An Ancient Ancestor of the U.S. Secured Overnight Financing Rate Determination: The Florin Fix

G. Geoffrey Booth
Eli Broad College of Business, Michigan State University, USA
and
Tommy and Victoria Baker School of Business, The Citadel, USA

Iordanis Karagiannidis *
Tommy and Victoria Baker School of Business, The Citadel, USA

The Secured Overnight Financing Rate (SOFR), defined by the U.S. Alternative Reference Rates Committee (ARRC) and now used by the U.S. Federal Reserve instead of the London Interbank Offer Rate (LIBOR) because of a loss of faith in its veracity, has clear and strong historical roots. Its calculation is closely related to that of the florin-denaro daily exchange rate that the Arte del Cambio (moneychangers guild) developed and implemented in the Repubblica Fiorentine (Florence) city-state located in what is now Italy from 1252 to 1532. This paper explores the how SOFR is defined and calculated by the U.S. Federal Reserve and its economic and mathematical relationship to what has become known as the Florin Fix, i.e., the calculation of Florences' exchange rate between its gold florin and silver billon denari.

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* Iordanis Karagiannidis. Mailing Address: Tommy and Victoria Baker School of Business, 118 Bastin Hall, The Citadel, 171 Moultrie Street, Charleston, SC 29409, U.S. Email address: iordanis@citadel.edu. Phone number: 1 (843) 953-4963. The authors thank Bryan J. Kazley, Thomas Kerrigan, and Deborah Scortino for sharing their institutional insights concerning the implications of the change of Libor to SOFR on the U.S banking and investment industry. We also thank Cynthia C. Craig and Lenisa V. Chang for their expert Italian to English translations of relevant text and archival documents. We are indebted to Mercedes Carrara for a tour of Florence's historical financial districts (plazas) and their nearby banks. She not only supplied valuable insights into the history and culture of the city, but also was instrumental in introducing the research team to Giampiero Nigro (International Institute of Economic History "F. Dantini", Prato). We thank him for hosting an evening meeting at his residence, during which he pointed out many important facts and nuances of Florence's domestic exchange rate system that was in effect during the study. Elizabeth B. Booth, Angela Orlandi and Francesco Ammannati, also in attendance, made many insightful contributions during this enlightening roundtable discussion. Finally, we thank Richard T. Baillie, Sanders S. Chang, and Umit G. Gurun for many years of discussions concerning the empirical and theoretical behavior of the florin-denaro exchange rate. All errors, however, are the authors' responsibility.

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"Does the past have useful economics? Of course it does."
(McCloskey, 1976, p. 545)

I. Introduction

A modern nation-state requires that its central bank routinely assesses the effect of its monetary policies on the economy. One aspect of this assessment process typically involves comparing market interest rates to the central bank's desired rate, which is determined by its policy. Because of a plethora of market interest rates present in each nation-state, its central bank uses a benchmark rate (i.e., a calculated summary interest rate) and compares this rate to its desired interest rate. From 1986 until recently, the benchmark rate for many countries has been the London Interbank Offer Rate (LIBOR).[1]

Libor is the cost of large banks borrowing from each other over short time intervals using a specific currency and repaying the loan in the same currency. Although the loan is not secured, the default risk associated with the transaction is very small, but other risks that involve time, liquidity, and an uncertain future may be present.

Libor fixing began in 1986 under the auspices of the British Banker's Association (BBA) and involved three currencies (U.S. dollar, British pound sterling, and Japanese yen).[2] Hou and Skeie (2014) report that the number of currencies increased over the years so that by 2012, the BBA

1. London Interbank Offer Rate is referred in print either as LIBOR or Libor. The first is an abbreviation and the second is a noun. In the literature they are used interchangeably.

