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Arbitrage: Historical Perspectives

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ABSTRACT

This article discusses the history of arbitrage from ancient times until the beginning of the twentieth century. The etymology and historical usage of the word 'arbitrage' and the associated 'arbitration of exchange' are traced. Opportunities for arbitrage trading in ancient times are related to the movement of goods over distance. The key role of the bill of exchange in arbitrage trading during the Middle Ages is identified and the connection to 'arbitration of exchange' discussed. A 17th century arbitrage involving the gold and bill of exchange markets is detailed. The connection between riskless arbitrage trading and the method of conducting arbitration of exchange in the 18th and 19th centuries, as reflected in merchant manuals of that period, is detailed. The article concludes with an overview of 19th century arbitrage trading in securities and commodities.

Keywords: Arbitrage; Bill of exchange; Arbitration of exchange; geographical arbitrage; triangular arbitrage; put-call parity.

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The concept of arbitrage has acquired technical and precise definitions in quantitative finance (see eqf03/003; eqf04/001; eqf04/017; eqf05/010). In theoretical pricing of derivative securities, an arbitrage is a riskless trading strategy that generates a positive profit with no net investment of funds. This definition can be loosened to allow the positive profit to be non-negative, with no possible future state having a negative outcome and at least one state with a positive outcome. Pricing formulas for specific contingent claims are derived by assuming an absence of arbitrage opportunities. Generalizing this notion of arbitrage, the fundamental theorem of asset pricing provides that an absence of arbitrage opportunities implies the existence of an equivalent martingale measure (see eqf04/002; eqf04/007). Combining absence of arbitrage with a linear model of asset returns, the arbitrage pricing theory decomposes the expected return of a financial asset into a linear function of various economic risk factors, including market indices. Sensitivity of expected return to changes in each factor is represented by a factor-specific beta coefficient. Significantly, while riskless arbitrage imposes restrictions on prices observed at a given point in time, the arbitrage pricing theory seeks to explain expected returns, which involve prices observed at different points in time.

In contrast to the technical definitions of arbitrage used in quantitative finance, colloquial usage of arbitrage in modern financial markets refers to range of trading strategies, including: municipal bond arbitrage; merger arbitrage; and convertible bond arbitrage. Correctly executed, these strategies involve trades that are low risk relative to the expected return but do have possible outcomes where profits can be negative. Similarly, uncovered interest arbitrage seeks to exploit differences between foreign and domestic interest rates leaving the risk of currency fluctuations unhedged. These notions

of risky arbitrage can be contrasted with covered interest arbitrage which corresponds to the arbitrage definition used in quantitative finance of a riskless trading strategy that generates a positive profit with no net investment of funds. Cash-and-carry arbitrages related to financial derivatives are other examples of arbitrages relevant to the quantitative finance usage. Tracing the historical roots of arbitrage trading provides some insight into the various and different definitions of arbitrage in modern usage.

Etymology and Historical Usage

The Oxford International Dictionary (1933) [25] defines arbitrage as: “The traffic in Bills of Exchange drawn on sundry places, and bought or sold in sight of the daily quotations of rates in several markets Also, the similar traffic in stock.” The initial usage is given as 1881. Reference is also directed to ‘arbitration of exchange’ where the definition is: ‘The determination of the rate of exchange to be obtained between two countries or currencies, when the operation is conducted through a third or several intermediate ones, in order to ascertain the most advantageous method of drawing or remitting bills.’ The singular position given to ‘arbitration of exchange’ trading using bills of exchange recognizes the practical importance of these securities in arbitrage activities up to that time. The Oxford International Dictionary definition does not recognize the specific concepts of arbitrage, such as triangular currency arbitrage or inter-exchange arbitrage, or that such arbitrage trading applies to coinage, bullion, commodities and shares as well as to trading bills of exchange. There is also no recognition that doing arbitrage with bills of exchange introduces two additional elements not relevant to triangular arbitrage for manual foreign exchange transactions: time and location.

