THE SOCIAL VALUE OF INNOVATION IN PAYMENTS

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ABSTRACT

Although there is a long literature on the social value of innovations, we know of no studies focused on quantifying the social value of innovation in payments. This article provides a model for such quantification. We focus on two recent payment innovations: contactless and tokenization. We quantify the benefits they have generated for the innovators and the benefits they have generated for society, including end-users. We also compare the social benefits of the innovations with the social costs of developing and adopting the innovations. To the extent that costs and benefits can be quantified, we find that the social benefits of these innovations are larger than the private benefits, and that the benefits the innovations have generated for society are larger than the investments society has made to develop and adopt them.[2]

Keywords: payments, innovation, contactless, tokenization, private and social returns

JEL codes: E42 (Payment Systems); O3 (Innovation; Research and Development; Technological Change; Intellectual Property Rights)

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Although there is a long literature on the social value of innovations, we know of no studies focused on quantifying the social value of innovation in payments. This article provides a model for such quantification. We focus on two recent payment innovations: contactless and tokenization. We quantify the benefits they have generated for the innovators and the benefits they have generated for society, including end-users. We also compare the social benefits of the innovations with the social costs of developing and adopting the innovations. To the extent that costs and benefits can be quantified, we find that the social benefits of these innovations are larger than the private benefits, and that the benefits the innovations have generated for society are larger than the investments society has made to develop and adopt them.

1 Introduction

Since Griliches (1958) published his classic study of the social value of hybrid corn, the literature on the private and social benefits of innovations has grown steadily. Mansfield and coauthors (1977) made an important contribution to this literature when they quantified private and social rates of return to specific innovations in various industries, including primary metals, machine tools, construction, drilling, paper, industrial controls, electronics, and chemicals.

Since these early studies, many other studies have estimated private and social returns to innovations. For a survey of the literature, see Hall, Mairesse, and Mohnen (2010). To the best of our knowledge, however, no study has focused on innovation in payments. This is remarkable, among other things because the technology of payments—and especially of digital payments—has changed dramatically over the years. In his historical study of technological innovation in electronic payments, Stearns (2011) points out that a payment-card transaction in the late 1960s required the clerk to enter personal and card information by hand, involved several phone calls, and took several minutes to complete. Today, by contrast, the transaction takes a few seconds and can be completed by tapping a card on a reader.

Our study attempts to start filling this gap in the literature. We estimate the private and social benefits of two recent innovations in payments: contactless and tokenization. We develop novel methodologies for quantifying these benefits with publicly available information. Further, we compare the benefits the innovations have generated for society—including benefits for end-users such as payers and payees—with those they have generated for the innovators. We also develop estimates of the R&D costs the innovators have incurred in the process of creating the innovations and of the costs merchants have incurred in adopting them, which allows us to compare social benefits with social costs for each innovation. To the extent that costs and benefits can be estimated, we find that the social benefits of contactless and tokenization are larger than their private benefits, and that the benefits these innovations have generated for society are larger than the investments society has made to develop and adopt these technologies.

Our study is organized as follows. Section 2 presents a short summary of the literature on the costs and benefits of innovation. Section 3 describes the essence of the innovations, and section 4 discusses the general tenets of our methodology for estimating costs and benefits of tokenization and contactless. In section 5, we estimate the benefits that tokenized payments have generated (and will continue to generate) for end-users (consumers and merchants), and in section 6 we do the same for contactless payments. In section 7, we estimate the costs of developing and adopting these technologies, and in section 8 we estimate private and social returns to the innovations. In section 9, we highlight the main conclusions of our investigation.

2 The literature: a brief review

Economists have carried out two types of studies to measure the returns to investments in R&D and other innovation assets. Many studies rely on an econometric approach based on firm data, industry data, or country data. This literature strand has two variants. The "primal" approach relates the output of a firm, a sector, or an economy to its stock of R&D or knowledge capital. The "dual" approach estimates a system of factor-demand equations derived from a cost-function representation of the technology. A comprehensive summary of these studies is in Hall, Mairesse, and Mohnen (2010).

The alternative approach relies on case studies of specific innovations, and this is the approach we follow in our study. The paper by Griliches (1958) on hybrid corn is usually considered the first in the case-study literature on the private and social value of innovations. Griliches used a mail survey to estimate the private and public research expenditures on hybrid corn between 1910 and 1955. He estimated the annual gross social returns by assuming they were roughly equal to the resulting increase in corn production plus a price-change adjustment. He concluded that the internal social rate of return from hybrid corn was between 35 and 40 percent.

Mansfield and coauthors (1977) conducted 17 case studies of innovation—some were product innovations used by firms, others were product innovations used by households, and yet others were process innovations. In each case, the new product resulted in a potential saving to end-users. By combining estimates of these benefits with estimates of the investments the relevant industries made to develop the innovations, Mansfield and coauthors estimated private and social internal rates of return for each of the 17 innovations. Private internal rates of return ranged from 4 percent to 214 percent with a median of 25 percent. Social internal rates of return were higher—they had a median of 56 percent and varied from 17 percent to 307 percent.

Tewksbury, Crandall, and Crane (1980) expanded the Mansfield approach to another 20 innovations—12 of those were industrial products, four were consumer products, and another four were industrial processes. They estimated a median private internal rate of return of 27 percent and a median social internal rate of return of 99 percent.

Sveikauskas (2007) summarized the case-study results presented in Mansfield et al (1977), Nathan Associates (1978), and Tewksbury et al (1980). He pointed out that, combined, these three publications covered 57 innovations. In these 57 case studies, the median private return to R&D was 28 percent, and the median social return was 71 percent.

A collection of recent studies of innovations is in Corrado et al (2021). Particularly interesting are the chapter by Byrne and Corrado (2021) on consumer digital services and the chapter by Byrne, Corrado, and Sichel (2021) on cloud computing. Byrne and Corrado (2021) estimate that, during the early years of content delivery systems (1987-2004), the innovation generated a surplus of USD 892 billion in 2017 dollars.

Our study of contactless and tokenization is, to our knowledge, the first that applies the case-study methodology to innovation in payments. We follow the general approach developed in Griliches (1958) and Mansfield (1977), the pioneering papers in this literature. That is, we estimate the resources that society has invested in the process of developing and adopting the innovations, and the benefits the innovations have generated for innovators, end-users, and society.

3 The innovations

Contactless and tokenized payments are relatively recent innovations. They are the latest examples of a long history of technological change in digital payments. For a detailed study of innovation in electronic payments through the 1980s, see Stearns (2011).

3.1 Tokenized payments

Tokenizing a payment involves replacing something of high value, such as a debit- or a credit-card account number, with something of low, or no, intrinsic value (Juniper Research, 2022a). The token is a random sequence of digits that maps to the account number it replaces, with the mapping kept in a secure vault. Since its introduction in 2005, payment tokenization has been used to enhance security in various types of transactions, including card-present ("CP"), card-not-present ("CNP"), mobile, and, more recently, Internet of Things ("IoT") payments. (Tokenization is used in areas other than payments as well.)

There are two main types of payment tokenization (Juniper Research, 2022a). In network tokenization, the major card networks—including Visa, Mastercard, American Express, Discover, JCB, and China Union Pay—issue the token. Each of them has its own token-generation service and its own vault. Network tokens are valid across the entire payment ecosystem and are applicable to a wide variety of use cases. In other types of payment tokenization, by contrast, tokens are issued by merchants, acquirers, third parties, and issuers. In this case, tokens replace personal account numbers at a specific point in the payment process or in a closed processing environment.

Further, tokens can be single-use or persistent. Single-use tokens are valid for a single transaction. Therefore, when a customer makes a new purchase at the same merchant, she will not be recognized, and a new token will have to be created. Persistent tokens, by contrast, can be used to secure recurring transactions, matching new purchases to the same account. Persistent tokens are frequently stored by the merchant, which simplifies the process of authorizing transactions in a subscription model and reduces checkout times via card-on-file (“COF”) payments. Persistent tokens can save consumers time when they make repeated purchases at a specific merchant.

Mobile wallets were the first payment-tokenization use cases in which the major payment-card networks were involved. Apple Pay, for example, was launched in 2014 and was developed in collaboration with the major networks, including Visa and Mastercard, and several large banks (Poper, 2014). Figure 1 tracks the number of tokenized transactions reported by Juniper Research from 2019 through 2027 and presents our forecasts through 2039.

<FIGURE 1 ABOUT HERE>

3.2 Contactless payments

Contactless payments include contactless cards, mobile wallets, and wearables (Juniper Research, 2022b). The idea of using Radio Frequency Identification (“RFID”) technology to transmit information between an object and a reader has been around for decades (Yang and Hancke, 2017). The first contactless payment card for commuters, the UPass, was introduced in Seoul, South Korea, in the mid-1990s (Park and Kim, 2013).

RFID is a short-distance wireless technology that today is used mainly for controlling inventory (Olenewa, 2017). RFID tags are small chips that have a CPU, memory, other electronic circuitry, and an antenna. RFID readers send electromagnetic waves that generate a small amount of current in the antenna. The current powers the chip, which in turn transmits the information stored in the tag's memory to the reader. Tags can be read at distances from less than one inch to 330 feet at a data rate of a few kilobits per second ("kbps").

Near Field Communication ("NFC") is similar to RFID. NFC is intended to work at distances between two and four inches with transmission speeds of about 250 kbps. NFC has been incorporated into many smartphones. Mobile wallets and contactless cards rely on NFC.

None of the major payment-card networks invented contactless payments, but they have contributed to developing and promoting them. Mastercard introduced its PayPass contactless technology in the London financial district in September 2007 (Osborne, 2007). Visa introduced its own contactless technology, PayWave, in the United Kingdom at around the same time (Juniper Research, 2022b). Figure 2 tracks the number of contactless transactions reported by RBR from 2017 to 2027 and presents our forecasts through 2037.

<FIGURE 2 ABOUT HERE>

4 Methodology and data: an introduction

We develop the details of the methodology for calculating the benefits of each technology in the next sections of this study. Here we present the main tenets of the methodology.

4.1 Benefits: for which transactions and where?

There are different types of payments. We focus on consumer-to-business payments, and we quantify benefits at the retail point of sale ("POS") and in online transactions.

4.2 Benefits: for whom?

For decades, the payments literature has emphasized that payments are a two-sided market (or platform). Payers (consumers) and payees (merchants) are the (joint) end-users of various payment technologies. Since at least Baxter (1983), it is well understood that there is a joint demand for a specific payment instrument, and that this joint demand is what makes a payment (with a specific payment instrument) feasible. In our study, we compute benefits for both groups of "customers" of the platform (consumers and merchants).

The entities that have developed the payment technologies have also received benefits from them and will continue to receive them. For example, the payment-card networks have contributed to developing the technologies and have received network fees associated with the incremental card transactions facilitated by each technology. Similarly, several of the payment-card issuing banks have contributed to developing the technologies and have received interchange fees associated with the incremental card transactions.

In line with the literature, we count as private benefits those that accrue to the innovators themselves. We count as end-user benefits those that accrue to the persons and organizations using the technologies—consumers and merchants in this case. Social benefits are the sum of private benefits and end-user benefits. On the distinction between private and social benefits, see, among others, Griliches (1958), Mansfield et al (1977), Tewksbury et al (1980), Tassey (2003), and Link and Scott (2012).

4.3 Benefits: compared with what?

To calculate the (private and social) benefits of these new technologies, we must establish a benchmark or comparator. That is, we must choose a payment instrument (for each technology) that we will use as a reference for quantifying the benefits.

We compare contactless and tokenized payments with the most frequently used alternative. This approach addresses what we think is the most relevant question, namely: In the absence of the new payment technologies, what alternative payment instrument would payees most likely use? The approach has the additional virtue that it can be implemented with the available data. Although the most frequently used alternative may vary somewhat across countries, we can compare the new payment technologies with those that are most frequently used globally. We compare tokenized transactions with traditional (non-tokenized) card transactions, and contactless transactions with contact-card transactions. For recent statistics on the use of various payment instrument across the world, see FIS (2023).

There are at least two alternative approaches. One would compare contactless and tokenized payments in each country and period with all payment instruments as they are used in that time and place. The approach requires us to have information on the distribution of transactions across payment instruments for each country in the pre-tokenization or pre-contactless world. In addition, because one would need to construct a weighted-average payment instrument for the pre-innovation world to serve as the comparator, this approach requires that we have information on the relevant characteristics for all payment instruments in the pre-innovation world. Such information is not available, which renders this approach infeasible.

The other alternative approach would compare contactless and tokenized payments with the most efficient alternative. This approach is frequently adopted in the literature on the social value of innovations, but it raises its own questions. First, although many of the relevant studies acknowledge that social benefits should be considered for assessing the efficiency of payment instruments, most of these studies end up focusing on costs only. Further, different studies reach different conclusions regarding the efficiency ranking of payment instruments, among other things because not all studies use exactly the same methodology and because, for a variety of reasons, efficiency rankings may vary across countries. Examples of these studies include Schmiedel et al (2012), Stewart et al (2014), Kosse et al (2017), Deutsche Bundesbank (2019), Norges Bank (2020), Sintonen and Takala (2022), and Sveriges Riksbank (2023).

4.4 Benefits: over what period?

In calculating the benefits, we consider the past and the future. We estimate contactless benefits for the years for which we have (actual and forecasted) contactless-transaction data—the RBR estimates for 2017 through 2027.

We estimate tokenization benefits for the years for which we have (actual and forecasted) tokenized-transaction data. Juniper Research provides estimates of the number of tokenized transactions for 2019 through 2027. Because this series is shorter than the contactless series, we forecast an additional two years of data (through 2029) for each country included in the analysis. This gives us an 11-year initial period for calculating benefits for each innovation.

If we stopped calculating benefits in 2027 (or 2029), however, our calculation of costs and benefits would be unbalanced. We go back to the year 2000 for estimating the costs of developing the innovations. Thus, if we stopped calculating benefits in 2027 (or 2029), we would count costs for more than 20 years and benefits for only 11 years. There is no reason to believe that the benefits of contactless and tokenization will stop in 2027 (or 2029). It is much more reasonable to assume that such benefits will continue to grow as the number of contactless and tokenized transactions grows. Thus, we forecast an additional 10 years of both costs and benefits through 2037 for contactless and through 2039 for tokenization. This follows the approach adopted in Griliches (1958) and Mansfield and coauthors (1977). Griliches (1958) estimated net social returns for 23 years and, in addition, assumed that the innovation would continue to generate positive net social returns in perpetuity after 1955. Mansfield and coauthors (1977) estimated social benefits until 1973 for innovations introduced mostly during the 1960s, but they noted that their estimates were conservative because benefits after 1973 were ignored. They further argued that their approach tended to seriously underestimate benefits when innovations were relatively new. In these cases, they forecasted consumers' surplus and innovators' profits until 1980 (Mansfield et al, 1977, p. 228). These remarks apply precisely to the two payment innovations we focus on in this study: they are relatively recent innovations, and we have only a few years of actual data to estimate the benefits they generate.