2. In financial parlance, the term "fixing" in this context refers is setting the official price of a tradeable asset or an exchange rate (ratio) between two monetary units. The "fix" occurs when the price is officially set.

was providing Libor rates for the euro and ten other currencies.[3] Each currency was available in 15 tenors (maturities) ranging from overnight to one year. In 2012, major changes were made to Libor in response to a gradual loss of faith in its being a reasonably accurate benchmark interest rate. The coup de grâce for these changes was a rate-setting scandal that became known in 2012 but it was traced back to the 2007-2008 credit crunch.[4]

The scandal involved several large banks that for many years had provided incorrect interest rate data with the intention of influencing Libor to increase their profitability (Vaugham and Finch, 2017).[5] As a result, the debt contracts based on Libor were mispriced and the public trust in the financial markets was severely damaged. Many believed that Libor process could have been modified to stop the inappropriate behavior of the banks involved and did not need to be replaced (e.g., Wheatley, 2012; Duffe and Stein,2015; Coulter, Shapiro and Zimmerman, 2018; Duffe and Dworczak, 2021). Nevertheless, to regain the market's trust, the U.S. and the other countries that relied on Libor and contributed to its calculation decided to create a new system

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3. Twenty countries of the 27 European Union countries adopted the euro (€) as their official currency. These, in alphabetical order, are Austria, Belgium, Croatia, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Lativia, Lithuania, Luxembourg, Malta, the Netherlands, Portugal, Slovakia, Slovenia, and Spain. Six of the nations (Bulgaria, Czechia, Hungary, Poland, Romania, and Sweden), however, will adopt the euro once they fully meet the binding economic and legal requirements set forth in the 1992 Maastrich Treaty. This process is required because the six countries are not original members of the European Union. The seventh country, Denmark, is a member of the European Union, but it has decided to keep its historical currency (the krone). The krone, however, is currently pegged to the euro.

4. Keenan (2012), a former Morgan Stanley trader, reports that he witnessed Libor manipulation as early as 1991. McBride (2016) contends that colluding began in 2000 to make trader positions profitable. Further, Mollenkamp (2012) claims that the New York Federal Reserve Bank knew about flaws in the Libor system in 2007 and proposed solutions to British authorities in 2008, but no action was taken at that time.

5. The list includes well known banks such as Barclays, City Group, Deutsche Bank, JPMorgan Chase, Rabobank and Royal Bank of Scotland. According to Fernando (2022), authorities in the United States and the United Kingdom levied a total of $9 billion in fines and criminal charges on the banks that were known to have participated in the fraud and some of their traders were fined, imprisoned or both. A study by Verity (2023) reveals that many traders were pressured by senior management to engage in this activity, negating the notion that the illicit behavior was conducted solely by rogue traders.

of reference rates that would not only be much harder to manipulate but also would be better sign of current economic conditions. As a temporary corrective measure, in 2013 the number of Libor benchmark rates was reduced to five currencies (British pound sterling, Euro, Japanese Yen, Swiss franc, and the U.S. dollar) and seven tenors instead of 15. This turned out to be a challenging task and it took a decade to accomplish. Stenfors and Lindo (2018) point out that, before the task was finished, Libor faced a lack of activity in its underlying markets that supplied its needed interest rate information, thereby reducing its interest rates' usefulness as benchmarks.

At the end of June 2023, The U.S. completed changing its benchmark interest rate for loans denominated in U.S. dollars from Libor to the Secured Overnight Financing Rate (SOFR). Many other countries that used Libor replaced their benchmark rate as well. These include Europe (€STR: Euro Short-Term Rate), Japan (TONAR a.k.a. TONA: Tokyo Overnight Average Rate), Switzerland (SARON: Swiss Average Rate Overnight), and the United Kingdom (SONIA: Sterling Overnight Index Average). SOFR and SARON are loan rates that are secured; the other four rates are not secured. The institutions in charge of determining these rates are, respectively, the Federal Reserve Bank of New York, Bank of England, European Central Bank (assisted by the Deutsche Bundesbank, Banco Espana, Banque de France, and Bank d'Italia), SIX Swiss Exchange, and Bank of Japan.[6] Each of the above benchmark rates meet the standards set forth by the International Organization of Securities Commissions (IOSCO).[7]

The purpose of this paper is to place the method in which Federal Reserve Bank of New York currently calculates SOFR in a historical context. This is accomplished by tracing its roots back to the Late Middle Ages and the Arte del Cambio (moneychangers guild). The Guild was domiciled in the city-state of Florence, and one of its functions was to

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6. SIX is the abbreviation for Swiss Infrastructure and Exchange. The Swiss Exchange is owned by the SIX group, which is an unlisted public company that is controlled by 122 banks and other financial institutions.

