Verified vintages: Leveraging blockchain to stop wine fraud

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Abstract. Wine fraud and counterfeiting is a problem that spans from entry level wines to cult bottles. It poses significant challenges such as impacting consumer trust and causing financial losses. The study explores potential blockchain-based applications used to prevent wine fraud. Responding to the research questions regarding how blockchain technology can help prevent wine fraud and what potential benefits and limitations may exist in this context, we performed a literature review and conducted an exploratory use case analysis of over 100 solutions. Our findings unveiled that only a few operationalized use cases exist. These are predominantly based on non-fungible tokens (NFTs), which are employed for verification of authenticity purposes. We also found that the adoption is at an early stage. While the benefits of using blockchain are promising, further research should be performed to address its potential limitations within the organizational, technical, as well as legal and regulatory realms.

1 Introduction

Wine Fraud has a long history and many faces: in the past, wines were tempered with in order to achieve better quality, mostly due to a lack of grape maturity, or to increase quantity by adding water or cheaper wine to the final product.

The latter is still a valid modus operandi, but modern wine fraud is also about counterfeiting and the forgery of expensive wines. The scope ranges from hundreds of thousands of liters of cheap red wine marketed as more expensive Bordeaux to high profile cases of fake cult wines such as the infamous example of Rudy Kurniawan who is famed to have forged wines worth more than one hundred million US dollars [1].

Considering the large grey area that surrounds such practices and given that many operations go undetected, it is difficult to quantify the total damage though such activities cause. However, Europol estimates that the economic loss for the wine and spirits industry in the EU alone amounts to 1.3 billion Euros [2]. Of course, this does not include the potentially serious impact on the health and safety of consumers, as well as negative environmental consequences and the reputational damage to producers.

This large number is pitted against the growing demand by consumers for more information about the origin, safety, and production process of their wines as is also evidenced by the upcoming changes to EU law concerning wine labels (Regulation EU 2021/2117 of the European Parliament and of the Council of 2 December 2021). This creates a somewhat puzzling situation as wine fraud, as any kind of fraud, often requires an element of ignorance or deceit: while clients become more educated and seek more information, the status quo regarding wine fraud can still be described as an arms race between producers on one side that use secretive measures such as invisible ink and engravings to protect their products and criminals on the other that become increasingly sophisticated and/or bold.

Looking for a solution, Blockchain Technology (BCT) has been hailed as the silver bullet to help producers prevent fraud and end a century old problem [3,4]. The technology's acclaimed benefits include increased trust, security, transparency, and the traceability of data shared across a business network [5]. As such, it suggests itself to apply BCT to the supply chain of products and the technology has, in fact, been applied to map the different stages along the supply chain of products in several industries.

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On this basis, our research focuses on two questions:

(a) How can BCT be used to protect from wine fraud and discover counterfeiting?

(b) What are the potential benefits and limitations of the technology and its application with regard to its desired function?

2 Data and methodology

Following an extensive literature review concerning the use of BCT in supply chain in general and with regard to the prevention of fraud and counterfeiting in particular, our research is based on a multiple exploratory case study approach; we analyzed use cases employing fungible and non-fungible tokens in the wine sector particularly targeted at preventing wine fraud. We found that current applications revolve around the application of both fungible and non-fungible tokens in combination technology focusing on the Internet of Things by using data storage on the actual device as well as distributed information. We also examined existing use cases in terms of underlying business models, associated costs, and the complexity of potential solutions, as well as the lack of a common standards that hampers interoperability which can be considered as adoption factors. Further, we explored legal and regulatory risk factors regarding contractual and intellectual property challenges as well as regulatory initiatives that are underway that aim to regulate blockchain technology and its different application models and its implications. Also, we examined technological elements such as NFT maintenance, marketplace risk, and the coding of the underlying smart contracts, the aspect of cybersecurity and fraudulent activity also needs to be considered.

In order to test our findings, we conducted a qualitative survey through semi-structured interviews with stakeholders in the wine sector that are involved in the use of tokenization with regard to fraud prevention and detection.