4.5 Geographic coverage

Our analysis of tokenization includes transactions from 54 countries and our analysis of contactless includes transactions from 67 countries. The relevant countries are listed in Appendix A.

We would like to express the costs and benefits of the innovations in a common currency. Transaction values, adoption costs, and wages in multiple foreign-country currencies can be dealt with in two ways. For one, we could express all values in US dollars relying simply on nominal exchange rates between each local currency and the US dollar. We prefer, however, to follow the literature in expressing all values in 2021 international dollars, an approach that relies on purchasing-power-parity (PPP) conversion factors. These factors account for cost-of-living differences across countries. On the use of international dollars, see Maddison (1995 and 2006), among many others.

This approach involves two steps. First, we deflate nominal transaction values, wages, and costs in local currency units with a price index for each country that takes on the value 100 in 2021. This step converts nominal values into real values in local currency units (at 2021 prices). Second, once we have real values in local currency units, we convert these figures into international dollars using the 2021 PPP conversion factor (expressed in units of the local currency per international dollar) for each country. More specifically, this final step involves dividing real values in local currency units at 2021 prices by the 2021 PPP conversion factor for each country to obtain values in 2021 international dollars. The PPP conversion factors for each country are generated by the International Comparison Program of the World Bank.

5 The benefits of tokenized payments

To capture the benefits that tokenization generates for both consumers and merchants, it is useful to keep in mind the potential paths of a transaction presented in Figure 3.

<FIGURE 3 ABOUT HERE>

A payment-card transaction can be legitimate or fraudulent. A legitimate transaction is one in which a consumer makes a purchase from a retailer using her own card. A fraudulent transaction is one in which, for example, a hacker steals a consumer’s card information and makes a purchase at a retailer using the stolen information. In this case, the consumer is charged for a transaction she did not make.

Both legitimate and fraudulent transactions can follow one of two paths: they can be authorized, or they can be declined. A legitimate transaction that is authorized benefits both consumers and merchants, and the same is true about a fraudulent transaction that is declined. Problems arise, however, when a legitimate transaction is declined and when a fraudulent transaction is authorized.

When a legitimate transaction is declined, the consumer loses at least the time she spent transacting. The consumer may value the transaction at a much higher level than the transaction cost. If, however, she did not value the transaction *at least* at the level of the transaction cost, she would not have attempted the transaction in the first place. Further, when a legitimate transaction is declined, the merchant loses the profits it would have made had the transaction been authorized. When a fraudulent transaction is authorized, the card issuer or the merchant experiences a loss—who suffers the loss depends on transaction types and liability rules.

Authorized transactions can be completed or not. Many consumers who shop online end up abandoning their carts for a variety of reasons. Many of them spend time browsing with no intention to purchase. Others have an intention to purchase but find the checkout process too long and convoluted. Yet others may not trust the web site enough to enter their personal and card information. When a consumer has an intention to purchase but abandons her cart and does not attempt to complete the transaction again, both the consumer and the merchant experience a loss: the consumer loses at least the cost of transacting, and the merchant loses the profits she would have realized had the transaction been completed. The consumer loses the cost of transacting even when she completes the transaction later (because she must incur the cost of transacting again).

Authorized transactions in which the cart is not abandoned can be completed quickly or slowly. They are completed quickly if the card is on file. They are completed slowly, by contrast, when the consumer must enter her personal and card information at checkout.

Tokenization generates benefits for consumers and merchants because it reduces fraud rates (and losses), it increases authorization rates, it reduces cart-abandonment rates, and it makes transactions faster by facilitating COF payments. We do not claim that these are all the benefits associated with tokenization, but we simply point out that these are the ones we can attempt to quantify.

5.1 Tokenized payments lower fraud rates and losses

During the 2000s, chip cards started replacing magnetic-stripe cards, and this led to a decline in fraud rates at the retail POS. When this happened, fraud attempts migrated to CNP transactions, and especially to e-commerce transactions (King, 2012). Payment tokenization was developed especially to enhance the security of mobile-wallet and e-commerce transactions (Cole and Ansari, 2022).

In the world without tokenization, a data breach (such as the Target breach that happened in the United States in December 2013) allowed hackers to access credit- and debit-card numbers and personal-information records. These data could then be used to complete fraudulent transactions (Shu et al, 2017). Had the data been tokenized, they would have been of little or no value to the hackers, who would have been unable to use them in fraudulent card transactions.

5.1.1 The fraud-reduction benefit

If we let $NFRAUD_t$ be the number of fraudulent transactions at t, and $NALL_t$ be the number of all transactions in that time period, then we can define the fraud rate at t as follows:

$$FR_t = \frac{NFRAUD_t}{NALL_t}$$

Similarly, if we let FL_t be the value lost to fraud at t, and $VALUE_t$ be the total value transacted in that period, then we can define the proportional fraud losses at t as follows:

$$PCTL_t = \frac{FL_t}{VALUE_t}$$

Since 2020, many estimates have been published of the extent to which tokenization reduces fraud rates. These estimates range from as low as 18 percent to as high as 50 percent. See, for example, BusinessWire (2020), Visa (2021), Deloitte (2023), Ho (2023), and J.P. Morgan (2024). We carry out our calculations using the 18-percent fraud-reduction figure, the lower bound of the publicly available estimates.

We calculate this benefit as follows. Tokenization reduces fraud rates (and losses). If it reduces fraud losses by α percent, then fraud losses for tokenized transactions (FL_T) can be expressed in relation to fraud losses for non-tokenized transactions (FL_{NT}) as follows:

$$FL_T = (1-\alpha)\times FL_{NT} \qquad (1)$$

In the absence of tokenization, fraud losses would have been higher by $1/(1-\alpha)$. We can thus calculate the benefit from lower fraud rates due to tokenization as the difference between the actual fraud losses (with tokenization) and the counterfactual fraud losses (without it). In practice, we start with the percentage loss due to payment-card fraud in the pre-tokenization world $(PCTL_{NT})$ and we multiply it by the value of tokenized transactions. This is the counterfactual value of fraud losses for each year:

$$FL_{NT} = PCTL_{NT} \times VALUE_{T} \qquad (2)$$

Using equation (1), the benefit from a reduction in fraud rates (and losses) is:

$$B_{LF} = FL_{NT} - FL_{T} = FL_{NT} - (1-\alpha) \times FL_{NT} = \alpha \times FL_{NT} \qquad (3)$$

Consider a simple numerical example. Consider an economy without tokenization in which, at the starting point, the value of all card transactions is USD 200. Assume that card-related fraud losses are one percent (two dollars). That is, two dollars are lost to fraud in the world without tokenization. The next year, tokenization is introduced. Assume that the value of all card transactions remains constant at USD 200 but half of that value becomes tokenized. Fraud losses on the non-tokenized value (USD 100) remain at one percent and are now one dollar. But fraud losses on the tokenized value decline by 50 percent, from one percent to one-half of one percent. That is, on the USD 100 tokenized value, fraud losses decline from one dollar to 50 cents. That 50-cent reduction in fraud losses is the basis for the calculation of the fraud-reduction benefit.

Table 1A reports the end-user (gross) benefits from fraud reduction due to tokenized payments by world region. These benefits are “gross” because we are not yet counting the costs that merchants incur when they adopt tokenization.

<TABLE 1A ABOUT HERE>

Table 1B reports the same end-user (gross) benefits globally but broken down between merchant and issuer benefits.

<TABLE 1B ABOUT HERE>

Both merchants and issuers benefit from fraud reduction. In our approach, the share of these benefits going to issuers is considerably larger than the share going to merchants. We explain this below.

5.1.2 Benefits for merchants and issuers

Historically, issuers were mostly responsible for fraud losses on CP transactions and merchants were mostly responsible for fraud losses on e-commerce transactions (Federal Reserve Bank of Minneapolis, 2016). In recent years, however, and especially since the introduction of EMV chip technology, liability for payment-card fraud has become more nuanced. For example, if a merchant does not support EMV chip technology and a fraudulent transaction happens on an EMV-enabled card, fraud liability shifts from the issuer to the merchant. In addition, if a merchant uses 3D Secure Authentication, liability may shift from the merchant to the issuer. On liability in cases of fraudulent transactions, see Checkout (2023), among others.

We calculate the fraud-reduction benefit on e-commerce, CP, and mobile-payment transactions because tokenization reduces fraud in all of them. In some cases, merchants will benefit directly, and in others, issuers will. Table 1B is constructed assuming that merchants benefit from fraud reduction in e-commerce transactions and issuers benefit from fraud reduction in CP and mobile-payment transactions. For the calculation of the social benefits of tokenization, both the benefits that accrue to merchants and those that accrue to issuers are relevant, regardless of the extent to which issuers pass through some of those benefits to consumers.

Our calculations likely underestimate considerably the benefits merchants receive from fraud reduction. This is so because we have disregarded "chargeback" fees, which are fees usually charged by the acquirer to the merchant when the customer disputes a charge with their bank. Industry reports suggest that these fees range between USD 15 and USD 50 (Cuervo, 2024). Somebody could argue that these fees are just transfer payments from the merchant to the acquirer, just like interchange fees are transfer payments from the merchant to the issuer. We carefully account for transfer payments in all our calculations. But it should be noted that benefits accruing to acquirers are not included in our model, and thus the benefits to merchants from reduced chargeback fees should be counted as a true benefit. More generally, some studies on the cost of fraud, such as LexisNexis (2023), point out that fraudulent transactions cost merchants almost three times the lost transaction value on average. Although some of these costs may be transfer payments (to issuers, for example), these studies suggest that we are likely underestimating the fraud-reduction benefit to merchants.

5.1.3 An alternative calculation: the cost of preventing fraud

Somebody could further argue that the fraud-reduction benefit should be calculated differently. More specifically, it could be argued that fraud losses for merchants and issuers are ultimately transfer payments to fraudsters, and that the welfare of fraudsters increases with these payments. Thus, a critic could allege that we are not considering the benefits that fraudsters obtain from their fraudulent activity, and that these benefits should also be counted as social benefits. From this perspective, the fraud-reduction benefit from tokenization should be calculated as a reduction in the costs that merchants and issuers incur *to prevent fraudulent activity* on payment cards.

Note that, according to the available information, merchants spend substantial portions of their revenues to prevent fraudulent activity. In fact, sources suggest that merchants spend a larger portion of their revenues in preventing fraud than the proportion they lose because of fraudulent activity. For example, recent surveys on payment fraud in various regions of the world suggest that e-commerce merchants lose between one and three percent of their revenues each year due to payment fraud, but they spend as much as 10 percent of their revenues in preventing fraudulent payments. See, for example, Cybersource (2021, 2022, and 2023). To put it differently, merchants lose what they lose from payment fraud because they spend what they spend on preventing fraud—they only lose, say, three percent of their revenues because they spend three times as much in preventing fraud in the first place. This suggests that our calculations may underestimate the fraud-reduction benefit from tokenization, and that the estimated benefit would likely be larger if it were calculated as a reduction in the cost of fraud-prevention activities.

5.2 Tokenized payments increase authorization rates

For any card transaction that looks potentially suspect, issuers and merchants face a dilemma: they can take precautions and reject the transaction, or they can give it the benefit of the doubt and authorize it. The dilemma involves a trade-off: on the one hand, if they take too many precautions, many legitimate transactions will not happen, at least on the first try; on the other, if they are too lenient and authorize too many transactions, fraud rates will most likely rise.

Because tokenization reduces fraud, it also increases authorizations without increasing the risk. Put differently, when the probability of fraud declines, issuers and merchants have incentives to give more transactions the benefit of the doubt, and thus more transactions happen on the first try.

Since 2019, various estimates have been published of the extent to which tokenization increases authorization rates. These estimates range from a low of 2 percentage points to a high of 6 percentage points. (One source even mentions a 13-percentage-point uplift in certain regions of the world.) See, for example, Stoorvogel (2019), Visa (2021), Deloitte (2023), Ho (2023), J.P. Morgan (2024), Begley and Nierat (2024), Leucht and Schropfer (2024), Discover (2023), Visa (2024), and American Express (2024). We carry out our calculations of the increased-authorization benefit using the 2-percentage-point figure, the lower bound of the range of publicly available estimates.

Before exploring the details of the benefit calculations, note that, because the authorization rate is less than 100 percent, the transactions observed are fewer than the transactions attempted. More specifically, if the authorization rate is β percent, and N_{OBS} is the number of observed transactions, then the number of attempted transactions is:

$$N_{ATT}^{AUTH} = \frac{N_{OBS}}{\beta} \qquad (4)$$

We use N_{ATT}^{AUTH} (the number of attempted transactions) in the calculation of the merchant benefits and the consumer benefits.

5.2.1 Benefits for consumers

Consider the benefits for consumers from increased authorization rates. To fix ideas, consider the following example. At the starting point, 200 non-tokenized transactions are attempted in an economy in which the authorization rate is 90 percent. Thus 180 transactions take place (and are observed). The next year, tokenization is introduced, the number of attempted transactions remains constant at 200, and 100 of those 200 transactions are tokenized. Assume that tokenization increases authorization rates by five percentage points. This means that non-tokenized transactions still have an authorization rate of 90 percent whereas tokenized transactions now have an authorization rate of 95 percent. Thus, of the 100 non-tokenized attempted transactions, 90 happen; and further, of the 100 tokenized attempted transactions, 95 happen. In this example, those additional five transactions that happen in the tokenized world but would not have happened without tokenization are the foundation of the increased-authorization benefit.

As the example above shows, if tokenization increases authorization rates by p_1 percentage points, then p_1 percent of tokenized transactions would not have happened in the first attempt in a counterfactual world without tokenization. Some of these transactions would have been attempted again and completed on the second try. In this case, the benefit to consumers from increased authorization rates is the avoided cost of transacting a second time. Some of the declined transactions would have never happened. In this case, the benefit to consumers from increased authorization rates must be *at least* the cost of completing the transaction: if the expected consumer benefit from a transaction that never happened had been lower than the transaction cost incurred by the consumer, then she would not have attempted the transaction in the first place.

Let D stand for the event that a transaction is authorized in the tokenized world and would have been declined in the non-tokenized world. Let $P(D) = p_1$ be the associated probability. Let CL stand for the event that a transaction is completed later, and NC for the event that a transaction is never completed. We are thus interested in transactions that would have been declined in the non-tokenized world *and* would have happened later. These transactions have an associated probability of $P(D \cap CL) = P(CL \mid D) \times P(D) = q_2 \times p_1$. We are also interested in transactions that would have been declined *and* would have never happened. These transactions have an associated probability of $P(D \cap NC) = P(NC \mid D) \times P(D) = q_3 \times p_1$. Note that, conditional on having been declined, transactions either happen later or not happen at all, and thus $q_2 + q_3 = 1$. Summary discussions of conditional probabilities are in Ross (1987) and Wasserman (2010).

