hype, actual examples of the application of blockchain are limited in the health sector and in vaccine supply chains. Pilots that were started before the pandemic are still underway. Subsequently, there are no examples of existing application at scale. The pharmaceutical supply chains are transnational, and involve producers,

distributors, and government actors, all of whom need to collaborate in a joint system. It may take years before this is achieved – if ever. Important lessons can be learnt from other sectors, such as the use of blockchain systems by global private-sector corporations in international freight management.

Closing the gap between potential and reality: How global organisations evaluate blockchain technologies

Over the last five years, blockchain's promise of secure, transparent database tools for monitoring funds or tracking physical items, including their potential for reducing the risk of corruption and leakage in aid, has caught the attention of international development organisations. UNDP, GIZ and USAID have all developed primers and guidelines for the possible application of blockchain to prevent fraud or corruption in development. Academic research has also suggested technical applications for blockchain to monitor the supply chains or distribution of Covid-19 vaccines.

In 2020, the World Economic Forum (WEF) published an article predicting that 'blockchain and distributed ledger technology will be essential for an equitable Covid-19 vaccine distribution.' It cited the tests performed by StaTwig (see above) and foresaw a transparent, digitised, and global vaccine supply chain, which could monitor the flow, prices, and physical conditions of vaccines. The authors were from the WEF's Centre for the Fourth Industrial Revolution in India and StaTwig. StaTwig has been recognised by the UNICEF Innovation Fund and The Trinity Challenge for its work on blockchain to secure vaccine distribution, responding to concerns about expected Covid-19 vaccine wastage. Yet there appears to be no publication that demonstrates the impact and feasibility of using blockchain and distributed ledger technology in different country settings.

Other commentaries have been more cautious. The 2018 USAID 'Primer on blockchain' provides a set of questions to assess whether blockchain technologies are the right solution for specific development problems. It emphasises how the technology may be more relevant in environments of 'incomplete trust,' where organisations struggle to 'interact without undue error' and in 'contexts with a certain level of digital infrastructure already in place.' The primer also highlights the possibility of using blockchain to enhance the supply chains of medical products, and to trace medical products and prevent their falsification.

The USAID primer proposes questions which should be asked before a blockchain solution is considered, including whether 'DLT applications would be preferable to other alternatives.' Also, when the implementation of blockchain is planned in a corrupt environment, the report poses a critical question: 'If a DLT application is intended to address or sidestep corruption, how will a corrupt actor be persuaded to adopt a DLT application?'

Since 2018, the annual OECD Blockchain Policy Forum has reviewed the status of blockchain applications in business, development, and government sectors, including supply chain management. Its 2020 Blockchain Policy Brief outlined the benefits and challenges. Blockchain is well suited to carry a short selection of data records where immutability and transparency is important – supply chain management for medical products is such an example. However, it is not well suited to storing large databases, such as those for medical records, due to the inefficiency of search queries in an encrypted database, and the high cost of keeping a large database in a distributed, consensus-dependent storage system.

Given its immutability, using blockchain to store personal data can also infringe upon people's right to privacy and the General Data Protection Regulation (GDPR) principles of erasure of personal data. The OECD concludes that depending on the identified needs, 'blockchain should be deployed where it is best suited and in combination with other technologies within a well-governed health information system.'

Moving from theory to application, GIZ set up a 'Blockchain Lab' in 2018. This now supports the 'authentic.network', a start-up providing a secure code label which can be used to follow medicine packages and prove authenticity of the contents through a smartphone app. GIZ's 2019 handbook provides a check-list for possible blockchain implementations: first, it is important to describe the problem to be solved, and then assess if blockchain is the right solution (that is, problem driven, not solution driven); second, if the need for a distributed database is clear, then the technical, legal, and political feasibility must be considered; and, third, if the conditions are not right, it is time to investigate what alternative interventions are available.

In 2020 GIZ mapped the status of blockchain in Africa, finding emerging use of digital currencies, cases of peer-to-peer trading of electricity, and pilot projects exploring blockchain in agricultural supply chains. However, regulatory frameworks were not in place in many countries. The report recommends policymakers and information and communications technology (ICT) decision

makers get to know the technology to 'regulate it in a way to drive innovation and not stifle it.'

To conclude, context-specific factors such as internet connectivity, knowledge of and skills in using blockchain, the quality and type of datasets used, political backing, and supportive regulatory frameworks, play critical roles in determining the potential of blockchain as an anti-corruption tool.

