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Volatility clustering and the bid–ask spread: Exchange rate behavior in early Renaissance Florence

G. Geoffrey Booth [a,*], Umit G. Gurun [b]

[a] *Eli Broad Graduate School of Management, 315 Eppley Center, Michigan State University, East Lansing, MI 48823, United States*
[b] *School of Management, University of Texas at Dallas, United States*

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Abstract

This paper investigates the nature and behavior of the domestic (local) currency market that existed in Florence (Italy) during the late 14th and early 15th centuries (a.k.a. the Early Renaissance). We find that the extant volatility and microstructure models developed for modern asset markets are able to describe the statistical volatility properties observed for the denaro-florin exchange rate. Volatility is clustered and is related to the bid–ask spread. This supports the notion that, although there are huge social, industrial and technological differences between capitalism then and now, individuals trading financial assets in an organized venue behave in a similar manner.

JEL classification: G10; N23; P12
Keywords: Volatility clustering; Bid–ask spread; Exchange rate; Renaissance

1. Introduction

Over 40 years ago Mandelbrot (1963) commented that price of assets commonly traded on financial markets are often characterized by large changes following each other without regard to whether these changes are positive or negative. Since his observation, this phenomenon, now dubbed volatility clustering, has been empirically documented numerous times for a variety of assets including commodities, equities and currencies.

Although the presence of volatility clustering has been well established, its linkage to trading costs via the bid–ask spread has not been as extensively explored. Several market microstructure models (e.g., Admati and Pfleiderer, 1988; Easley et al., 1997; Kelly and Steigerwald, 2004), however, offer plausible interpretations. These models assume asymmetric information and are concerned with how prices incorporate information using some type of trading scheme. All of the models are predicated on today's financial infrastructure and are devised by economists trained in today's generally accepted paradigm, which is based on the 18th century notion of human rationality.

* Corresponding author. Tel.: +1 517 353 1745; fax: +1 517 432 1080.
E-mail address: boothg@msu.edu (G.G. Booth).

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Do these explanations only pertain to modern times or do they hold true for capitalistic financial markets in general? The purpose of this paper is to answer this question. Our approach is to look to northern Italy in the 14th and 15th centuries, where and when modern capitalism and financial markets were in their infancy.[1] These Italians were sophisticated merchants and bankers who created large companies for their time, each having an extensive network of foreign branches that facilitated commerce throughout Europe as well as the Levant and the Maghreb.[2] Communication within the company networks was typically accomplished by written correspondence, and most large companies had their own couriers.[3] In this environment, foreign and domestic currency exchange markets flourished. How were these currency markets organized? Are they institutionally similar to today's financial markets? If so, do today's extant models describe the economic workings of these markets? In particular, what was the nature of the exchange rate volatility and, more precisely, did these markets exhibit volatility clustering and was this volatility associated with the cost of trading?

We investigate these questions by examining the domestic currency market that existed in Florence during the Early Renaissance, which, along with Genoa and Venice, was considered a major northern Italian trading center. The purpose of this market was to facilitate the exchange of two monies (one gold and the other containing silver and base metals) minted by the Florentine government. This bimetallic system was unique to Florence and Venice, and the relative value of the gold and silver-content coins fluctuated on a daily basis. We find evidence that volatility clustering in exchange rate changes exists and, as Bollerslev and Melvin (1994) predict, is positively related to the bid–ask spread. This finding is consistent, for example, with Admati and Pfleiderer (1988) who suggest that the clustering of noise trading leads to the clustering of informed trading. The latter, in turn, leads to the widening of the bid–ask spread by the dealers to compensate for the increase in informed trading.

We divide the remainder of this paper into four sections. The immediately following section provides a description of the Florentine domestic currency market. This includes an overview of the city-state's monetary system as well as the way its exchange market was organized and where it was located. We present and discuss the data in Section 3. The Section 4 reports the relevant empirical analyses and results, and Section 5 offers the concluding remarks.

2. An early Renaissance economy

2.1. The Florentine Environment

Around the turn of the 15th century, the City of Florence boasted a population in the neighborhood of 50,000 and its territory, which included towns under its rule, was home to slightly more than 600,000 individuals. de Roover (1963), among others, speculates that Florence was Europe's leading banking center, with the Medici Bank (1397–1494) being one of the most prominent banking institutions. In addition, being the birthplace and home of Donatello (1386–1466), Leonardo da Vinci (1452–1519), Michelangelo (1475–1564), among others of valued artistic stature, the city arguably was the cultural center of the western world, an achievement largely due to the economic success of the Florentine business families and their willingness to be patrons of the arts as well as protectors and guiders of the interests of the Roman Catholic Church. Veseth (1990, p. 20) argues that even among northern Italians the Florentine people were considered to be worldly and creative. He asserts that they were motivated by individual self-interest and "… provide[d]

[1] Earlier examples of capitalistic behavior exist. For instance, Hallo and Simpson (1971, p. 89) report that some residents of Ur in the early Old Babylonian period (2000–1900 BC) not only profited from trading but also from domestic lending, and Van De Mieroop (1992) indicates that there was a market for promissory notes denominated in silver during the same period. Nevertheless, it was under the Italian hegemony that the foundations for modern business were laid. In this environment important innovations such as double-entry bookkeeping, codified mercantile law, and the partnership organization emerged. Formal education in commercial mathematics was provided in "reckoning" schools. The focus was on arithmetic and its applications to practical business problems. Probability was not covered because it was not formally "discovered" until the middle of the 17th century. According to Swetz (1987), in the middle of the 14th century Florence boasted 13 schools, an institution that Poitras (2000) suggests is the precursor to the modern university business school. Taking even a broader view, Brucker (1958) provides evidence that Renaissance Italy may well have been the birthplace of the modern world.

[2] The Levant is a region now containing Syria, Lebanon, Jordan, Palestine, Israel and parts of Turkey and Iraq. Modern day Morocco, Algeria and Tunisia define the Maghreb.

[3] Origo (1957, p. 99), in a chronicle of the life of Datini (1335 – 1410), a Medieval merchant banker, reports that it was not uncommon for messages to be sent twice a day from Florence to the fairs in Champagne region. These fairs brought together merchants from northern Italy and those from European cities located north of the Alps.

the spark, the special fifth element that caused the growth of wealth and knowledge that we call the Renaissance."[4] Along the same lines, Braudel (1984, p. 621) remarks that the Florentine economy as early as the 13th century exhibited many forms of capitalism.