Let TC be the transaction cost incurred by consumers. In line with a long literature, we define the consumer transaction cost to be the time spent completing a (non-tokenized) transaction (TT) multiplied by the opportunity cost of time, which is usually measured as a fraction φ of the average (or median) wage in the economy (W_t):

$$TC_t = TT \times \varphi \times W_t \qquad (5)$$

With the probabilities defined as above, the benefits for consumers from increased authorization rates can be expressed as follows:

$$BC_{IA} = \{p_1 \times q_2 \times TC + p_1 \times q_3 \times TC\} \times N_{ATT}^{AUTH} =$$

$$p_1 \times (q_2 + q_3) \times TC \times N_{ATT}^{AUTH} = p_1 \times TC \times N_{ATT}^{AUTH} \qquad (6)$$

5.2.2 Benefits for merchants

Now consider the benefits for merchants from increased authorization rates. Some of the attempted transactions not authorized in the world without tokenization would have been attempted again and completed without the merchant's intervention (at the same merchant or at a different one). For these transactions, tokenization generates no merchant benefits. Other declined transactions would have been completed after the merchant incurred a customer re-engagement cost. The benefit from tokenization for the merchant in this case is the avoided re-engagement cost. Finally, another group of declined transactions would have never been completed. For these transactions, the benefit from tokenization for the merchant is the average profit margin times the average transaction size.

Let CLR stand for the event that a transaction is completed later after the merchant incurs a re-engagement cost and let NC stand for the event that a transaction is never completed. We have defined p_1 to be the proportion of transactions authorized in the world with tokenization that would have been declined in the world without it. We are interested in transactions that would have been declined in the non-tokenized world *and* would have been completed later after the merchant incurred a reengagement cost. These transactions have an associated probability $P(D \cap CLR) = P(CLR \mid D) \times P(D) = q_4 \times p_1$. We are also interested in transactions that would have been declined in the non-tokenized world *and* would have never happened. We have already defined the associated probability as $P(D \cap NC) = P(NC \mid D) \times P(D) = q_3 \times p_1$.

Let MRC be the merchant re-engagement cost, let ATS be the average transaction size, and let APM be the average profit margin the merchant collects on each transaction. With the probabilities defined as above, the benefits to merchants from increased authorization rates due to tokenization can be expressed as follows:

$$BM_{IA} = \{p_1 \times q_4 \times MRC + p_1 \times q_3 \times ATS \times APM\} \times N_{ATT}^{AUTH} \qquad (7)$$

Table 2 presents estimates of consumer and merchant benefits associated with increased-authorization rates.

<TABLE 2 ABOUT HERE>

The table shows that the share of these benefits going to merchants is significantly larger than the share going to consumers.

5.3 Tokenized payments lower cart-abandonment rates

Not all transactions that are authorized—or, more precisely, that would have been authorized had they been completed—are in fact completed. Surveys reveal that online shoppers abandon their carts quite frequently.

Surveys report the cart-abandonment rate—that is, the number of e-commerce transactions that are not completed because the cart is abandoned divided by the total number of initiated transactions. This rate has varied across surveys and over time. For the United States, some surveys report abandonment rates of 60 percent for 2012 and others report rates of 80 percent for 2023 (Baymard Institute, 2024). Further, cart-abandonment rates vary across world regions as well. For example, in 2023 it was reported that the cart-abandonment rate was about 79 percent in the Asia Pacific region, around 75 percent in Europe, the Middle East, and Africa, and about 71 in the Americas. Further, the same source reported a global abandonment rate of about 71 percent in 2023 (Brophy, 2023).

Shoppers abandon online shopping carts for multiple reasons. Very often, they are just browsing with no intention to purchase. When consumers have no intention to purchase, tokenization generates no benefits by lowering cart-abandonment rates. In other cases, consumers do have an intention to purchase but face a long and convoluted checkout process. Sometimes, they have an intention to purchase but do not trust the web site enough to provide their personal and card-account information (Baymard Institute, 2024).

Further, having abandoned their carts, shoppers follow different paths. Sometimes, shoppers complete the purchase later (at the same online merchant or at a different one, or at a brick-and-mortar store). In other cases, the cart is abandoned, and the transaction is not attempted again (Royal Mail, 2020).

As explained earlier, persistent tokens facilitate COF transactions. When a transaction is tokenized, the merchant does not retain payment-card information (the sensitive data) but rather a token (the non-sensitive data). The mapping between token and card number is securely kept in the digital vault of the token provider. When tokens are persistent across transactions, consumers do not need to enter personal and payment-card information every time they attempt a new purchase. Thus, tokenization reduces cart-abandonment rates because it addresses the problem of a long and convoluted checkout process. In addition, because the merchant does not retain the sensitive information, tokenization reduces cart-abandonment rates by addressing the lack-of-trust problem. By reducing cart-abandonment rates, tokenization generates benefits for both consumers and merchants.

Before discussing the calculation of these benefits in detail, note that, precisely because carts are abandoned frequently, the number of attempted transactions is higher than the number of observed transactions. If the cart-abandonment rate is γ, and the number of observed transactions is N_{OBS}, then the number of attempted transactions is

$$N_{ATT}^{DCA} = \frac{N_{OBS}}{(1-\gamma)} \qquad (8)$$

In our calculations, N_{OBS} is the number of observed transactions involving persistent tokens, which are the tokens that facilitate COF payments.

5.3.1 Benefits for consumers

Tokenization generates benefits for consumers because it lowers cart-abandonment rates. To quantify these benefits, we focus on situations in which online shoppers who have an intention to make a purchase abandon their carts for specific reasons—namely, a long and convoluted checkout process or a lack of trust. Those are the problems that tokenization addresses.

We are interested in the probability that a cart is abandoned, *and* the shopper has an intention to purchase, *and* she abandons the cart for the relevant reasons, *and* she either completes the transaction later or never completes it. In both cases, tokenization generates benefits for consumers. If the transaction is completed later, then the benefit is the avoided transaction cost. If the transaction is never completed, then the benefit is *at least* the lost transaction cost.

Let A stand for the event that an online shopping cart is abandoned. (Strictly speaking, this event is such that the cart is not abandoned with tokenization but would have been abandoned in the non-tokenized world.) Let IP stand for the event that the online shopper has an intention to purchase. Let R stand for the event that the cart is abandoned due to a long and convoluted checkout process or a lack of trust. Let CL represent the event that the transaction is completed later and let NC represent the event that the transaction is never completed.

We are interested in cases in which the transaction is completed later. The probability of such transactions can be expressed as follows:

$$P(A \cap IP \cap R \cap CL) = P(A) \times P(IP \mid A) \times P(R \mid A \cap IP) \times P(CL \mid A \cap IP \cap R) \qquad (9)$$

We are also interested in cases in which the transaction is never completed. The probability of such transactions can be expressed as follows:

$$P(A \cap IP \cap R \cap NC) = P(A) \times P(IP \mid A) \times P(R \mid A \cap IP) \times P(NC \mid A \cap IP \cap R) \qquad (10)$$

If we let $P(A) = r_1, P(IP \mid A) = r_2, P(R \mid A \cap IP) = r_3, and\ P(NC \mid A \cap IP \cap R) = r_4,$ and we recall that TC stands for the consumer transaction cost, then the benefit for consumers in cases in which the transaction is never completed can be expressed as

$$BC_{DCA}^{NC} = r_1 \times r_2 \times r_3 \times r_4 \times TC \times N_{ATT}^{DCA} \qquad (11)$$

If we now focus on transactions that are completed later, and we let $P(CL \mid A \cap IP \cap R) = r_5,$ then the benefit for consumers in such cases can be expressed as

$$BC_{DCA}^{CL} = r_1 \times r_2 \times r_3 \times r_5 \times TC \times N_{ATT}^{DCA} \qquad (12)$$

Note that the total benefit to the consumer is the sum of (11) and (12), namely

$$BC_{DCA} = r_1 \times r_2 \times r_3 \times r_4 \times TC \times N_{ATT}^{DCA} + r_1 \times r_2 \times r_3 \times r_5 \times TC \times N_{ATT}^{DCA} = r_1 \times r_2 \times r_3 \times TC \times N_{ATT}^{DCA} \times (r_4 + r_5) \qquad (13)$$

Further, note that, conditional on all the prior events happening, $r_4 + r_5 = 1$. Therefore, the total benefit to consumers can be expressed as follows:

$$BC_{DCA} = r_1 \times r_2 \times r_3 \times TC \times N_{ATT}^{DCA} \qquad (14)$$

5.3.2 Benefits for merchants

When the cart-abandonment rate declines due to tokenization, merchants also benefit. The main difference between the merchant benefit and the consumer benefit is that merchants do not benefit from tokenization in cases in which a cart is abandoned for the relevant reasons and the transaction is completed later without the merchant's intervention. Put differently, if a transaction is completed later (at the same or at a different merchant) without the merchant's intervention, merchants do not benefit from the decreased cart-abandonment rates driven by tokenization.

For transactions that are never completed in the world without tokenization, the merchant benefit from tokenization is the average profit margin (APM) times the average transaction size (ATS). Thus, the merchant benefit can be expressed as follows:

$$BM_{DCA}^{NC} = r_1 \times r_2 \times r_3 \times r_4 \times APM \times ATS \times N_{ATT}^{DCA} \qquad (15)$$

Merchants also benefit from tokenization in situations in which the cart is abandoned and the transaction is completed after the merchant incurs a reengagement cost. Let CLR stand for the event that the transaction is completed later after the merchant incurs a reengagement cost. We can express the proportion of those situations in which the transaction is completed later after the merchant incurs a reengagement cost as follows:

$$P(A \cap IP \cap R \cap CL \cap CLR) =$$
$$P(A) \times P(IP \mid A) \times P(R \mid A \cap IP)$$
$$\times P(CL \mid A \cap IP \cap R) \times P(CLR \mid A \cap IP \cap R \cap CL) \quad (16)$$

In this case, the merchant benefit is the avoided reengagement cost. If we let $P(CLR \mid A \cap IP \cap R \cap CL) = r_6$, then the merchant benefit can be expressed as follows:

$$BM_{DCA}^{CLMR} = r_1 \times r_2 \times r_3 \times (1 - r_4^*) \times r_6 \times MRC \times N_{ATT}^{DCA} \qquad (17)$$

In this formula, $(1 - r_4^*)$ is the proportion of situations in which the transaction is completed later online. (Among transactions completed later, a small portion is completed at a brick-and-mortar store.)

Table 3 presents consumer and merchant benefits associated with reduced cart-abandonment rates.

<TABLE 3 ABOUT HERE>

The table shows that the share of these benefits going to merchants is substantially larger than the share going to consumers.

5.4 Tokenized payments save shoppers time via COF

Some e-commerce transactions face neither authorization nor cart-abandonment problems. They are initiated, authorized, and completed on the first try. Not all these transactions, however, are completed at the same speed—some take considerably longer to complete than others—and tokenization plays a role in shortening transaction times.

Without persistent tokens, consumers must enter their personal and card information every time they attempt an e-commerce transaction. With persistent tokens, COF is feasible, and the transaction becomes considerably shorter. The benefit to the consumer is the value of the time saved.

Let TC_{COF}^{T} be the transaction cost incurred by the consumer when she completes a tokenized COF e-commerce transaction. Let TC_{MANUAL} be the transaction cost incurred by the consumer when she must enter her personal and card information every time she transacts. We define the transaction cost for the COF transaction as follows:

$$TC_{COF,t}^{T} = TT_{COF}^{T} \times \varphi \times W_t \qquad (18)$$

Here, TT_{COF}^{T} is the time spent by the consumer in completing a COF transaction and W_t is a measure of the average (or median) wage. In practice, and in agreement with the findings of the literature on the value of time, the opportunity cost of time is usually estimated as a fraction φ of the economywide average (or median) wage. For a review of the extensive literature on the value of time, see, for example, Zamparini and Reggiani (2007). For a more recent summary, see Victoria Transport Policy Institute (2023).

We define the transaction cost for the transaction involving manual entry of personal and card information in an analogous way:

$$TC_{MANUAL,t} = TT_{MANUAL} \times \varphi \times W_t \qquad (19)$$

Let $NTPERS_t$ be the number of transactions involving persistent tokens at time t. The time-saving benefit for consumers from COF tokenization can thus be expressed as follows:

$$BC_{COF,t} = (TT_{MANUAL} - TT_{COF}^{T}) \times W_t \times \varphi \times NTPERS_t \qquad (20)$$

Table 4 presents time-saving consumer benefits associated with COF tokenization.

<TABLE 4 ABOUT HERE>

6 The benefits of contactless payments

Starting in the early 2010s, as contactless payments became more pervasive, several studies attempted to measure how fast contactless transactions were in comparison with contact-card transactions and cash transactions. These studies include Polasik et al (2013), Krűger and Seitz (2014), Stewart (2014), Kosse et al (2017), Norges Bank (2020), and Sveriges Riksbank (2023). The general picture one obtains from these studies—except for the Canadian study by Kosse et (2017)—is that contact cards and cash have similar transaction times at the retail POS, while contactless cards and mobile wallets are faster than both. The most recent report, the Norges Bank (2020) study, estimates that contactless-card payments take an average of 7.8 seconds to complete compared with 14.8 seconds for contact cards. (The Sveriges Riksbank (2023) study relies on the Norges Bank (2020) study for these calculations.) Other studies, including Roubini ThoughtLab (2017), suggest that contactless payments are substantially faster than cash.

6.1 Benefits for consumers

Let $NCLESS_t$ be the number of contactless transactions at time t. If we let TT_{CLESS} be the time it takes to transact with a contactless payment instrument at the retail POS, and we let TT_{CTACT} be the time it takes to transact with a contact card (or with cash), then the benefit from contactless payments for consumers can be expressed as follows:

$$BC_{CLESS,t} = (TT_{CTACT} - TT_{CTLESS}) \times \varphi \times W_t \times NCLESS_t \qquad (21)$$

Here, as earlier, W_t stands for the average (or median) economywide wage. Put differently, the benefit for consumers is measured as the transaction time differential between contact and contactless payments multiplied by the opportunity cost of time. Table 5A presents the consumer benefits from contactless payments.

<TABLE 5A ABOUT HERE>

The magnitude of the consumer benefits depends on the volume of transactions and on the level of average (or median) wages in each region. Average wages determine the opportunity cost of time for consumers and, holding other factors constant, consumers in regions with higher wages receive higher benefits.