7. IOSCO is located in Spain and currently consists of 234 members who regulate more than 95 percent of the world's security markets in 130 jurisdictions, which include all the major emerging markets (IOSCO, 2022). Its purpose is to 1) protect investors, 2) ensure that markets are fair, transparent, and efficient, and 3) reduce systematic risk (IOSCO, 2023). It accomplishes its task by reviewing and approving/disapproving changes to a market's microstructure. If it disapproves of a change, it indicates the reason and may make revision suggestions to make the change acceptable.

determine the exchange rate between its gold and silver-based coins. De Roover (1963) maintains that during the late Middle Ages and the early Renaissance, Florence became Europe's main banking center and its banks routinely transacted with their branches and sometimes the branches of other banks that were in major cities such as Barcelona, Bruges, and London. The guild was also responsible for minting Florence's coins. Thus, in some ways the Arte del Cambio performed the functions of a central bank. Bruckner (1958, 1969) expands Roover's belief and speculates that Renaissance Italy was the birthplace of the modern business world. Heller (2011) agrees with these positions and argues that Florence not only began the transition from feudalism to capitalism, which led to the industrial revolution (1780-1850), but also it created commercial links with other northern Italian cities (e.g., Geneo, Milan and Venice). As a result, it dominated European wholesale markets in the 13th through 15th centuries by controlling the markets for raw materials and outlets for manufactured goods. In addition, Florentine banks created new financial instruments and land and sea trade networks were developed and routinely used throughout Europe, Levant and the Maghrib (Heller, 2011).

The remainder of this paper is divided into three main sections. Section 2 reports how SOFR is determined. Section 3 describes the procedures used to calculate the florin-denaro exchange rate (dubbed the Florin fix by Booth and Chang, 2017a, 2017b, which in modern Italian translates to Fiorino d'Oro Fisso). Both sections mention some pertinent recent quantitative research relating to their respective measures. Concluding remarks are provided in the fourth and final section.

II. Secured Overnight Financing Rate (SOFR)

A. What is SOFR

The Federal Reserve Bank of New York (2022, 2023) oversees the calculating and publishing SOFR, an interest rate that measures the cost of borrowing U.S. dollars overnight using U.S. Treasury securities as collateral. This market is used by banks that need to borrow overnight to meet their liquidity needs as well as their reserve requirements. This repurchase venue was chosen to supply transaction data because it is very

robust with daily trades currently (first six months of 2023) amounting to around 1.5 trillion dollars, making interest rates exceedingly difficult to manipulate by any of the market participants either singly or in a small group.

Two different versions of SOFR are available to the public. The first and least complex is the "daily simple SOFR" and the second is "term SOFR." The first version (the one considered in this article) is defined as the volume-weighted median of the annualized daily repurchase agreement interest rates. "Volume-weighted" recognizes that all repurchase agreements are not the same and the important concept is the dollar value of the transactions and not the number of transactions, and "annualized" communicates the magnitude of the interest rate in a more recognizable form. SOFR is available to the public every business day at approximately 8:00 a.m. ET and, if an error was made or missing data found, it is revised at 2:30 p.m. on the same day. The data used to make this calculation are from the previous day. Thus, simple SOFR is a backward-looking calculation and concept.[8]

The data required for the calculation are provided from the Bank of New York Mellon and the U.S. Treasury's Office of Financial Research (OFR). The information includes all trades that OFR obtains, i.e., transactions made at the General Collateral Function (GCF) rate as well as repurchase agreements cleared through the Delivery versus Payment (DVP) service provided by the Fixed Income Clearing Corporation (FICC). DVP removes those contracts that they consider special, e.g., contracts that exhibit lower lending rates because of cash providers wanting a specific security to back the loan. This process complies with IOSCO's Principles of Financial Benchmarks, and a statement of compliance is issued annually. The Federal Reserve Bank of New York's Auditing Group is responsible for this statement and the gathering of appropriate data to support it. This group operates independently and reports directly to the bank's Board of Directors to mitigate any outside influences.

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8. In contrast, term SOFR is forward looking and is an important factor in the calculation of the value of interest rate derivatives and swaps. Currently, it is being calculated and made available by the Chicago Mercantile Exchange (CME), and its approach is endorsed by the Federal Reserve Bank of New York's Alternative Reference Rates Committee (AARC) and is compliant with IOSCO's principles. Currently, term SOFR is available in 30-, 60-, 180- and 360-day tenors (CME Group, 2023).