2.2. The monetary system

Florence used a bimetallic monetary standard based on the florin (a gold coin with the *fleur-de-lis*, the emblem of the city, stamped on one side and *Florentia* on the other) and *moneta di piccioli* (petty coins). The latter consists of two silver coins, the denaro and the quattrino with the face value of the quattrino equal to four denari. Each petty coin contained different amounts of silver and a base metal.[5] Another silver coin, the grosso, was also in circulation. According to Bernocchi (1978), one grosso was the equivalent of 30 denari and was more widely used than the quattrini because of its higher silver content. The number of coins in circulation was not regulated by the Florentine government, although it did so indirectly by determining the coins' silver content. Thus, after accounting for the seigniorage imposed by Florence's Republican Mint, if the monetary value of the coin was higher than its commodity value, bullion was minted into coins. If the reverse were the case, coins were melted and once again became bullion.[6] Unlike the gold and silver bimetallic systems that existed in the 19th and 20th centuries, there was no mandated exchange rate between the gold and silver coins. Thus, this domestic (local) exchange rate fluctuated according to market conditions.

The limited number of coins as well as their changing values made the physical monetary system inadequate for record keeping so that a system of "money of account" was established. This system, consisting of real (physical) and imaginary (ghost) coins, was based on the 1:20:12 multiple scheme established by Charlemagne (742–814) after his coronation in 800. The gold florin was divided into 20 *soldi a oro* (of gold), and this imaginary coin was equal to 12 *denari a oro*.[7] In contrast, the imaginary silver coins were multiples of the *denaro di piccioli* with 12 of this coin being the equivalent of one *soldi di piccioli*, 20 of which are equal to one *lira* (pound) *di piccioli*.

Florence's economic structure was based on a guild system containing 21 guilds of varying economic importance. By guild statute, members of the cloth finishers', money-changers', cloth and silk manufacturers', grocers', and furriers' guilds transacted their business and kept their books in florins. Members of all other guilds were required to deal and reckon in *piccioli*. This split resulted in wholesale prices being quoted in gold and retail prices set in silver. International transactions were conducted using florins and, according to Cippola (1956, p. 21), the florin was considered, along with the Venetian ducat, the U. S. dollar of its time in terms of general acceptance. Wages were typically paid in silver regardless of the type of business.

According to Brucker (1971, p. 2), wages at the turn of the century for the typical worker ranged from 30 to 60 quattrini per day and for a senior civil servant the salary might be as much as a florin, which, if settled weekly in quattrini, would require 150 to 1150 physical coins. Everyday living expenses could generally be conveniently handled in silver. Spufford (1988, p. 335), however, points out that it is apparent that ordinary people used gold as well as silver. For instance, de la Roncière (1976, pp. 310–313) reports that not only were skilled craftsmen sometimes paid by the job in gold and but also peasants who seasonally sold their produce at harvest time often used gold as well. In sum, both businesses and individuals were in regular need of the money-changer's services, and it is reasonable to believe that the

[4] The term "fifth element" first applied to Florentine merchants is attributed to Pope Boniface VIII in 1300. According to Veseth (1990, p. 19), the Pope's statement reflects the popular view that the people of Florence had a spark that enabled them to combine the then known four physical elements (earth, air, water and fire) in innovative ways. Cronin (1967, pp. 25 – 26) suggests that this spark is boldness tempered by prudence, exactness, and honesty. These latter traits may be the result of the strong humanistic influences on Florentine society that are aptly described by Holmes (1969, pp. 37 – 67). Humanistic philosophy emphasizes the dignity and worth of the individual and the achievement of self-worth through reason.

[5] The florin contained 3.5 g (approximately) of 24 carat gold (currently worth about $50–60). The precious metal content of the two petty coins was less that 50%; e.g., in the period of our study the denaro was 8.3% silver and the remainder was copper. The technical name of this silver–copper alloy is billion and its dark gray color gives rise to the coins made of this metal being called "black" money. Cipolla (1983) refers to this money as "small change".

[6] Cipolla (1983) describes how differences in face and commodity value can lead to coin shortages in a chapter he colorfully calls "The Affair of the Quattrini."

[7] A parallel scheme consisting of entirely imaginary coins was sometimes used. In this system, the florin was equal to 1.45 *lira affiorino*. See Evans (1931) for additional details of the Florentine monetary system. He also discusses other medieval monetary systems and mentions that the Venetian system is similar to the one used in Florence.

abilities to gather, process and act on information concerning the local exchange rate differ not only between these two groups but within them as well.

2.3. The money-changers

de Roover (1963) points out that the fluctuations in the local exchange rate provided those engaged in money changing with a ready source of generous profits. These money-changers can be classified as belonging to either small (local) banks (*banchi a minuto*) or to large (international) banks (*banchi grossi*). Detailed descriptions of these banks may be found in Goldthwaithe (1985) and de Roover (1963), respectively.

Local and international banks were controlled by their guild (*Arte del Cambio*) in which membership of individual money-changers was mandatory. Much like modern day security exchanges and other similar trading venues, the guild was a self-regulatory body. Membership certified that the money-changer was honest, financially sound and obeyed the guild's rules. The guild, however, was restricted to monitoring only the local banking activities of international banks. The foreign operations of these banks were governed by merchant custom, and their activities included not only financing trade but also providing financial services to European royalty and the Roman Catholic Church.[8] In the period that we are concerned with, approximately 70 banking houses existed in Florence. Typically, representatives of these banking houses were open for business Monday through Saturday. Exceptions included holidays (of which they were many), inclement weather, and epidemics.

Money-changers transacted their business in the center of Florence near the *Mercato Nuovo* and *Mercato Vecchio* (New and Old Market, respectively), around the *Or San Michele*, and at the *Oltr*'*Arno*, the latter being located across the Arno River from the other three.[9] The money-changer sat behind a desk or counter (typically covered with a green cloth) on which were placed his open account book and small inventory of coins. All business had to be conducted in his shop. He attended to his customers by always being willing to physically exchange coins or to make transfer payments via book entries.[10] Transactions not only involved Florentine gold and silver coins alone but also exchanges between these monies and those issued by other city-states.[11] Detailed records were kept and archived. In the case of a dispute, they were open to the guild manager to assist in its resolution. Failure of the money-changer to submit these records on a daily basis resulted in a fine, with the amount of the fine depending on the number and extent of prior transgressions.