3 Blockchain technology as a solution

3.1 Underlying fundamentals of blockchain technology

Blockchain is a distributed ledger technology (DLT), a constantly synchronized data storage entity distributed across locations and entities. One of the key characteristics of blockchain is that it enables the implementation of smart contracts with contractual commitments to safeguard transactions. Smart contracts are software programs that are based on BCT with fixed rules for automatically executed transactions based on a set of predefined conditions that have to be met. They allow the tracking of products along the supply chain, manage ownerships, and authorize automatic actions such as payments. They could further replace the trust that has been established by intermediaries so that parties, that have not met and performed trades before, can rely on the integrity of the transaction. Key benefits of smart contracts are the increased transparency and trust in a decentralized system with no single ruling authority [6] and the reduction of ex-ante and ex-post transaction costs [7]. Smart contracts in BCT can be seen as coordination mechanisms applying an institutional perspective over coordination [8]. The simplest form of a smart contract is a token. For the purpose of understanding, it is paramount to understand that a token can either be fungible or non-fungible. Fungibility in the economic sense can be defined as the ability of a good or asset to be interchanged with other individual goods or assets of the same type such as a dollar bill [9]. The same applies to digital currencies such as Bitcoin where each Bitcoin has the same attributes as any other Bitcoin.

In contrast, a non-fungible good or asset such as the original Mona Lisa painting is unique and while it may be possible to reproduce a painting with the same features, it would never be the same since important aspects such as the identity of the creator, the painting's age and reputation are not reproduceable. The same holds true for digital art works: while an image can be copied in the way that its underlying code is identical, some aspects cannot such as, for example, the fact that a certain image is the first to ever be created in a series of identical images. Such items are not simply interchangeable and are therefore non-fungible. With regard to non-fungible token (NFT), we use the definition established by Valeonti et al. and the work of Bal and Ner, Regner et al. and Leech, whereas a non-fungible token is a cryptographically unique, indivisible, irreplaceable and verifiable token that represents a given asset, be it digital, or physical, on a blockchain [10-12].

Applied to the wine sector, this means that a bottle of wine depending on its specifics could be either: a fungible asset where all bottles have the same attributes (assuming that the lot number on a bottle does not provide additional value); or a non-fungible asset where, for instance, a rare bottle could not be exchanged with any other because of some peculiarities, say, being the first bottle to be filled in the respective vintage or because of a special exclusive label and as a result has a value because of its uniqueness.

3.2 Application generally to supply chain management and in the wine sector in particular

Given the benefits outlined above, the application of BCT to supply chain management shows obvious opportunities. Over the last decades, agri-food supply chains have changed from vertically integrated to vertically collaborating networks. The redefinition and change of food quality - also caused by food scandals in the early 2000s - promoted the transition to vertical cooperation in supply chains coordinated by a central company [13].

Trust is a key driver of vertical cooperation [14], and trust and cooperation are also the key organizational drivers of the food sector [15]. Since trust is also used in the agricultural food supply chain to manage the risk of cooperation problems, it is another driver of vertically cooperating supply chains [13]. A trustless solution based

on BCT would therefore present important advantages for supply chain management in general and the wine sector in particular.

This belief is emphasized in the report that was published by the OIV in November 2021 as part of its symposium on the digital transformation of the vitivinicultural sector [16]. Having conducted expert interviews in the OIV's member countries, BCT was voted as the technology that is expected to receive the highest level of prioritization in the short to medium term. According to the report, this expectation was based on the view that the technology promises a wide range of benefits to the industry, despite the early stage of adoption such as transparency, traceability, fraud prevention, enhanced marketability and accessibility, transaction security, as well as increased and faster legal compliance with administrative burdens.

Our research shows that while the application of BCT in the wine sector has so far only seen a limited uptake, several use cases of BCT as a reproduction of the different elements of the wine supply chain in full or in part can be found. Generally, these cases can be described as an implementation of BCT by wineries for the collection of data during different stages of production and distribution. Through the use of instruments such as sensors, satellite imagery and geographical information as well as manual data entry where necessary, data is collected, time stamped and recorded on an immutable blockchain. Data can be collected at different times and stages in the vineyard, the winery and distribution channels. Variations of this model are also used with the purpose of wine fraud prevention and will be discussed in detail below.

4 Analysis

4.1 Overview and underlying models

As part of our research, we analyzed over hundred cases that claim to employ BCT in the wine sector. While proofing authenticity and provenance of the product is an often-stated purpose, not all cases include this and have as such been excluded from this work. The remaining use cases can be classified into three models, but shares the common feature that the different elements of a supply chain in full or in part are digitally reproduced and refers to cases where wineries implement BCT for the collection of data during different stages of production and distribution. Either through manual data entry or through the use of instruments such as sensors, satellite imagery and geographical information as well as manual data entry where necessary, data is collected, time stamped and recorded on an immutable blockchain. Data can be collected at different times and stages in the vineyard, the winery and distribution channels.