B. Recent SOFR Research

In addition to the Federal Reserve Bank of New York's research on SOFR to understand its viability as a benchmark (e.g., Anbil, Anderson and Senyuz, 2020; Bowman, 2019; Heitfield and Park, 2019), several important academic papers have emerged that compare it to Libor. For instance, Jermann (2019) develops a hypothetical model and reports that during normal times SOFR and Libor behave similarly but in periods of stress they may not, thereby supporting Schrimf and Shusko's (2019) conjecture the movement of the two interest rates may not be synchronous.

Fassas (2021) also confirms this behavior by finding that although SOFR and Libor usually behave similarly, SOFR tends to be more volatile when markets are under stress. Indriawan, et al. (2021), however, demonstrate that SOFR more closely follows the Federal Reserve's stated policies and U.S. short term rates are more responsive to SOFR than Libor. Finally, Schlögl, Skov and Skovmand (2023) develop a model that is capable of handling short-term dynamics. They demonstrate that the daily SOFR observations are characterized by discontinuities when the Federal Open Market Committee meets. This phenomenon lessens as the tenor of SOFR increases.

III. The Florin Fix Rate

A. Florence and the Medici Bankers

Florence was founded by the Romans in what is now Italy in 59 BCE. It was conquered by Charlemagne in 774 and became part of Tuscany. In 1115 the Florentines rebelled and won the right to become an independent republic (Repubblica Fiorentina). Its cultural achievements in art and literature became the foundation of the European Renaissance, and its economic development focused on international trade and, to a large extent, was the result of its citizens' entrepreneurship and the city's banking system. Pagett (2010) points out that Florentines invented or used many business practices that are still used today, e.g., double-entry

bookkeeping, the partnership system, and limited liability.[9] Once the florin became the "coin of the realm" in 1252, Florence continued to face many social, political, and economic difficulties. These include the bubonic plague, internal major disputes, rebellions, external wars, and political intrigue. Nevertheless, in 1397, Giovanni Medici relocated his small bank from Rome to Florence. Prior to the move, he was one of the better papal bankers, but in 1410 he became one of the top papal bankers having developed close friendship with the sitting pope (John XXIII). On top of this papal patronage, he built a banking dynasty that is still talked and written about in the 21st century (Goldwaithe, 1987). In 1434 the Medici family and allies, under the lead of Cosimo Medici (son of Giovanni) assumed ownership of the Medici banks. Shortly after, the Medici and their allies took control of Florence's governing bodies and ruled the city until 1494.

The next 18 years was a period of social turmoil. For example, some residents believed that the city-state was becoming less religious than it had been in the past. Circa 1497, this belief enabled Savonarola, a Dominican friar, to collect valuable items such as art, jewelry and books whose usage mightlead to sin, from all the residents and then publicly burn them in the center of town for all to witness. Supposedly this bonfire would lessen the anger of their Christian God.

The Medici family regained control in 1512 but lost it again 15 years later as the result of still another war that involved Spain. In 1530, with the help of some important allies, including the Holy Roman Empire, the Medici clan returned to power. Alessandro de' Medici ruled Florence in 1531 and in 1532 Pope Clement VII (a.k.a. Giulio di Giuliano de' Medici) appointed him the Duke of the Duchy of Florence.[10] Alessandro was assassinated in 1537, and Pope Clement VII responded by appointing Cosimo de' Medici to be the Grand Duke of Tuscany, a region in north central present Italy that includes Florence in its center. Cosimo resigned in 1574, but a member of the Medici dynasty served in this position until 1737. Padgett and Adams (2011) posit that

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9. Although Luca Bartolomeo de Pacioli (1447-1517) is usually referred to as the father of accounting and double-entry bookkeeping, Lee (1973, 1977) and Basu and Waymire (2023) provide strong evidence that bookkeeping was used in Florence as early as 1211.

10. As an aside, Machiavelli (1532/1897) published his masterwork, The Prince, in 1532. He wrote it to instruct princes and similarly ranked individuals how to govern. Its theme is straight forward: The ends justify the means.

the dominance of the Medici was their ability to create a strong family network not only within Florence but also with France, Spain, and other Italian city-states.[11]