The word ‘arbitrage’ is derived from a Latin root (*arbitrari*, to give judgment; *arbitrio*, arbitration)

with variants appearing in the Romance languages. Consider the modern Italian variants: *arbitraggio* is the term for arbitrage; *arbitrato* is arbitration or umpiring; and, *arbitrарer* is to arbitrate. Similarly, for modern French variants: *arbitrage* is arbitration; *arbitrer* is to arbitrate a quarrel or to umpire; and *arbitre* is an arbitrator or umpire. Recognizing that the ‘arbitration of prices’ concept underlying arbitrage predates Roman times, the historical origin where the word arbitrage or a close variant was first used in relation to arbitrating differences in prices is unknown. A possible candidate involves arbitration of exchange rates for different currencies observed at the medieval fairs, circa the time of the First Crusade (1100). The dominance of Italian bankers in this era indicates the first usage was the close variant, *arbitrio*, with the French ‘*arbitrage*’ coming into usage during the 18th century. Religious and social restrictions effectively barred public discussion of the execution and profitability of such banking activities during the Middle Ages, though account books of the merchant banks do remain as evidence that there was significant arbitrage trading.

Until well after the development of bourse trading in the 16th century, only the Italian merchant bankers, the Fuggers of Augsburg, and a few other significant houses large enough to have a correspondent network in the important banking centres were able to engage actively in arbitration of exchange. As late as the 17th century, important English sources on the Law Merchant such as Gerard Malynes, *Lex Mercatoria* (1622) [10], make no reference to arbitrage trading strategies in bills of exchange. In contrast, a similar text in Italian, *Il Negotiante* (1638) by Giovanni Peri [11], a 17th century Italian merchant, has a detailed discussion on exchange dealings. Peri states that profit is the objective of all trade and that the ‘activity directed to this end is subject to chance, which mocks at every calculation. Yet there is still ample space for reasonable calculation in which the possibility of adverse fortunes is never left out of account’ [19, p.327]. This mental activity engaged

in the service of business is called "*arbitrio*". Peri identifies a connection between speculation on future exchange rate movements and the *arbitrio* concept of arbitrage: 'the profits from exchange dealings originate in price differences and not in time' with profits turning to losses if re-exchange is unfavourable [11, p.150]. For Peri, the connection between speculation and arbitrage applies to commodities and specie, as well as bills of exchange.

The first published usage of 'arbitrage' in discussing the relationship between exchange rates and the most profitable locations for issuing and settling a bill of exchange appears in French in Mathieu de la Porte, *La Science des Négocians et Teneurs de Livres* (1704) [9, p.452]. From the brief reference in a glossary of terms by de la Porte, a number of French sources, including the section *Traité des arbitrages* by J. Mondoteguy in J. Le Moine, *Le Negoce d'Amsterdam* (1710) [8] and J. Savary, *Dictionnaire Universel de Commerce* (1730, 2nd ed.) [14], developed a more detailed presentation of arbitrage transactions involving bills of exchange. An important 18th century English source, M. Postlethwayt *The Universal Dictionary of Trade and Commerce* (1751) [12], is an expanded translation of Savary where the French word 'arbitrage' is translated into English as 'arbitration'. This is consistent with the linguistic convention of referring to arbitration instead of arbitrage found in the earlier English source M. Postlethwayt, *The Merchant's Public Counting House* (1750) [13]. This led to the common English use of the terms 'simple arbitrations', 'compound arbitrations' and 'arbitrated rates'. The practice of using arbitration instead of arbitrage continues into 19th century works by Patrick Kelly, *The Universal Cambist* (1811) [7] and William Tate, *The Modern Cambist* (1820) [15]. The latter book went into six editions.

Following the usage of 'arbitrage' in German and Dutch works in the 1860's, common usage of 'arbitrageur' in English appears with Ottomar Haupt, *The London Arbitrageur* (1870) [5], though

reference is still made to ‘arbitration of exchange’ as the activity of the arbitrageur. Haupt produced similar works in German and French that used ‘arbitrage’ to describe the calculation of parity relationships. A pamphlet by Maurice Cohn, *The Stock Exchange Arbitrageur* (1874) [3] describes “arbitrage transactions” between bourses but also uses “arbitration” to refer to calculated parity relationships. Charles Castelli, *The Theory of “Options” in Stocks and Shares* (1877) [1] concludes with a section on “combination of options with arbitrage operations” where arbitrage has exclusive use and no mention is made of ‘arbitration’ of prices or rates across different locations. With Henry Deutsch, *Arbitrage in Bullion, Coins, Bills, Stocks, Shares and Options* (1904) [4] ‘arbitration of exchange’ is no longer commonly used.