The benefits of blockchain in vaccine distribution

Drawing on our interviews with experts from pharmaceutical companies, academia, start-ups, governments, and international organisations, we have identified the following advantages of using blockchain technology in the distribution of vaccines.

Strengthening trust in supply chains

Blockchain's features – such as immutability, data availability, digital recording of transactions, transparency, and decentralisation – should ideally increase trust. Blockchain can help actors, who usually do not trust each other, to share information in a more secure and transparent manner in which there is no information asymmetry. By using blockchain technologies, transactions are recorded, cannot be modified, and stakeholders can verify and access that information. This could be especially important in the process of vaccines' quality assurance.

> 'The main advantage or benefit that can be found when using blockchain is trust. This feature is even more relevant in contexts of corruption, bribery, and abuse of the system in a supply chain. Thanks to blockchain technologies, there are multiple copies of the records encrypted in different computers all over the world.' (Expert from academia, USA)

In addition, logistical complexity in supply chains can be addressed using blockchain.

> ‘Blockchain represents a great advantage in ensuring the quality of vaccines. Covid-19 vaccines have very demanding logistical requirements such as the cold chain, the shelf life once the vials are opened, and the high shortage component. The characteristics of the vaccine and the current context conditions make it very vulnerable to [falsification], reuse, or theft, and blockchain can contribute in this case.’ (Practitioner from an international organisation, Costa Rica)

Some experts, however, pointed out that improving trust between different actors would not happen in the short term.

> ‘A blockchain-based solution is not going to create trust overnight. The project needs to be carefully designed, people need to be trained and educated in how to use the blockchain system and you need to test it to see how reliable it is, how easy (or difficult) it is to be tampered and defeated.’ (Expert from academia, UK)

For Covid-19 vaccines, it is also important to note that using blockchain to increase trust in distribution does not necessarily lead to higher public trust in the vaccine.

Preventing corruption with blockchain

Most experts interviewed argued that blockchain technologies may reduce the probability of corruption owing to the transparent management of data, since it is available to all stakeholders in real time, every node has a copy of it, and it cannot be tampered with. For instance, if someone tries to change information along the chain, all participants will be notified.

> ‘Blockchain helps to fight corruption because it reduces ‘discretionality’. If there is discretionality in decision-making, there is a great potential for undesirable practices. By automating the pharmaceutical supply chain and including mechanisms such as blockchain and smart contracts, it is possible to prevent actors who could make discretionary decisions from altering the chain.’ (Technical expert from a private company, Mexico)

Furthermore, blockchain can securely hold data inputs from the supply chain of a product. This technology, along with IoT and smart contracts, could allow updating and verification of data at each point of a supply chain, from manufacturing to final delivery. This could help reduce the falsified medical products entering the supply chain. For example, the German start-up authentic.network has developed a concept to ensure that medical products are

not falsified. By developing a secure, cryptographic code printed on the package, the recipient – or anyone along its journey – can scan the code through an app and verify the authenticity of a product. In collaboration with GIZ, authentic.network is testing this to verify anti-malaria drugs in Ivory Coast. There are further plans to use the same blockchain to secure and verify Covid-19 test kits manufactured in the country and, if successful, to roll out the concept in more West African countries.

It is important to remember that blockchain is only a tool, and unscrupulous actors could still use it to pursue their own benefit. If there are no strong verification processes when the data are entered into the system, these entries could be substandard or false. Additionally, even if the digital trail of a shipment looks valid on the blockchain, the product itself could be compromised – eg if a package is broken into during transit, and the contents replaced with fake medical products. However, when combined with other technologies, such as IoT and smart contracts, blockchain has clear potential as an effective anti-corruption monitoring tool.

Increasing data transparency to aid monitoring

By using blockchain, information is available in an open-decentralised platform that records every transaction and allows authorised stakeholders, depending on the type of blockchain, to review and scrutinise data in real time. As well as fostering trust, the features can also facilitate monitoring and audit, so that corruption risks such as falsification of medical products and embezzlement/ theft can be better mitigated.

> 'Everyone involved in the chain can see the information in real time, thus it is difficult to create information asymmetries and it reduces corruption because everyone is seeing what is happening. On the issue of vaccines, it would help the different stakeholders to be able to what is happening: pharmaceutical companies, funding agencies and patients. They can trace the vaccine from manufacturing until it reaches the patient.' (Expert from academia, Mexico)

Nonetheless, there can be a trade-off between transparency and efficiency. By including all the protocols and verifications, the process could become more complex, slow, and less efficient.