B. The Guilds

Businesses were grouped together to form 21 guilds (arti). Seven of these guilds, which included the banking and finance guild (Arte del Cambio), were designated as major (maggiori) guilds while the remaining 14 guilds were referred to as minor (minori). At various times during the Republic's existence, the top five of the 14 minor guilds were considered a separate middle group (Mediane). These guilds can also be classified as craft or merchant. Individuals that were not a member of one of the guilds wereconsidered to belong to the popolo minuto. This group made up slightly more than fifty percent of Florences's population and consisted of many skilled workers such as laborers, and peddlers, and weavers. By today's standards, the economic distribution of the city-state's wealth would be considered highly unequal. For example, Alfani and Ammannati (2017) show that Florence's economic inequality as measures by the Gini Coefficient (Ceriani and Verme, 2012), which measures how income and opportunity are allocated in a population, typically ranged between 0.5 and 0.6 from 1300 and 1500, although there was a noticeable dip in the late 1330's because of the Bubonic Plague.[12]

The Arte del Cambio was a self-regulating business organization and social unit that focused on monetary transactions involving the local community and interregional trade. Becoming a member of the guild

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11. The Medici saga did not end in the 18th Century. In 2019 Lorzeno de' Medici and Ed Boyle launched the Medici International Bank (Khatri,2021). Its head office is in Puerto Rico (San Juan) a with branches in New York City, Rio de Janeiro, and Tel Aviv. It is U.S. regulated and holds a International Financial Entity (IFE) license. In announcing the bank's establishment, Medici stated that "[t]he original Medici Bank of Florence, founded by my family in the 14th century, revolutionized the world's economy. Many of their innovations that drove the development of international commerce – like holding companies, double-entry bookkeeping, and letters of credit – are still in use."

12. To put this number in perspective, the latest data from the World Bank (2023) show that Slovenia has the most equitable income distribution with a Gini coefficient of 24.6 in 2018. South Africa is the least equitable with a coefficient of 63.0 (2014). The U.S. is the middle group of countries with a Gini Coefficient of 41.1 (2015).

was not an easy task. Applicants were required pass a rigorous exam that not only assessed their character but also tested their abilities to use commercial mathematics including, according to Van Egmond (1976), vigesimal and duodecimal counting systems and the Florentine monetary system and its relationship to its foreign counterparts.[13] In addition, they had to be related to a guild member and were required to pay an entry fee.

The Guild (Arte del Cambio) was governed by the Signoria of Florence (a civic government whose representatives were elected by all the city-state's guilds) and, in some ways, functioned as a central bank for Florence. Unlike today's central banks, the Arte del Cambio members did not directly use interest rates. Although there was a small Jewish community in Florence, the vast majority of the city-state's residents followed the dictates of the Roman Catholic Church, which at that time was very averse to using interest rates in a financial transaction. One of its several rationales was that a loan was a gratuitous contract, whichmeant receiving any payment more than the loan amount, which would occur if interest was charged, was considered a sin. According to the rules of the Roman Catholic Church that were in effect from the Crusades until the middle if the 16th century, a sin might be lessened if an indulgence was paid to the Church (Akpoigbe, 2021).[14]

It was, however, acceptable to profit from transactions involving bills

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13. According to Swetz (1987), there were at least a dozen schools located in Florence that taught commercial mathematics. The first known book that addressed this topic was written in 1478 by an unknown author.

14. There are two popular explanations why someone might want to purchase an indulgence. First, is the hope that it would signal God that he was sorry, and this would make his life on earth more tolerable. Second, as pointed out by Alighieri (1320/2003), who was Florentine by birth, in his epic poem, The Divine Comedy, it would lessen the time that the individual would spend in purgatory after his death before being allowed in Heaven. Nevertheless, many people did not approve of indulgences, including Martin Luther, a German priest. In 1517, Luther posted 95 theses on the entry door of his church. One of the major themes covered involved indulgences. It is often believed that the trigger to this event was the actions of Johannes Tecelius, a Catholic priest who was authorized by to sell indulgences under the condition that the buyer was truly remorseful for his sinful behavior. Instead, Tecelius sold them to anyone that wanted one without any restrictions (Tarr and Randell, 2015).

of exchange.[15] Florentine banks, individuals and companies involved in trade or related transactions between regions that used different currencies often employed bills of exchange to exploit differences in exchange rates.

De Roover (1944), for example, reports that the Barcelona branch of a Florentine bank earned 31 percent of its gross profit from foreign exchange transactions. Booth (2009) finds that a Florentine bank with branches in Barcelona and Bruges from 1384 to 1411 earned a mean annual gross return of 12.8 percent return for bills of exchange originating in Barcelona and ending in Bruges and 14.3 percent for those originating in Bruges and ending in Barcelona. De Roover (1963) indicates that from 1437 to 1464 transactions of the Medici bank between London and Venice returned, on an annual basis, -5.5 to 28.8 percent. For transactions originating in Barcelona and ending in Bruges, the annualized returns ranged from -5.0 percent to 39.7 percent. The corresponding returns for Bruges to Barcelona were -7.39 and 48.8 percent.