6.2 Benefits for merchants

Note that the benefit to merchants can be calculated in two different ways. One assumes that, because contactless transactions are faster, the merchant can process more transactions in the same amount of time and at the same wage cost as before. The alternative approach assumes that the merchant can process the same number of transactions as before but in a shorter amount of time (and at a lower wage cost). We use this second approach because it produces a more conservative estimate of the benefit.

Thus, the contactless benefit for merchants can be expressed as follows:

$$BM_{CLESS,t} = (TT_{CTACT} - TT_{CLESS}) \times W_t^M \times NCLESS_t \qquad (22)$$

Here, W_t^M stands for the average wage paid by the merchant to the employees in charge of checking customers out at the store.

Note that the way we calculate the benefit does not require assuming that the merchant closes her store earlier than in the world without contactless payments and sends her employees home. It simply requires assuming that, once the new payment method is introduced, the merchant can reallocate the idle labor to other tasks within the store, and the productivity of these employees increases. Table 5B presents the merchant benefits from contactless payments.

<TABLE 5B ABOUT HERE>

The magnitude of the merchant benefits depends on transaction volumes and on the level of average retail wages. Again, holding other factors constant, merchants in regions with higher average retail wages receive higher benefits.

7 Development costs and adoption costs

To calculate internal rates of return (IRRs) for contactless and tokenized payments, we need estimates of the resources that have been spent in developing and adopting the innovations. Specifically, to calculate private IRRs, we need an estimate of the investments individual innovators have made; and to calculate social IRRs, we need an estimate of the investments all innovators combined have made. Further, we also need estimates of the resources that merchants have spent in adopting contactless and tokenized payments.

7.1 Innovators' development costs

We do not have direct information on the resources individual innovators (and society) have invested in the process of developing contactless and tokenized payments. What we have is information on the patents various organizations have applied for (and obtained) covering different aspects of these technologies over many years. Appendix B presents detailed information on the patent datasets we have used in this study and on the methodologies we have relied on to analyze them.

Figure 4 presents the flow of contactless and tokenization patent families over time. Most of these patent families are, in fact, families of one patent, but several families comprise two or more. Our patent-family numbers are generally in line with the numbers reported in the few third-party reports that focus on either contactless or tokenization and are publicly available. Examples of such reports include PATSEER (2018) and CIPHER (2020). The figure shows that the number of contactless patent families applied for reached its peak in the late 2010s and declined steadily thereafter. Further, the figure shows that the number of payment-tokenization patent families applied for also reached its peak in the late 2010s and declined thereafter, although less steadily.

<FIGURE 4 ABOUT HERE>

Table 6 presents the tokenization patent families applied for by the top ten assignees, the number of citations to those patent families, and the average number of citations per patent family.

<TABLE 6 ABOUT HERE>

Some of the international payment card networks and several large banks that issue payment cards are among the top patent assignees. As of 2023, Mastercard had the largest share of patent families and Visa had the second largest. Further, Visa had the largest share of patent-family citations. In addition, Capital One, Wells Fargo, Visa, and Chase Bank (in that order) had the most highly cited patent families, on average.

Table 7 presents the contactless patent families applied for by the top ten assignees, the number of citations to those patent families, and the average number of citations per patent family.

<TABLE 7 ABOUT HERE>

As of 2023, Capital One had the largest share of patent families and of citations to those patent families, Visa had the second largest number of patent families, and Mastercard had the third. Further, AB Dynamics, Capital One, Block (owner of Square and CashApp), and Visa (in that order) had the most highly cited patent families, on average.

More than three decades ago, Samuel Trajtenberg (1990) published a seminal paper on patents, R&D, and citations. His empirical analysis confirmed two hypotheses: first, patents weighted by citations are a good proxy for the value of the innovations described in the patents, but the raw counts of patents are not; and second, the raw counts of patents are a good proxy for the R&D investments companies make in developing the innovations. Researchers have explored both hypotheses. Among other things, they have tracked the evolution of the patent-to-R&D ratio over time: Samuel Kortum (1993), for example, showed that the ratio declined from about 3.5 in the 1950s to about one in the late 1980s. That is, if in the 1950s companies obtained, on average, 3.5 patents per million dollars spent on R&D, by the late 1980s they were obtaining one patent per million dollars spent. Important surveys of the literature on patents include Griliches (1990) and Nagaoka, Motohashi, and Goto (2010). For evidence on the patent-to-R&D ratio in various industrial sectors between 1975 and 2002, see Arora and Gambardella (2010).

Researchers have also studied the inverse of the patent-to-R&D ratio, namely the R&D-to-patent ratio. This ratio measures the R&D resources companies need to invest, on average, in any given year to obtain one patent. This is the metric we use in this study. We use two sources of information: one is the annual report on the top patenting companies published by the United

States Patent and Trademark Office ("USPTO"), and the other is publicly available information on the R&D resources those companies invested each year. With this information, we construct an average R&D-to-patent ratio, which we then apply to the patent families applied for in tokenization and contactless technologies. More specifically, we calculate the average R&D-to-patent ratio for a sample of companies in the USPTO reports between 2007 and 2020. We focused on the top 20 patenting companies in the USPTO reports covering the period when the contactless and tokenization patents were applied for. We ended up using a subset of those companies—those for which R&D information is publicly available.

Table 8 presents the total patents obtained over the relevant period and the total R&D investments made in the same period by the companies tracked in the USPTO reports. At the bottom, the table presents average R&D spending per patent—that is, the amount of R&D resources these companies invested, on average, to obtain a patent. This is the R&D-to-patent ratio.

<TABLE 8 ABOUT HERE>

Once we have the average R&D-to-patent ratio over the relevant period, we multiply this ratio by all the patent families applied for by all inventors for tokenized and contactless payments each year to obtain an estimate of the resources society has invested annually in developing each technology. Table 9A presents an estimate of the resources society has invested in the development of contactless and tokenization by year.

<TABLE 9A ABOUT HERE>

Further, multiplying the R&D-to-patent ratio by the patent families applied for by each inventor for each technology generates an estimate of the resources each invested in developing each technology. This is an estimate of the private development costs incurred by each inventor in generating the innovations. Table 9B presents such estimates for Visa and Mastercard, two of the top patent-family assignees.

<TABLE 9B ABOUT HERE>

7.2 Merchants' adoption costs

To generate benefits for end-users, innovations must be both developed and adopted. Merchants usually incur the adoption costs for contactless and tokenized payments.

For tokenization, Juniper Research (2022a) reports estimates of the tokenization revenues that token providers have received (and are forecasted to receive). These are also estimates of the costs that merchants have incurred (and are forecasted to incur) to tokenize their transactions. Tokenization adoption costs are mostly variable, and the modal token price is 10 cents per token. For contactless, we use data on the annual increase in contactless terminals (RBR, 2022) together with an average cost figure of USD 100 per terminal (Swipesum, 2019) to estimate annual merchant adoption costs. As explained earlier, we express adoption costs in 2021 international dollars with the same approach we used to convert transaction values and wages. Table 10 presents evidence of such costs for each technology over time.

<TABLE 10 ABOUT HERE>

8 Private and social returns from the innovations

Researchers who focus on the private and social value of innovations usually rely on various metrics to assess private and social returns.

8.1 Metrics

One such metric is the net present value of an innovation, which is the sum of the discounted flow of net benefits arising from it (Au and Au, 1983; and Beninga, 2000). We calculate the flow of "net" benefits because the flow of costs incurred in generating (and adopting) each innovation must be subtracted from the flow of gross benefits generated by it:

$$NPV = \frac{(B_0 - C_0)}{(1+r)^0} + \frac{(B_1 - C_1)}{(1+r)^1} + ... + \frac{(B_T - C_T)}{(1+r)^T} \qquad (23)$$

The IRR is the value of the discount rate that equates the present value of the stream of net benefits from each innovation to zero.

Further, the benefit-to-cost ratio is the ratio of the present value of the benefits from each innovation to the present value of the costs incurred in developing and adopting it:

$$BC = \frac{\sum_{t=0}^{t=T} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{t=T} \frac{C_t}{(1+r)^t}} \qquad (24)$$

8.2 Private returns

Our research has generated a time series of end-user benefits derived from the innovations as well as time series of the development costs incurred by the innovators and the adoption costs incurred by merchants. To calculate private and social returns from the innovations, we still need to consider the private benefits from the innovations accruing to the innovators themselves. The social returns from the innovation are then calculated as the sum of the returns accruing to the innovators and those accruing to end-users (consumers and merchants).

We focus on those innovators for which we can develop estimates of private returns. Among these are the international payment networks–such as Visa and Mastercard—and the banks that issue payment cards. The private returns for the innovators arise from the incremental card transactions facilitated by each technology.

8.2.1 Incremental transactions

Although end-users receive benefits on all tokenized and contactless transactions (because such transactions are more efficient than the alternatives), innovators such as the international payment networks and the issuing banks only receive benefits on incremental card transactions. Consider the following example. Assume an economy in which, at the starting point, there are 100 transactions per year, 50 on cash and 50 on contact cards. The next year, contactless cards are introduced. Assume that the number of transactions stays the same at 100 per year, but now 45 happen on cash, 45 on contact cards, and 10 on contactless cards. Now 10 transactions take place on the new technology, and end-users receive benefits on all 10 (because contactless cards are more efficient than both contact cards and cash). However, only five of those 10—namely, the five in which contactless cards replaced cash—are incremental card transactions, and the payment networks receive incremental benefits only on those five.

Contactless payments and incremental transactions

Contactless payments generate some incremental card transactions. Studies that explore the impact of contactless payments on consumer behavior include Fujiki and Tanaka (2014), Fung et al (2014), Chen et al (2014), Trűtsch (2020), and Brown et al (2020). The Brown et al (2020) study is particularly useful. The authors use anonymized bank-account data for a random sample of 21,000 customers of a Swiss retail bank. The data cover all card transactions and cash withdrawals between 2015 and 2018. The authors divide the clients into three groups: early adopters of contactless cards, late adopters, and non-adopters, depending on when the clients received a new contactless card from the bank. They find that contactless payments do lead consumers to use their debit cards more often. After receiving a contactless card, clients make an average of seven additional card purchases per year, which represent an increase of over eight percent relative to the sample mean of 79 transactions.

For several reasons, we rely on the Brown et al (2020) study of the impact of contactless payments. For one, the study is the only one that precisely addresses the question we are interested in, namely: how many incremental card transactions are driven by contactless payments. Further, the study uses the (exogenously determined) differential timing of adoption of contactless payments to identify the impact of contactless on consumers' payment behavior (and especially on incremental card usage). The bank delivered contactless cards to clients as their old cards expired. Since expiration dates were random, this setting created a "natural experiment" that allowed the authors to isolate the impact of the new payment technology on payment behavior. Following this study, we assume that contactless payments increase card transactions by 8.6 percent.

As in the example above, some of these incremental card transactions are ones that, in the absence of contactless technology, would have taken place on less efficient payment instruments. But some of them are likely transactions that simply would not have taken place at all. This is consistent with the key conclusion of our investigation—namely, that contactless and tokenization eliminate frictions and lower transaction costs and, by doing so, make individuals and society more productive. On this, see Hasan, De Renzis, and Schmiedel (2013), and Zhang, Zhang, Liu, De Renzis, and Schmiedel (2019).

Tokenized payments and incremental transactions

Tokenized payments lower the cart-abandonment rate and increase the authorization rate and, by doing so, generate some incremental card transactions. These are card transactions that, in a world without tokenization, consumers initiate and are not able to complete due to authorization problems or checkout frictions (as opposed to card transactions they would not have initiated at all in the absence of the technologies). We estimate incremental card transactions from tokenization based on our findings on decreased cart-abandonment rates and increased authorization rates associated with tokenized payments.

Somebody could argue that this is simply a transfer of consumption tomorrow to consumption today. The argument would be that tokenization does not create any additional wealth—it simply facilitates consumption today and, by doing so, it lowers consumption tomorrow. But this need not be so. As explained earlier, tokenization eliminates frictions and lowers transaction costs, and thus truly makes individuals and society more productive. See Hasan, De Renzis, and Schmiedel (2013), Zhang, Zhang, Liu, De Renzis, and Schmiedel (2019), and Aguilar, Frost, Guerra, Kamin, and Tombini (2024).

8.2.2 Private per-transaction and total returns

Having established that these technologies lead to some incremental card transactions, we still need an estimate of the per-transaction return to the innovators. For some of the international payment networks, we can compute a per-transaction return. From Visa's publicly available annual reports, we can develop an estimate of Visa's per-transaction revenue on incremental transactions. In 2022, for example, Visa had annual net revenues of USD 29.3 billion and total volume of payments of USD 11.6 trillion (Visa, 2022). This suggests that, at the time, Visa received about 25 basis points per transaction. (Strictly speaking, these are revenues rather than profits, but we take them as a proxy for the per-transaction return.) We calculate these per-transaction returns for both Visa and Mastercard from 2017 through 2023.

Let $NTOK_t^i$ stand for the number of tokenized transactions happening at time t on payment network i. Let ATS_t^i stand for the average transaction size in network i at time t. Let δ stand for the percent increase in card transactions facilitated by tokenization. Let RT_t^i stand for the return that network i receives at time t on each incremental transaction. With this notation, the private returns from tokenized payments to international payment network i at time t can be expressed as follows:

$$PRTOK_t^i = NTOK_t^i \times \delta \times ATS_t^i \times RT_t^i \qquad (25)$$

For Visa and Mastercard, Table 11A presents the private benefits accruing to each network from tokenization and the private development costs incurred by each (that is, the R&D investments each network has made in helping develop the technology). The “net benefits” column for each network is simply benefits minus costs for each network (for all relevant years). At the bottom of the net-benefits column, the table presents the IRR associated with tokenization for each network.

<TABLE 11A ABOUT HERE>

Analogously, let $NCLESS_t^i$ stand for the number of contactless transactions happening at time t on payment network i. Let ATS_t^i stand for the average transaction size in network i at time t. Let λ stand for the percent increase in card transactions facilitated by contactless payments. Let RT_t^i stand for the return that network i receives at time t on each incremental transaction. With this notation, the private returns from contactless payments to international payment network i at time t can be expressed as follows:

$$PRCLESS_t^i = NCLESS_t^i \times \lambda \times ATS_t^i \times RT_t^i \qquad (26)$$

For each network, Table 11B presents the private benefits accruing to each and the private costs incurred by each in helping develop the technology. For each network, the third column captures net benefits. At the bottom of this column, the table includes the IRR for each technology for each network.