2.4. Price formation

At day's end, the official exchange rate and a trading commission were established and announced in the four local markets. This rate plus the accompanying commission were used by all of the money-changers acting as a single

[8] Royal families often used international banks to finance their wars. Although this type of lending was risky, banks accommodated this need because not only did these families pay the amount of interest that the banks believed was commensurate with the risk but also the royalty and their entourages were the primary customers of Florentine exports. A loan default, however, could be catastrophic. For instance, in 1343, King Edward III of England defaulted, resulting in the bankruptcy of several large Florentine banks with losses totaling 1,700,000 florins by 1346 (Cronin, 1967, p. 25). The Roman Catholic Church used Florentine banks to transfer papal monies throughout its domain and by doing so ensured that Florentine banks were international in scope. The Church also used these banks to help them collect the taxes that the Holy See imposed throughout Latin Christendom.

[9] The *Mercato Nuovo* venue was also used by merchants to trade shares of the *Monte Commune*, i.e., Florentine public debt. Villari (1901, p. 327) points out that merchants speculated on the rise and fall of these shares and that there was a 2% tax levied on each transaction.

[10] Paintings of money-changers are not uncommon. Examples are Reymerswael's "The Banker and His Wife" (*Museo Nazionale*, Florence) and "The Money-Changer and His Customer" (Royal Gallery, Windsor Castle). The former depicts the money-changer at his table counting and sorting coins with his wife observing. The latter shows a customer carefully watching the money-changer recording the transaction after, presumably, accepting a pile of coins. Both paintings are reproduced in de Roover (1948, immediately following pp. 206 and 270, respectively).

[11] Transactions with gold on both sides were often initiated by written order and specified a future settlement. Large sums were typically involved and the exchange rate was set to include a return in lieu of an interest payment. This payment was used to avoid the charge of usury, an approach that was accepted by the theologians of the time because of the perceived risk in foreign exchange transactions. For descriptions of this interface between money-changing and lending (often referred to "dry exchange"), see de Roover (1963, Ch. VI) and Parks (2005, pp. 39 – 46). Langholm (1992) provides a seminal work describing scholasticism, the Christian-based economic school of thought prevalent in the Early Renaissance. Interest rates and theology are thoroughly discussed. A briefer, but well done, discussion is provided by Poitras (2000) in the context of the early history (1478 – 1776) of financial economics.

economic unit for all their transactions throughout the next trading day. According to Bernocchi (1978), the official rate was created by the money-changers first submitting their estimates of the next day's "true" exchange rate to the guild manager. The manager then calculated the official rate by taking the arithmetic average of all submitted prices, of which there may be one or many.[12] This approach differs from a pure Walrasian auction because price revisions based on learning the competitors' exchange rate estimates did not occur. Thus, it is possible that money-changers acted as a cartel or used some sort of tacit price leadership mechanism. We conjecture that the latter is more likely because guild rules did not require that a money-changer submit a daily price and because not all money-changers had equal access to information. Bernocchi (1978) is silent concerning how the commission to be charged to the customer was calculated, but as we discuss in the data section that immediately follows, it was most likely calculated in a similar fashion. In any case, the Florentine exchange rate market may be considered a single dealership market that uses an end-of-the-day price-fixing scheme.[13] Thus, we can think of the trading environment as one in which the bid and ask quotes are valid for a complete day rather than for seconds, minutes and so forth.

We can only conjecture how the money-changers arrived at their estimates. Presumably, the exchange rate estimate was based on their view of the relevant domestic and foreign fundamentals and trading pressures, with the commission being set to cover the costs of doing business. These costs include those associated with maintaining their inventory of coins and bullion, order-processing costs, and costs relating to information-based trading with (more) knowledgeable individuals (informed traders) as opposed to trading with individuals who seek liquidity (uninformed traders). Thus, it is sensible to believe that they considered short-run local and regional factors such as the seasonal needs relating to harvests, fairs, paydays, and shopping patterns. Irregularly occurring factors, such as the intercity flow of coins and unanticipated (good or bad) business events, are also likely to have entered their estimation calculus.[14]

In addition, the general economic environment must have been a concern. For instance, Florence was at war with Milan and then Naples (with the assistance of Genoa) from 1390 until 1413. Brucker (1969, pp. 80–81) provides quotes from business correspondence dated between 1400 and 1404 that indicate that trade was severely affected by the war and was exacerbated by the recurrence of the Black Death (bubonic plague) in 1400. After a decade of peace, hostilities again broke out with Milan and lasted for more than 20 years. This war resulted in the establishment of the *catasto*, a hybrid wealth and income tax established in 1427. Quotes from the *catasto* records, also provided by Brucker (1969, p. 85), indicate that the Florentine economy was severely depressed throughout the 1420s.

Undoubtedly, the money-changers also factored in the opening and closing of foreign mines as well as the long run trends in gold and silver movements among regions. Watson (1967) points out Christian Europe was shipping silver to the Muslim world and receiving gold in return, partially to accommodate the balance of trade and partially to exploit the difference in the relative values of the two metals.[15] This resulted in a silver bullion shortage throughout Europe for a score of years beginning in 1400. de Roover (1963, pp. 31–32) maintains that the denaro-florin exchange rate steadily but slowly rose as the result of the continuous debasement of the silver monies.

Regardless of what factors the money-changers considered to arrive at the rate that they submitted to the guild manager, the information coming from outside Florence was one or more days old. Would the fact that the information may have been out of date have affected the denaro-florin price formation process? We do not think so, because it is a local exchange rate and Florence was its supereminent market. If there were material markets located elsewhere, the denaro-florin exchange rates in these markets might have diverged from those quoted in Florence because of

[12] Bernocchi's (1978) description of how the official rate was calculated is based on a document dated May 21, 1493 that reports a discussion held by the Conservators of the Mint concerning the way in which the daily rate was set. He asserts that this procedure had been in effect for a century or longer.

[13] Price-fixing schemes are used today. For example, gold and silver prices are set twice a day by the London Bullion Market Association. Using a Walrasian call process, representatives of the major precious metal traders determine a price that clears the market. These prices serve as a worldwide benchmark for trades until the next price fixing. Another example is that U. S. mutual funds set their price at the close of the day and this price is used for all transactions from the previous day's close. Prior to 1967, the fund price that was set at the end of the day was used for transactions occurring during the next trading day.