The first model can be described as collecting such information in a central database, which is recorded on a blockchain with the objective to notarize this information. For instance, information such as the date of the bottling could be stored and made visible publicly, but because of the addition of further blocks cannot be altered afterwards. This can be done through the use of fungible tokens or, as is the second group of use cases, through the use of non-fungible tokens. This is the most prominent application in terms of numbers and market penetration. The method envisages that the NFT is to be a digital representation of the underlying physical asset, i.e., a specific bottle of wine, and oftentimes comes with additional elements such as digital artwork as well as supplementary benefits.

The third model differs in such a way that the information that is stored on a blockchain and can be made available to a stakeholder or customer through the use of, for example, on an app on a smartphone in combination with differing kinds of QR-code or chips using Near Field Communication (NFC) applied to the bottle. The use of RFID-tag based solutions is based on a similar approach, but may be highly platform dependent, as RFID readers are not broadly available [17] (Popovic et al. 2021).

In those cases, where NFC tags are deployed, these tags in conjunction with BCT can be described as the production of a digital version of a selected number of bottles, which is intended to be sold as a token. For that purpose, the bottles are identified and fitted with a small microchip under the capsules that are the protective sleeves covering the cork and top of the bottle. The chip is NFC tag that is programmed with basic information that can be read, for example, through an app on a smartphone.

The architecture and the different elements involved have been summarized in Fig. 1. In this model, a digital replication of a real-world physical object that describes the object through digital information with all its attributes spanning from an atomic level to the geometric level thus creating an individual entity [18] is created. Since the microchip on the bottle can hold only very little data, the information provided on the NFC tag is in most cases only an identifier.

However, the use of an NFC chip or similar technology can also serve as an instrument to automatically update information on the blockchain such as change of location or ownership as well as a security measure to record damage to the seal of the bottle that could indicate tampering. Thanks to an electric circuit, the NFC can transmit a 0/1 signal that communicates whether the seal has been broken or not.

Using the identifier saved on the NFC, information is displayed through an app that is stored elsewhere, as part of a decentralized network that is used for a blockchain and as a distributed ledger on several systems, but for the avoidance of doubt, could also be kept a centralized, cloud-based storage unit.

The amount of data is predetermined and can be provided through manual data input, e.g. provision of name, vintage, and issue number, or automatically through the use of sensors that register for instance the filling data. The idea in most use cases is that a consumer, investor or collector can use a simple smartphone with the provider's app to read out basic information that is, for example, required to verify authenticity and provenance, but could also be used to

engage a consumer through the provision of essential information such as tasting profile or food pairing as well as additional benefits in the form of better data management and compliance with regulatory requirements.

The implementation of the technical element is in almost all cases done by service providers. As described above, the programming into smart contracts of the underlying information and tokenization can result in fungible or non-fungible tokens. In either case, certain events or addition of additional information such as the sale of the bottle or even the removal of the capsule can be recorded either manually or automatically depending on the system used.

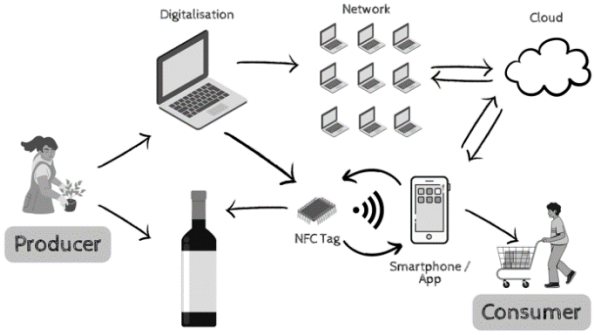

Figure 1. Overview Process NFC/FT/NFT/Blockchain Model (Source: authors).

As a result of our analysis, we found that the different solutions bring various benefits in addition to a supplementary security layer, which however appear to have been explored only to a very limited extent and as such offer significant potential.