<TABLE 11B ABOUT HERE>

8.3 Social returns

We have all the ingredients we need to calculate social IRRs for each technology. On the cost side, this calculation includes development costs incurred by innovators and adoption costs incurred by merchants. On the benefits side, this calculation includes end-user benefits and innovator benefits to the extent we can measure them. We measure the innovators' benefits for only two of the major payment-card networks and for banks that issue payment cards. In practice, this means that we underestimate social benefits. For example, China Union Pay is one of the innovators and we include its patents in the calculation of social costs (as we include the patents of all other innovators). Further, in recent years China Union Pay has accounted for about 30 percent of all the relevant transactions globally. If we were to count as benefits the revenues the network and its banks collect per transaction on the incremental transactions generated by the innovations, our estimates of social benefits would clearly increase. Given that there is some uncertainty as to the returns that China Union Pay and its banks collect per transaction, we have chosen not to include such revenues.

We have already explained the calculation of private benefits for the payment networks. Banks that issue payment cards receive private benefits in the form of profits on incremental transactions. We use interchange revenue as a proxy for issuers' benefits from incremental transactions. Table 12 presents social costs, social benefits, and social net benefits for each technology. At the bottom of the net-benefits column for each technology, the table includes the social IRR for each technology.

<TABLE 12 ABOUT HERE>

The methodology and results presented in this table are in line with the methodology and results in the seminal Griliches (1958) paper (and in subsequent papers in the case-study literature strand). As Griliches did, we count all costs incurred in developing and adopting each innovation. We also count as many benefits as can be quantified for the innovators themselves and for end-users. Griliches (1958) calculated a social IRR between 35 and 40 percent for hybrid corn, and our estimates of social IRRs for contactless and tokenization are somewhat below this range. It should be noted, however, that our approach tends to underestimate the social IRRs for the payment technologies because, among other things, we are counting costs for all innovators but we are counting benefits for only some of them.

8.4 A comparison of private and social returns

We have all the elements we need to compare private and social IRRs for tokenized and contactless payments. To make an appropriate comparison, however, an adjustment must be made.

The private rates of return we have calculated are based on an innovator's own investments and incremental benefits (based on its own incremental transactions). Contactless and tokenization, however, are innovations that have been developed over time by multiple companies and organizations. Thus, the social rates of return we have calculated are based on all costs incurred and all benefits received by all end-users and a few innovators (the innovators for which benefits can be calculated). To properly compare private and social rates of return, we need to focus *on the costs and benefits that can be attributed to each innovator*. A natural way to allocate these benefits for each payment network is to calculate costs based on the patents obtained by that network and to calculate benefits based on the transactions processed by that network. That is the approach we adopt here.

More specifically, the calculation of Visa's private IRR for contactless includes the following. On the cost side, we include the investments Visa has made to help develop the innovation; and on the benefits side, the network-fee revenue Visa has collected on the incremental Visa card transactions generated by the contactless innovation. Further, the calculation of Visa's social IRR for contactless includes the following. On the cost side, we include the investments Visa has made to help develop the innovation, the investments the issuers have made to help develop the innovation (scaled by Visa's share of all relevant transactions), and the merchants' adoption costs. On the benefits side, we include the network-fee revenue Visa has collected on the incremental Visa card transactions, the interchange-fee revenue issuers have collected on such transactions, and the end-user benefits from contactless on all the Visa contactless transactions.

The calculation of Visa's private IRR for tokenization includes the following. On the cost side, we include the investments Visa has made to help develop the innovation; and on the benefits side, the network-fee revenue Visa has collected on the incremental Visa card transactions generated by the tokenization innovation. Further, the calculation of Visa's social IRR for tokenization includes the following. On the cost side, we include the investments Visa has made to help develop the innovation, the investments the issuers have made to help develop the innovation (scaled by Visa's share of all relevant transactions), and the merchants' adoption costs (scaled by Visa's share). On the benefits side, we include the network-fee revenue Visa has collected on the incremental Visa card transactions, the interchange-fee revenue issuers have collected on such transactions, the fraud-reduction benefit accruing to the issuers on all the Visa tokenized transactions, and the end-user benefits from tokenization on all the Visa tokenized transactions. This approach allows for a fair comparison of private and social rates of return from the innovations for each one of these innovators.

Table 13A presents two calculations of the private and social IRRs for tokenization ("baseline" and "upper bound") and one for contactless.

<TABLE 13A ABOUT HERE>

The baseline private IRRs for tokenization are those reported in Tables 11A. They are calculated under the assumption that tokenization improves authorizations by two percentage points and reduces fraud by 18 percent. This assumption leads to a conservative calculation of social benefits. The assumption that tokenization improves authorizations by only two percentage points, however, may also lead us to underestimate the private IRRs from tokenization for Visa and Mastercard. This is so because each private IRR is a function of incremental transactions, and underestimating improvements in authorizations will lead us to underestimate the number of incremental transactions generated by tokenization. For this reason, and as a sensitivity exercise, in Table 13A we also report upper-bound private and social IRRs for tokenization, calculated under the assumption that tokenization improves authorizations by 4.3 percentage points. This number has recently been reported by Visa (2024) as the authorization uplift that tokenization delivers globally. In addition, the 4.3-percentage-point improvement is very close to the mid-point of the range of estimates made public by various entities between 2020 and 2024. The table shows that changing the authorization improvement from two percentage points to 4.3 percentage points barely changes the social IRRs but raises the private IRRs considerably.

We carry out a different sensitivity exercise in Table 13B. Although our patent-family counts track closely those reported in third-party publications for these technologies, in a few cases these third-party reports identify fewer Visa and Mastercard patents than we do. For this reason, and as a robustness exercise, we also report private and social IRRs for these innovators assuming that the Visa and Mastercard shares of all patents are the ones calculated in third-party reports. Table 13B presents these calculations. In this table, the baseline calculations assume that tokenization improves authorizations by two percentage points and reduces fraud by 18 percent. The upper-bound calculations assume that tokenization improves authorizations by 4.3-percentage points.

<TABLE 13B ABOUT HERE>

In any case, Table 13A and Table 13B show that our key conclusion does not change. For both technologies, tokenization and contactless, the social returns are considerably larger than the private returns. Put differently, these technologies have generated (and will continue to generate) larger net benefits for society than for the innovators themselves.

8.5 The benefits-to-costs ratio

We have also calculated the benefits-to-cost ratio for each innovation. First, we have calculated the overall ratio by dividing the present value of all the benefits—including those accruing to end users and those accruing to the innovators for which benefits can be estimated—by the present value of all the costs—including development costs incurred by all innovators and adoption costs incurred by all merchants on all relevant transactions. This calculation is a response to the question: How do the benefits that society has obtained from each payment innovation relate to the resources society has invested in developing and adopting them?

In addition, we have calculated the social-benefits-to-social-costs ratio for specific innovators. Consider Visa, for example. For each innovation, we count only the social benefits that can be attributed to Visa, and we divide them by the sum of a) the development resources Visa has invested in developing each innovation, b) the development resources issuers have invested in developing each innovation (scaled by Visa's share of the relevant transactions), and c) the resources merchants have invested in adopting each innovation for Visa transactions only.

Table 14 presents the overall social-benefits-to-social-costs ratio for each innovation in the "total social" column. In addition, it also presents the social-benefits-to-social-costs ratio for Visa and Mastercard. The calculations have been made under the assumption that tokenization improves authorizations by two percentage points and reduces fraud by 18 percent.

<TABLE 14 ABOUT HERE>

The table shows that the present discounted value of the benefits derived from each technology is larger than the present discounted value of the costs in all cases. Put differently, social benefits are considerably larger than social costs, no matter whether we focus on specific innovators (such as Visa and Mastercard) or on all innovators combined.

9 Conclusions

The literature on the social value of innovations is extensive. To our knowledge, however, no studies have explored the social value of specific payment innovations. This paper is an attempt to start filling this gap in the literature.

We focus on two recent payment innovations: contactless and tokenization. We develop novel methodologies for estimating the benefits these innovations have generated for the innovators themselves and for end-users. Further, we rely on the academic literature on patents to quantify the R&D investments innovators have made to develop these technologies. In addition, we estimate the costs merchants have incurred in the process of adopting the technologies. These various estimates cover multiple countries in different regions of the world, and we express foreign-currency values in 2021 international dollars with a standard methodology that is widely used in multi-country studies.

To the extent that costs and benefits can be calculated, we conclude that both payment technologies have generated larger benefits for society than for the individual innovators themselves, and that the benefits these technologies have generated for society are larger than the resources society has invested in developing and adopting them.

10 Appendix A: sources of data and information

This appendix presents detailed information on the sources we have relied on for our calculations of costs and benefits.

Table A.1 Data Sources for Contactless Calculations

Parameter	Time Period	Value(s)	Source(s)
Countries	2017 to 2037	Argentina, Australia, Austria, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, Colombia, Costa Rica, Croatia, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, Estonia, Finland, France, Germany, Greece, Hong Kong, Hungary, India, Indonesia, Iran , Ireland, Israel, Italy, Japan, Kazakhstan, Kuwait, Latvia, Lithuania, Malaysia, Mexico, Netherlands, New Zealand, Nigeria, Norway, Pakistan, Peru, Philippines, Poland, Portugal, Romania, Russia, Saudi Arabia, Serbia, Singapore, Slovakia, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Thailand, Turkey, UAE, UK, USA and Ukraine	RBR Global Payment Cards Data and Forecasts to 2027 – International Overview
Total Number of Contactless Transactions	2017 to 2027	Varies by country and year	RBR Global Payment Cards Data and Forecasts to 2027 – International Overview
	2028 to 2037	Forecasted, by country and year, using a linear regression with 2017-2027 data from the RBR Report	Authors' calculations
Total Value of Contactless Transactions	2017 to 2027	Varies by country and year	RBR Global Payment Cards Data and Forecasts to 2027 – International Overview
	2028 to 2037	Forecasted, by country and year, using a linear regression with 2017-2027 data from the RBR Report	Authors' calculations
Number of Visa Contactless Transactions	2017 to 2021	Varies by country and year	RBR Global Payment Cards Data and Forecasts to 2027 – International Overview
	2028 to 2037	Numbers are estimated, by country and year, applying the Visa share of the total number of contactless transactions in 2021 to the total number of all contactless transactions from 2022 to 2032	Authors' calculations
Number of Mastercard Contactless Transactions	2017 to 2021	Varies by country and year	RBR Global Payment Cards Data and Forecasts to 2027 – International Overview
	2028 to 2037	Numbers are estimated, by country and year, applying the Mastercard share of the total number of contactless transactions in 2021 to the total number of all contactless transactions from 2022 to 2032	Authors' calculations

Table A.1. Data Sources for Contactless Calculations (continued)

Value of Visa Contactless Transactions	2017 to 2021	Varies by country and year	RBR Global Payment Cards Data and Forecasts to 2027 – International Overview
	2028 to 2037	Values are estimated, by country and year, applying the Visa share of the total value of contactless transactions in 2021 to the total value of all contactless transactions from 2022 to 2032	Authors' calculations
Value of Mastercard Contactless Transactions	2017 to 2021	Varies by country and year	RBR Global Payment Cards Data and Forecasts to 2027 – International Overview
	2028 to 2037	Values are estimated, by country and year, applying the Mastercard share of the total value of contactless transactions in 2021 to the total value of all contactless transactions from 2022 to 2032	Authors' calculations
PPP conversion factor, GDP (LCU per international $)	2017 to 2023	Varies by country and year	The World Bank - World Development Indicators
	2024 to 2037	Factors are forecasted, by country and year, using a linear regression with data from 2017 - 2023	Authors' calculations
GDP deflator: linked series (base year varies by country)	2017 to 2023	Varies by country and year	The World Bank - World Development Indicators
	2024 to 2037	Price indices are forecasted, by country and year, using a linear regression with data from 2017 - 2023	Authors' calculations

Table A.1. Data Sources for Contactless Calculations (continued)

Average wage	2017 to 2022 (or 2023, if available)	We collected wage data, in the national currency, for countries between 2017 and 2022 as reported by each country's statistical authority. Monthly or annual wage data are frequently presented in the sources. We converted the data to hourly wages using the OECD Annual Average Worked Hours data by country and year. If worked-hours are not available, we assume 2,000 hours worked per year and 170 hours worked per month. For the remaining countries included in the RBR and Juniper sources for which labour data are not available, we use GNI per capita (Atlas Method) from the World Bank as an estimate for the wage	Multiple country-specific sources
	2023 to 2037	Wages are forecasted using the forecasted GDP deflator, by country and year, under the assumption that wages will grow with inflation	Authors' calculations
Value of Time (as % of average wage)	2017 to 2037	West Europe: 82.92% Central & East Europe: 102% North America: 67.72% AUS and NZ: 51.86% Rest of the World: 82.54%	L. Zamparini and A. Reggiani, "Meta-Analysis and the Value of Travel Time Savings," Networks and Spatial Economics 7 (2007), pp. 377-396.
Number of Contactless EFTPOS Terminals	2017 to 2021 & 2027	Varies by country and year	RBR Global Payment Cards Data and Forecasts to 2027 – International Overview
	2022 to 2026 & 2028 to 2037	Numbers are forecasted, by year and country, under the assumption that the number of terminals will grow at the 2021-2027 rate	Authors' calculations
EFTPOS Terminal Cost	2017 to 2037	We use a cost figure of $100 per terminal, in 2019 US dollars, converted to 2021 international dollars	Swipesum, "What Does it Cost to Accept Mobile Payments?" July 8, 2019, available at https://www.swipesum.com/insights/cost-to-accept-mobile-payments.