> 'Transparency is not a given. The question is how you produce evidence of transparency as a result of using blockchain. What are the reporting mechanisms behind it?' (Expert from academia, Netherlands)

One expert argued that blockchain could contribute to decreasing the costs and time required in auditing processes, as all the relevant information is on the chain. Therefore, it would be easier to report the results of a project and increase transparency in the project's implementation and evaluation phases.

Supporting accountability and smoothing out supply chains

The decentralised features of blockchain allow different stakeholders to verify and scrutinise the information on the chain. One interviewee argued that the fact that the data cannot be modified can also help to keep governments accountable. Other stakeholders in the network, including citizens, could also track this information and use it to hold other actors – governments, NGOs, international organisations, and private companies – accountable for the transactions recorded in the chain.

Real-time monitoring could be particularly useful for Covid-19, where a rapid distribution of the vaccines can reduce local infection rates.

Some experts highlighted that blockchain could also help with the stock management along the supply chain. Real-time information makes it possible to know which locations have surpluses or shortages, as well as identifying which types of corruption (such as embezzlement and falsification) are occurring, and where, in the supply chain. Real-time monitoring could be particularly useful for Covid-19, where a rapid distribution of the vaccines can reduce local infection rates.

Extending anti-corruption benefits beyond Covid-19

Most experts agreed that the pandemic highlighted the need for a reliable and corruption-proof system to track and trace not only Covid-19 vaccines, but also all medical products. Blockchain could support health sector delivery more widely.

> ‘This solution works not only for the Covid-19 vaccines: it is a larger problem, traceability problem, one example is the vaccine distribution, but also [falsified] medicines. This has potential for more areas.’ (Technical expert from a private company, Mexico)

> ‘The problems of traceability of vaccines and medicines in general around the world are the same: risks of [falsified] drugs, inadequate transport, inadequate temperature. So, the use of blockchain should be a collective effort.’ (Technical expert from a private company, Mexico)

Other vaccination programmes are now struggling as a result of the focus on Covid-19 vaccines, so there is an opportunity to also use blockchain to trace non-Covid vaccines and other medical products. Blockchain could help make their distribution process more transparent, accountable, efficient, and less prone to corruption.

Identifying the challenges in blockchain applications

Although blockchain could, in theory, help advance anti-corruption efforts, accountability, or transparency, experts highlighted several real technical and governance challenges.

Lack of infrastructure and data exchange

The infrastructure required to use blockchain in low- and middle-income countries is often limited or absent. Some interviewees, especially policymakers and academics, noted that advanced digital infrastructure, technical support, and stable connections are required to use blockchain technologies and these are not the norm in such countries.

An additional challenge is the interoperability of the systems. There is a lack of technical standardisation and data trust between systems. There are also different maturity levels between health systems, and this can create an obstacle.

> ‘A lot of digitalisation is missing. Public and private entities need to have digital platforms that can easily be integrated with blockchain networks.’ (Expert from an international development organisation, USA)

Other experts, however, argued that blockchain could be used without an internet connection, as there are networks already established and available for everyone to use for pilots.

> 'Infrastructure is no longer an obstacle to implementing solutions such as blockchain in developing countries – with the cloud, the use of mobile phones and broad connectivity, it is possible to start pilots. One example is the use of cryptocurrencies in Africa. Even without smartphones, SMS can be used to make transactions.' (Technical expert from a private company, Mexico)

Nonetheless, the lack of infrastructure remains an obstacle, especially in remote rural areas. The International Telecommunication Union (ITU) publishes and maintains the Digital Development Dashboard, which provides data on digital infrastructure in countries around the world. It includes a section on the affordability of internet and mobile access, which may be crucial for deciding on a realistic digital intervention. Some interviewees still claim that connectivity is not an issue.

> 'There is no challenge in the technical side, it's more about seeing the need and being willing to implement such a solution. It is necessary to have a partner, there is no way to do this in silos.' (Technical expert and start-up founder, Costa Rica)

Availability and quality of data

In many low- and middle-income countries, it is not possible to collect data across all key points of the supply chain, which can make it impossible to effectively track and trace Covid-19 vaccines. As a result, the products might look like they were 'stuck' at the airport, warehouse, or pharmacy. This may lead to accusations of mismanagement, while the real reason could be a lack of training in using the system.