[14] Brucker (1969, pp. 74 – 75) indicates Florentine merchants had to deal with losses due to shipwrecks, pirates and bandits, broken agreements, and theft. As an example of theft, in 1387 a factor of the Pecora Company embezzled 1,500 florins using letters of credit in order to support his gambling activities, an act that seriously compromised the firm's finances.

[15] Watson (1967) points out that from 1000 to the middle of the 13th century Europe minted very little gold but was awash in silver coins. The opposite was true in the Arab world. This situation reversed itself during the following 250 years. As he mentions, however, it is important not to consider these two regions a closed system. The roles of India and China also need to be included.

information being incorporated in the rates at different times.[16] This would result in the risks associated with arbitrage having to be considered.

3. Data

Daily data are provided by Bernocchi (1978).[17] Using documents from the State Archives of Florence (folio *Miscellanea Repubblicana*, bin 33), he constructs a series of exchange rates from January 4, 1389 to February 11, 1432 with 10,514 observations. The documents consist of three registers containing data supplied by various money-changers (sometimes named) and compiled by an unknown archivist. The formats of these registers are different, and notations made in the beginning of the first register and the end of the third indicate that there were other registers for the periods before and after our sample. However, these registers either did not survive or have not yet been found.

Bernocchi (1978) points out that these exchange rates are the actual market prices for the gold florin. Two daily rate quotations are recorded in terms of soldi and denari for the quattrino prior to February 1418 and for the grosso beginning on this date.[18] One is a gross rate and the other is a rate net of commission. In a very few instances (43), the gross rate is less than or equal to the net rate. This means either that the money-changers gave their customers a risk-free source of profits until the money-changers went bankrupt or closed down their tables or that they provided them a free service. Neither of the two outcomes is plausible, and, thus, we cannot offer an explanation for these perverse observations other than data transcription errors were made at some time. These entries are omitted, leaving 10,471 observations for analysis. There are 933 instances when the gross rate and commission did not change from one day to the next. Moreover, there are 825 cases when the gross rate changed but the commission did not and 1364 occurrences when the commission changed and the gross rate did not.

A sample of Bernocchi's (1978) data is provided in Table 1. The rates are for January and February 1389 and are partitioned by week, with the first day of each week being Monday (*Lunedi*). Sundays (*Domenicha*) and holidays (in this case, *las festa di Befania* and so forth) are marked. Occasionally a rate is recorded after the last day in a week or the last day in a month. These are simply the average period price. Both rates vary over time, typically in multiples of 1/5 of a denaro, and the commission is not constant. Thus, the structure of the data indicates that the net rate is the bid rate, i.e., the rate at which the dealer was willing to buy a single gold florin in terms of silver coins, and the gross rate is the midpoint between the bid and ask rates. By way of illustration, on Wednesday, January 13, 1389 the gross exchange rate of one gold florin was 75 soldi, 2 denari and the commission was two denari. This means that the bid rate was 75 soldi and the ask rate was 75 soldi, 4 denari. The bid–ask spread, therefore, is twice the commission. In our case, the spread amounts to 0.44% of the gross rate, using the imaginary equivalence of one soldo and 12 denari.

4. Empirical analysis and results

We begin by plotting the daily gross rate of the denaro-florin exchange rate and its return, the latter defined as the first difference of the natural logarithm of the exchange rate, in Fig. 1. According to Panel A, the exchange rate contains

[16] In the 19th and early 20th centuries, the value of the dollar was not the same throughout the U. S. The two major "foreign exchange" cities were New York and New Orleans. Garbade and Silber (1979) show that the establishment of a telegraph connection between New Orleans and New York in 1848 increased the speed of communication between the two cities, which, in turn, led to a significant narrowing of the inter-market dollar price differences in bills of exchange. As explained by Perkins (1975), these bills of exchange were purchased by foreign exchange dealers from exporters (mainly from the southern states) and then sold them to importers (primarily located in the northern states).

[17] Financial data prior to 1800 suitable for rigorous time series analyses are rare. Sardy (1968) provides daily foreign exchanges rates between several city states during approximately the same period of our study, but the observations are highly irregular, making them more suitable for monthly (perhaps weekly) rather than daily analysis. In addition, some annual and monthly exchange rate data are available. See Spufford (1986) and Rutgers University's Scholarly Communication Center's (www.scc.rutgers.edu) Medieval and Early Modern DataBank as well as Weber (1996). This does not mean that data were not collected; they were. It means, however, either the data were not safely archived or that the archives have not been fully exploited. The former point is underscored by Origo (1957, p. vi) who reports that the now famous Datini (a well-known merchant banker in 14th century Prato and Florence) papers were lost for at least 300 years and were found "… in sacks in a dusty recess under the stairs" in his house in Prato, a subject city 15 miles from Florence.

[18] In the beginning of our sample period, the denaro was no longer being minted and the quattrino was the smallest denomination coin routinely being used. The conversion from quattrini to soldi and denari was accomplished using face values. The secular upward trend in the local exchange rate subsequently resulted in the grosso assuming this role.