Table A.2. Data Sources for Tokenization Calculations

Parameter	Time Period	Value(s)	Source(s)
Countries	2019 to 2039	Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Colombia, Croatia, Czech Republic, Denmark, Ecuador, Egypt, Finland, France, Germany, Greece, Hong Kong, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Kuwait, Malaysia, Mexico, Netherlands, New Zealand, Nigeria, Norway, Pakistan, Peru, Philippines, Poland, Portugal, Romania, Russia, Saudi Arabia, Singapore, South Africa, South Korea, Spain, Sweden, Switzerland, Thailand, Turkey, UK, USA, Ukraine, United Arab Emirates	Juniper Research Payment Tokenization Forecast
Total Number of Tokenized Transactions	2019 to 2027	Varies by country, year, and type (e-commerce single use, e-commerce persisent, mobile payment, and card present)	Juniper Research Payment Tokenization Forecast
	2028 to 2039	Forecasted by country and year, using a linear regression with data from 2022-2027	Authors' calculations
Average transaction value	2019 to 2027	Varies by country and year	RBR Global Payment Cards Data and Forecasts to 2027 – International Overview
	2028 to 2039	We use 2027 values	Authors' calculations
Average e-commerce transaction value	2019 to 2027	Varies by country and year	RBR Global Payment Cards Data and Forecasts to 2027 – International Overview
	2028 to 2039	We use 2027 values	Authors' calculations
Average online retail margins	2019 to 2022	Gross and net margins for online retail are available for Global, Emerging Markets, Japan, the US, and Western Europe	Operating Net Margins, by Industry - Damodaran Online, available at https://pages.stern.nyu.edu/~adamodar/New_Home_Page/dataarchived.html
	2023 to 2039	We use 2022 values	Authors' calculations
Interchange rates	2019 to 2039	Varies by country. For the countries for which no interchangerate information is publicly available, we have used a weighted average interchange rate.	Multiple sources - country specific

Table A.2. Data Sources for Tokenization Calculations (continued)

Merchant service charge	2019 to 2039	0.60%	PSR, Market review into card-acquiring services Final report, Figure 11.
Fraud rate	2019 to 2039	18.71 basis points for CNP transactions and 9.34 basis points for CP and MP transactions	Board of Governors of the Federal Reserve System, "Changes in U.S. Payments Fraud from 2012 to 2016: Evidence from the Federal Reserve Payments Study," October 2018
Fraud reduction	2019 to 2039	We use 18 percent, which is the lower bound of various estimates that have been made publicly available	The estimates come from BusinessWire (2020), Visa (2021), Deloitte (2023), Ho (2023), and J.P. Morgan (2024)
Increased authorization	2019 to 2039	We use two percentage points, which is the lower bound various estimates that have been made publicly available	The estimates come from Stoorvogel (2019), Visa (2021), Deloitte (2023), Ho (2023), Discover (2023), J.P. Morgan (2024), Begley and Nierat (2024), Leucht and Schropfer (2024), Visa (2024), and American Express (2024)
Share of online transactions that are never completed after declined due to authorization issues	2019 to 2039	2.0%	Baymard Institute - "How to Recoup 30% of Card Declined Abandonments," available at https://baymard.com/blog/credit-card-declined
Share of online transactions that, after declined due to authorization issues, are completed with re-engagement costs	2019 to 2039	26.0%	Growth Natives, "Leverage Ecommerce Retargeting to Win Back Your Customers," 18 August 2022, available at https://growthnatives.com/blogs/marketo/ecommerce-retargeting-to-winback-your-customers/.
Engagement/Remarketing Costs	2019 to 2039	USD 0.66	DigiSocial, "How Much Does Google Retargeting Cost for Google Ads" - 12 September 2023, available at https://digisocial.com.bd/google-adsretargeting-cost/.

Table A.2. Data Sources for Tokenization Calculations (continued)

Share of attempted transactions that are abandoned	2019 to 2039	71.4%	Baymard Institute, "49 Cart Abandonment Statistics for 2024," available at https://baymard.com/lists/cart-abandonment-rate, last visited on March 29, 2024
Share of situations in which the consumer has the intention to make a purchase	2019 to 2039	52.0%	Baymard Institute, "49 Cart Abandonment Statistics for 2024," available at https://baymard.com/lists/cart-abandonment-rate, last visited on March 29, 2024
Share of purchases in which the cart has been abandoned that are never completed	2019 to 2039	16.0%	Royal Mail, "Delivery Matters UK 2020," available at https://www.royalmail.com/sites/royalmail.com/files/2020-10/delivery-matters-uk-2020.pdf, last visited on April 2, 2024.
Share of consumers who have an intention to buy and abandon their cart because of a long and convoluted checkout process or because they do not trust the web site with their card information	2019 to 2039	35.25% (Note: the original source reports that 22% abandon due to a convulated checkout process and 25% due to trust issues. Percentages in the survey add up to more than 100, so that there may be some overlap. The extent of overlap, if any, is not reported and we use 0.75 of the sum.)	Baymard Institute, "49 Cart Abandonment Statistics for 2024," available at https://baymard.com/lists/cart-abandonment-rate, last visited on March 29, 2024
Time savings from card-on-file	2019 to 2039	26.9 seconds; this is the difference between the duration of a non-tokenized online-purchase (34.7 seconds) and the duration of a COF tokenized-transaction (7.8 seconds)	See Norges Bank, "Costs in the Norwegian Payment System 2020," Norges Bank Papers No. 3, 2022, available at https://www.norges-bank.no/contentassets/f23389f85e92430ea0920bc2705d635a/nb_papers_3_22_payment_system.pdf?v=23112022152523

11 Appendix B: contactless and tokenization patents

GlobalData provided us with the patent data on contactless and tokenization through 2024. (Full-year data cover only through 2023. We forecasted future patents using trends calculated from the existing data.) The datasets include patent "application" records and patent "grant" records for the technologies over time. The contactless dataset also includes a few records categorized as "abstracts," "reissues," and "search reports."

11.1 Identifying the relevant patents

The contactless patents were selected because they belong to the "contactless" sector. There is no "tokenization" sector, however, and thus different criteria were used to select those patents. We requested that GlobalData provide patent records containing the word "token" (and variations thereof) in the text of the patent, including the title. We received records that belonged to at least one of the following sectors: bank transfers, card security, cards, contactless, credit cards, ecommerce and online payments, exchanges, insurance, lending, mobile and electronic wallets, mobile banking, mutual funds, online, payments, POS, prepaid cards, self-service and ATMs, and third-party processing.

Keeping all these records in the relevant dataset would have led us to include many patents that are unrelated to tokenization in payments. The payment-tokenization patents were selected from the set described above based on a keyword search for the following words (and variations of these words) in the patent title: “token,” “card,” “payment,” “transaction,” “fraud,” and “management.”

We checked how closely our numbers of relevant patents for each technology track the numbers presented in the very few third-party reports on contactless and payment-tokenization patents that are publicly available. We confirmed that our numbers are indeed very close to what third-party organizations define as “contactless” patents and “payment tokenization” patents.

For example, our contactless patent-family numbers are very close to the numbers reported in PATSEER (2018) and Reynolds and Garcell (2020). Both are reports on patenting in contactless payments. Further, our tokenization patent-family numbers are also close to the numbers reported in CIPHER (2020). The CIPHER (2020) report focuses on tokenization in payments and includes patents covering “tokens for financial applications” and “token management.” Both our *total* patent-family numbers and our calculated *patenting trends over time* are close to those presented in these reports.

It should be noted that “payment tokenization” patents are more difficult to define than “contactless payments” patents. Thus, we tested our results against different definitions of the relevant tokenization patents, and we confirmed that our key results on IRRs are robust. Put differently, although the level of private and social IRRs will change with the number of patents (because development costs are a function of the number of relevant patents, and IRRs are in turn a function of development costs), the finding that the social IRR is higher than the private IRR for each technology is robust to different specifications.

11.2 Applications and grants

In each dataset, some of the records are "applications" and some are "grants," and in some cases we have the application and the grant for the same patent. If we counted both in such cases, we would be double-counting the number of patents for a subset of the data. In cases in which there was duplication of this sort, we kept the application record because, as Nagaoka, Motohashi, and Goto (2010) point out, applications are most closely associated with inventive activity and with the R&D resources invested to develop an invention. As a general rule, we kept the record with the earliest publication date among all records associated with a given application number.

11.3 Individual patents and patent families

Further, a distinction must be made between an individual patent and a patent family. Nagaoka, Motohashi, and Goto (2010) explain that a patent family is a set of patents that cover roughly the same invention and share a "priority date." This date is the date of the first patent application and remains the same in subsequent filings when applications filed later—either in the same country or in foreign countries—cover an equivalent invention. To avoid overestimating the level of investment activity, we counted all patents in a family as one unit (one invention and also one patent) for the purposes of estimating development costs. We defined a patent family in our data as a collection of records that have the same title, priority date, and assignee. If the priority date was missing, we used the filing date. If the assignee was missing, we first used the inventor and then the application number if the inventor was also missing.

For both individual patents and patent families, we used the priority year as the year when the R&D investment was made. This is the approach recommended in Nagaoka, Motohashi, and Goto (2010). In our data, most patent families are "families" of one patent, but several families comprise two or more.

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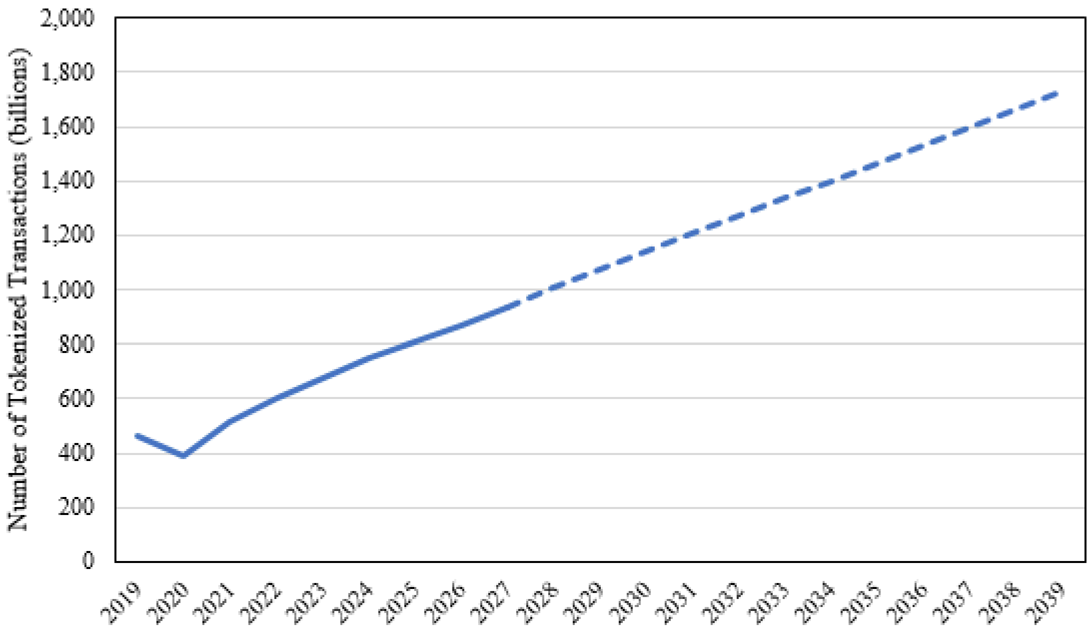
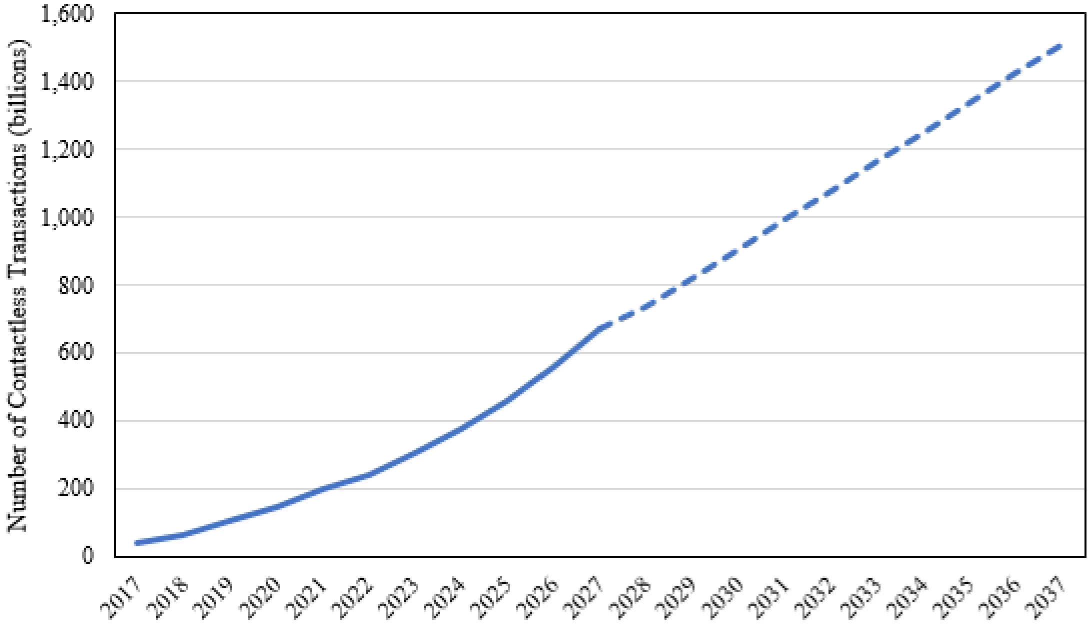
Figure 1. Number of tokenized transactions, 2019-2039, in billions



Source: Juniper Research and Authors' calculations. Dotted line represents authors' forecasts.

Figure 2. Number of contactless transactions, 2017-2037, in billions



Source : RBR and Authors' calculations. Dotted line represents authors' forecast.