Arbitrage in Ancient Times

Records about business practices in antiquity are scarce and incomplete. Available evidence is primarily from the Middle East and suggests that mercantile trade in ancient markets was extensive and provided a number of avenues for risky arbitrage. Potential opportunities were tempered by: the lack of liquidity in markets; the difficulties of obtaining information and moving goods over distances; and, inherent political and economic risks. Trading institutions and available securities were relatively simple. Circa 1760 BC, the Code of Hammurabi dealt extensively with matters of trade and finance. Sumerian cuneiform tablets from that era indicate a rudimentary form of bill of exchange transaction was in use where a payment (disbursement) would be made in one location in the local unit of account, e.g., barley, in exchange for disbursement (payment) at a later date in another location of an agreed upon amount of that local currency, e.g., lead [20]. The date was typically determined by the accepted transport time between the locations. Two weeks to a month was a commonly observed time between the payment and repayment. The specific payment location

was often a temple.

Ancient merchants developed novel and complex solutions to address the difficulties and risks in executing various arbitrage transactions. Because the two payments involved in the ancient bill of exchange were separated by distance and time, a network of agents, often bound together by family or tribal ties, was required to disburse and receive funds or goods in the different locations. Members of the caravan or ship transport were often involved in taking goods on consignment for sale in a different location where the cost of the goods would be repaid [20, p.15-6]. The merchant arbitrageur would offset the cost of purchasing the goods given on consignment with payments from other merchants seeking to avoid the risks of carrying significant sums of money over long distance, making a local payment in exchange for a disbursement of the local currency in a different location. The basic cash-and-carry arbitrage is complicated by the presence of different payment locations and currency units. The significant risk of delivery failure or non-payment was controlled through the close-knit organizational structure of the merchant networks [21]. These same networks provided information on changing prices in different regions that could be used in geographical goods arbitrage.

The gradual introduction of standardized coinage starting around the 650 BC expanded available arbitraging opportunities to include geographical arbitrage of physical coins to exploit differing exchange ratios [20, p.19-20]. For example, during the era of the Athenian empire (480-404 BC), Persia maintained a bimetallic coinage system where silver was undervalued relative to gold. The resulting export of silver coin from Persia to Greece and elsewhere in the Mediterranean is an early instance of a type of arbitrage activity that became a mainstay of the arbitrageur in later years. This type of arbitrage trading was confined to money changers with the special skills and tools to measure

the bullion value of coins. In addition to the costs and risks of transportation, the arbitrage was restricted by the seigniorage and minting charges levied in the different political jurisdictions. Because coinage was exchanged by weight and trading by bills of exchange was rudimentary, there were no arbitrageurs specializing solely in 'arbitrating of exchange rates'. Rather, arbitrage opportunities arose from the trading activities of networks of merchants and moneychangers. These opportunities included uncovered interest arbitrage between areas with low interest rates, such as Jewish Palestine, and those with high rates, such as Babylonia [20, p.18-9].

Evolution of the Bill of Exchange

Though the precise origin of the practice is unknown, 'arbitration of exchange' first developed during the Middle Ages. Around the time of the First Crusade, Genoa had emerged as a major sea power and important trading centre. The Genoa fairs had become sufficiently important economic and financial events that traders from around the Mediterranean were attracted. To deal with the problems of reconciling transactions using different coinages and units of account, a forum for arbitrating exchange rates was introduced. On the third day of each fair, a representative body composed of recognized merchant bankers would assemble and determine the exchange rates that would prevail for that fair. The process involved each banker suggesting an exchange rate and, after some discussion, a voting process would determine the exchange rates that would apply at that fair. Similar practices were adopted at other important fairs later in the Middle Ages. At Lyon, for example, Florentine, Genoese and Lucca bankers would meet separately to determine rates, with the average of these group rates becoming the official rate. These rates would then apply to bill transactions and other business conducted at the fair. Rates typically stayed constant between fairs in a particular location providing the opportunity for arbitrating of exchange rates across fairs in

different locations.

From ancient beginnings involving commodity transactions of merchants, the bill of exchange evolved during the Middle Ages to address the difficulties of using specie or bullion to conduct foreign exchange transactions in different geographical locations. In general, a bill of exchange contract involved four persons and two payments. The bill is created when a ‘deliverer’ exchanges domestic cash money for a bill issued by a ‘taker’. The issued bill of exchange is drawn on a correspondent or agent of the taker who is situated abroad. The correspondent, the ‘payor’ is required to pay a stated amount of foreign cash money to the ‘payee’, to whom the bill is made payable. Consider the precise text of an actual bill of exchange from the early 17th century that appeared just prior to the introduction of negotiability [18, p.123]:

March 14, 1611

In London for £69.15.7 at 33.9

At half usance pay by this first of exchange to Francesco Rois Serra sixty-nine pounds, fifteen shillings, and seven pence sterling at thirty-three shillings and nine pence groat per £ sterling, value [received] from Master Francesco Pinto de Britto, and put it into our account, God be with you.