Blockchain cannot verify the accuracy of manually entered data – that is beyond its scope. However, when an actor enters inaccurate data at any point of the supply chain, it will be easier to identify them.

> 'Blockchain helps to reach a consensus of truth, it doesn't prevent wrong data being entered.' (Technical expert and start-up founder, Costa Rica)

For some experts, the immutability of blockchain could pose a challenge too, as it is not possible to 'erase and correct' a genuine mistake. So, there is a risk that

if the data entered is not valid or truthful, the blockchain loses its status as a trusted database. The database would be inefficient if corrections are required, as the data in a blockchain are hashed, interlinked, and the blocks thereby protected from corrections. Error may come from faulty IoT devices or manual inputs. In neither case can blockchain solve the data accuracy problem.

Decision makers lacking knowledge

Several experts highlighted that a lack of knowledge and digital literacy as a critical constraint. It is essential that the end user understands how blockchain works, to increase public trust and encourage its use.

> 'The greatest resistance comes from lack of knowledge, as decision makers lack knowledge of what blockchain is or even have a partial perspective of what blockchain is, as they only relate the tool to cryptocurrencies and that is only one application of blockchain.' (Technical expert from a private company, Mexico)

Additionally, in low- and middle-income countries there is less access to the technical and legal expertise required to make effective use of blockchain technologies. But it is important to mention that human capital may not be a big challenge everywhere, especially in contexts where there are organisations and trained people who are willing to contribute to its development and implementation.

> 'There is a big existing innovative community of start-ups and people who want to create good solutions and do good for the world… In the blockchain ecosystem, there is obviously a lot of capital from international organisations and other sources, so there is a good set of resources available, human and financial.' (Expert from an international development organisation, Germany)

Possible high costs

It is not yet possible to estimate the technical, organisational, or monetary costs of establishing a blockchain to strengthen the supply chain of Covid-19 vaccines without a full technical description of a project. Developing a blockchain application depends on various factors such as features, complexity, type of blockchain, blockchain platform, and interoperability between other systems.

Many have heard of the enormous energy consumption of the Bitcoin blockchain. However, blockchain technologies deployed for supply chains are normally consortium blockchains and they are less power-consuming, using different calculation protocols to secure the entries.

Nonetheless, for some policy experts, the costs in the short term are considered to outweigh the benefits, because of the infrastructure needed and the time it would take to implement blockchain technologies. In addition to the technical costs, training people would also need substantial financial resources.

However, other technical experts claimed that the potential benefits exceed the initial investments by far. There are existing public blockchain networks that can be built upon, as well as free open-source knowledge.

> 'Blockchain is a technology that uses a cloud and is open source. So, the initial infrastructure is accessible to anyone who wants to use it. This reduces the initial capital investment that a government would have to make to start implementing blockchain.' (Technical expert from a private company, Mexico)

Politicians may not support disclosure

Unlike other products or services that could be delivered using blockchain technologies, vaccines in the current context are meant to be a public good and, therefore, their distribution process should include governments. For many experts, the main challenge – even more relevant than technical or infrastructure challenges – is 'political will' (or an active political commitment to the proposed reforms, and tackling the vested interests that benefit from corruption in the Covid-19 vaccine supply chain).

Governments may not be interested in publicly sharing data. First, public health data are inherently political and by revealing information, governments and ruling elites could feel that they are giving up control. Second, transparency could mean that policy failures are exposed, as this kind of technology could highlight inefficiencies, corruption, and unnecessary bureaucracy, and governments may be unwilling to reveal such weaknesses. Some government officials are the beneficiaries of corruption, which thrives in inefficient and bureaucratic procedures, and so are unlikely to support the use of blockchain for anti-corruption purposes.

Blockchain technology is sometimes associated with cryptocurrencies and corrupt practices. This may affect the public reception of blockchain technologies. Introducing this technology may raise concern rather than increase public trust.

> 'Governments don't want someone telling them that there are failures in their supply chain, they just want to say that they get the vaccines for their country. Transparency could go against their political motivations.' (Expert from an international development organisation, USA)

As many experts pointed out, the current context of a pandemic could represent additional pressure on governments to limit disclosure and transparency.