Figure 3. The potential paths of a payment-card transaction

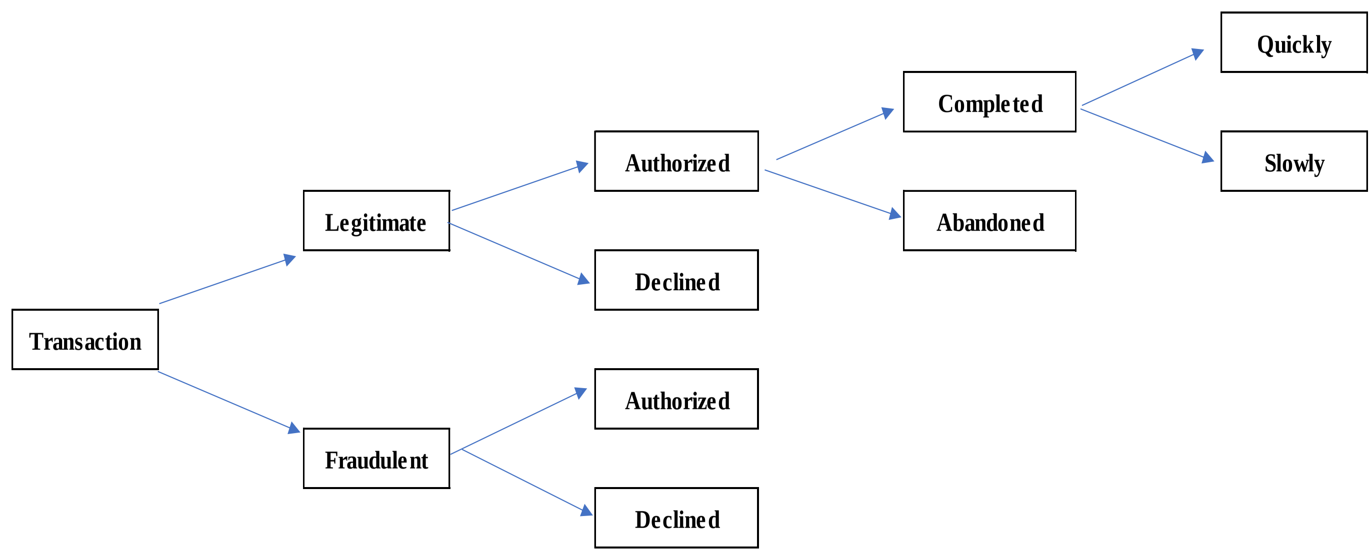


Figure 4. Flow of contactless and tokenization patent families, 2000-2023

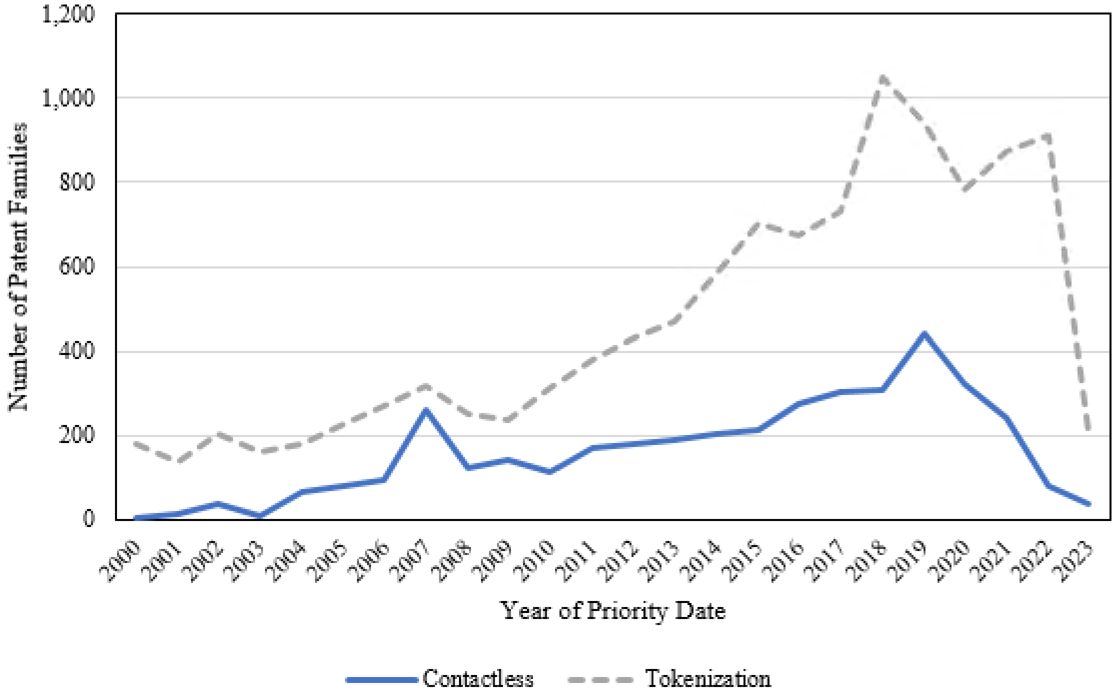


Table 1A:
Fraud reduction benefits by region
Millions of 2021 International Dollars

Year	Africa	Asia	Europe	Latin America	North America	Total
2019	$321	$5,145	$1,572	$336	$1,171	$8,544
2020	$207	$4,842	$1,206	$254	$882	$7,391
2021	$267	$5,610	$1,550	$312	$1,194	$8,932
2022	$269	$6,623	$1,791	$299	$1,234	$10,216
2023	$283	$7,600	$1,956	$301	$1,293	$11,433
2024	$307	$8,294	$2,359	$334	$1,418	$12,712
2025	$316	$8,902	$2,413	$340	$1,497	$13,468
2026	$324	$9,522	$2,466	$356	$1,594	$14,262
2027	$333	$10,225	$2,520	$383	$1,711	$15,173
2028	$351	$10,823	$2,714	$386	$1,753	$16,026
2029	$370	$11,397	$2,841	$397	$1,815	$16,821
2030	$389	$11,946	$2,964	$408	$1,875	$17,582
2031	$406	$12,472	$3,082	$418	$1,932	$18,310
2032	$423	$12,976	$3,196	$427	$1,987	$19,009
2033	$440	$13,459	$3,305	$436	$2,040	$19,680
2034	$456	$13,923	$3,411	$444	$2,091	$20,324
2035	$471	$14,369	$3,512	$451	$2,140	$20,944
2036	$486	$14,798	$3,611	$458	$2,188	$21,541
2037	$500	$15,212	$3,706	$465	$2,233	$22,116
2038	$513	$15,610	$3,798	$472	$2,277	$22,670
2039	$527	$15,994	$3,887	$478	$2,320	$23,205
Total	***$7,958***	***$229,743***	***$57,858***	***$8,155***	***$36,644***	***$340,358***

Source: Authors' calculations. See text and Appendix A.

Table 1B:
Fraud reduction benefits
Millions of 2021 International Dollars

Year	Merchant	Issuer	Total
2019	$876	$7,668	$8,544
2020	$766	$6,624	$7,391
2021	$878	$8,054	$8,932
2022	$1,008	$9,207	$10,216
2023	$1,121	$10,312	$11,433
2024	$1,284	$11,428	$12,712
2025	$1,478	$11,990	$13,468
2026	$1,761	$12,501	$14,262
2027	$2,136	$13,038	$15,173
2028	$2,189	$13,837	$16,026
2029	$2,363	$14,458	$16,821
2030	$2,528	$15,054	$17,582
2031	$2,684	$15,627	$18,310
2032	$2,832	$16,177	$19,009
2033	$2,972	$16,707	$19,680
2034	$3,106	$17,218	$20,324
2035	$3,234	$17,710	$20,944
2036	$3,356	$18,185	$21,541
2037	$3,472	$18,643	$22,116
2038	$3,584	$19,086	$22,670
2039	$3,691	$19,515	$23,205
Total	***$47,319***	***$293,039***	***$340,358***

Source: Authors' calculations. See text and Appendix A.

Table 2:
Increased authorization benefits
Millions of 2021 International Dollars

Year	Consumer	Merchant	Total
2019	$79	$286	$364
2020	$66	$242	$309
2021	$78	$259	$337
2022	$89	$361	$450
2023	$96	$404	$500
2024	$104	$465	$569
2025	$113	$536	$649
2026	$124	$637	$761
2027	$137	$771	$908
2028	$144	$790	$934
2029	$153	$853	$1,006
2030	$162	$912	$1,074
2031	$172	$968	$1,140
2032	$181	$1,021	$1,202
2033	$190	$1,072	$1,262
2034	$200	$1,120	$1,320
2035	$209	$1,166	$1,375
2036	$219	$1,210	$1,428
2037	$228	$1,251	$1,479
2038	$237	$1,291	$1,529
2039	$247	$1,329	$1,576
Total	***$3,229***	***$16,944***	***$20,173***

Source: Authors' calculations. See text and Appendix A.

Table 3:
Decreased cart abandonment benefits
Millions of 2021 International Dollars

Year	Consumer	Merchant	Total
2019	$650	$8,192	$8,842
2020	$570	$7,042	$7,613
2021	$686	$6,264	$6,950
2022	$810	$10,797	$11,607
2023	$905	$11,901	$12,806
2024	$1,010	$13,629	$14,639
2025	$1,120	$15,401	$16,521
2026	$1,250	$17,780	$19,031
2027	$1,397	$20,813	$22,210
2028	$1,487	$21,587	$23,074
2029	$1,602	$23,231	$24,833
2030	$1,717	$24,797	$26,514
2031	$1,832	$26,290	$28,122
2032	$1,947	$27,716	$29,663
2033	$2,062	$29,080	$31,142
2034	$2,177	$30,385	$32,562
2035	$2,292	$31,637	$33,928
2036	$2,407	$32,837	$35,244
2037	$2,522	$33,991	$36,512
2038	$2,637	$35,100	$37,736
2039	$2,752	$36,167	$38,918
Total	***$33,831***	***$464,636***	***$498,466***

Source: Authors' calculations. See text and Appendix A.

Table 4:
Time savings benefit from card-on-file
Millions of 2021 International Dollars

Year	Benefit
2019	$1,103
2020	$967
2021	$1,163
2022	$1,374
2023	$1,535
2024	$1,713
2025	$1,899
2026	$2,120
2027	$2,369
2028	$2,521
2029	$2,716
2030	$2,911
2031	$3,106
2032	$3,301
2033	$3,496
2034	$3,691
2035	$3,886
2036	$4,081
2037	$4,276
2038	$4,471
2039	$4,666
Total	***$57,367***

Source: Authors' calculations. See text and Appendix A.

Table 5A:
Consumer time savings benefit from contactless
Millions of 2021 International Dollars

Year	Africa	Asia	Europe	Latin America	North America	Total
2017	$13	$266	$942	$3	$122	$1,346
2018	$31	$473	$1,628	$6	$176	$2,313
2019	$49	$845	$2,470	$16	$243	$3,623
2020	$102	$1,204	$3,457	$32	$343	$5,139
2021	$179	$1,659	$4,504	$90	$456	$6,888
2022	$217	$1,795	$5,299	$163	$683	$8,157
2023	$318	$2,266	$6,190	$290	$1,019	$10,082
2024	$382	$2,839	$7,099	$425	$1,407	$12,152
2025	$466	$3,564	$8,010	$575	$1,974	$14,589
2026	$560	$4,411	$8,989	$721	$2,769	$17,451
2027	$670	$5,373	$10,015	$881	$3,876	$20,814
2028	$734	$5,897	$10,847	$1,010	$4,129	$22,617
2029	$819	$6,620	$11,767	$1,153	$4,749	$25,108
2030	$903	$7,343	$12,688	$1,296	$5,370	$27,599
2031	$988	$8,066	$13,608	$1,439	$5,990	$30,090
2032	$1,073	$8,789	$14,528	$1,581	$6,611	$32,582
2033	$1,157	$9,512	$15,449	$1,724	$7,232	$35,073
2034	$1,242	$10,235	$16,369	$1,867	$7,852	$37,564
2035	$1,326	$10,958	$17,289	$2,010	$8,473	$40,055
2036	$1,411	$11,681	$18,210	$2,153	$9,093	$42,546
2037	$1,495	$12,404	$19,130	$2,295	$9,714	$45,038
Total	***$14,134***	***$116,195***	***$208,486***	***$19,731***	***$82,279***	***$440,826***

Source: Authors' calculations. See text and Appendix A.

Table 5B:
Merchant time savings benefit from contactless
Millions of 2021 International Dollars

Year	Africa	Asia	Europe	Latin America	North America	Total
2017	$8	$192	$541	$2	$90	$834
2018	$19	$327	$925	$4	$130	$1,404
2019	$30	$560	$1,390	$10	$179	$2,168
2020	$62	$791	$1,934	$20	$253	$3,060
2021	$108	$1,077	$2,526	$55	$336	$4,102
2022	$132	$1,165	$2,969	$99	$504	$4,868
2023	$193	$1,462	$3,457	$176	$752	$6,040
2024	$231	$1,815	$3,962	$257	$1,039	$7,304
2025	$282	$2,260	$4,465	$349	$1,458	$8,813
2026	$339	$2,779	$5,005	$437	$2,044	$10,605
2027	$406	$3,368	$5,571	$534	$2,862	$12,739
2028	$445	$3,692	$6,030	$612	$3,048	$13,827
2029	$496	$4,136	$6,537	$698	$3,506	$15,374
2030	$547	$4,580	$7,045	$785	$3,965	$16,922
2031	$599	$5,025	$7,553	$871	$4,423	$18,470
2032	$650	$5,469	$8,060	$958	$4,881	$20,018
2033	$701	$5,913	$8,568	$1,044	$5,339	$21,566
2034	$752	$6,358	$9,075	$1,131	$5,797	$23,114
2035	$803	$6,802	$9,583	$1,217	$6,256	$24,661
2036	$854	$7,246	$10,091	$1,304	$6,714	$26,209
2037	$906	$7,691	$10,598	$1,390	$7,172	$27,757
Total	***$8,562***	***$72,707***	***$115,885***	***$11,952***	***$60,749***	***$269,856***

Source: Authors' calculations. See text and Appendix A.

Table 6:
Number of tokenization patent families and citations for the top 10 tokenization assignees
Priority Years 2000-2023

Assignee	**Number of Patents Families**	**Share of Patent Families**	**Number of Citations**	**Share of Citations**	**Number of Citations per Patent Family**
Mastercard	706	6.3%	20,804	3.4%	29.5
Visa	615	5.5%	81,351	13.3%	132.3
Capital One	305	2.7%	63,403	10.4%	207.9
PayPal	213	1.9%	6,819	1.1%	32.0
Bank of America	186	1.7%	10,461	1.7%	56.2
Samsung	137	1.2%	3,465	0.6%	25.3
Wells Fargo	119	1.1%	22,188	3.6%	186.5
IBM	113	1.0%	2,905	0.5%	25.7
Chase Bank	112	1.0%	11,520	1.9%	102.9
Nchain Holdings Ltd	104	0.9%	2,578	0.4%	24.8
All Others (4,445)	8,628	76.8%	387,034	63.2%	44.9
Total	***11,238***	***100%***	***612,528***	***100%***	***54.5***

Source : Authors' calculations based on GlobalData patents dataset.

Table 7:
Number of contactless patent families and citations for the top 10 contactless assignees
Priority Years 2000-2023

Assignee	**Number of Patents Families**	**Share of Patent Families**	**Number of Citations**	**Share of Citations**	**Number of Citations per Patent Family**
Capital One	492	12.6%	70,441	39.3%	143.2
Visa	166	4.2%	7,371	4.1%	44.4
Mastercard	158	4.0%	1,457	0.8%	9.2
Sony	78	2.0%	2,751	1.5%	35.3
Xard Group	64	1.6%	264	0.1%	4.1
Samsung	57	1.5%	623	0.3%	10.9
Bank of America	49	1.3%	1,130	0.6%	23.1
Huawei	43	1.1%	292	0.2%	6.8
Block	41	1.0%	5,559	3.1%	135.6
AB Dynamics	40	1.0%	15,568	8.7%	389.2
All Others (1,330)	2,722	69.6%	73,963	41.2%	27.2
Total	***3,910***	***100.0%***	***179,419***	***100.0%***	***45.9***

Source : Authors' calculations based on GlobalData patents dataset.