Table 1
Bernocchi (1978) domestic exchange rate quotes: a sample page

1389							
GIENNAIO	Day	Net rate	Gross rate	FEBRAIO	Day	Net rate	Gross rate
Lunedi	4	s. 75 d. 2 2/3	s. 75 d. 4 5/6	Lunedi	1°	s. 75	s. 75 d. 2
	5	s. 75 d. 2 ½	s. 75 d. 4 5/6		2	fu nostra Donna	
	6	fu la festa di Befania			3	s. 75	s. 75 d. 2
	7	s. 75 d. 2	s. 75 d. 4 1/5		4	s. 75 d.–½	s. 75 d. 2 ½
	8	s. 74 d. 10 ½	s. 75 d.–3/5		5	s. 75 d.–½	s. 75 d. 2 ½
	9	s. 74 d. 10 4/5	s. 75 d.–4/5		6	s. 75 d.–½	s. 75 d. 2 ½
	10	fu domenicha			7	fu domenicha	
		s. 74 d. 11 s. 75 3/5					
				Lunedi	8	s. 75 d. 1	s. 75 d. 3
Lunedi	11	s. 74 d. 11	s. 75 d.–3/5		9	s. 75 d. 2	s. 75 d. 4 ½
	12	s. 74 d. 11 2/5	s. 75 d. 1 2/5		10	s. 75 d. 1 ½	s. 75 d. 3 ½
	13	s. 75	s. 75 d. 2		11	s. 75 d. 1	s. 75 d. 3 1/5
	14	s. 74 d. 11 4/5	s. 75 d. 2		12	s. 75	s. 75 d. 2
	15	s. 74 d. 11 2/5	s. 75 d. 1		13	s. 74 d. 11 3/5	s. 75 d. 1 3/5
	16	s. 74 d. 11 2/5	s. 75 d. 1 1/5		14	fu domenicha	
	17	fu domenicha					
				Lunedi	15	s. 74 d. 10 3/5	s. 75 d.–3/5
Lunedi	18	s. 74 d. 11	s. 75 d. 1		16	s. 74 d. 6 2/5	s. 74 d. 8 2/5
	19	s. 74 d. 11	s. 75 d. 1		17	s. 74 d. 7	s. 74 d. 9
	20	s. 74 d. 10 4/5	(s.) 75 d. 1 2/5		18	s. 74 d. 7	s. 74 d. 9
	21	s. 74 d. 10 3/5	s. 75 d.–4/5		19	s. 74 d. 7	s. 74 d. 9
	22	s. 74 d. 11 1/5	s. 75 d. 1		20	s. 74 d. 6	s. 74 d. 8
	23	s. 74 d. 10 2/5	s. 75 d.–3/5		21	fu domenicha	
	24	fu domenicha					
				Lunedi	22	s. 74 d. 6 3/5	s. 74 d. 8 3/5
Lunedi	25	s. 74 d. 11	s. 75 d. 1		23	s. 74 d. 6	s. 74 d. 8
	26	s. 74 d. 11	s. 75 d. 1		24	fu l'Apostolo	
	27	s. 74 d. 11 2/5	s. 75 d. 1 1/5		25	fu Berlinghacio	
	28	s. 74 d. 11	s. 75 d. 1 1/5		26	s. 74 d. 6	s. 74 d. 8
	29	s. 74 d. 11	s. 75 d. 1		27	s. 76 d. 6	s. 74 d. 8
	30	s. 75	s. 75 d. 1 4/5		28	fu domenicha	
	31	fu domenicha					
		s. 75 d. 1 ½				s. 75	

Source: Bernocchi (1978, p. 4). Quotes are for one gold Florin in terms of silver soldi (s.) and denari (d.), with 12 denari equaling one soldo. "Day", "Net rate" and "Gross rate" are added for clarity. The difference between these two exchange rates is the commission. The English translation follows Italian word or phrase in parentheses: *Giennaio* (January), *Febraio* (February), *Lunedi* (Monday), *fu domenicha* (it is Sunday), and *fu la festa di Befania* (it is the festival of Befania) and so forth. The entry for February 27 illustrates a transcription error.

an upward time trend, which documents the long-run depreciation (0.25% per year) of the quattrino and then the grosso expressed in denari relative to the florin, whose gold content remained essentially the same. Panel B clearly shows that daily return volatility is clustered.

Some statistics describing the daily as well as weekly, monthly, and annual returns are provided in Table 2 and Fig. 2.[19] Linear dependence is present in daily, weekly and monthly returns but not annual ones. The unconditional daily return distribution is non-Gaussian, a result caused primarily by the empirical distribution's relatively thick tails. This thick-tailed phenomenon decreases in strength as the differencing interval increases and disappears for annual returns. Finally, ARCH effects are detected by the Lagrangian Multiplier test for all but the annual returns. As illustrated by the plots of the

[19] Noting the economic vs. statistical significance issue that is raised by the Lindley paradox, we generally select 0.1% ($p=0.001$) to be the critical value for the daily sample statistics, although a p-value less than 0.01 merits attention. For the weekly sample we use 1% ($p=0.01$) and in the remaining two instances we use the conventional 5% ($p=0.05$) critical value. By doing so, we are acknowledging that for very large samples the probability of making a Type II error is very small at conventional critical significance values. Thus, we make the critical value dearer in order to ensure that we do not overemphasize statistical significance at the expense of economic significance. We use $p=0.0000$ to represent a probability value smaller than 0.00005.

autocorrelograms for daily absolute and squared returns, substantial persistence is not present as these autocorrelations die out within 5–10 days.[20]

Nevertheless, these general time series characteristics of the denaro-florin exchange rate are similar to those typically observed in 20th century asset returns. They are also similar to the results found by the very few studies that have examined returns series from earlier periods. For example, Mitchell, Brown and Easton (2002) examine the daily returns of British consols from 1821 to 1860. They detect ARCH effects as well as linear dependence. Kearns and Pagan (1993) also report ARCH effects in monthly returns of the Australian stock market index for 1875 to 1925, as does Lundblad (2004) for U. S. monthly stock returns from 1836 to 2002.

A different perspective is given by the behavior of the daily bid–ask spread, or more conveniently, the half-spread (commission). We also plot this latter metric, which is expressed in relative terms (i.e., the difference between the logarithms of gross and net quotes), in Fig. 1. In many respects the half-spread plot is similar to that of the daily returns. In the half-spread case, however, the clustering is less dramatic and the spikes are more common. These physical characteristics are confirmed by the statistical test results given in Table 2. We conjecture that the seemingly high autocorrelations are due to the spikes. Equally important, however, is that the half-spread is mean stationary.[21] Operationally, this means that if money-changers receive more buy (sell) orders than sell (buy) orders, they might increase (decrease) their next day's estimate of the official rate in response to market pressure. They might also change the half-spread. If they did, the change would dissipate over time until the equilibrium half-spread was reached.[22] The money-changers, therefore, maintained an orderly market.

Bollerslev and Melvin (1994) construct a microstructure model that shows how price volatility and the bid–ask spreads are linked. Underlying their framework is the notion that the spread can be decomposed into inventory, order-processing, and adverse information cost components.[23] Expected price volatility is positively related to the cost of adverse information, which is incurred by the dealer when trading with informed customers. It is also positively related to inventory costs because of the risk caused by portfolio imbalances. Thus, an increase in expected volatility goes hand in hand with an increase in the bid–ask spread, or, in our case, the half-spread. In Bollerslev and Melvin's (1994) set up, the equilibrium relationship between the volatility and the spread is proportional as long as the information arises exogenously. They point out if the model is modified to include endogenous information, spread and volatility are still positively related, although the relationship between the two is more complicated than a simple proportion.