Frameworks are not yet ready

In order to use blockchain in the public sector, there must be a legal framework that regulates the technology. Some policy frameworks, such as the US FDA's Drug Supply Chain Security Act or the EU's Falsified Medicines Directive, appear to adapt well to blockchain technology. Although some countries already have regulations for digital signatures and digital documents, globally there is a lack of current regulations to support blockchain technologies. This situation contributes to the mistrust of new technologies, as there are no clear guidelines as to its use.

> 'Since it is not known what the potential could be, it is not possible to make a better regulation to set limits or boundaries for when it is applicable. Although the Covid crisis brought some digital acceleration in governments, blockchain is still too sophisticated for them.' (Expert from an international development organisation, Colombia)

> 'Most countries in the Americas have regulations that recognise digital signatures and electronic documents, so there is a basis there. It is necessary to have a regulatory framework that has electronic signatures, digital signatures, electronic records, so that all the elements that makeup blockchain technology can be recognised at a legal level.' (Expert from an international development organisation, USA)

Blockchain technologies also face specific regulatory challenges. For example, authorities cannot filter the data that are entered in blockchains, which theoretically can lead to mistakes. If IoT or smart contracts are used to

automate processes, any error in the code may lead to accidental violations. This presents challenges with regards to liability issues.

Limited incentives to participate

The interviewees identified two main governance challenges when creating a blockchain.

First, it is difficult to ensure that all those involved in vaccine supply chains understand the benefits and costs of being part of the blockchain network, and as a result, it is not easy to convince them to share their information in the chain. Information that is relevant to a supply chain system may be confidential and contain business-sensitive data which the partners may not want to share. However, in certain types of blockchain, it is possible to regulate what data are shared. Some experts argued that there must be coordination between all parties, the costs must be covered by the whole network, and the benefits must be aligned.

> 'The idea to follow the supply chain is not new, the problem is to convince all the actors with different business models to join the blockchain, that is the main problem. If you are powerful, you can get all the actors in the supply chain to jump in.' (Expert from an international development organisation, USA)

> Second, if proper inclusion of all parties is not guaranteed when designing the blockchain, there is a risk of a technological imposition, and this could hinder the use of the technology. For instance, if an actor has no agency in the tool's setup, it might not be motivated to share its data in the chain.

'There is a problem of governments refusing transparency but also a problem of oppressive approaches to technology, in terms of imposing technologies and models that are not designed with everyone at the table while expecting that everybody throws their dirty clothes in it for everyone to look at.' (Expert from government, Mexico)

The Covid-19 pandemic may hamper innovation

While all interviewees agreed that the use of blockchain could contribute to the traceability of Covid-19 vaccines, some felt that the pandemic presents additional challenges for the adoption of these technologies.

Some experts were concerned that the political costs of implementing new, unknown technologies could prevent governments from adopting this type of tool. In their view, governments are under high levels of pressure to manage the health crisis and the introduction of new technologies could be perceived as risky.

> 'It is complex to carry out proofs of concept of solutions that are in the development stage in the context of Covid. This involves logistical and ethical complexity as many countries are unwilling to take a risk that may result in their management of the pandemic being undermined. Governments want an efficient and scandal-free process and including blockchain, a technology that is not that well known, may be considered a risk.' (Expert from an international development organisation, Costa Rica)

One expert expressed that, if the technologies are not ready for use in the current context, it would be prudent to postpone their implementation.

> 'Under the pandemic circumstances, if the blockchain is not ready to use it is foolish to use blockchain, you don't want to experiment in an emergency.' (Expert from an international development organisation, USA)

Others considered that this is precisely the time to start implementing the technology. In case it is not possible to develop an effective blockchain solution for the distribution of the Covid-19 vaccines, the concept would be undoubtedly helpful for other types of emergencies or the distribution of other vaccines or medicines.

> 'What a better start than during the current pandemic: if you manage to have it ready on time, great, if not at least you will have this tool ready and available for future roll-outs of other services in the humanitarian field.' (Expert from academia, Netherlands)

Fairer vaccine distribution for all: Can blockchain contribute?

Distribution of Covid-19 vaccines has been deeply unequal, contributing to a protracted global crisis. Key corruption risks across the supply chains, such as falsified medicines and theft of vaccines, exacerbated the problem of unequal distribution and slow coverage.

Many start-ups, tech companies, development organisations, multilaterals, and donor countries have considered blockchain as a potential tool to enhance the management of supply chains for medical products.