Another example involves individuals who, for one reason or another, needed a small loan. In this case, an individual would contact a moneychanger, usually one that he had done business within the past. The moneychanger would grant the loan and at the same time initiate a bill of exchange to a known counterparty in another region to exploit the difference in exchange rates between his counterpart's region and Florence. The profit made on the cashless exchange was the moneychanger's interest earned on the loan.

C. The Monetary System

The Republic of Florence's bimetallic monetary system from 1252-1532 was based on the fiorino d'oro (florin), a gold coin typically weighing about 3.5 grams and three coins (denaro, quattrino and grosso). These three coins were considered petty coins and were a mixture of silver

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15. Braudel (1981) points out that money and written agreements have been existence since at least 2000 BCE but that this arrangement disappeared during the so-called "Dark Ages". Thus, bills of exchange were a Florentine re-innovation that permitted the non-physical exchange of monies, thereby eliminating the need to send gold and silver coins or bullion over distances. Not only did this save the cost of shipping and possible financial loss due to robbery, but it also dramatically reduced the transaction time.

and copper. This mixture is usually referred to as "billon" becasue the copper portion was always greater than 50 percent. Their exchange rate was fixed with one quattrino equal to four denari and one grosso equal to 30 quattrini. There was also a money of account system that incorporated the physical coins plus imaginary coins, which was based on the Carolingian Monetary Reform (Livre Carolinienne, 790-802). This system uses scores and dozens as its counting base, i.e., 1:20:12.

The florin was mainly used to facilitate trade among the lands surrounding the Mediterranean Sea and what has become known as Europe. Its main competitor was the Venetian ducat, which is remarkably like the florin in size and weight. The ducat was first minted in 1284 and circulated well into the 19th century. Together, the two gold coins filled the interregional role that the U.S. dollar does today for the nations of the world.

Transactions within Florence's city walls were conducted with florins, denari, and other Florentine silver billon coins (Spufford, 1988; Goldwaithe, 1987), although moneychangers sometimes dealt with coins from other regions. Transactions typically occurred on four plazas that were strategically placed to give easy access to the Florentine citizens, and physical banks were adjacent to these plazas. Moneychangers staked out a location in one of the plazas and placed their coins and account books on a narrow table (bench) that they brought with them. Once opened for business, they would engage in the physical exchange of coins, book entry exchanges or combinations of both. Each exchange that was made was associated with a commission to compensate the moneychanger for his service.[16] Regardless of the type of exchange, a written record was made so that all the transactions and their details

16. As mentioned in Booth and Chang (2012), the commission varied over time (even daily) and the variation could be large. A reasonable explanation for this behavior is that the trader not only thought of the commission as payment for the daily handling costs incurred in making the trade such as time, bookkeeping, failure to detect fraud but also to the possibility that news would arrive that would have to be compensated for in one way or the other. Today the compensation for this possibility would be incorporated in the bid-ask spread. This interpretation of the commission is that it equivalent to the bid-ask spread.

would be accurately reported to the Arte del Cambio.[17] It was not uncommon for a florin to be slightly altered by shaving a minute strip of gold from its edge. Thus, if the transaction involved receiving a physical coin, the moneychanger examined it carefully not only to determine its authenticity but also to ensure that it was the official weight.

The official gold-silver coin exchange rate was posted daily by the Arte del Cambio as required by Florentine statute law (Conservatori della Zecca [Governers of the Mint], 1493).[18] At the end of each trading day, all moneychangers located in the city of Florence were required to provide detailed written information to the guild manager concerning all the transactions that they made on that day.[19] Failure to do so resulted in severe fines that could be as large as a year's income.[20] The guild officials averaged the exchange rate of all the transactions supplied to them. The average was deemed the official exchange rate for the next business day and was posted for public consumption. This daily rate served as a reference point for transactions throughout the day. As the trading day progressed and added information arrived, transaction prices changed in response to this information. These changes would be reflected in the next trading day's reference rate.