Recent empirical studies supporting this positive relationship include Hasbrouck (1999), Bollerslev and Melvin (1994) and Kalimipalli and Warga (2002), who show that this phenomenon exists in common stocks, foreign exchange rates and corporate bonds, respectively. Hasbrouck (1999) reaches his conclusion using a GARCH setup, while the other two studies use a two-step ordered probit analysis in which spreads are classified into distinct probability categories and GARCH models are applied to returns to provide an estimate of expected volatility.

We rely on these analyses to motivate our investigation of the daily behavior of the denaro-florin rate with respect to its volatility as reflected in the conditional volatility of its returns and its half-spread, both of which exhibit time

[20] This decay is much quicker than noted by Ding et al. (1993) in their analysis of the S&P 500 stock index., although it is similar to some of the examples provided by Karanasos and Kim (2006). The lack of strong persistence is confirmed by a Hurst coefficient (Whittle estimate) value of 0.4925. A value of 0.5 indicates no persistence.

[21] The Phillips–Perron test statistic value is − 141.0 ($p=10^{-4}$). The stationary of the half-spread is the result of the bid and the ask prices being determined by the same economic fundamentals, thereby ensuring that these two prices do not wander away from each other in the long run.

[22] Engle and Patton (2004) note that the bid–ask spread is stationary and is the result of being the cointegrating vector of unit root price processes. Following their lead, we construct a bivariate VECM with the error correction variable being the spread minus the average spread. The dependent variable in each equation is employed as a lagged explanatory variable. We also include a trade indicator variable that we construct using the Lee and Ready (1991) method. A value of +1 (−1) signifies that for any particular day the buying (selling) pressure outweighs the selling (buying) price impact. Similar to Engle and Patton (2004), we find that net buying (selling) pressure increases (decreases) both the bid and the ask prices. Nevertheless, we also find that the spread does not statistically change. Using Gonzalo and Granger's VECM component share metric (see Baillie et al., 2002 for details), we find that the price discovery function is primarily provided by the bid price (75.4% share) as opposed to the ask price (24.6% share), which indicates that the ask price responds more quickly to news than does the bid price. It is the bid price and not the ask price that was officially recorded by the money-changers' guild.

[23] Using the Lin et al. (1995) spread decomposition method, we find the adverse selection component of the half-spread is, on average, 31.7%. The portion attributed to order processing and inventory costs is 37.3%, while order persistence accounts for 31.0%. The latter percentage means that there is a 65.5% probability that a day that has more buyer (seller) than seller (buyer) initiated transactions will be followed by a similar day. These percentages are similar to those found for modern markets.

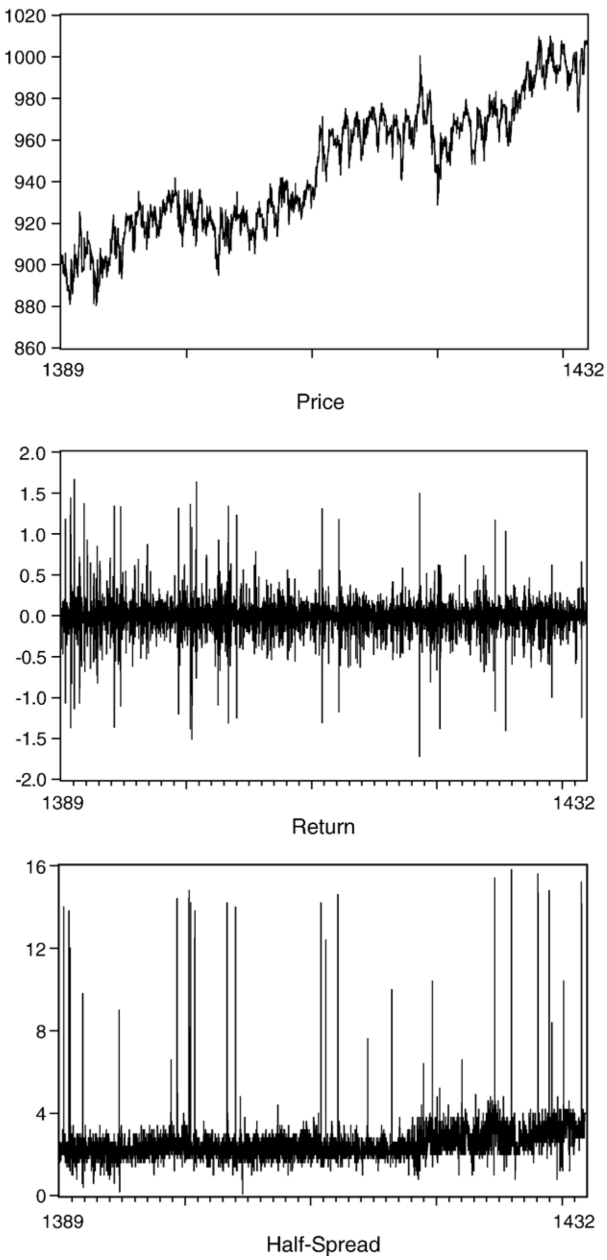

Fig. 1. Daily denaro-florin price, return and half-spreads, 1389–1432.

clustering. Following Bollerslev and Melvin's (1994) approach, we begin by fitting a MA(1)-GARCH (1,1) model to the return data that takes the following form:

$$R_t = \mu + \theta\varepsilon_{R,t-1} + \varepsilon_{R,t} \tag{1}$$

$$\varepsilon_{R,t} = z_{R,t}\sigma_{R,t} \tag{2}$$

$$\sigma^2_{R,t} = w + \alpha\varepsilon^2_{R,t-1} + \beta\sigma^2_{R,t-1}. \tag{3}$$