In countries where the technical infrastructure is in place, blockchain is making its way from pilot testing to production. If the end user has the tools and skills to verify what the blockchain tells – such as confirming that a vaccine is genuine – the blockchain could prevent falsified drugs from being distributed.

No single technology can prevent corruption or fraud, and for blockchain to secure the supply chain of Covid-19 vaccines, technology to track the batches on their way to the end beneficiary would be needed.

Nonetheless, the drive to better understand how to use blockchain technologies remains, and there has been a growing interest to examine how blockchain could contribute to enhancing the distribution of Covid-19 vaccines, so they could reach everyone and reduce the opportunities that may exist for unscrupulous actors to steal them and sell them in black markets in substandard conditions, as well as produce and distribute falsified versions.

The findings reveal that deciding when to use blockchain technologies, to safeguard the quality and distribution of Covid-19 vaccines or other medical products, comes down to carefully assessing the context in which this technology can be used. As with any other digital tool, blockchain's potential as an anti-corruption measure depends on how people use it and the quality of data entries.

After assessing the selected literature of blockchain and anti-corruption in research in health and development, and integrating the views of multisectoral experts, we conclude that context matters, and both technical and political challenges may limit blockchain's potential as an anti-corruption tool for Covid-19 vaccines. Although blockchains may represent optimal devices for securing and monitoring supply chains, when it comes to developing pilots to address the distribution of Covid-19 vaccines or other medical products, it is key to first assess the corruption problem that needs to be addressed, and then whether that particular technology is the right solution for it. It may be that other digital tools or non-digital interventions, or a combination of both, could deal with such problems more effectively and cost-efficiently. So, context is essential when evaluating how valuable blockchain can be to mitigate corruption risks in the supply chain of medical products.

The following recommendations should be considered by donors – and indeed the wider development community – wishing to engage with blockchain technologies to tackle corruption risks in the distribution of medical products, such as Covid-19 vaccines.

The way forward for donors

1. **Be problem led: Examine whether blockchain is the right approach to address a specific corruption problem.** In the case of medical supply chain management, there should be a careful evaluation of what is threatening the distribution of medical products, who is benefiting from this and who is not, and if blockchain technologies could help address these factors. For example, if the priority problem is falsified medical products because of poor monitoring of medical products' distribution, blockchain could in theory support tracking and tracing medical products across their supply chains. Once it is clear that blockchain could help, then it is important to assess the technical capacities of actors across the supply chain to collect and manage data; the strength of regulations to protect data and tackle misuse; and the political backing that needs to be secured to run the project.
2. **Invest in learning and training to understand emerging technologies, such as blockchain, as an anti-corruption tool in supply chains.** This means deepening donors' knowledge on how the technologies work and their costs, identifying potential partners, and being aware of the role of socio-political contexts and digital infrastructure. This will help donors to ask the right questions when considering using blockchain as an anti-corruption measure in medical supply chains and enable them to choose evidence-based and responsible digital intervention in partner countries.
3. **Provide technical support for the creation, evaluation, and standardisation of legal frameworks to regulate the use of emerging technologies, such as blockchain technologies, for development and anti-corruption purposes.** Robust commitment from a diverse set of partners can be a path forward. There should be a comprehensive regulatory environment that addresses the legal challenges that arise from blockchain's immutability, and builds in regulations that enable transparent information sharing, quality assurance, and technology audit processes. This should be done not only across a nation and its regions, but also international borders, to ensure that global legal frameworks

promote a secure and transparent value chain.

4. **Involve all relevant stakeholders early on and promote risk sharing.** Blockchain's potential as an anti-corruption tool becomes stronger when all relevant stakeholders are committed to sharing information, costs, and risks. It is important to identify how the blockchain would benefit each stakeholder, and therefore making it easier to convince them to actively participate in the development and implementation of this technology. Multistakeholder participation will help promote a more transparent and open data culture, enable peer-to-peer accountability for the quality of their data entries, and lead to overall higher data quality.
5. **Promote insurance and verification processes.** In the context of medical supply chain management, strong insurance and verification processes will ensure that data entries are not substandard or false, and will reduce the risk of embezzlement and theft of products. Quality insurance processes could include developing tools to help minimise errors in code writing – for example, having independent programmers and teams to test the quality of the blockchain that has been developed, and running verification techniques prior to the deployment of the blockchain to ensure that the software is ready to operate properly. In addition, external verification processes should be employed to ensure the validity of each entry aligns with the consensus reached by all parties involved.

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