Giovanni Calandrini and Filippo Burlamachi

Accepted

[On the back:]

First

To Balthasar Andrea in Antwerp

117.15.0 [pounds groat]

The essential features of the bill of exchange all appear: the four separate parties; the final payment being made in a different location from the original payment; and the element of currency exchange. ‘Usance’ is the period of time, set by custom, before a bill of exchange could be redeemed at its destination. For example, usance was 3 months between Italy and London and 4 weeks between Holland and London. The practice of issuing bills at usance, as opposed to specifying any number

of days to maturity, did not disappear until the 19th century [15, p.7].

Commercial and financial activities in the Middle Ages were profoundly impacted by Church doctrine and arbitrage trading was no exception. Exchange rates determined for a given fair would have to be roughly consistent with triangular arbitrage to avoid Church sanctions. In addition, the Church usury prohibition impacted the payment of interest on money loans. Because foreign exchange transactions were licit under canon law, it was possible to disguise the payment of interest in a combination of bill of exchange transactions referred to as ‘dry exchange’ or ‘fictitious exchange’ [10, p.380-1], [26], [16]. The associated exchange and re-exchange of bills was a risky set of transactions that could be covertly used to invest money balances or to borrow funds to finance the contractual obligations. The expansion of bill trading for financial purposes combined with the variation in the exchange rates obtained at fairs in different locations provided the opportunity of geographical arbitrage of exchange rates using bills of exchange. It was this financial practice of exploiting differences in bill exchange rates between financial centres that evolved into the ‘arbitration of exchange’ identified by la Porte, Savary and Postelwayte in the 18th century.

The bill of exchange contract evolved over time to meet the requirements of merchant bankers. As monetary units became based on coinage with specific bullion content, the relationship between exchange rates in different geographical locations for bills of exchange, coinage and physical bullion became the mainstay of traders involved in ‘arbitration of exchange’. Until the development of the ‘inland’ bill in early 17th century in England, all bills of exchange involved some form of foreign exchange trading, hence the name bill of ‘exchange’. Contractual features of the bill of exchange, such as negotiability and priority of claim, evolved over time producing a number of different contractual variations [6], [23], [16]. The market for bills of exchange also went through a number

of different stages. At the largest and most strategic medieval fairs, financial activities, especially settlement and creation of bills of exchange, came to dominate the trading in goods [17]. By the 16th century, bourses such as the Antwerp Exchange were replacing the fairs as the key international venues for bill trading.

Arbitrage in Coinage and Bullion

Arbitrage trading in coins and bullion can be traced to ancient times. Reflecting the importance of the activity to ordinary merchants in the Middle Ages, methods of determining the bullion content of coins from assay results, and rates of exchange between coins once bullion content had been determined, formed a substantial part of important commercial arithmetics, such as the *Triparty* (1484) of Nicolas Chuquet [2]. The complications involved in trading without a standardized unit of account were imposing. There were a sizeable number of political jurisdictions that minted coins, each with distinct characteristics and weights [22]. Different metals and combinations of metals were used to mint coinage. The value of silver coins, the type of coins most commonly used for ordinary transactions, was constantly changing due to debasement and ‘clipping’. Over time, significant changes in the relative supply of gold and silver, especially due to inflows from the New World, altered the relative values of bullion. As a result, merchants in a particular political jurisdiction were reluctant to accept foreign coinage at the par value set by the originating jurisdiction. It was common practice for foreign coinage to be assayed and a value set by the mint conducting the assay. Over time, this led to considerable market pressures to develop a unit of account that would alleviate the expensive and time consuming practice of determining coinage value.