Table 2
Selected statistics for denaro-florin returns and half-spread

Statistics	Returns				
	Daily	Weekly	Monthly	Annual	Half-spread
No. of observations	10470	2187	516	40	10471
Shape and location					
Mean	0.001	0.005	0.021	0.251	0.005
	(0.4898)	(0.5066)	(0.4603)	(0.0907)	(0.0000)
Std. Deviation	0.152	0.356	0.657	0.916	0.002
Skewness	− 0.256	− 6.00	0.05	0.36	8.33
	(0.0000)	(0.0000)	(0.4920)	(0.3164)	(0.0000)
Kurtosis	26.66	7.10	3.74	4.13	125.45
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
Jarque–Bera	2.44×10^5	1567.48	11.85	3.02	6.66×10^6
	(0.0000)	(0.0000)	(0.0026)	(0.2212)	(0.0000)
Dependence					
Autocorrelation (1)	0.012	− 0.138	− 0.164	− 0.236	0.309
	(0.6500)	(0.0000)	(0.0002)	(0.0784)	(0.0000)
Ljung–Box Q (12)	33.95	69.31	89.36	17.79	1281.3
	(0.0007)	(0.0000)	(0.0000)	(0.1226)	(0.0000)
ARCH-LM (12)	126.10	9.58	2.52	0.31	26.75
	(0.0000)	(0.0000)	(0.0030)	(0.975)	(0.0000)

p-values are contained in parentheses below the statistic, with 0.0000 signifying a value less than 0.00005. The null hypotheses for the mean, skewness and kurtosis measures are that they are 0.0, 0.0 and 3.0, respectively. For the Jarque–Bera statistic, the null is that the distribution is Gaussian. The number in parentheses immediately to the right of the dependence statistic name is the number of lag terms. The nulls for autocorrelation and the Ljung–Box statistic are that there is no autocorrelation. For the ARCH-LM test the null is that there are no ARCH effects.

R_t represents daily return in period t, and $z_{R,t}\sim$ i.i.d. (0,1). We present the quasi maximum likelihood estimates of μ, θ, w, α and β in Table 3, column 2. Except for μ, all of the coefficients are highly significant ($p=10^{-4}$), and the sum of α and β is less than one, indicating a stationary volatility process. An ARCH-LM test performed on the standardized GARCH residuals indicates that the clustering has been fully accounted for by the model specification. Although these residuals remain relatively thick-tailed, they are not skewed, a characteristic that is shared with modern exchange rates. We use this model to provide our estimate of the conditional volatility of returns.

We specify our ordered probit model to express H^*, an unobservable continuous random variable that represents the probability that a specific value of the observed half-spread (H) occurs, as a function of conditional volatility ($\hat{\sigma}^2_{R,t}$). In particular,

$$H_t^* = \delta_0 + \delta_1\hat{\sigma}^2_{R,t} + \delta_2 H_{t-1} + \varepsilon_{H,t} \tag{4}$$

$$\varepsilon_{H,t} = z_{H,t}\sigma_{H,t} \tag{5}$$

$$\sigma_{H,t} = \exp(\gamma_1\hat{\sigma}^2_{R,t} + \gamma_2 H_{t-1}), \tag{6}$$

where $z_{H,t}\sim$ i.i.d. (0,1) and $\hat{\sigma}^2_{R,t}$ is generated by Eqs. (1), (2) and (3). H_{t-1} is included because the half-spread's autocorrelations, and Eq. (6) is formulated to account for heteroscedasticity in the half-spread. With the exception of H^*, all variables are expressed in logarithms.

We quantify H^* by constructing probability bins so that the probability of a value of H occurring is equal to the probability that H^* falls into the appropriate bin. We use three bins, with the mode defining the middle bin. The empirical bins in ascending numerical order contain H denari values less than 2.0, exactly 2.0, and greater than 2.0. These bins contain 7.86%, 23.38% and 68.76% of the observations, respectively. The most common half-spread value is 2.0 with 2,448 occurrences. The three corresponding probability bins for H^*, the latent variable, are completely described by λ (the delimeter separating the first and second bins is normalized to zero), which is estimated with the other model parameters.

Table 3, column 5, displays the ordered probit regression results obtained using LIMDEP. Four of the six parameter values are significantly different from zero with three at the $p=10^{-4}$ level. Most importantly, the estimated conditional

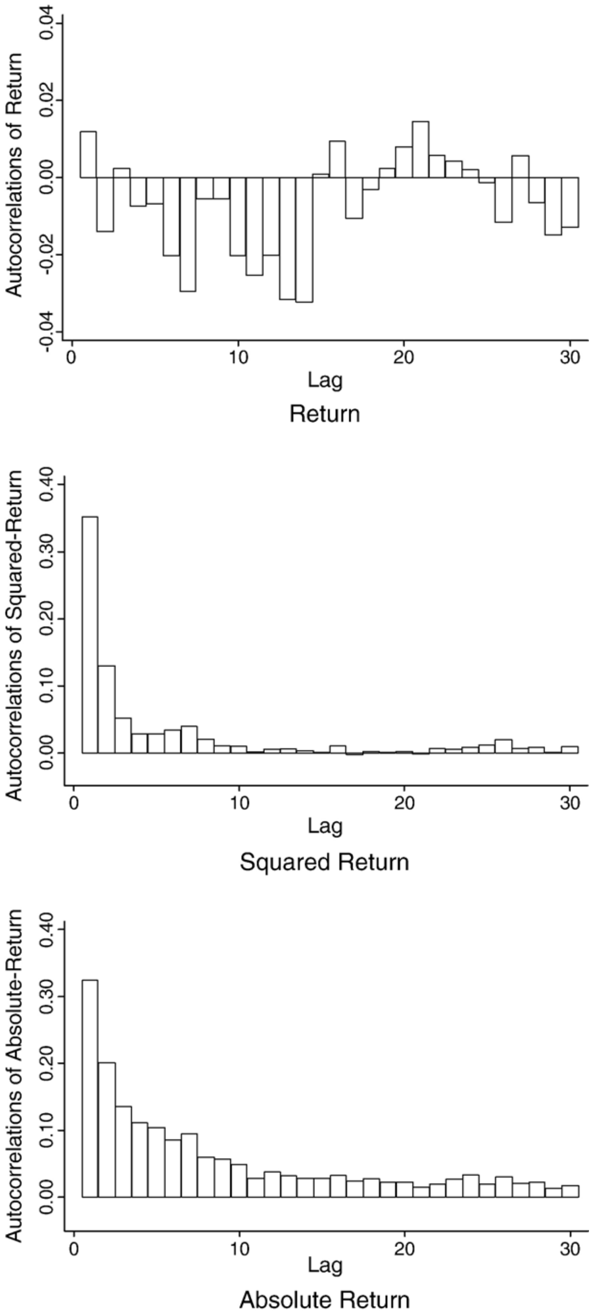

Fig. 2. Autocorrelograms of denaro-florin daily return, squared return and absolute return.

volatility is positively related to the half-spread. This means that increases in volatility of gross rate returns are associated with increases in the probability that half-spreads will fall into the higher probability bins. The opposite obtains if there is a decrease in the volatility. From this we infer that the observed volatility clustering characteristics of the denaro-florin half-spread and its gross returns are also related to each other because they both measure the impact of information.