With regard to the three models described above, only the third model provides a direct connection between physical object and digital record and the first two models described above do not. This matters as both the fungible and the non-fungible token represent a separate asset from the container and as such, for instance, only provide contractual obligations for fulfilment in case of a transfer of property. Despite the value this could represent in particular to collectors or investors with regard to an immutable ledger that stores information on ownerships as well as other details, it gives no guarantee that the bottle has not been tempered with. For example, one could extract the content of a wine bottle and refill it with something else.

For this reason, we have focused on the third group of use cases as the previous two offer only limited protection and means to tackle fraud and counterfeiting and consequently do not fit the desired purpose to use BCT for efficient protection from wine fraud and discovery of counterfeiting.

4.2 Examples

One example that is based on the model outlined above would be the Enseal/Entrust system that according to its provider uses “a secure, comprehensive digital system that records every stage of an agricultural supply chain from produce, harvesting, processing and packaging” [19]. The project was launched by a group of producers in Clare Valley in Australia by Jeff Grosset and David Travers and a group of wineries from the region covering more than 100 vineyard blocks. It was originally developed with the purpose to improve fraud protection and strengthen provenance and authenticity of their products to protect the reputation of the participating wineries. In addition, the Enseal/Entrust system also uses Near Field Communication (NFC) technology provenance, authenticity and seal integrity. For this purpose, the company developed the SaaS (software as a service) platform “Entrust”, and the digital screwcap “Enseal”.

The goal to provide an anti-fraud solution for wines and spirits based on Blockchain technology is also at the center of the ChaiVault project. The objective is to allow potential buyers to know a bottle is authentic and view provable provenance, before purchase, without physical proximity to the bottle, by using an online ledger that can be kept private or made visible to the public for a licensed vendor to use for online marketing purposes, according to the company’s website [20]. Whenever ownership is transferred, provenance information can be updated to include new ownership and storage information.

A similar concept is employed by the Swiss company VinID [21] through a combination of blockchain and NFC technology to ensure each product has its own unique and dynamically encrypted ID based on the model outlined in the illustration in Fig. 1 above. Other than to guaranteeing authenticity and providing provenance information, the product aims to enable supply control and inventory intelligence using digital twins and promotes additional opportunities such as reaching new customer groups, increased costumer engagement, enabling subscriptions and DTC–Sales as well as premiumization of a product offering.

Although all three use cases employ a similar model, they show important variations to such an extent that they mostly target different starting points: Enseal commences the programmed registration of information in the vineyard that is automatically added to the database and subsequently to the blockchain with a focus on transparency of the supply chain from an early stage of production on. VinID targets the primary market with provision of service at the stage of the producer once the product is ready for distribution, while Chai Vault predominantly focuses on the authentication of bottles that have already passed ownership, adding another level of service that is based on the existing experience gained in the field of combatting wine fraud.

5 Results and Discussion

Having examined not only the working mechanisms of the use cases within the scope of this article, but as a result of our ongoing work in the field of BCT research, we deem it necessary to emphasize as a general observation before entering into details of the use of BCT in the wine sector that for the information that is stored on the blockchain to be infallible and therefore of value,

the information itself must be infallible. For example, if the information on the blockchain represents that the wine has been bottled at the estate, it would need to be recorded in a certified way that guarantees the accuracy of this information, which could be an approved sensor at the bottling station that is verified, for instance, by an official institution. Were it only to be on the basis of an affirmation of, for example, the producer, the information stored on the blockchain would merely confirm the producer's affirmation that the wine was bottled at estate and would as such require an element of trust in the producer's word, but would not provide the infallible information that it actually had been bottled there. Based on past cases, the word of a producer can, unfortunately, not suffice, and the objective of BCT should be to provide a solution that does not require trust but is trustless in itself. Furthermore, with every additional step along the supply chain the risk of incorrect information being replicated on the blockchain increases. For example, if a merchant claims to have bought the bottle directly at estate and sticks an NFC chip on a bottle and registers this information on the blockchain, it does not certify this information as it only guarantees that said merchant is or was the owner of the bottle with the chip.

With regard to blockchain adoption in the wine sector and given the relative recency, several challenges to its implementation exist. With a view to the model outlined above, practical issues could occur with a view to the integrity of the secondary technology, e.g., the NFC chip. Technical issues could also ensue with regard to the coding and adoption of BCT. While BCT offers increased security through cryptology, cybersecurity is another threat to the successful adoption.