An important step in the development of such a standardized unit of account occurred in 1284

when the Doge of Venice began minting the gold ducat: a coin weighing about 3.5 grams and struck in .986 gold. While ducats did circulate, the primary function was as a trade coin. Over time, the ducat was adopted as a standard for gold coins in other countries, including other Italian city states, Spain, Austria, the German city states, France, Switzerland and England. Holland first issued a ducat in 1487 and, as a consequence of the global trading power of Holland in the 16th and 17th centuries, the ducat became the primary trade coin for the world. Unlike similar coins such as the florin and guinea, the ducat specifications of about 3.5 grams of .986 gold did not change over time. The use of mint parities for specific coins and market prices for others did result in the gold-silver exchange ratio differing across jurisdictions. For example, in 1688 the Amsterdam gold-silver ratio for the silver rixdollar mint price and gold ducat market price was 14.93 and, in London, the mint price ratio was 15.58 for the silver shilling and gold guinea [30, p.475]. Given transport and other costs of moving bullion, such gold/silver price ratio differences were not usually sufficient to generate significant bullion flows. However, combined in trading with bills of exchange, substantial bullion flows did occur from arbitrage trading.

Details of a May 1686 arbitrage by a London goldsmith involving bills of exchange and gold coins are provided by Quinn [30, p.479]. The arbitrage illustrates how the markets for gold, silver and bills of exchange interacted. At that time, silver was the primary monetary metal used for transactions though gold coins were available. Prior to 1663, when the English Mint introduced milling of coins with serrated edges to prevent clipping, all English coins were 'hammered' [28]. The minting technology of hammering coins was little changed from Roman times. The process produced imperfect coins, not milled at the edges, that were only approximately equal in size, weight and imprint making altered coins difficult to identify [31, ch.4]. Such coins were susceptible to

clipping, resulting in circulating silver coins that were usually under the nominal Mint weight. Despite a number of legislative attempts at remedying the situation, circa 1686 the bulk of the circulating coins in England were still hammered silver. The Mint would buy silver and gold by weight in exchange for milled silver shilling coins at a set price per ounce. When the market price of silver rose sufficiently above the mint price, English goldsmiths would melt the milled silver coin issued by the Mint, though it was technically illegal to do so.

In addition to mint prices for silver and gold, there was also market prices for gold and silver. Circa 1686, the Mint would issue guineas in exchange for silver shillings at a fixed price (£1.075 = 21s. 6d./oz.). In Amsterdam, the market price for a Dutch gold ducat was 17.5 schellingen (*S*). Observing that the ducat contained 0.1091 ounces of recoverable gold and the guinea 0.2471 ounces, it follows that 36.87 *S* could be obtained for 1 £ if gold was used to effect the exchange. Or, put differently, 1 ducat would produce £0.4746. Because transportation of coins and bullion was expensive, there was a sizeable band within which rates on bills of exchange could fluctuate without producing bullion flows. If the bill exchange rate rose (*S*/£) above the rate of exchange for gold plus transport costs, merchants in Amsterdam seeking funds in London would prefer to send gold rather than buy bills of exchange on London. Merchants in London seeking funds in Amsterdam would buy bills on Amsterdam to benefit from the favourable exchange. Similarly, if the bill exchange rate fell below the rate of exchange for silver plus transport costs, merchants in London would gain by exporting silver to Amsterdam rather than buying a bill on Amsterdam.

To reconstruct the 1686 goldsmith arbitrage, observe that the exchange rate for a 4 week bill in London on Amsterdam at the time of the arbitrage was 37.8 (*S*/£). Obtaining gold ducats in Holland for £0.4746 and allowing for transport costs of 1.5% and transport time of one week produces gold

in London for £0.4676. Using this gold to purchase a bill of exchange on Amsterdam produces 17.6715 *S* in Amsterdam five weeks after the trade is initiated, an arbitrage profit of 0.1715 *S*. Even if the gold can be borrowed in Amsterdam and repaid in silver, the trade is not riskless due to the transport risk and the possible movement in bill rates before the bill is purchased in London. These costs would be mitigated significantly for a London firm also operating in the bill and bullion market of Amsterdam, as was the case with a number of London goldsmiths. The strength of the pound sterling in the bill market from 1685-1688 generated gold inflows to England from this trade higher than any other four years in the 17th century [30, p.478]. The subsequent weakening of the pound in the bill market from 1689 until the great recoinage in 1696 led to arbitrage trades switching from producing gold inflows to substantial outflows of silver from melted coins and clipping.