To refine our analysis, we examine whether volatility clustering is affected by seasonal and cyclical factors. To this end we modify Eqs. (3) and (4) to include binary indicator variables to handle day-of-the-week and harvest effects. In a similar manner, we used different dummy variable configurations to investigate the impact of war. In no instance (results not reported) do we find that volatility clustering is affected by these events. We do find, however, that the

Table 3
Bollerslev and Melvin (1994) model results

MA (1)–GARCH (1,1)			Ordered probit		
(1)	(2)Initial	(3)*Catasto*	(4)	(5)Initial	(6)*Catasto*
μ	0.003	0.003	δ_0	0.014	0.136
	(0.0791)	(0.0658)		(0.7911)	(0.0148)
θ	0.155	0.168	δ_1	0.040	0.036
	(0.0000)	(0.0000)		(0.0002)	(0.0029)
ω	0.003	0.003	δ_2	1.034	0.965
	(0.0000)	(0.0000)		(0.0000)	(0.0000)
α	0.333	0.336	δ_3		0.613
	(0.0000)	(0.0000)			(0.0000)
β	0.623	0.6128	γ_1	0.172	0.138
	(0.0000)	(0.0000)		(0.0000)	(0.0000)
κ		− 0.001	γ_2	− 0.014	− 0.017
		(0.0045)		(0.4224)	(0.1586)
			λ	0.485	0.567
				(0.0000)	(0.0000)
Std. residuals					
ARCH-LM(12)	0.593(0.8498)	0.618(0.8272)			
Skewness	0.437 (0.7316)	0.343 (0.6620)			
Kurtosis	28.125 (0.0000)	26.719 (0.0000)			

p-values are contained in parentheses below the parameter estimate or statistic, with 0.0000 signifying a value of less than 0.00005. The MA(1)–GARCH (1, 1) parameters are defined in Eqs. (1), (2) and (3) and are found using quasi maximum likelihood estimation. The ordered probit parameters are identified in Eqs. (4), (5) and (6) with λ being the delimiter for the probit independent variables probability bins. κ and δ_3 are parameters for the *catasto* effect in Eqs. (3) and (4), respectively. The value of this indicator variable is one for 1427 onward and zero for earlier years. The MA(1)–GARCH (1, 1) *p*-values are calculated using the Bollerslev–Wooldridge robust standard errors. For the ARCH-LM test the null hypothesis is that there are no ARCH effects.

catasto, the hybrid wealth and income tax, impacts both the conditional return volatility and the half-spread, with the latter impact being observable in the far right hand portion of the half-spread plot in Fig. 1. In the analysis period, the wealth was determined by capitalizing money income (real and imputed) from all sources at the annual rate of 7%. Wealth related to business investments was defined to be invested capital plus accrued profits, and wealth related to *Monte Commune* stock (see fn. 9) was set by tax officials who were guided by its current market prices.

We report the GARCH and probit results that reflect the *catasto* in Table 3, columns 3 and 6. As indicated in column 3, the addition of a *catasto* variable (and its coefficient κ) reduces the conditional volatility of returns ($p=0.45(10^{-2})$). Other parameter values remain essentially unchanged. In the probit model, the *catasto* parameter, δ_3, is positive ($p=10^{-4}$). The value of δ_1, the $\hat{\sigma}^2_{R,t}$ parameter, remains about the same, although its *p*-value modestly increases to $0.29(10^{-2})$. That the effect is positive is supported by de Roover (1963, p. 99). He asserts that Florentine businessmen concealed assets in order to escape the tax and that this fraud became so extensive and pervasive that it eventually led to the elimination of the tax on business investments. Thus, our results suggest that the money-changers attempted to mitigate the impact of the *catasto* on their profits by increasing their commission (the half-spread). In other words, they turned the wealth-income tax into a de facto financial transactions tax and, although the money-changers paid the tax, the incidence (at least partial) of the tax fell on their customers.[24]

5. Conclusions

As McCloskey (1976) cogently argues, history has the potential to provide unusual settings in which to investigate economic theories. The domestic exchange market that existed in Florence (Italy) during the early Renaissance is such

[24] In a modern context, Wrobel (1996) points out that the proponents of this type of Tobin tax argue that it reduces speculation and hence price volatility. He goes on to suggest that imposing taxes on trades of intermediaries and market specialists may well result in them increasing their bid–ask spreads in order to pass the cost of liquidity on to their customers. Our results support this view. As mentioned by Werner (2004), empirical evidence to the contrary is sparse and questionable.

a setting. Florence employed an unusual bimetallic monetary system that permitted a flexible exchange rate between gold (florin) and silver-content (denaro) coins. Money-changers, who charged commissions, and customers exchanged monies in a single-dealer market that employed a daily price-fixing scheme. The dealers (money-changers), acting in concert, traded in several nearby markets within the city under the auspices of their guild, which ensured the financial and ethical credibility of their members.

The Florentine domestic currency market is similar in many institutional respects to modern financial markets. Its trading rules were clearly prescribed and enforced. Market participants dealt with economic uncertainties and they possessed different levels and kinds of information. They also exchanged monies for purposes not related to information. The similarity to modern financial markets extends to the statistical behavior of the denaro-florin exchange rate. We find that returns, i.e., the changes in the midpoint exchange rate, exhibit strong volatility clustering, especially in the case of daily data. We also find that volatility clustering occurs in the half-spread and that the volatilities from the two sources are positively related, supporting the notion that they measure relevant pricing information.

In sum, we find that these current economic models are able to describe the price dynamics of a financial market that existed 600 years ago when modern capitalism was in its early stages. This is so despite the dramatic social, economic and technological changes that occurred during the intervening six centuries. What appears to have not changed, however, is that in a capitalist environment individuals collectively trade rationally or, at least, act in a way that can be explained by assuming that they do (Friedman, 1953, p. 21) or that they internalize "non-rational" cultural behavior (Granovetter, 1985).

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