Reputational aspects such as the ecological impact of tokenization in some cases as well as the lack of a common market or the mentality of a fragmented sector are further challenges that need to be taken into consideration. The lack of standards together with the scarcity of skilled workforce are other factors. In particular the former has been an aspect that has been nominated by the companies we interviewed and could be a starting point. Research and practical examples from other sectors [22,23] have also shown that regulatory bodies and institutions actively promoting innovation to enable interoperability between different solutions and prevent market fragmentation to improve the speed and security of technology adoption.

On the other side, from a regulatory perspective, producers need to consider the potential application of securities laws and anti-money laundering regulations. The digital token related to a specific bottle primarily only represents a contractual obligation for fulfillment, resulting in a potential disconnect between physical and digital asset, so that legal aspects need to contemplated, too.

With regard to the solutions examined in particular, we found that while several aspects of the front end of the supply chain are addressed by the existing solutions, the consumer facing end appears to have gained limited traction. This is in part due to the fragmentation of the market and its application and the relative novelty of the use of BCT in the wine sector in general. One aspect to improve acceptance among consumers would be the increased communication by industry stakeholder to create greater awareness and improve speed of implementation.

And lastly, the benefits of employing BCT must outweigh its costs, which, given the considerable investment required as well as the technology's complexity in combination with the described obstacles, must not be disregarded.

However, as already touched upon, the use of BCT in the wine sector also provides significant benefits that go beyond the improvements regarding authenticity and provenance and therefore should not be disregarded:

While the motivation for producers to employ the BCT in combination with other technologies is first and foremost the prevention of wine fraud and to improve authenticity and provenance with a view to protect reputation. However, other than the publicity that is generated by the use of innovative solutions, it also offers a way to reach new customers as well as to intensify the exchange with existing purchasers and participate in the on-sale of their products to engage customers or profit from royalties. Lastly, as has been documented in the use case of the VinoTrust project that used Enseal additional benefits quickly emerged through the improvements regarding data management and compliance with reporting requirements.

On the other hand, although the direct benefit of BCT in the wine sector for consumers, investors and collectors stems from the improved protection against wine fraud and counterfeiting, an additional benefit lies in the increased fungibility of an asset as the digital representation of the wine bottle in form of a token can easily be traded. Through the use of other incentives such as the use of digital art for NFTs connected to a specific wine bottle or perks such as discounts for future purchases or winery visits, further marketing gains are generated that could lead consumers to choose such products over traditional ones.

Despite the potential of BCT with regard to combatting wine fraud and counterfeiting, however, to provide a value-adding solution currently a substantial cost per bottle is incurred. Considering the margins of entry-level wines, which represent the vast majority of the market, this means that the use of such solutions for this important market segment is not yet feasible. As outlined above, wine fraud is not limited to the premium segment as is highlighted, for example, by recent cases of counterfeit versions of the Yellow Tail brand being discovered across the UK [24] or the discovery of a fraud scheme which saw up to five million bottles of cheap Spanish wine disguised as Bordeaux appellations and French table wine with an overall quantity of wine involved equivalent to 4.6 million bottles [25]. Applying a model using the combination of BCT and other technologies as described above might still prove too costly and as a consequence cannot be applied to the mass market before the cost for the underlying technologies can be reduced significantly.

6 Conclusion

The implementation of BCT in the wine sector in particular with regard to the prevention of wine fraud is as demonstrated still at an early stage. Yet, our analysis demonstrates despite the several existing challenges the potential benefits for using blockchain technology in the wine sector to combat fraud and counterfeiting and how this could result in the prevention of significant damages to the reputation and prevent financial losses as well as increased consumer confidence and customer engagement.

We also found that increasing awareness could benefit the adoption of BCT in the wine sector and offer the providers of the solutions described herein as well as potential newcomers. The promotion of innovation and the setting of market standards could also contribute to the adaption of the technology.

We have conducted intensive research to identify relevant use case but given the novelty and the consequential scarcity of examples presents a limitation of our results. As the adoption of BCT in the wine sector is still in its infancy further research should be conducted to gain a better understanding regarding its potential limitations within the organizational, technical, as well as legal and regulatory realms.

Yet, this paper presents in our opinion a valuable overview of the current situation and the benefits of and challenges to the adoption of BCT to combat wine fraud and counterfeiting that serves as a foundation for future work in this field.

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