Bill of Exchange Arbitrage

The roots of 'arbitration of exchange' can be traced to the transactions of medieval merchant bankers seeking to profit from discrepancies in bill exchange rates across geographical locations [17, 18]. For example, if sterling bills on London were cheaper in Paris than in Bruges, then medieval bankers would profit by selling sterling in Bruges and buying in Paris. The effect of such transactions was to keep all exchange rates roughly in parity with the triangular arbitrage condition. Temporary discrepancies did occur but such trading provided a mechanism of adjustment. The arbitrages were risky even when done entirely with bills of exchange. Due to the slowness of communications, market conditions could change before bills of exchange reached their destination and the re-exchange could be completed. As late as the 16th century, only the Italian merchant-bankers, the Fuggers of Augsburg, and a few other houses with correspondents in all banking centres were able to engage actively in arbitrage [18, p.137]. It is not until the 18th century that markets for

bills were sufficiently developed to permit arbitration of exchange to become standard practice of merchants deciding on the most profitable method of remitting or drawing funds offshore.

The transactions in arbitration of exchange by medieval bankers are complicated by absence of offsetting cash flows in the locations where bills are bought and sold. In the example above, the purchase of a bill in Paris would require funds which are generated by the bill sale in Bruges. The profits are realized in London. Merchant bankers would be able to temporarily mitigate the associated geographical fund imbalances with internally generated capital, but re-exchanges or movements of bullion were necessary if imbalances persisted. To be consistent with the spirit of the self-financing element of modern riskless arbitrage, the example of medieval banker arbitrage between Paris, Bruges and London can be extended to two issuing locations and two payment centres. It is possible for the same location to be used as both the issuing and payment location but that will not be assumed. Let the two issuing locations be, say, Antwerp and Hamburg, with the two payment locations being London and Venice. The basic strategy involves making offsetting bill transactions in the two issuing locations and then matching the settlements in the payment centres.

In the following example, $\$G$ is the domestic currency in Hamburg and $\$A$ is the domestic currency in Antwerp, the forward exchange rate imbedded in the bill transaction is denoted as: F_1 for Ducats/ $\$A$; F_2 for Ducats/ $\$G$; F_3 for $\pounds/\$G$; and, F_4 for $\pounds/\$A$.

At $t = 0$

In Hamburg:

Acquire $\$G Q_G$ using a bill
which agrees to pay ($\$G Q_G F_2$)
in Venice at time T

Deliver the $\$G Q_G$
on another bill which
agrees to be repaid ($\$G Q_G F_3$)
in London at time T

In Antwerp:

Acquire \$A Q_A using a bill which agrees to pay (\$A $Q_A F_4$) in London at time T	Deliver the \$A Q_A on another bill which agrees to be repaid (\$A $Q_A F_1$) in Venice at time T
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At $t = 0$, the cash flows from all the bill transactions at $t = 0$ offset. If the size of the borrowings in the two issuing centres is calculated to produce the same maturity value, in terms of the domestic currencies of the two payment centres, then the profit on the transaction depends on the relative values of the payment centre currencies in the issuing centres. If there is sufficient liquidity in the Hamburg and Antwerp bill markets, the banker can generate triangular arbitrage trades designed to profit from discrepancies in bid/offer rates arising in different geographical locations.

To see the precise connection to triangular arbitrage, consider the profit function from the trading strategy. At time T in Venice, the cash flows would provide (\$A $Q_A F_1$) - (\$G $Q_G F_2$). And, in London, the cash flows would provide (\$G $Q_G F_3$) - (\$A $Q_A F_4$). For the intermediary operating in both locations, the resulting profit (π) on the trade would be the sum of the two cash flows:

$$\begin{aligned}\pi(T) &= (\$A Q_A F_1 - \$G Q_G F_2) + (\$G Q_G F_3 - \$A Q_A F_4) \\ &= \$A Q_A (F_1 - F_4) + \$G Q_G (F_3 - F_2)\end{aligned}$$

Constructing the principal values of the two transactions to be of equal value now permits the substitution of $Q_G = Q_A (\$G/\$A)$, where $(\$G/\$A) = F_0$ is the prevailing exchange rate between \$G and \$A:

$$\begin{aligned}\pi(T) &= \$A Q_A [(F_1 - F_0 F_2) - (F_4 - F_0 F_3)] \\ &= \$A Q_A \left[\left(\frac{\text{Ducats}}{\$A} - \frac{\$G}{\$A} \frac{\text{Ducats}}{G} \right) - \left(\frac{\pounds}{\$A} - \frac{\$G}{\$A} \frac{\pounds}{\$G} \right) \right]\end{aligned}$$

The two values in brackets will be zero if triangular arbitrage holds for both currencies. If the direct

and indirect exchange rates for one of the currencies are not consistent with triangular arbitrage, then the banker can obtain a self-financing arbitrage profit .