Table 8:
R&D-to-Patent Ratio for Top Companies with Patents Granted
Millions of 2021 International Dollars

Company	Number of Patents		R&D Spend	Cost per Patent
	2007-2020	For Years with R&D Spend Data		
IBM	96,708	89,414	$79,099	$0.88
Samsung	68,879	62,654	$181,434	$2.90
Canon	43,597	39,507	$43,206	$1.09
Microsoft	35,645	31,982	$164,905	$5.16
Sony	31,051	24,350	$49,000	$2.01
Intel	28,839	25,203	$150,644	$5.98
LG	26,591	24,040	$11,546	$0.48
Qualcomm	23,828	23,264	$62,279	$2.68
Google	21,759	21,701	$168,481	$7.76
General Electric	20,851	5,167	$9,666	$1.87
Apple	20,426	20,123	$108,188	$5.38
Hewlett Packard	19,059	12,115	$18,464	$1.52
Taiwan Semiconductor	19,051	18,219	$27,106	$1.49
Panasonic	15,343	15,088	$62,181	$4.12
Micron	14,900	12,174	$19,442	$1.60
Total	***486,527***	***425,001***	***$1,155,643***	***$2.72***

Sources : Authors' calculations based on USPTO, MacroTrends, and annual reports.

Table 9A:
Estimates of Social R&D Expenditures by Year and Technology
Millions of 2021 International Dollars

Year	Contactless		Tokenization	
	Number of Patent Families	**R&D Spend**	**Number of Patent Families**	**R&D Spend**
2000	6	$25	180	$742
2001	15	$60	137	$552
2002	36	$143	202	$802
2003	11	$43	159	$619
2004	64	$243	181	$686
2005	80	$294	227	$834
2006	94	$335	269	$959
2007	259	$899	317	$1,100
2008	124	$422	253	$861
2009	144	$487	235	$795
2010	113	$378	311	$1,040
2011	170	$557	378	$1,238
2012	180	$579	430	$1,383
2013	189	$598	470	$1,486
2014	204	$634	582	$1,809
2015	211	$650	702	$2,162
2016	277	$845	672	$2,050
2017	301	$902	732	$2,194
2018	306	$897	1050	$3,076
2019	439	$1,265	939	$2,706
2020	322	$916	781	$2,221
2021	242	$658	873	$2,374
2022	80	$203	913	$2,319
2023	39	$96	210	$515
2024	21	$52	152	$378
2025	12	$29	110	$267
2026	6	$14	80	$190
2027	3	$7	58	$135
2028	2	$5	42	$96
2029	1	$2	30	$67
2030	1	$2	22	$48
2031			16	$34
2032			12	$25
2033			8	$16
2034			6	$12
2035			4	$8
2036			3	$6
2037			2	$4
2038			2	$4
2039			1	$2
Total	***3,951***	***$12,236***	***11,156***	***$32,255***

Sources : Authors' calcluations based on GlobalData patent dataset, USPTO, MacroTrends, and annual reports.

Table 9B:
Estimates of R&D Expenditures by Year, Technology, and Network
Millions of 2021 International Dollars

Year	**Contactless**		**Tokenization**	
	Visa	**Mastercard**	**Visa**	**Mastercard**
2000				$4.1
2001			$8.1	$16.1
2002		$19.8	$19.8	$35.7
2003			$3.9	$15.6
2004			$3.8	$11.4
2005	$44.1	$11.0	$14.7	$62.5
2006	$17.8	$10.7	$49.9	$25.0
2007	$52.1	$20.8	$86.8	$65.9
2008	$57.9	$13.6	$61.3	$23.8
2009	$60.9	$13.5	$71.1	$23.7
2010	$30.1	$3.3	$97.0	$20.1
2011			$111.4	$16.4
2012	$19.3		$54.7	$48.2
2013	$19.0	$37.9	$173.9	$72.7
2014	$24.9	$65.3	$96.4	$177.2
2015	$12.3	$27.7	$117.0	$227.9
2016	$54.9	$45.8	$122.0	$283.7
2017	$27.0	$42.0	$146.8	$305.7
2018	$20.5	$43.9	$167.0	$225.6
2019	$28.8	$34.6	$213.2	$195.9
2020	$17.1	$39.8	$122.3	$150.7
2021	$35.3	$27.2	$73.4	$70.7
2022	$7.6	$20.3	$50.8	$73.7
2023		$4.9	$7.4	$14.7
2024		$5.0	$2.5	$9.9
2025		$2.4	$2.4	$4.9
2026		$2.4		$2.4
2027		$2.3		$2.3
2028		$2.3		$2.3
Total	***$530***	***$497***	***$1,877***	***$2,185***

Sources : Authors' calcluations based on GlobalData patent dataset, USPTO, MacroTrends, and annual reports.

Table 10:
Merchant adoption costs
Millions of 2021 International Dollars

Year	Contactless	Tokenization
2017	$1,893	
2018	$5,711	
2019	$1,868	$3,441
2020	$4,759	$2,854
2021	$2,775	$3,196
2022	$1,914	$3,561
2023	$1,761	$3,973
2024	$1,807	$4,624
2025	$1,727	$5,321
2026	$1,656	$6,299
2027	$1,592	$7,585
2028	$1,535	$7,764
2029	$1,482	$8,364
2030	$1,434	$8,929
2031	$1,390	$9,463
2032	$1,349	$9,968
2033	$1,311	$10,446
2034	$1,275	$10,900
2035	$1,241	$11,331
2036	$1,210	$11,742
2037	$1,180	$12,133
2038		$12,506
2039		$12,862
Total	***$30,478***	***$56,983***

Source: Authors' calculations. See text and Appendix A.

Table 11A:
Estimates of the Private Costs and Benefits of Tokenization by Year and Scheme
Millions of 2021 International Dollars

Year	Visa			Mastercard		
	Costs	Benefits	Net Benefits	Costs	Benefits	Net Benefits
2000				$4.1		-$4.1
2001	$8.1		-$8.1	$16.1		-$16.1
2002	$19.8		-$19.8	$35.7		-$35.7
2003	$3.9		-$3.9	$15.6		-$15.6
2004	$3.8		-$3.8	$11.4		-$11.4
2005	$14.7		-$14.7	$62.5		-$62.5
2006	$49.9		-$49.9	$25.0		-$25.0
2007	$86.8		-$86.8	$65.9		-$65.9
2008	$61.3		-$61.3	$23.8		-$23.8
2009	$71.1		-$71.1	$23.7		-$23.7
2010	$97.0		-$97.0	$20.1		-$20.1
2011	$111.4		-$111.4	$16.4		-$16.4
2012	$54.7		-$54.7	$48.2		-$48.2
2013	$173.9		-$173.9	$72.7		-$72.7
2014	$96.4		-$96.4	$177.2		-$177.2
2015	$117.0		-$117.0	$227.9		-$227.9
2016	$122.0		-$122.0	$283.7		-$283.7
2017	$146.8		-$146.8	$305.7		-$305.7
2018	$167.0		-$167.0	$225.6		-$225.6
2019	$213.2	$60.1	-$153.1	$195.9	$42.1	-$153.9
2020	$122.3	$45.1	-$77.1	$150.7	$37.6	-$113.2
2021	$73.4	$49.3	-$24.1	$70.7	$45.3	-$25.4
2022	$50.8	$61.6	$10.8	$73.7	$57.5	-$16.2
2023	$7.4	$72.7	$65.3	$14.7	$65.1	$50.4
2024	$2.5	$86.8	$84.3	$9.9	$76.4	$66.5
2025	$2.4	$102.2	$99.7	$4.9	$88.9	$84.1
2026		$124.7	$124.7	$2.4	$107.2	$104.8
2027		$154.7	$154.7	$2.3	$131.2	$128.9
2028		$158.5	$158.5	$2.3	$134.7	$132.5
2029		$171.9	$171.9		$145.9	$145.9
2030		$184.6	$184.6		$156.5	$156.5
2031		$196.6	$196.6		$166.5	$166.5
2032		$208.0	$208.0		$176.1	$176.1
2033		$218.8	$218.8		$185.1	$185.1
2034		$229.1	$229.1		$193.8	$193.8
2035		$238.9	$238.9		$202.0	$202.0
2036		$248.3	$248.3		$209.8	$209.8
2037		$257.2	$257.2		$217.4	$217.4
2038		$265.8	$265.8		$224.5	$224.5
2039		$273.9	$273.9		$231.4	$231.4
Private IRR			***4%***			***2%***

Source: Authors' calculations. See text and Appendix A.

Table 11B:
Estimates of the Private Costs and Benefits of Contactless by Year and Scheme
Millions of 2021 International Dollars

Year	**Visa**			**Mastercard**		
	Costs	**Benefits**	**Net Benefits**	**Costs**	**Benefits**	**Net Benefits**
2002				$19.8		-$19.8
2003						$0.0
2004						$0.0
2005	$44.1		-$44.1	$11.0		-$11.0
2006	$17.8		-$17.8	$10.7		-$10.7
2007	$52.1		-$52.1	$20.8		-$20.8
2008	$57.9		-$57.9	$13.6		-$13.6
2009	$60.9		-$60.9	$13.5		-$13.5
2010	$30.1		-$30.1	$3.3		-$3.3
2011			$0.0			$0.0
2012	$19.3		-$19.3			$0.0
2013	$19.0		-$19.0	$37.9		-$37.9
2014	$24.9		-$24.9	$65.3		-$65.3
2015	$12.3		-$12.3	$27.7		-$27.7
2016	$54.9		-$54.9	$45.8		-$45.8
2017	$27.0	$105.2	$78.3	$42.0	$74.2	$32.3
2018	$20.5	$181.2	$160.7	$43.9	$139.5	$95.5
2019	$28.8	$279.0	$250.2	$34.6	$227.7	$193.2
2020	$17.1	$413.0	$396.0	$39.8	$313.2	$273.4
2021	$35.3	$517.9	$482.6	$27.2	$393.2	$366.0
2022	$7.6	$682.2	$674.6	$20.3	$503.3	$482.9
2023		$871.9	$871.9	$4.9	$633.2	$628.3
2024		$1,109.7	$1,109.7	$5.0	$803.1	$798.1
2025		$1,331.3	$1,331.3	$2.4	$948.5	$946.1
2026		$1,582.6	$1,582.6	$2.4	$1,111.9	$1,109.6
2027		$1,871.7	$1,871.7	$2.3	$1,296.7	$1,294.4
2028		$1,770.3	$1,770.3	$2.3	$1,237.7	$1,235.4
2029		$1,892.6	$1,892.6		$1,317.5	$1,317.5
2030		$2,009.6	$2,009.6		$1,393.4	$1,393.4
2031		$2,121.7	$2,121.7		$1,465.7	$1,465.7
2032		$2,229.2	$2,229.2		$1,534.7	$1,534.7
2033		$2,332.6	$2,332.6		$1,600.7	$1,600.7
2034		$2,432.1	$2,432.1		$1,663.9	$1,663.9
2035		$2,527.9	$2,527.9		$1,724.5	$1,724.5
2036		$2,620.3	$2,620.3		$1,782.7	$1,782.7
2037		$2,709.5	$2,709.5		$1,838.6	$1,838.6
Private IRR			***26%***			***27%***

Source: Authors' calculations. See text and Appendix A.

Table 12:
The Total Social Costs, Benefits, and Internal Rate of Return by Innovation
Millions of 2021 International Dollars

Year	**Contactless**			**Tokenization**		
	Costs	**Benefits**	**Net Benefits**	**Costs**	**Benefits**	**Net Benefits**
2000	$25		-$25	$742		-$742
2001	$60		-$60	$552		-$552
2002	$143		-$143	$802		-$802
2003	$43		-$43	$619		-$619
2004	$243		-$243	$686		-$686
2005	$294		-$294	$834		-$834
2006	$335		-$335	$959		-$959
2007	$899		-$899	$1,100		-$1,100
2008	$422		-$422	$861		-$861
2009	$487		-$487	$795		-$795
2010	$378		-$378	$1,040		-$1,040
2011	$557		-$557	$1,238		-$1,238
2012	$579		-$579	$1,383		-$1,383
2013	$598		-$598	$1,486		-$1,486
2014	$634		-$634	$1,809		-$1,809
2015	$650		-$650	$2,162		-$2,162
2016	$845		-$845	$2,050		-$2,050
2017	$2,795	$2,894	$99	$2,194		-$2,194
2018	$6,607	$5,171	-$1,436	$3,076		-$3,076
2019	$3,133	$8,342	$5,209	$6,147	$19,440	$13,293
2020	$5,674	$12,261	$6,587	$5,075	$16,773	$11,698
2021	$3,433	$16,521	$13,088	$5,570	$17,944	$12,374
2022	$2,118	$19,464	$17,346	$5,880	$24,295	$18,415
2023	$1,857	$24,282	$22,425	$4,488	$26,998	$22,510
2024	$1,859	$29,975	$28,116	$5,002	$30,469	$25,468
2025	$1,756	$36,221	$34,465	$5,588	$33,495	$27,907
2026	$1,670	$43,508	$41,838	$6,489	$37,307	$30,818
2027	$1,599	$52,064	$50,465	$7,720	$42,022	$34,302
2028	$1,539	$53,618	$52,079	$7,860	$43,954	$36,094
2029	$1,484	$58,841	$57,356	$8,431	$46,883	$38,452
2030	$1,436	$64,008	$62,572	$8,977	$49,690	$40,712
2031	$1,390	$69,125	$67,735	$9,497	$52,383	$42,886
2032	$1,349	$74,195	$72,846	$9,993	$54,972	$44,979
2033	$1,311	$79,222	$77,912	$10,463	$57,463	$47,001
2034	$1,275	$84,210	$82,935	$10,912	$59,864	$48,952
2035	$1,241	$89,160	$87,919	$11,339	$62,179	$50,840
2036	$1,210	$94,076	$92,866	$11,748	$64,416	$52,668
2037	$1,180	$98,959	$97,779	$12,137	$66,577	$54,441
2038				$12,509	$68,669	$56,160
2039				$12,864	$70,695	$57,831
Social IRR			***28%***			***19%***

Source: Authors' calculations. See text and Appendix A.

Table 13A:
Private and Social Internal Rates of Return by Innovation
Costs and Benefits Attributed to Each Scheme

		Visa		Mastercard	
		Private	**Social**	**Private**	**Social**
Tokenization	Baseline	4%	34%	2%	31%
	Upper Bound	7%	34%	6%	32%
Contactless		26%	39%	27%	34%

Source: Authors' calculations. See text and Appendix A.

Table 13B:
Private and Social Internal Rates of Return by Innovation
Costs and Benefits Attributed to Each Scheme
With Visa and Mastercard Patent Shares Revised to Match Third-Party Sources

		Visa		Mastercard	
		Private	**Social**	**Private**	**Social**
Tokenization	Baseline	6%	33%	5%	31%
	Upper Bound	10%	34%	9%	32%
Contactless		37%	48%	27%	35%

Source: Authors' calculations. See text and Appendix A.

Table 14:
Social Benefit to Social Cost Ratios

	Attributed to Visa	Attributed to Mastercard	Total Social
Tokenization	12.0	11.8	9.7
Contactless	13.7	10.8	27.9

Source: Authors' calculations. See text and Appendix A.