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17. If for some reason the moneychanger did not have enough physical coins to honor a withdrawal, he went out of business acknowledged this event by breaking his bench. Zimmer (2023) suggests that this action may have led to the term "bankruptcy". He reasons that *banca* in the Italian vernacular used by Florentines at that time in with conjunction *rotta* translates to "broken bench". *Rotta*, however, is derived from the Latin word *ruptus*. As a result, when translated to English in the 16th century, *banca* plus *ruptus* became bankrupt

18. The original document is housed in the *Archivio di Stato di Firenze* and is a handwritten document contained in *Deliberazioni, Zecca*, 1491-1494. According to Bernocchi (1978), the 1493 microstructure design is the same that existed 1252.

19. Money changers located outside the city limits were exempted from this requirement.

20. If fictious reporting or other serious infractions of the Guild's rules were detected, the punishment could be much worse by today's standards. For example, the moneychanger involved might be subjected to the rack or the strappado. Both types of torture are extremely painful and involve the separation of one or more body joints. Booth and Chang (2012) facetiously suggested that, if such punishment was permitted in the 21st century, there might not have been a Libor scandal.

D. Recent Studies

There are several recent research studies that have investigated the time series behavior of the Florin Fix. Booth and Chang (2017) examine and analyze the Florentine reference rate protocol from a game theoretic perspective and find that it results in a Nash equilibrium. Assuming that individual money changers and the Guild are profit maximizers, they show in a static game framework that when information diffusion is low (high) and money changers receive noisy (more accurate) signals, in equilibrium uninformed (more informed) money changers use (do not use) the official rate in their transactions. If there is full information diffusion, the exchange rate is efficient and Guild profits are maximized. They demonstrate that if the game is dynamic (and it likely was), over time the reference rate is efficient without any further input from the Guild.

Using daily florin-denaro exchange rates from 1389 to 1432, Booth and Chang (2017a) conclude that an information shock takes six to seven months to be fully absorbed in the market, suggesting that the Florin protocol leads to weak-form efficiency. It might be argued that this is a long time for inefficiency to last. However, Da Uzzano (1442), De Roover (1963) and Booth, Booth and Broussard (2014) point out that information transmission was much slower than today's markets. Moreover, some of the Arte del Cambio members were relatively large banks. Because of their interregional scope and corresponding networks, large banks (banco grosso), although slow to receive information, received it more quickly than the other guild members (small banks [banco minuto] and individual moneychangers). Using the same data, Booth and Gurun (2008) show that the florin-denaro bid-ask spread (transaction price less commission) is positively related to the volatility of transaction prices. In addition, Ballie, Booth, and Chang (2014) report that an Autoregressive Fractionally Integrated Moving Average (ARFIMA) model is a good choice to model the time series behavior of the florin-denaro time series because this specification yields the best out-of-sample forecasts better than more simple time series models.[21]

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21. From an economic perspective, the fractional integrated (FI) component of the series measures nonstationary behavior, and the autoregressive moving average (ARMA) contribution models a time series stationary evolution. Baillie, Booth and Chang (2013), also estimated threshold autoregression model (TAR). This model permits an autoregressive (AR) model to switch from one AR model to another AR model as time progresses. The TAR model fit the data well, but it was rejected because its residuals displayed dependency, making the model for unsuitable for forecasting.

IV. Final Commentary

As delineated in Sections 2 and 3, the Florin fix and SOFR share three important characteristics. First, both are backward-looking rates because they are computed using the previous day's information. Second, ignoring the "special" exceptions permitted by SOFR and a similar rule by the Arte del Cambio, both calculation procedures use all of transactions available. Third, both are secured transactions, with the Guild overseeing of the honesty of the moneychangers and SOFR being associated with a repurchase agreement. Finally, both use some type of measure of central tendency of their respective recorded rates to arrive at the next day's posted benchmark rate. SOFR is calculated as a volume-weighted median. In contrast, Florentine records indicate that the exchange rates provided by the moneychangers are averaged and volume is not mentioned even though it was most likely reported. Thus, there could be a difference in the way that the rates that the two rates are "averaged".

Regardless of how the Arte del Cambio calculated its "average", it did choose a mathematical measure of central tendency, and, by doing so, deserves the recognition of designing and using the ancientancestor of the Secured Overnight Financing Rate (SOFR). Moreover, this recognition supports the belief of many economic historians that Florence gave birth to an economic system that today is called capitalism.

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