Arbitration of Exchange

By the 18th century, the bill market in key financial centres such as Amsterdam, London, Hamburg and Paris had developed to the point where merchants as well as bankers could engage in arbitration of exchange to determine the most profitable method of remitting funds to or drawing funds from offshore. From a relatively brief treatment in early 17th century sources, e.g, [10], merchant's manuals detailing technical aspects of bill trading were available by the beginning of the 18th century. The English work by A. Justice, *A General Treatise on Money and Exchanges* (1707) [6], an expanded translation of an earlier treatise in French by M. Ricard, details the workings of bill transactions, recognizing subtle characteristics in the bill contract. However, as a reflection of the rudimentary state of the English bill market in the early 18th century, Justice did not approve of “drawing bills upon one country payable in another” due to the “difference in the Laws of Exchange, in different countries” giving rise to “a great many inconveniences” [6, p.28]. As the 18th century progressed, there was substantial growth in the breadth and depth of the bill market supported by increases in speed of communication between key financial centres with London emerging as the focal point [24], [32]. This progress was reflected in the increasingly sophisticated treatment of arbitration of exchange in merchant's manuals.

Merchant's manuals of the 18th and 19th centuries typically present arbitration of exchange from the perspective of a merchant engaged in transferring funds. In some sources, self-financing arbitrage opportunities created by combining remitting and drawing opportunities are identified. Discussions

of the practice invariably involve calculations of the ‘arbitrated rates’. Earlier manuals such as J. Le Moine (1710) [8] only provide a few basic calculations aimed to illustrate the transactions involved. The expanded treatment in Postlewayt (1751) [12] provides a number of worked calculations. In one example, exchange rates at London are given as: London-Paris 31 $\frac{3}{4}$ pence sterling for 1 French crown; London-Amsterdam is 240 pence sterling for 414 groats. Worked calculations are given for the problem: ‘What is the proportional arbitrated price between Amsterdam and Paris?’ Considerable effort is given to show the arithmetic involved in determining this arbitrated rate as 54 $\frac{123}{160}$ groat for 1 crown. Using this calculated arbitrated exchange rate and the already known actual London-Paris rate, Postlewayt then proceeds to determine the arbitrated rate for London-Amsterdam using these exchange rates for Paris-London and Paris-Amsterdam finding that it equals 240 pence sterling for 414 groats.

Having shown how to determine arbitrated rates, Postlewayt provides worked examples of appropriate arbitrage trades when the actual exchange rate is above or below the arbitrated rate. For example, when the arbitrated Amsterdam-Paris rate is above the actual rate, calculations are provided to demonstrate that drawing sterling in London by selling a bill on Paris, using the funds to buy a bill on Amsterdam and then exchanging the guilders/groats received in Amsterdam at the actual rate to cover the crown liability in Paris will produce a self-financing arbitrage profit. Similarly, when the arbitrated Amsterdam-Paris rate is below the actual rate, the trades in the arbitrage involve drawing sterling in London by selling a bill on Amsterdam, using the funds to buy a bill on Paris and then exchanging at the actual Amsterdam-Paris exchange rate the crowns received in Paris to cover the guilder liability. This is similar to the risky medieval banker arbitrage where the rate on re-exchange is uncertain. Though the actual rate is assumed to be known, in practice this rate could change over

the time period it takes to settle the relevant bill transactions. However, the degree of risk facing the medieval banker were mitigated by considerably increased speed of communication between centres and subsequent developments in the bill contract, such as negotiability and priority of claim.

Earlier writers on arbitration of exchange, such as Postlewayt, accurately portrayed the concept but did not adequately detail all costs involved in the transactions. By the 19th century, merchant's manuals such Tate (1820) [15] accurately described the range of adjustments required for actual execution of the trades. Taking the perspective of a London merchant with sterling seeking to create a fund of francs in Paris, a difference is recognized between two methods of determining the direct rate of exchange: buying a bill in the London market for payment in Paris; or having correspondents in Paris issue for francs a bill for sterling payment in London. In comparing with the arbitrated rates, the more advantageous direct rate is used. In determining direct rates, 3 month bill exchange rates are used even though the trade is of shorter duration. These rates are then adjusted to 'short' rates to account for the interest factor. Arbitrated rates are calculated and, in comparing with direct rates, an additional brokerage charge (plus postage) is deducted from the indirect trade due to the extra transaction involved, e.g., London merchant buys a bill for payment in Frankfort which is then sold in Paris. No commissions are charged as it is assumed the trade is done by "between branches of the same house, or on joint account" [15, p.98].

Arbitrage in Securities and Commodities

Arbitrage involving bills of exchange survives into modern times in the foreign exchange swap trades of international banks. Though this arbitrage is of central historical importance, it attracts less modern attention than a range of arbitrage activities involving securities and commodities that benefited from the financial and derivative security market developments of the 19th century. Inter-

exchange and geographical arbitrages were facilitated by developments in communication. In 1866, Europe and America were joined by cable, significantly enhancing the speed at which price discrepancies across markets could be identified. Telegraph technology allowed the introduction of the stock market ticker in 1867. Opportunity for arbitraging differences in securities prices across markets was further aided by expansion of the number and variety of stocks and shares, many of which were inter-listed on different exchanges. (Where applicable, the 19th century convention of referring to fixed income securities as ‘stocks’ and common stocks as ‘shares’ will be used.) For example, after 1873 arbitraging the share price of Rio Tinto between the London and Paris stock exchanges was a popular trade.

Cohn (1874) [3, p.3] attributes “the enormous increase in business on the London Stock Exchange within the last few years” to the development of “Arbitrage transactions between London and Continental Bourses”. In addition to various government bond issues, available securities liquid enough for arbitrage trading included numerous railway securities that appeared around the middle of the century. For example, both Haupt (1870) [5] and Cohn (1874) specifically identify over a dozen securities traded in Amsterdam that were sufficiently liquid to be available for arbitrage with London. Included on both lists are securities as diverse as the Illinois and Erie Railway shares and the Austrian government silver loan. Securities of mines and banks increased in importance as the century progressed. The expansion in railway securities, particularly during the US consolidations of the 1860's, led to the introduction of traded contingencies associated with these securities such as rights issues, warrant options, and convertible securities. Weinstein [34] identifies this development as the beginning of arbitrage in equivalent securities, which in modern times encompasses convertible bond arbitrage and municipal bond arbitrage. However, early 18th century

English and French subscriptions shares do have a similar claim [33]. Increased liquidity in the share market provided increased opportunities for option trading in stocks and shares.

Also during the 19th century, trading in ‘time bargains’ evolved with the commencement of trading in such contracts for agricultural commodities on the Chicago Board of Trade in 1851. While initially structured as forward contracts, adoption of the General Rules of the Board of Trade in 1865 laid a foundation for trading of modern futures contracts. Securities and contracts with contingencies have a history stretching to ancient times when trading was often done using samples and merchandise contracts had to allow for the time to delivery and the possibility that the sample was not representative of the delivered goods. Such contingencies were embedded in merchandise contracts and were not suited to arbitrage trading. The securitization of such contingencies into forward contracts that are adaptable to cash-and-carry arbitrage trading can be traced to the introduction of ‘to arrive’ contracts on the Antwerp bourse during the 16th century [27, ch.9]. Options trading was a natural development on the trade in time bargains, where buyers could either take delivery or could pay a fixed fee in lieu of delivery. In effect, such forward contracts were bundled with an option contract having the premium paid at delivery.

Unlike arbitration of exchange using bills of exchange, which was widely used and understood by the 18th century, arbitrage trades involving options – also known as “privileges” and “premiums” – were not. Available sources on such trades conducted in Amsterdam, Joseph de la Vega (1688) [29, ch.3] and Isaac da Pinto (1771) [27, p.366-77], were written by observers not the actual traders so only crude details of the arbitrage trades are provided. Conversion arbitrages for put and call options, which involves knowledge of put-call parity, are described by both de la Vega and da Pinto. Despite this, prior to the mid-19th century, options trading was a relatively esoteric activity confined

to a specialized group of traders. Having attracted passing mention in Cohn (1874) [3], Castelli (1877) [1, p.2] identifies “the great want of a popular treatise” on options as the reason for undertaking a detailed treatment of mostly speculative option trading strategies. In a brief treatment, Castelli uses put-call parity in an arbitrage trade combining a short position in “Turks 5%” in Constantinople with a written put and purchased call in London. The trade is executed to take advantage of “*enormous contangoes* collected at Constantinople” [1, p.74-7], effectively interest payments on the balance raised by the short position.

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